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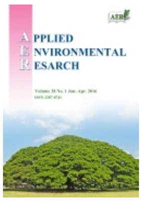

RS-GIS Approach on Biomass Energy Potential Estimation of Sugarcane Residues in Medellin, Cebu

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Abstract

The need to use alternative energy sources is driven by the continued rise in fossil fuel price, increasing population and energy demand most particularly in a developing country like the Philippines. Biomass resources such as sugarcane residues provide alternative means to utilize its untapped potential for renewable energy. The use of remote sensing technology and geographic information system enables detailed assessment on the quantification of its distribution, abundance and quality that will yield an effective and efficient use of its potential. Available energy potential measurement was conducted in the town of Medellin, part of Bogo-Medellin mill district, in the northern region of Cebu province. The calculation was assessed using the remote sensing technology of Light Detection and Ranging (LiDAR) data. This baseline valuation serves as primary input to obtain detailed resource information on specific cultivation land areas for sugarcane with the aid of GIS-based calculations. The calculation considered crop yield, residue-to-product ratio, cultivation area, moisture content and heating value of the crop for a detailed resource assessment. The results revealed the georeferenced location of specific sugarcane residue energy potential in the town of Medellin. The RS-GIS approach in biomass energy potential estimation provides a cost effective way to obtain the overview of spatial variation in agricultural bioresource of the locality.

Keywords: Biomass; Geographic information system; LiDAR; Remote sensing; Renewable energy; RS-GIS

Introduction

The Philippines is a low-middle-income nation with economic growth that has averaged 6.2 percent GDP growth per year since 2010. Energy demand is rising in parallel with the country's economic growth. Renewable energy (RE) is gaining popularity due to its renewable,

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green, and healthy characteristics. It pushes the energy structure towards sustainability by offering a competitive solution to energy production [1–2] and leading to long-term greenhouse gas mitigation [3]. It is also critical to the overall plan for sustainable development [3]. The significance of renewable energy reaches beyond energy protection to economic and local growth.

Addressing the problems for energy generation which continues to increase involves necessary utilization of alternative sources. One alternative source that is considered is through the utilization of biomass in the form of remains or residue from agricultural products, plantation or forest products. Biomass as a type of sustainable renewable energy source has the advantage of being easily stored, transported, and used with an adaptable burden and applications at the spot and season of energy need making biomass as a unique option among other sustainable sources. Specifically, biomass in the form of agricultural residues as a significant source of cellulosic plant material gained growing interest to use for bioenergy production. Agricultural residue being widely available and low cost is one potential solution for energy generation that can be developed in order to aid in the increase of electrification ratio and achieve the national energy security of the country.

However, it needs analysis of potential sources to be able to determine the amount of potential energy that can be used as an alternate generation of electricity. The bioenergy potential of a residue in a given region is accounted for by resource assessment. In the same manner, resource assessment leads to identifying areas with high energy potential [4–7]. Similarly, resource assessment directs decision-makers to find appropriate areas for the development of power facilities. Initial evaluation of the potential for biomass energy involves the identification of potential area, viability, development and use.

Biomass potential refers to the amount of biomass resources that a region generates. The number of biomass sources accessed for the purpose of energy conversion is the actual supply of biomass. Biomass access is limited by factors such as topography, legislation and local practices. In the Philippine setting, several studies have tried to estimate the potentially available amount of biomass bounded by these limiting factors [4–7]. All of these studies demonstrate the number of agricultural crops that can be used for bioenergy. Future agricultural output and demand forecasts, in particular, have a substantial impact on the results. However, there is uncertainty in the Visayas Region, especially in the municipality of Medellin, about the amount of available waste and residue resources that could be tapped for renewable energy sources. In this context, the main aim of this study is to assess the potential biomass that can be measured considering the challenges of wide coverage and data availability by using geospatial technology approaches.

Geospatial technology includes remote sensing (RS), geographic information system (GIS), and global positioning system (GPS) [8]. Remote sensing data, such as aerial and satellite images, offer a reliable and effective way to track the resources of biomass over time. This technique provides a cost effective way to gather necessary information in outlying and inaccessible areas [8]. By comparing images collected at various times, the resulting patterns can be studied and such data can be further evaluated using a GIS. Similar approach was done in a number of attempts made to assess the spatial potential of biomass using a GIS and a mathematical model for biomass selection in the field [9–11]. Remote sensing images are a realistic tool for evaluating large economic land use and land cover changes.

