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Research paper

Potential of bio-energy production in Ethiopia based on available biomass residues

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ABSTRACT

Biomass is one of the most important and emerging sources of energy. The objective of this study was, therefore, to explore the potential of energy production from biomass resources available in Ethiopia. The study involved the estimation of bio-energy potential from crop residues, forest, livestock waste, and municipal solid waste (MSW) in the major towns of the country. The paper also presents policy recommendations for sustainable bio-energy development. The crop, forest, and livestock population data were extracted from the Food and Agriculture Organization statistics database (FAOSTAT) and the country's national and regional reports. The results revealed that Ethiopia has a substantial amount of biomass residues, which are not currently being utilized and collected, that can be used without negatively affecting the socio-economic as well as environmental requirements and without compromising food security. The total bio-energy availability of the country was estimated to be 750 PJ per year (46.5% forest residue, 34% crops residue, 18.8% livestock waste, and 0.05% MSW). The study concludes that an integrated bio-energy database, research development, and identification of feasible bio-energy feedstock value chains are needed to fully realize the potential availability of biomass energy. It also recommends that assessment of the bio-energy value chain should be conducted along its life cycle.

1. Introduction

Biomass is a natural resource used all over the world for different purposes, including energy. It is considered to be a backbone of energy sources in developing countries, especially sub-Saharan countries like Ethiopia [1]. Biomass resources can be classified as woody biomass, agricultural waste and municipal solid waste [2]. At the global level, the current share of biomass as energy is estimated to be in the range of 9–15% [3]. The need of reducing dependence on fossil fuels and their adverse contribution to global warming pushes the world community to shift to biomass energy which is supposed to be relatively clean [4]. The amount of future bio-energy is highly dependent on the available biomass resources as well as their sustainable utilization [5]. In sub-Saharan countries, the biomass resources are used mainly by direct burning in open fire systems which becomes a cause for indoor air pollution that contributes to health problems of women and children as these sections of the community have direct exposure to the risk [6]. The population suffering from this problem is living in off-grid areas and was estimated to be as large as 585 million in 2009 [1].

The largest part of the Ethiopian population lives in rural areas of the country and is highly dependent on agriculture [7]. This largest segment of the country is consuming energy nearly entirely from biomass (woody biomass and agricultural residues), whereas a small fraction of kerosene is for lighting [8]. This dependency on wood fuel has been causing depletion of forests for the last 35 years; and farmers need to go far for collecting fuel wood spending a lot of time and money [9]. Nearly 90% of the energy demand is fulfilled from traditional use of biomass for cooking and baking within the country [10], in both rural and urban areas.

Geographical information system (GIS) has been used by researchers as a tool for assessment of different resources, including biomass. It has been used to show the spatial distribution of bioenergy potential for instance in Zambia by producing resource assessment maps for different provinces of the country [2]. Spatial and non-spatial data have been integrated with GIS to identify the sites for optimum production of biogas using anaerobic digesters [11]. In this study, the potential and geographical distribution of biogas feedstock has been evaluated using GIS by including criteria for three dimensions – ecological, technical and economic.

GIS has also been utilized to estimate the biomass resources density

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areas by using production data, area coverage as well as population density data. Indicators and production areas of biomass were computed using the country's Agricultural Census Database and the Regional Technique Map (RTM) of the study area [12]. The relationship between the existing biomass resources and the power plants' wood fuel demand has been analyzed based on GIS, which addresses the biomass distribution patterns so that the possible hotspot high biogas density areas are clearly seen on the kernel density map [13].

Currently, Remote Sensing (RS)-GIS is emerging as a tool to assess renewable energy resources, but they require very high resolution images as well as data in the same reference year as that of the images, which are still lacking in Ethiopia [14].

Ethiopia is considered as the number one country in the world facing energy poverty which makes the development of alternative energy resources reasonable [15] in the sense that energy poverty has a direct contribution to poverty [16]. The introduction of alternative energy will improve the lifestyle and make economic sustainability attainable [17]. For example, production of charcoal to fulfill the energy requirement has a direct implication on economic growth as people can sell the extra charcoal, and it also helps decrease indoor air pollution when used as a fuel [18]. This indicates that it is important to explore the country's potential energy sources so that the level of poverty will be reduced by availing adequate supply of energy to the society. Ethiopia's electricity generation is from hydropower; however, it has been difficult to connect all the regions to the grid because of the geographical topology of the country makeing it extremely costly to distribute to the remote areas [19]. More than 85% of the society is not connected to electricity access [5]. On the other hand, the waste generation rate is increasing proportionally with the development of the country as well as population growth. As a result, disposing the generated waste, municipal solid waste (MSW) having a high amount of organic constituents, is becoming a devastating problem in the country. Managing MSW in a sustainable manner should not be undermined [20]; but MSW, which would have the potential to benefit the energy as well as the agricultural sectors, can be considered as a loss of resource if it is not handled properly.

