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Methodology for Bioenergy Potential and Assessment for Energy Deployment in Rural Vhembe District Areas

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***Abstract*—**Biomass resources such as animal waste, agricultural and acro-industrial residues, forestry and woodland waste, and industrial and municipal solid wastes provide alternative means to utilize its untapped potential for biomass/biofuel renewable energy systems. In addition, crop residues (i.e., grain, starch, and energy crops) are commonly available in the district and play an essential role in community farming activities. The remote sensing technology (mappings) and geographic information systems tool will be used to determine the biomass potential in the Vhembe District Municipality. The detailed assessment, estimation, and modeling in quantifying their distribution, abundance, and quality yield an effective and efficient use of their potential. This paper aims to examine the potential and prospects of deploying bioenergy systems in small or micro-systems in the district for community use and applications. This deployment of the biofuels/biomass systems will help communities for sustainable energy supply from their traditional energy use into innovative and suitable methods that improve their livelihood. The study demonstrates the potential applications of Geographical Information Systems (GIS) in spatial mapping analysis, evaluation, modeling, and decision support for easy access to renewable energy systems.

***Keywords*—**Agricultural crops, waste materials, biomass potentials, bioenergy potentials, GIS mappings, environmental data, renewable energy deployment, sustainable energy supply.

I. Introduction

IN the Limpopo Province, the fuel wood and crop residues are dominants use of the rural communities for heating and cooking. The area is predominant of agricultural activities, hence interested in exploring the bioenergy potential in the area. Most research has been exploited on the application of Geographical Information Systems (GIS) through application in health, agriculture, urban and town planning, telecommunication, climate change, disaster management, wetland planning, environment, and energy use [1]-[4], [6]-[9], [26], [27]. Nevertheless, for the most part, these assessments have been limited in their scope. In many cases the focus has simply been on a single possible source, such as solar [1], [2], wind [3], [4], and biomass [5]-[7]. Although there are a few instances where an exploration of the potential for multiple resources, and the development of a map for each source independently of the other source/s, has been undertaken, a GIS for bioenergy in spatial mapping and evaluation is of interest as part of the renewable energy systems [8]-[11]. For these reasons, a web-based spatial decision support system (SDSS) is a valuable solution in the exploration of energy resources as it has multiple benefits or capabilities such as spatial analysis, modeling, decision support, a friendly user interface, and easy access. However, there have been minimal applications. It is still a relatively new research field integrating GIS, the Internet, databases, technical reports, maps, and modeling to create a virtual instrument for the region's decision support system on renewable energy potentials [12].

Biomass is also the primary energy source for most of southern Africa. However, the justification for its growth differs from Western Europe, where the emphasis focuses on reducing greenhouse gas emissions [13], [14]. The true potential of bioenergy in Africa is social development and economic sustainability. Therefore, Africa's vast resources are essential in developing a socially acceptable, inclusive, and innovative bioenergy sector with balanced financials for sustainable food production and quality of life [15].

Additionally, since energy is not only essential for the advancement of civilizations, but also provides vital services and means to improve the quality of life of individuals and communities, there is therefore a growing need to consider the energy used by households from wood fuel. In terms of the latter, firewood remains the cheapest option [16], [17]. Furthermore, in developing bioenergy systems to complement energy sustainability, there is a need to assess, estimate, and model biomass energy resources in mitigating energy supplies as bioenergy comes from bioresources, biofuels, and bio-residues [18]. These resources include solid biofuels, liquid biofuels, biogases, industrial waste, and municipal waste [19]. Hence, biomass is essential to this study for assessing, estimating, and modeling the Vhembe District to determine its potential for energy deployment using spatial planning maps, environment, and land suitability for the area.

Biomass provides alternative energy supplies to rural communities from the fuel wood and forestry residues [20]. Biomass, a type of renewable energy source, is an alternative to conventional energy sources. These are organic materials that are used as energy for direct heating and combustion, or indirectly as biofuels [6]. In addition, as part of the waste, municipal, manufacturing, food and acro-processing wastes must also be considered in generating alternative energy supply to the communities. As part of the South African energy

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scenario, it is evident from the energy outlook that many people still use electricity, gas, biogas, and biofuels, as shown in Fig. 1.