GIS is a set of tools used for inputs, storage and retrieval, manipulation and analysis and process outputs of spatial data. GIS used in the agricultural sector is an essential tool to manage the agricultural sector in acquiring and implementing the accurate information into a mapping environment [12]. In agriculture, the use of GIS also helps to monitor and regulate agricultural resources. However, the quality of the GIS map is dependent on input data resolution and accuracy. To have a better and more accurate GIS map, the input data should have significantly high spatial resolution and accuracy. These data can be acquired via RS technology such as Light Detection and Ranging (LiDAR).

To assess urban landscape coverage, RS tools such as aerial photography, satellite imaging and airborne LiDAR are increasingly used. The use of these technologies can be more cost-effective and time-efficient than field-based inventories of urban vegetation cover when collected at an acceptable spatial resolution during an appropriate time of the year [10–11]. Due to its ability to produce three dimensional point cloud data, airborne LiDAR technology has been used for vertical feature description. Airborne LiDAR is a laser system that contrasts laser pulses emitted by an airborne sensor with travel time variations, communicating with earth objects, and returning to the sensor [11–13]. The application of remote sensing technology extends to science-based resource inventory. The classification and mapping of agricultural crops particularly sugarcane growth utilizing orthophotos and LiDAR datasets provide a unique ability to monitor crop growth and estimate crop yield [17]. The classification accuracy of LiDAR in the field mapping of sugarcane crops achieved a high result coupled with multispectral orthoimages processed using object-based image analysis technique [18].

In the field of bioenergy the question of correctly determining the availability of resources is challenging. The evaluation of indigenous biomass resources, their potential energy contribution and the effect on local development is a serious challenge in order to fully realize the possibilities of bioenergy. The shortage of periodic data relating to agricultural production is a concern in developing countries. Remote sensing and GIS architecture gives an infinite possibility of determining the availability of biomass resources. In this particular study, the use of RS and GIS aid in the estimate of agricultural residues and its production. The RS-GIS methodology used in locating residue sources provides the particular locations that yield higher biomass residue energy potential for future exploration. The resulting map of this study is necessary to specifically determine the availability of biomass sources in order to establish renewable energy policies and make plans based on the biomass residue potential of the locality.

Materials and methods

In a developing country like the Philippines, biomass for power generation plays an important role in the energy mix. It will bring rural areas out of poverty, moving to a future that is prosperous and equal. For economically and environmentally sustainable growth, access to safe and inexpensive energy is indispensable. Biomass in the form of sugar cane is the most abundant crop grown in the Philippines, with around 68% of its production concentrated in the Central Islands (Visayas Region) [19]. Estimates of the collective biomass capacity in the Philippines are wide and varied. Sugarcane is the country's top agricultural crop that can be used for energy production, leaving behind residues during its processing [19]. Biomass as a low cost and important renewable source and considering over 28 thousand sugarcane farms in the Visayas region can provide bioenergy potential for sugarcane residues.

1) Study area

Medellin, is a 2nd class municipality in the province of Cebu, Philippines (see Figure 1). It is a town with an abundance of sugarcane plantations in the Visayas Region. It's about 120 km north of Cebu Town via Barangay Curva, or

113 km via Barangay Luy-a. Medellin is bordered on the north by the town of Daanbantayan, on the west by the Taon Strait, on the east by the Sea of Camotes, on the southwest by the town of San Remigio, and on the southeast by the town of Bogo. The municipality is part of the Bogo-Medellin mill district in the province of Cebu along with Bogo, Borbon, San Remegio, Daanbantayan and Tabogon. Cebu is part of the Central Visayas Region with a 9.88 percent sugarcane crop percentage output distribution. The municipality is abundant in sugarcane, for the crop year 2013-14, the mill district has a total sugarcane area of 7,900 ha with a total sugar production of 27,297 t, representing 1.12% of the national production [20].

Figure 1 Municipality of Medellin in Cebu Province.

