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Development of bioenergy conversion alternatives for climate change mitigation

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Abstract
Traditional charcoal production, firewood sourcing and over-dependence on the national grid for electricity are associated with high greenhouse gas emissions relative to other common energy options. However, there have been few attempts to analyze the potential of cogeneration and briquetting as favourable energy options for climate change mitigation. The possibility of utilizing abundant wood residues to produce energy for domestic and industrial application through co-generation and sawdust briquetting was assessed. Annual residues generated in the three mills studied ranged from 19,230 m^3 to 32,610 m^3. Annual output of semi-carbonized and carbonized sawdust briquette from the briquette factory studied was 1400 tonnes. Heating values of the wood species ranged from 8.2 to 20.3 MJ/kg. Power requirements for the mills, necessary for sizing co-generation units were derived from their monthly electricity bills. Power ratings for co-generation units were specified between 400 kWe to 2000 kWe with heat to power ratios of 19 to 21. The energy generated could be used to produce electrical power and reduce dependency on the national grid. Conversion of sawdust in the briquette factory potentially contributes a saving of 5,600 tonnes of trees/year that would have been cut from the forest. Thus, adoption of co-generation and sawdust briquetting nationwide could be of immense benefit to the country in terms of climate change mitigation.

Keywords: Bioenergy, Briquette, Carbon dioxide emissions, Cogeneration, Wood residue.

1. Introduction

Ghana has been working with the global community in finding solutions to problems that threaten the very existence of humankind on the earth. It is against this background, that Ghana signed the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio de Janeiro Earth Summit in June 1992, after the Convention was adopted on 9 May 1992. The climate Convention entered into force globally on 21 March, 1994 and specifically for Ghana on 5 December 1995 after ratification on 6 September 1995.
Electricity in Ghana is obtained primarily from two hydro stations and two light-crude-oil fired thermal plants. It is also obtained to a limited extent from solar energy in remote rural communities [1]. In the

year 2000, about 94.8% of the total household electricity consumption in Ghana went to the urban households, lighting alone accounted for about 45% of the total urban household electricity consumption. Miscellaneous uses of electricity and refrigeration accounted for 22% and 20% of the urban household consumption respectively [1].

Power from the national grid is not reliable and many high-income urban households in the country use diesel/petrol generator set as standby power supply in event of power failure. The energy consumption of this category of consumers in 2000 represented about 50% of the total household electricity consumption which stood at 2374 GWh [1]. Biomass-fired cogeneration plant offers a more attractive economic proposition as a standby power supply.

The majority of energy interventions in Ghana have been in the traditional and renewable energy sub-sector. Statistics indicate that close to 90% of households in Ghana use either firewood or charcoal for cooking, the primary energy end use application as there is not a space or water heating requirement. It is also used to provide process heat in the wood processing industries for drying [2]. Ghana’s Forest Policy objective is to manage, protect, conserve and develop her forest in order to ensure sustainable wood (as well as Non-Timber Forest Products) production and utilization to optimize the economic, social and environmental benefit, to the people and to provide sustainable support for the country’s forest-based industries [3].

Woodfuel exists in three main forms namely, fuelwood, charcoal and briquette. In Ghana gross national woodfuel consumption is estimated at 18 million tonnes per annum [4]. In 2000, the annual production of wood in Ghana was about 30 million tonnes were available and accessible for woodfuel. If this consumption trend continues, Ghana is likely to consume more than 25 million tonnes of fuel wood by the year 2020 [4]. In Ghana woodfuels (fuelwood and charcoal) accounted for about 66% of the country’s total annual energy consumption with imported petroleum and electricity making up the balance for 20% and 14% respectively [5].

Carbon (C) emissions from deforestation and degradation account for about 20% of global anthropogenic emissions [6]. Deforestation is the single largest source of land-use change emissions, resulting in emissions of more than 8Gt CO2/yr [7]. Tropical deforestation has been offset to some extent by the increase in world’s temperate and boreal forests, but the overall size of global forests is declining. Estimated net annual decline in the forest area globally in the 1990s was 9.4Mha (million hectares), representing the difference between the annual deforestation of 14.6Mha and the annual afforestation of 5.2Mha [8]. The Stern Review [9] reinforces the finding that forest conservation, afforestation, reforestation and sustainable forest management can provide up to 25% of the emission reductions needed to effectively combat climate change. The international carbon market is a promising channel for improving livelihood opportunities for the rural poor in the forest areas [10].

