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Trigeneration based on biomass - specific field case: agricultural residues from smallholder farms in Ghana

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Abstract

Many remote rural communities are ignored in rural electrification plans due to their remoteness or their relatively low demand potential. Many of those communities are rural agricultural villages that cultivate crops whose residue is a potential solid biomass fuel for power generation using appropriate technologies. This research proposes a feasibility study of trigeneration (heat, power and cold) from small farm typologies with enough clustered crop residue in selected communities in Ghana, as well as definition (prototype level) of the best generation technology. A sample of 11 districts in Ghana were surveyed in order to assess the levels of agricultural waste produced in small holder farms and their possible clustering for supplying these wastes to a hypothetical centralized trigeneration plant. The results obtained in terms of plant capacity, biomass waste yields, energy output flows and economic analysis indicate good prospects for the deployment of trigeneration as a solution in rural agricultural areas of Sub-Saharan Africa

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1. Introduction

Ghana's official electrification policy is to extend grid electricity access to all communities that have a human population of at least 500 by 2020 [1, 2]. Many remote rural communities, including some with population above 500 are ignored because of poor access roads which inhibit the extension of the national electricity grid. Many of the inaccessible communities are rural agricultural villages that cultivate crops whose residue is a potential solid biomass fuel for power generation using appropriate technologies [3, 4]. On the basis of this field case, the feasibility of trigeneration (heat, power and cold) based on agricultural waste is assessed in this study.

In local socioeconomic terms, producing energy from this biomass would support farmers in several ways [4, 5]: (1) they could power modern irrigation facilities to cultivate crops during the 'dry' season, using plots closer to the community where power supply could be economically extended; (2) Farmer households would have the opportunity to become suppliers of biomass resources for energy production and thereby broaden their income generation sources; (3) The introduction of electricity supply in remote rural communities would enable the use of crop handling and pre-processing machinery which will serve two main purposes: ensure that perishable produce (such as tomatoes) could be stored safely and processed before it is transported to markets; and (4) The collection and utilization of crop residues would help curb bush fires that often start with residues burnt on harvested fields and spread to forests and un-harvested fields during the dry season.

Recent projections in Ghana [4, 6] have shown the socio-economic benefits of promoting biogas from agro waste (cassava peels) to displace currently used firewood; the needed investments would have a 7-year Payback Period, and yield an Internal rate of return of about 19 % over a 20-year analysis.

Although low-level thermal (not for cooking) and cooling requirements in these rural communities are not abundant nowadays, the existence of an important residual heat resource could trigger industrial development in the agro food transformation sector [4]. This could help the communities move from being merely self-sufficient communities to be able to transform part of their product (heat), store it (cold) and sell it elsewhere.

2. Methods

Previous studies [6, 7, 8, 9, 10] have proposed that to be technically and economically feasible, crop residues must meet two important criteria: (i) they should be produced within a certain radius or distance to a central point where the energy generation plant would be located, depending on the plant generation capacity; and (ii) the energy contents of the residues must meet a certain minimum value. However, presently in Ghana there are no studies determining the availability and location of crop residues with respect to potential biomass-to-power plant sites [11], which are key factors to assess the financial viability of such investments. This research proposes a feasibility study of electricity generation from small farm typologies with enough clustered crop residue in selected communities in Ghana, as well as definition (prototype level) of the best generation technology. The application of appropriate methodology will facilitate investment into clean energy technologies using biomass.

The prospects of using crop residues from small-scale aggregated farms in the country were investigated with an estimation of the quantities of crop residue that could be available and farm sizes. In practice, not all the existing crop residues can be collected and used for bioenergy production due to technical constraints, ecosystem functions, and other factors [12, 13].

Estimation of the amount of crop residue available was done using the Residue to Product Ratio (RPR), which is the ratio, by mass, of a crop's residue to the actual product. Fieldwork was conducted in twenty-two (22) farming communities selected from eleven (11) districts in the country, to determine RPRs of some of the key bioenergy crops in the country. The districts were chosen to reflect the different agro-ecological zones in the country. Data on farm sizes in the districts were obtained from district offices of the Ministry of Food and Agriculture. Field measurements were conducted on farms to determine RPRs. In all, two hundred and twenty (220) farms were selected, ten (10) from each farming community. A snowball sampling technique was employed and farmers who agreed to participate in the study were enrolled. The following procedure was used for the measurements:

a) Four plots each of size 20m by 20m square was obtained by random sampling from each of the farms.
b) The RPR of the various residues was determined using the weight of the product and residues from the plots.
c) An average RPR was determined for each farm from the different plots.