2) Data Extraction from LiDAR-derived Map

The main layers and characteristics for image processing and classification of major high-value crops are specially used in LiDAR remote sensing technique. The approach included pattern detection based on the physical structure and LiDAR intensity values that helped in the classification of land cover. The use of agricultural land-cover map obtained from the Department of Science and Technology (DOST) PHIL-LiDAR2 DREAM Project taken from July 23, 2014 to July 24, 2014 using LiDAR data sets resulted in providing overview of the vegetation cover in the municipality of Medellin as illustrated in Figure 2.

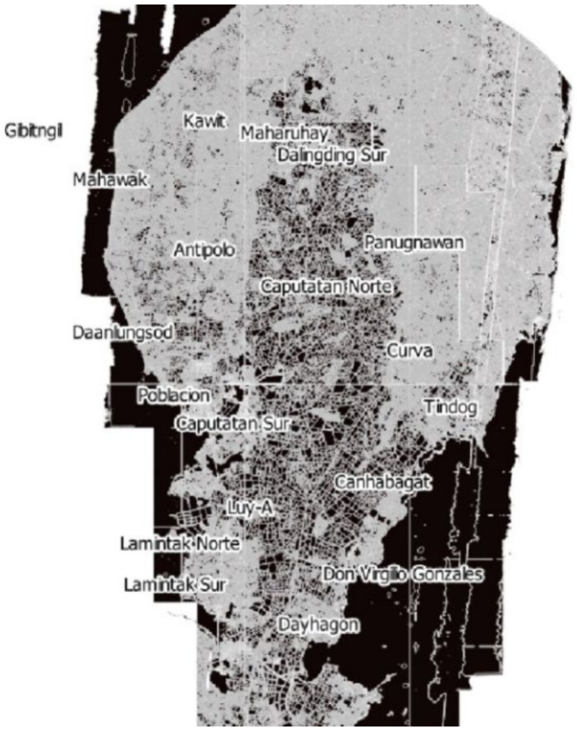

Figure 2 LiDAR –based agricultural coverage of Medellin.

Accompanying LiDAR data of Medellin's Agricultural Land-cover Map from Philippine Agricultural Resources Mapping was further assessed using GIS tools to aid sugarcane classification and obtain crop cultivation area as shown in Table 1. It enables identification of sugarcane distribution and abundance with respect to each barangays or village in the locality. The cultivation area of sugarcane is defined based on the obtained sugarcane spatial distribution map using GIS tools from open source software, QuantumGIS (QGIS) version 3.4.11.

Table 1 LiDAR-derived cultivation area using GIS tools

Name of Barangays or villages	Sugarcane cultivation area (ha)
Antipolo	68.84
Canhabagat	297.22
Caputatan Norte	429.00
Caputatan Sur	331.61
Curva	110.46
Daanlungsod	58.29
Dalingding Sur	83.31
Dayhagon	128.09
Don Virgilio Gonzales	109.86
Kawit	1.15
Lamintak Norte	82.31
Lamintak Sur	42.61
Luy-A	103.77
Maharuhay	7.33
Mahawak	0.08
Panugnawan	286.74
Poblacion	49.68
Tindog	198.49

Note: Based on the attribute table extracted from the LiDAR-based map.

In QGIS, the collection and extraction of data resources enable it to interactively select features and display the highlighted selection as part of a feature layer. The geoprocessing tool equivalents are select layer by attribute and select layer by location, while the build feature layer geoprocessing tool creates a layer that makes calculations and preferences. In this particular study, feature selection emphasizes on the data pertaining to the most abundant crop in the LiDAR-derived map for Medellin. Sugarcane data selection was highlighted in the attribute table and a new layer was created to collect data on crop cultivation area. Further resource potential calculation was done on the newly selected feature extracted from LiDAR-derived map.