Biomass power generation is a crucial component of the energy mix in a developing nation like South Africa. Rural communities, especially in the Vhembe District, will be lifted out of poverty and move towards a wealthy and equal future using biomass as an energy system. Access to affordable, reliable energy is essential for sustainable growth on both economic and environmental levels, as the most prevalent crops in the district in terms of biomass are mangos, oranges, apples, litchis, bananas, and sugar cane, which are produced in larger quantities as an agricultural area. There are many different estimates of the total biomass capacity with the leading agricultural crop in the area that can be processed to provide electricity from the leftovers and waste on farms.

Biogas digests can turn waste, such as kitchen scraps and cow dung, into methane gas used for cooking and heating. Biomass can be supplied by dedicated crops of arboreous and herbaceous species, such as annual crops (corn, soy, sunflower, and sorghum), as further illustrated in Fig. 2.

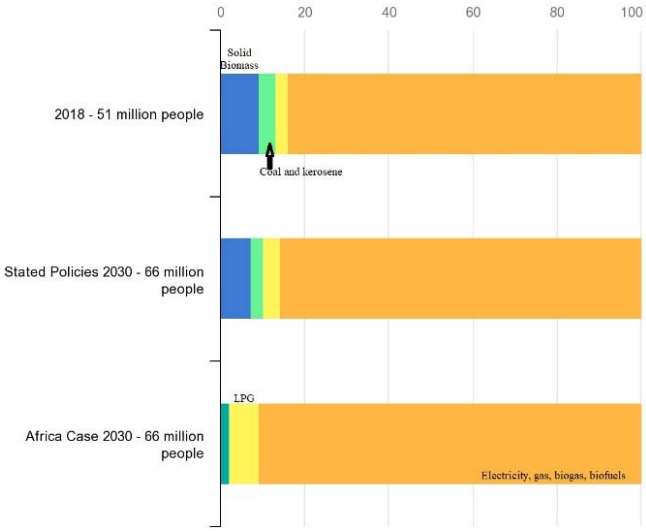

Fig. 1 Impact of South Africans using fuels and technologies for cooking [24]

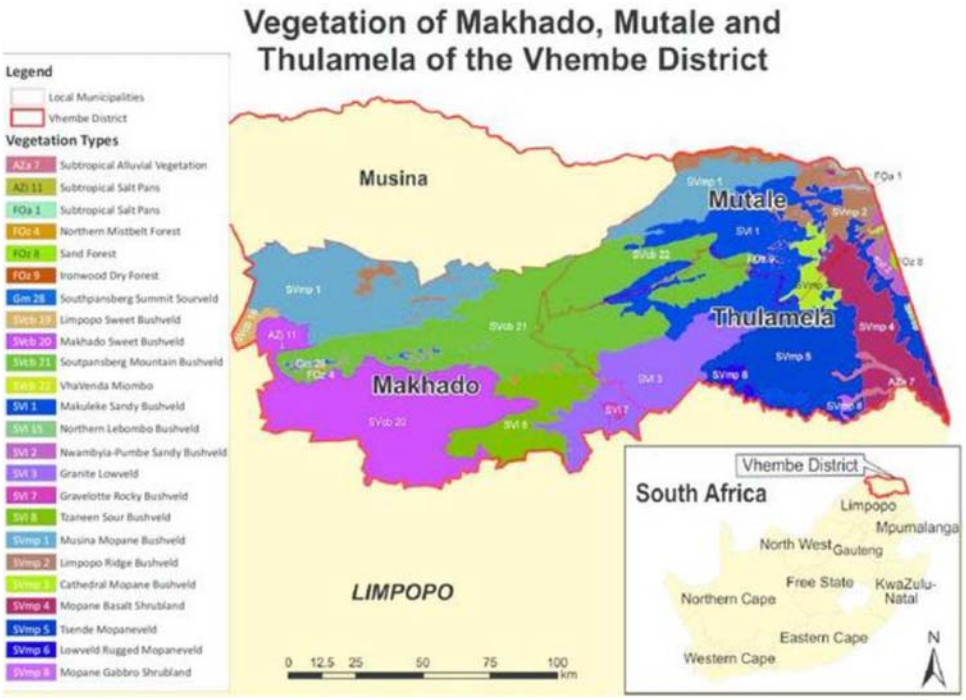

Fig. 2 Vegetation map of the Vhembe District [25]

Several models for biomass and biofuels were developed to support the decisions over which species to grow; the local climate, morphology, soil characteristics, water, and nutrient needs commonly determine the species suitable for a specific area [21].

