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Electricity generation prospects from clustered smallholder and irrigated rice farms in Ghana

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ABSTRACT

In farming communities in Ghana and the West African region, crop residues are often unused and remain available for valorisation. This study has analysed the prospects of electricity generation using crop residues from smallholder farms within defined clusters. Data was collected from 14 administrative districts in Ghana, where surveys were conducted and residue-to-product ratios determined in farmer fields. Thermochemical characterisation of residues was performed in the laboratory. The number of clustered farms, reference residue yields and residue densities were determined to assess the distances within which it would be feasible to supply feedstock to CHP plants. The findings show that in most districts, a minimum of 22–54 larger (10 ha) farms would need to be clustered to enable an economically viable biomass supply to a 1000 kWe plant. A 600 kWe plant would require 13 to 30 farms. Financial analysis for a 1000 kWe CHP plant case indicate that such investment would not be viable under the current renewable feed-in-tariff rates in Ghana; increased tariff by 25% or subsidies from a minimum 30% of investment cost are needed to ensure viability using internal rate of return as an indicator. Carbon finance options are also discussed.

1. Introduction

Rising fossil fuel prices and increasing concerns about climate change are creating a growing demand for new sources of raw material for sustainable electricity and heat production [13,18,30]. For countries with poor access to electricity and modern fuels, biomass provides an alternative raw material source that can be explored for the production of modern energy to meet rising energy demand and spur socio-economic development [4,8,19,21,25]. Home grown biomass resources offer significant potential for increasing the quantity and controlling the rising costs of raw material to produce energy. Many of these biomass resources are usually underutilized and, in theory, there are considerable opportunities to use them as an energy source [38,42,44].

Already, biomass plays a very important role in global energy provision. In 2014, biomass contributed 14% to global final energy consumption [36]. The so-called 'modern biomass', in the form of heat and power, contributed approximately 5.1%, while traditional biomass contributed 8.9%. Total primary energy supplied from biomass reached approximately 60 EJ [36] and is the main cooking fuel source for about 2.6 billion people in developing countries. It has been predicted that biomass is likely to remain an important global source in developing countries well into the next century [19]. Presently however and as presented from the statistics above, the use of biomass has principally been in traditional forms, as charcoal and firewood, with very low efficiencies. The inefficiencies associated with the use of biomass in traditional forms, as well as associated harmful environmental, health and social effects has enhanced the growing interest in the search for better application of biomass globally [17,47].

The task facing technology developers and policy makers is to move beyond the use of biomass in traditional forms and to introduce technologies that utilize biomass to produce modern fuels such as electricity and heat at both small and large-scale levels [15]. Current research and analysis is therefore geared towards shifting away from the use of biomass in traditional cook stoves and other inefficient conversion systems to its use as raw material for the production of energy carriers using more efficient conversion processes [16,20,40,44]. The use of biomass in modern forms can contribute to increasing the share of renewable energy and decrease the reliance on fossil fuels. In addition, the use of biomass

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in modern forms can have important environmental benefits [5,10,14,26]. Biomass is also an indigenous energy source available in most countries and its deployment on a larger scale may help diversify the fuel-supply in many situations, which in turn may lead to a more secure energy supply [3,41].

The successes of any new form of biomass energy will most probably depend upon the use of advanced technology at a reasonable cost. Among the important drawbacks of modern bioenergy is the complexity of the supply chain (from biomass sourcing to energy consumption) and the economic costs associated with the conversion of the resource. For this reason, the integration of biomass in the energy planning of a community/country requires the development of advanced planning and economic tools that allow for assessing and optimizing costs in order to identify the optimal location for biomass investments [9,14]. Indeed, if bioenergy is to have a long-term future, it must be able to provide affordable, clean and efficient energy forms. A number of studies have been conducted into the potential of biomass to provide modern fuels (see for example [6,28,29,32,37,39,44]).