3) Supplementary data

Data for the calculation of the energy potentials was gathered from a combination of sources. Statistical data from Sugar Regulatory Administration (SRA) and Philippine Statistics Authority (PSA) was obtained to aid the determination of sugarcane annual production volume and crop yield (see Figure 3 and Table 2). The collected information provides an over-view of sugarcane production performance for Central Visayas. This study highlights the crop yield for crop year 2013–2014 data of SRA and PSA to complement the LiDAR data collected from July 23, 2014 to July 24, 2014 of DOST. This study emphasizes crop distribution and abundance in the study area by combining remote sensing data from LiDAR technology with field data statistics. Since only the crop year 2013–2014 were sampled using the technique of LiDAR technology, the statistical data of sugarcane plantation area and volume of production were incorporated to support further assessment on the theoretical energy potential of sugarcane crop residues. Data from SRA and PSA are further supplemented by parameters obtained from related literature of biomass resource assessments (shown in Table 3).

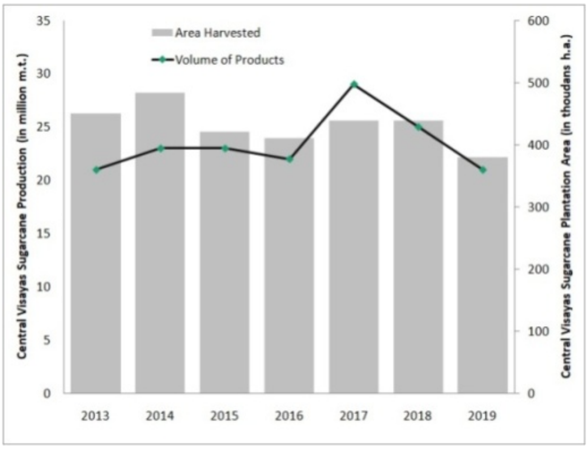

Figure 3 Summary of statistical data.
Source: Philippine Statistics Office

Table 2 Crop yield for sugarcane in Central Visayas 2013–2019

Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Crop Yield	46.67	47.62	54.63	53.66	66.21	57.08	55.41

Source: Sugar Regulatory Administration

Table 3 Overview of the parameters used in this study

Sugarcane residue type	**RPR**	**Moisture content (%)**	**LHV (MJ/kg)**	**Availability (%)**
Tops/ Straw	0.34	50	17.38	100
Bagasse	0.30	50	17.71	50

Source from [21]

4) Available energy potential calculation

The equation indicated below was used to calculate the available energy potential (AEP) of sugarcane residues using Eq. 1.

$$AEP = Y * RPR * \left[\frac{100-MC}{100}\right] * LHV * A \qquad \text{(Eq. 1)}$$

where, Y as the amount of product produced per year as tons, RPR is the residue-production ratio, MC indicates the relative moisture content in percentage terms, LHV of plant shows the lower heating value of plant as MJ/kg and A is the availability of residue ratio as percentage in this equation. Theoretical biomass energy potential was calculated in many literatures in similar ways [22–27]. It describes the amount of energy that is physically available from a certain source.

The amount of residues produced, and thus potentially available for bioenergy production, is calculated using average values for the residue-to-product ratio, heating value, moisture content and availability based on related literatures [6, 8–9, 28] as summarized in Table II. Specifically, the residue-to-product ratio changes with time. It is affected by a number of factors, including yield but also stresses experienced by the crop during development, such as drought. The heating value of harvesting residues is determined by the composition of the biomass; the more woody material present in the mixture, the lower the ash content and the higher the heating value. While there is some variance in the lower heating value for a particular residue type, the variation is mostly between residue types. The moisture content of crop residues varies according to the time of harvest. The moisture content of the residues will be treated as a constant factor in this analysis, as measured when the crop has reached maturity. The parameters to address AEP take into account the effects of other influences such as plant stresses faced during development as a result of annual climatic variability and crop variety produced. There are significant differences between residue-to-product ratio, heating value and moisture content used in different studies, however, recent studies generally assume average ratios.

5) GIS-based model

A GIS-based methodology was developed as shown in Figure 4 to estimate the bioenergy potential of sugarcane residues based on LiDAR data source. Sugarcane crop distribution and abundance were classified and mapped based on LiDAR data of Medellin agricultural land-cover map. The resulting cultivation area was used to determine the residue potential of the municipality. The data required as parameters were derived from related literatures that perform biomass assessment. This would include the data on the type of crop with respect to its moisture content and heating value, crop yield, plantation density and residue to product ratio. This work describes both harvesting and processing residues of sugarcane. Harvest residues comprise all above-ground biomass other than the main produce, such as tops and straw. Process residues, on the other hand, apply to the biomass produced when crops are processed into marketable products such as bagasse.