II. Study Area

The study domain and characteristics form part of the Limpopo province by the edge of the borders of Botswana, Zimbabwe, and Mozambique through to the Kruger National Park. It shares borders with the Capricorn and Mopani District Municipalities in the south and east, respectively. The Vhembe District Municipality area is one of the five districts of the Limpopo province of South Africa. It is in the country's northernmost district and shares its northern border with the Beitbridge District in Matabeleland South, Zimbabwe. The municipality is in the north of Limpopo province, and its district capital is Thohoyandou. For administrative purposes, the district, as shown in Fig. 3, has been divided into four local municipalities, namely: Makhado, Thulamela, Musina, and

Mutale, with a population of approximately 1,3 million people according to the South African local government [22].

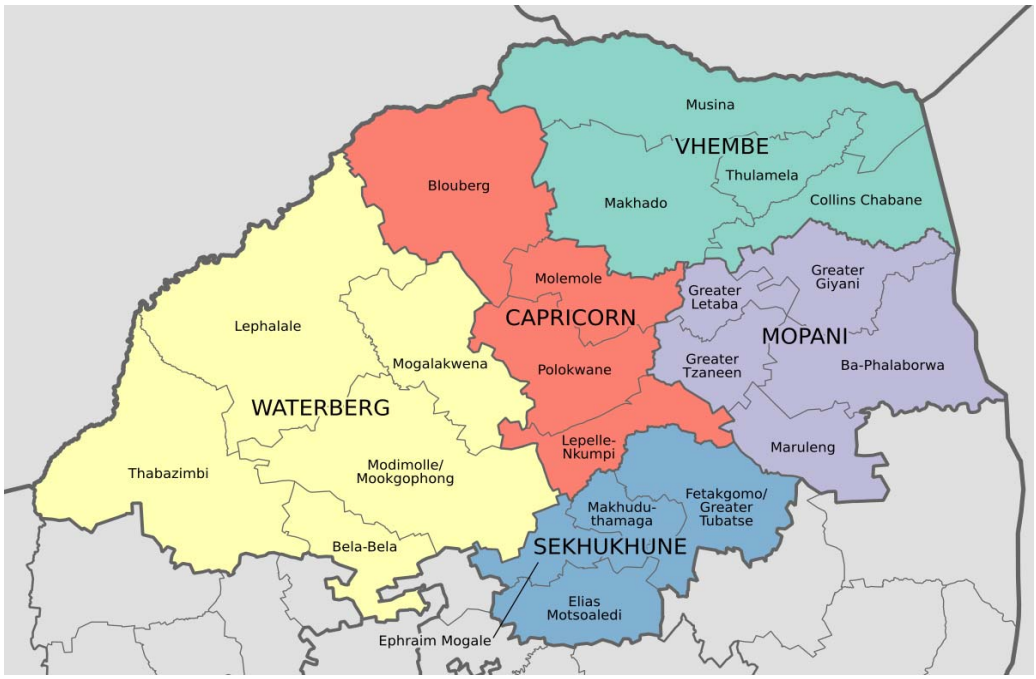

Fig. 3 Vhembe District local municipalities – Makhado, Thulamela, Musina, and Mutale [25]

The annual population growth is increasing; however, new census statistics will determine the percentage. The district is the second lowest on access to infrastructure amongst districts in the province, with a high unemployment rate of 53%. The poverty rate is 32%, making it one of the lowest socio-economic areas in Limpopo Province [21], [22]. The land is very fertile and suitable for agriculture. A large part of the land falls under the tribal authorities. This makes it difficult for development, as the land tenure system could be more favorable towards commercial development. The population comprises 54,4% women and 45,5% men, with 51,3% under 20. The district settlement pattern is mainly rural, with approximately 774 dispersed villages and 287,190 households [22], [25].