Modern conversion of MSW to energy will overcome environmental challenges while providing energy for the society [21]. The MSW generated for example in the city of Jimma alone, located in Oromia region of Ethiopia, is 88000 kg d^{-1}, 87% of which is from households [22]. The study in the capital city, Addis Ababa, also shows that the waste generation rate ranges from 52 kg cap^{-1} y^{-1} to 219 kg cap^{-1} y^{-1} [23] depending on the lifestyle and level of income of the households. In addition to MSW, there are plenty of other residues such as agricultural residues, forest residues and livestock excreta from daily, seasonal and annual activities of the society, particularly in rural areas. Consequently, the aim of this study is to investigate the potentially available bio-energy from these residues including MSW generated from some of the major cities of the country.

Biomass resources can be assessed following two approaches: Resource focused approach and/or Demand driven approach [24]. Resource based approach is the most common approach used all over the world for biomass and bio-energy potential assessment. This method considers specific biomass type, such as agricultural residue, forest residue and their processing by-products [25]. Accordingly, this paper presents the resource assessment following the resource focused approach.

2. Methods

Several scholarly published papers are available in Ethiopia, sub-Saharan countries and other developing countries using only one or two data gathering tool(s). However, this study touched the possibility of using the following data gathering tools to examine the potential availability of biomass energy in Ethiopia. Data are collected from the Food and Agriculture Organization statistics database (FAOSTAT) [26]. Since there are no scholarly studies published on the area in Ethiopia, most of the data are sourced from different national and regional official reports such as population census [27], agricultural sample survey data for major crops [28], strategy documents [29] and yearly official reports within the country. Therefore, the data may be a bit on the theoretical side and the results, somewhat exaggerated. For missing data, the data of crops, which are equivalent in yield per hectare and with similar orientation, are taken (for example, wheat data for barley). Formulas used for calculation of bio-energy potential from livestock, MSW, and forest residues are shown below.

2.1. Livestock

Bio-energy potentially available from livestock is calculated using the equation (1).

$$E_j = 365 \sum_{i=1}^{n} N_{ij} * D_i * \eta_i * LHV_i \tag{1}$$

where Ej is the bio-energy potential at location j, N_{ij} is population of animals of ith species at location j, Di is dry dung output per day for ith animal species, η_i is collection efficiency of ith animal dung and LHV_i is the lower heating value of ith animal dung.

2.2. Municipal solid waste

The bio-energy potential from municipal solid waste is estimated using equation (2).

$$Ep_i = 365 \sum_{i=1}^{n} N_i * Q_i * P_i * LHV_i \tag{2}$$

where Ep_i is the bio-energy potential from municipal solid waste at location i, N_i is human population in i^{th} town, Q_i is the quantity of waste generated per capita per day at i^{th} town, P_i is percentage of waste collected at i^{th} town and LHV_i is lower heating value of MSW collected from i^{th} town.

2.3. Agricultural residues

Even though crop residues have different categories (gross residues and surplus residues), here only the surplus residues are considered since the farmers use the others for different purposes. The formula used for calculating the bio-energy from crop residues is adopted from Refs. [30,31]. The gross residue has to be determined first as the surplus residue depends on it and area covered by cultivation and it is given by equation (3).

$$Rg_j = \sum_{i=1}^{n} A_{ij} * Y_{ij} * RPR_{ij} \tag{3}$$

where Rg_j is gross residue potential at the location j from n amount of crops, A_{ij} the area of crop i at location j, Y_{ij} is the yield ith crop at location j and RPR_{ij} is the residue to product ratio of ith crop at location j. Data for Ethiopia are taken from FAOSTAT 2014. The RPR values are sourced from different papers published from developing countries in Sub-Saharan Africa.

Surplus availability is defined as the fraction of available residues from crop production after other parts are used for different purposes [32]. The residue potentially available is estimated from equation (4).

$$Rs_j = \sum_{i=1}^{n} Rg_{ij} * SAF_{ij} \tag{4}$$

where R_{sj} is the surplus residue potential at location j, R_{gj} is gross residue potential at the location j from n amount of crops and SAF_{ij} is the surplus availability factor of ith crop at location j [Table 2].

Finally the bio-energy crop residue potential is estimated from