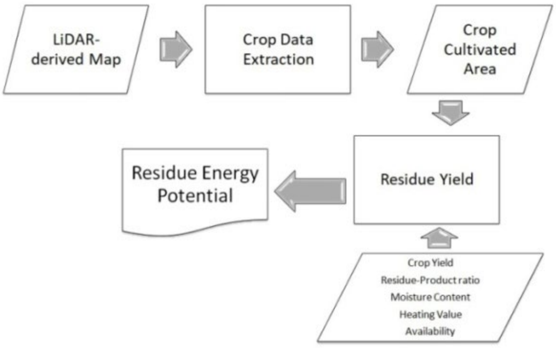

Figure 4 Process flow diagram.

Results and discussion

The LiDAR datasets obtained from the Department of Science and Technology in Figure 2 provide high spatial resolution agricultural resource map cover. The prevailing height characteristics obtained from the LiDAR point cloud and the potential to collect 3D topography data can be due to the high precision of the airborne LiDAR technology for ground cover classification and object recognition. Remotely sensed data gives a synoptic image of the region of interest on the land, capturing the spatial heterogeneity of interest attributes as seen in Figure 5.

The municipality of Medellin in the province of Cebu is composed of 19 barangays, also called as villages, and shown in Figure 1 with a total land area of 73.19 km^2. Medellin is an agricultural village 120 km from Cebu City, with sugarcane plantations covering most of its land area. This northern town is more than just Cebu Province's sugar bowl. Medellin boasts white-sand beaches, coral reefs, rivers, a man-made canal, and adventure rides for tourists, in addition to its extensive sugarcane fields. Barangay Gibitngil is an island barangay famed for its flawless coral reefs, extensive stretches of sand beaches, and stunning rock formations. This study excluded the Barangay Gibitngil in the calculation of available energy potential because of unavailability of data up to this research date. As the area does not lend itself to agricultural activity, offering tourism adventure was a more popular activity in the village than sugarcane farming. Based on the attribute table from LiDAR data, the 18 villages are feedstock sources of sugarcane. These villages form part of the Bogo-Medellin mill district. Extracted data attributes from the agricultural land-cover map of Medellin Cebu in Figure 2 served as the major data input in the calculation of land area and cultivated area for sugarcane. The map contains various agricultural features and sugarcane has been segregated. The cultivated area for sugarcane in Figure 5 has a total area of 23.89 km^2.

The resulting residue available energy potential is influenced by several factors. Those factors include the yield, residue-to-product ratio, heating values and moisture content from harvest to the process of sugarcane that is left as residues. RPR depends on the yield but also on stresses the crop experiences during growth caused by annual climatic variations and specific crop variety growth. The amount of sugar cane tops and trash, that is including green and dry leaves, depends to some extent on the sugar cane variety, crop age at harvest, climatic conditions, topping height and soil type. The amount of bagasse produced per tonne of cane stalks pressed might vary for the different cane varieties and pressing techniques used. The moisture content is the key factor assessing the biomass material's net energy content. Dry biomass, since it requires less of its energy to evaporate the moisture, has a larger heating efficiency or net energy potential. In addition, the moisture content of the harvest residues depends on the time of residue harvest.