The district has 15 primary commodities produced by the smallholder farmers to improve their livelihoods and creation of employment. These include tomato, mango, litchi, citrus, avocado, garlic, banana, macadamia, vegetable gardens, poultry, fish, guava, livestock (cattle, sheep, and goats), pigs, and backyard vegetable products [22]. With such commodities, the idea of waste to bio-energy plants could enable the communities to use their waste materials and turn them into energy. In addition, it can benefit them in meeting their energy needs or a marketable product as the source of income in supplying waste to the bio-energy plant within their area. Providing the waste will give the communities a cleaner, healthier environment; foster job creation; and facilitate access to improved energy which will uplift their living standards.

The municipality is mainly rural, and the citizens depend on agriculture as the main economic activity to sustain and improve their livelihood [22]. Moreover, the municipality is composed of many farmers whose lives could be improved using renewable resources such as livestock waste from chickens, pigs, and cows for economic development, and an increase in employment in the municipality. In addition, with the availability of land, potential crops such as soya beans and sweet sorghum could be commercialized with a view to biodiesel power production [22]. Furthermore, biomass will be converted into biofuels as a form of alternative energy mix. To produce energy, it makes use of organic materials such as those made from wood shavings, sawdust, and firewood, fruit stones like avocado, olive, and nutshells, wastewater, manure, paper waste, and pellets for direct heat and burning [23].

III. Mathematical Proposal

The biomass or bioenergy potentials are assessed through the compilation and computation of bio-resource supply of all the available waste, agricultural residue, fruits and crops, forest, horticulture residue, plantation and livestock dung, and municipal wastes. The data to be used for this bioenergy resource will be assessed and estimated by applying the following methods:

A. Potential of the Crop Residue

The amount of crop residue in the district is determined by the products available as weighted through the scaled-balanced method. The amount collected is determined by tons of residues which yield the spatial distributions based on the farmland areas.

B. Mapping of the Crop Residue Distributions

Understanding the spatial distributions of the biomass residues throughout the district farmland is based on the availability of field maps and characteristics of the estimated

potentials. These forestry residues, including farmed crops such as wheat, sorghum, maize, sunflower, and other wastes, add energy to other forms of waste from grass, trees, and others for biodiesel, bioethanol, and thermal production by using technology to transform them into energy.

C. Mapping of the Biogas from Animal Residue

The animal residues are a vital component of the study which provides a primary indicator of the number of available animals as part of another method for assessing the domestic biogas potential in the district.

D. Mapping of the Forestry Residue

The district has many trees, which offer a viable habitat for evaluating biomass potential and supporting the need to produce electricity. This energy source's tribunal and territorial topology controls it through the timber and plantations available within the district as forest residues.

E. Spatial Mapping Waste Residue

Ordinary solid wastes in municipal garbage include grass, leaves, food scraps, and waste from bioproduction. These wastes produce steam for power production and energy as a form of heating. Landfills and biomass materials such as manure, refuse, garden, and industrial waste combustion are converted into gas to produce energy.

IV. Case Study and Discussions

Much interest has been in estimating biomass, which will continue to increase due to global warming and its consequences. As discussed, various biomass estimation methods have advantages and disadvantages. In some cases, it is about the accuracy of a particular method. In other cases, it is the cost associated with carrying out a particular method, time, and the labor-intensive nature of the method used. The challenge still lies in available infrastructure, human resources, and funding in developing countries to carry out such development in building biomass projects.

As a result, most African nations use biomass as a valuable energy source for thermal purposes in addition to cooking and electricity production. It is crucial to have an alternative energy source because a significant portion of the continent lacks direct access to electricity and other conventional energy sources.

According to the overall findings, collecting biomass waste is still challenging based on calculated biomass. As a result, the study can inform the decisions and actions of the government, public and private investors, and communities interested in developing renewable energy.

V. Conclusion

The methodology for bioenergy potential and assessment for energy deployment in rural Vhembe District areas is a complex, comprehensive, and systematic process. It involves identifying potential bioenergy sources, assessing their potential for energy production through a techno-economic analysis, and deploying bioenergy systems such as biogas digesters and biomass gasifiers. The methodology considers a wide range of factors, including the availability of biomass resources, technical feasibility, and socio-economic factors. It is flexible and can be adapted to different settings. Deploying bioenergy technologies can reduce reliance on fossil fuels and promote sustainable and renewable energy sources.

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