Like many other developing countries, biomass is a dominant energy source in Ghana [24]. In 2014, traditional biomass contributed 39% to primary energy supply. In rural communities, a little below 90% of households use woodfuel as their main cooking fuel. Because of the agrarian nature of Ghana's rural economy, there are opportunities to use biomass resources for the production of modern fuels such as biogas, to complement traditional biomass use in rural communities [7]. In urban communities, residues from oil palm mills and timber processing, as well as waste from fruit processing and crop residue, offer interesting possibilities for the production of electricity and heat for internal applications and also for export into the grid. One of the aims of Ghana's Renewable Energy Act (RE Act), which was enacted by parliament in 2011, is to promote the utilisation of biomass for the generation of electricity and heat. In line with this, a number of scientific studies have been conducted which indicate a high potential for modern biomass fuels in Ghana. Notable studies include those by Duku et al. [12], Mohammed et al. [31] and Kemausuor et al. [24]. However, these studies have focused on aggregated feedstocks at the national level. There is limited study on potentials of feedstock at the community level, where crop residues could be used in small and medium scale technologies for distributed generation. The aim of this study was therefore to analyse small farm typologies and irrigated rice farms in selected districts in Ghana to determine prospects of using crop residues within defined clusters to generate electricity, with a high replication potential across the country.

2. Methodology

2.1. Crop residue assessment methodology

The first stage in the analysis of biomass for electricity generation is the assessment of biomass resource availability. The resource assessment is important as it goes hand-in-hand with technical feasibility study, and provides the baseline for financial pre-feasibility studies. For this study, the prospects of using crop residues from small-scale aggregated farms and irrigated large rice farms were investigated in a fieldwork that principally considered types of crops cultivated, farm sizes, and potential residue yield from fourteen (14) districts in Ghana. A summary of the methodology is presented in Fig. 1. The districts were selected to reflect the different agro-ecological zones in the country, from the forest zone, through the transitional zone, to the savannah zone. The selection was also based on districts that have relatively high crop production figures within each agro-ecological zone, based on earlier studies by Kemausuor et al. [22]. Crop residue available was estimated using the Residue-to-Product Ratio (RPR). Fieldwork to determine RPR was conducted in twenty-eight (28) farming communities, two (2) each from the fourteen selected districts (see Table 1). Maize is cultivated in all the selected districts and is also the commonest crop cultivated in the country by area. Every district

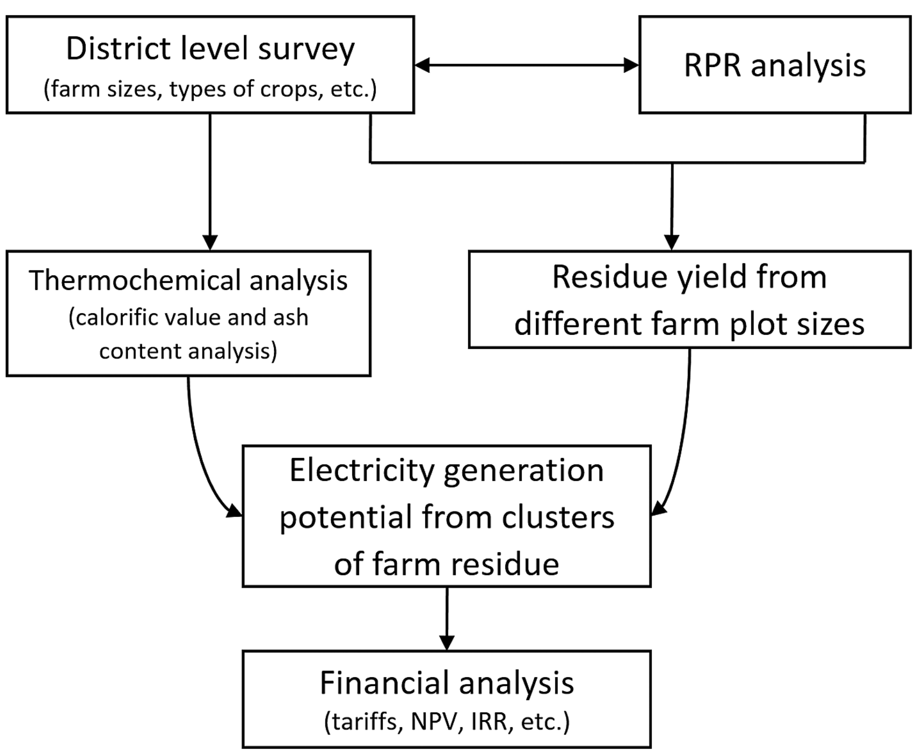

Fig. 1. Summary of methodology.