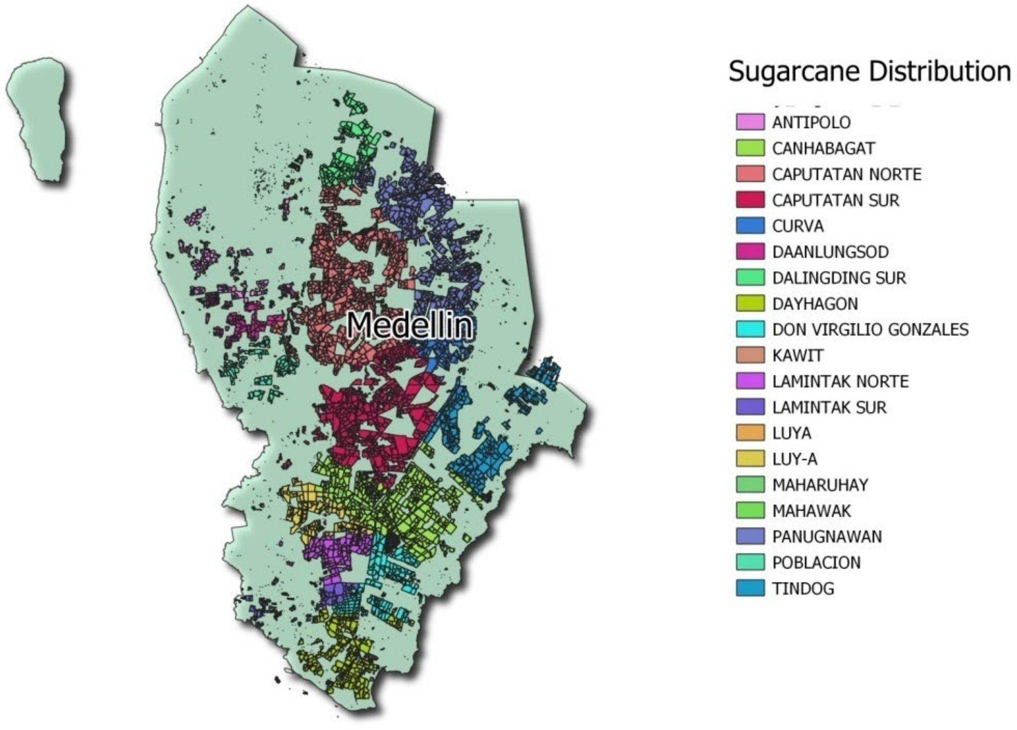

Figure 5 GIS processed village-scale sugarcane distribution in Medellin.
Source: Lidar data from DOST and processed using QGIS tools

In order to allow derivation of other resource maps at different scales, the LiDAR-derived agricultural resource map has very detailed crop details and high spatial resolution. Without losing the resolution of the consequent submap, a municipality-scale LiDAR-derived resource plot can be subdivided into village-scale resource maps. Figure 6 shows the resulting cultivated area obtained from the attribute table of the LIDAR-derived map of Medellin that serves as one of the primary in-puts in the calculation of residue potential as compared to the field surveyed geographical boundaries. It must be observed that the villages of Caputatan Norte utilized 35% of their land area for sugarcane planting, 33% for Caputatan Sur, 35% for Canhabagat, and 29% for Panugnawan. Similarly, except for Canhabagat, which is topped by Kawit, these four villages are among the largest in terms of land area.

The biomass available energy potential (AEP) of Medellin, Cebu sums up to 10953.58 MJ of bagasse and 24387.71 MJ of tops and straw coming from sugarcane. This potential is distributed to 33% of Medellin’s total land area which is dedicated to sugarcane cultivation. By inspection of GIS-based calculations it shows that Brgy. Caputatan Norte, Brgy. Caputatan Sur, Brgy. Canhabagat and Brgy. Panugnawan were the top four largest cultivated areas for sugarcane with 429.0 ha, 331.61 ha, 297.22 ha and 286.74 ha, respectively. Biomass residues are directly related to the area of cultivation, which is proportional to crop yield during agricultural crop production. It was observed that a larger cultivation area addresses the question about a consistent supply of residues for energy production. A large sugarcane plantation guarantees an abundant supply of sugarcane as well as the residue left behind during harvesting and processing.

As illustrated in Figure 7, remote sensing data used in a GIS platform help in the precise and low-cost assessment of biomass resources and energy potential in the municipality of Medellin. The ones highlighted with the darkest color show that biomass has a high energy potential and that residues can be used to produce energy as alternative renewable energy sources. The villages of Caputatan Norte, Caputatan Sur, Canhabagat and Panugnawan combined potential reaches 56.28% of the total sugarcane residue potential of the locality. The potential map depicts Medellin's biomass potential as a result of the extensive array of landscape structural data suitable for estimating volume and biomass.

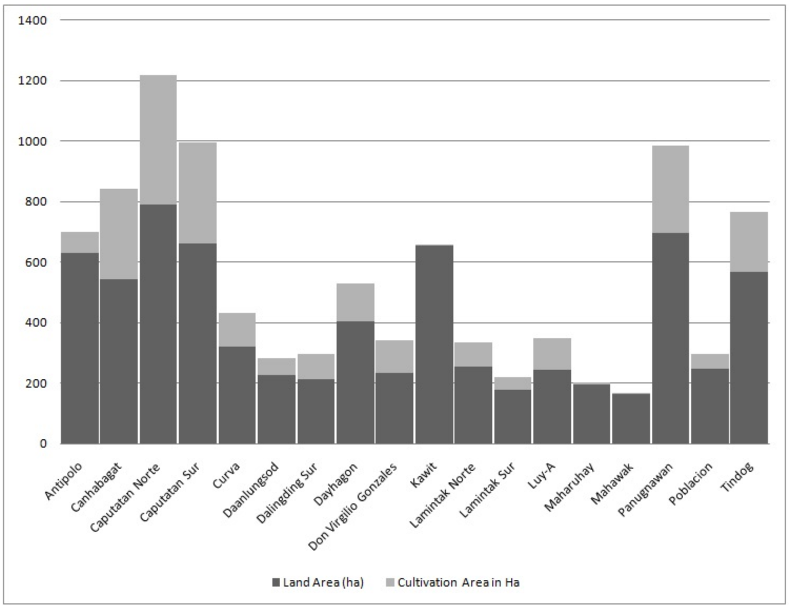

Figure 6 GIS processed village-scale sugarcane distribution and boundaries in Medellin.

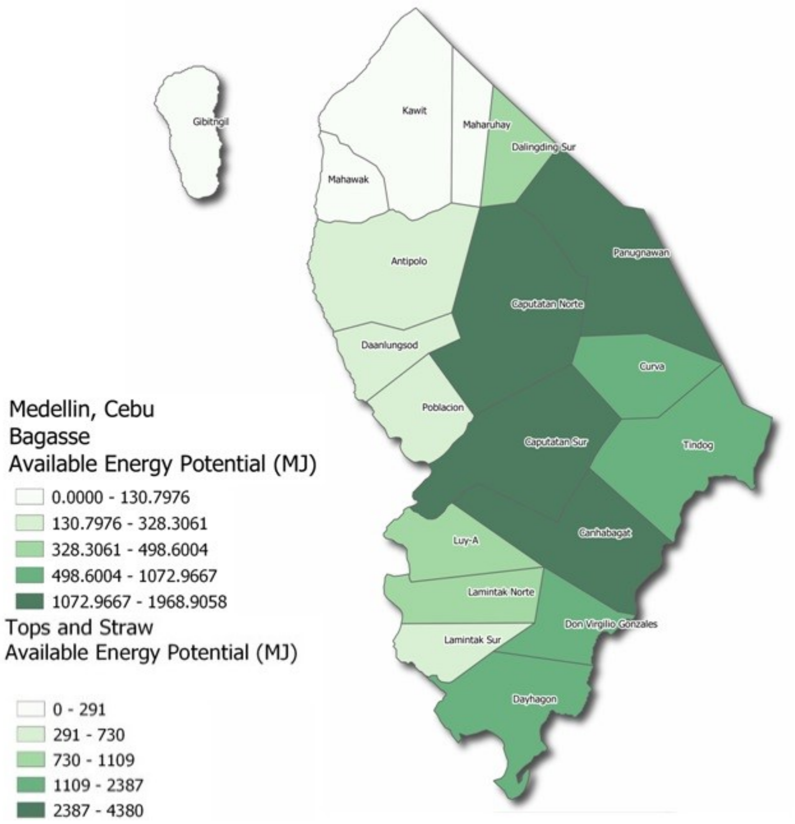

Figure 7 Sugarcane bagasse, tops and straw AEP of Medellin, Cebu.

The crop yield from 2013 onward, as presented in Table 2, has an upward trend that peaked in 2017 and has dropped for the last couple of years. Similarly, the residue that can be collected from the volume of sugarcane production as illustrated in Figure 8 shows a declining trend. The dependence of residue availability for energy generation is affected by various factors such as cultivation area, volume of yearly production, competitive uses, and the climatic situation for a certain period of the year. However, the minimal drop can be raised by promoting awareness of the valorization of agricultural waste to serve as a guide for stakeholders like government units and business operators who are interested in considering sugarcane residue for developing renewable energy policies and strategies. The sugarcane residues from the harvesting process that left behind tops and straw have higher available energy potential than process residues in the form of bagasse due to its competing uses as illustrated in Figure 8.

Several nations and areas have looked into the availability of bioenergy using a variety of techniques and layers of data. The geographies span from local to national to global, and the methods are as diverse as the places being studied, necessitating a variety of input datasets and analysis procedures. Energy potentials from a variety of renewable energy sources have been analyzed using GIS-based methods. Qiu et al. [29] evaluated agricultural residue output and the potential for energy generation using up-to-date statistical data and remote sensing photography. They also displayed GIS-processed agricultural residue distribution in the research region. The GIS method accurately detected the distribution of residue potential concentration rapidly. For Southeast Asian countries Stich et al. [30] looked at biomass leftovers from agriculture, livestock, and forestry. They looked at the overall amount of biomass residues and where they were, and then used a cost optimization model to find the most cost-effective biomass residue power generating alternatives. The method examines in great depth GIS-based estimates of power generation potential from agricultural, forestry, and animal wastes.

Similarly, the methodology of the present study utilized geographic information systems to collect data in relation to time restriction. The remote sensing technology of LiDAR that generates agricultural maps gives more precise data that can aid in evaluating biomass resources at the barangay or village level. This thorough GIS-based computation makes it easier and faster to get the parameters required for biomass resource assessment. This also guarantees that the lowest level of administration, such as the local government unit, has a method of looking at the geographical distribution of its resources.

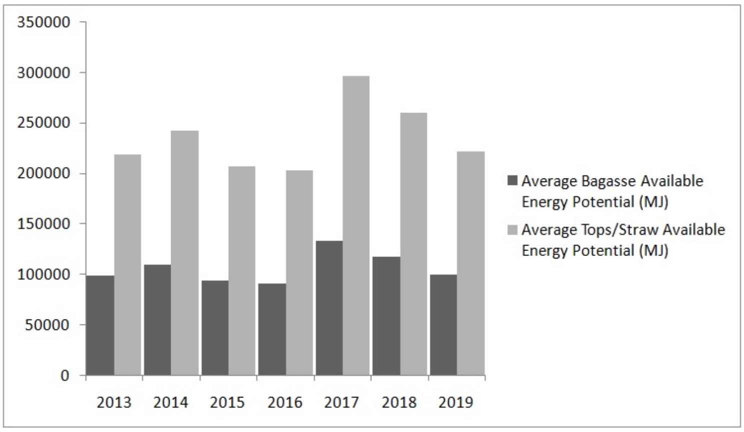

Figure 8 Sugarcane bagasse, tops and straw average AEP of Bogo-Medellin mill District from 2013–2019.

Conclusions

LIDAR technology, particularly airborne LiDAR, has numerous applications with respect to its capabilities. The use of Lidar-derived maps leads the way for a biomass resource that combines statistical resources and the advantage of technology availability. LiDAR is a cost effective means in bioresource assessment. It fastens data acquisition that aids in calculation for generation of enhanced spatial resource maps. The georeferenced resource map generated showed biomass energy that can be produced from bagasse that amounted to 10963.58 MJ, whereas the potential of tops and straws from sugarcane amounted to 24387.71 MJ.

Based on the RS-GIS methodology and statistical evidence, the estimate and assessment of biomass and bioenergy potential counteracts the challenges of heavy workloads, large scale, long upgrade cycles and lack of spatial knowledge. The resulting map of this study is important to direct the intensive and productive use of resources and allocation of bioenergy based projects and industries.

The spatial resolution for LiDAR imaginary is helpful for more than just georeferenced input. This study's geographic information system combines geographical context with environmental detection. Further work with LiDAR data can be done, focusing on remote sensing classification techniques to generate an exact mapping of agricultural crop areas, as well as the use of LiDAR height information in estimating the growth stages of the mapped resource to provide valuable aid in estimating potential crop yield in the future. This research may be used to improve the assessment of potential energy available from biomass residues when converted to electricity, or it could be used to analyze the logistic costs and/or the ideal placement and size of bioenergy facilities.

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