Waste disposal and the availability of cleaner energy sources are two major issues facing Ghana and the rest of the world. Landfills and the emission of greenhouse gases present serious health and environmental threats. Finding solutions to these threats therefore advance waste-to-energy (WTE) concept as a potential option that should not be overlooked. To appreciate the contribution of the global WTE industry to the conservation of fossil fuels, it is worth pointing out that the energy it generates reduces the use of coal by an estimated 35 million tonnes [11]. Application of waste as an energy source would reduce the amount of fossil fuels used. Under normal conditions, one tonne of waste can generate 3.5 MW of energy, as much energy as contained in 300 kg of fuel oil [12]. An intervention had been made earlier in converting sawdust into briquettes for medium to large scale heating requirements such as for firing furnaces and kilns, pottering and the brick and tile industry [13]. Briquettes are more compact and uniform than firewood, making it easier to transport or store [14].

Cogeneration or combined heat and power (CHP) means using both the electricity and heat produced together, thus wasting less energy in production. These systems can also be installed close to users, reducing power transmission losses. It is a highly efficient and environment-friendly way of producing electricity and heat simultaneously. Cogeneration technologies have been developed which can generate both heat and electricity from the energy in biomass fuels with the principal objective of saving fuel [15]. These technologies should be of interest in Ghana where many rural communities are far from the national grid and the many wood processing industries generate substantial wood residue. Though cogeneration offers effective way of using biomass fuels, its adoption depends on its economic viability. Cogeneration equipment and their costs are fairly standard [16].

Cogeneration reinforces efforts to fight climate change by reducing CO_2 emissions (100 Mt CO_2 per year) and decreasing network losses. At the same time, it contributes to increasing competition in the electricity market. For these reasons, the European Union finds it necessary to ensure and exploit the full potential of cogeneration throughout the European Union [17].

More than 80% of the worldwide energy supply is based on fossil fuels. The replacement of fossil energy by renewable energy sources has a high signigicance with respect to the disadvantages of the utilization of fossil energy sources. With more than 75% biomass having the highest share of the energy generation from renewables [18]. In order to maximize the timber products and reduce deforestation as well as decreased dependence on the national grid for electricity, it is possible to use the residue to generate energy for domestic and industrial application through briquetting (with and without carbonization) and process heat and or power generation (cogeneration) [19]. This work therefore sought to assess the potential of cogeneration and wood waste briquetting to mitigate climate change in Ghana.

2. Methods

We identified potential sites for cogeneration by visiting a number of important and well-known wood processing mills in Ghana. During on-site visits to these mills, we used structured questionnaires and also had direct discussions with the mill management.

We used bomb calorimeter to determine the heating values of the wood species. We crushed the solid fuel (wood), sieved and then pressed them into the form of pellets in a special press. We dried the samples in a furnace and determined their moisture content. The measured temperature rise was corrected for various losses. The cooling loss was the largest but corrections were made for the heat released by the combustion of the wire itself. We determined the cooling corrections by the Regnault and Pfaunder, formula, and also determined the higher heating value (HHV) and lower heating value (LHV) of the 13 selected hard wood species.

In the absence of instrumentation for regular monitoring of electrical energy consumed, we derived the electricity consumption patterns from the monthly electricity bills over a period of one year. A bill for a particular month indicates the maximum demand for the month and the total energy consumed for the month.

Wood processing mills in Ghana obtain electric power from the national grid and use on-site boilers to meet the thermal energy need. The introduction of cogeneration in the mills is meant to achieve higher utilization efficiency of the wood residue by converting part of the wasted primary energy associated with the existing energy conversion system into electricity. Consequently, we sized the cogeneration plant for thermal load matching. Since information on thermal energy usage patterns was lacking, the peak process heat requirement was assumed to be the installed thermal capacity at the sites.

We selected the backpressure steam turbine due to the high steam consumption in the mills compared to availability of wood residues. We determined the size of a single-stage backpressure steam turbine topping cycle cogeneration plant for typical inlet pressures of 20, 30 and 40 bars and at superheated temperatures of 300°C and 400°C. We calculated the actual work done by the turbine by multiplying the isentropic efficiency by the work done by an ideal turbine under the same conditions. For small turbines, the turbine efficiency is generally 60 to 80%, for large turbines, it is generally about 90% [20]. The calculations were done assuming typical boiler, generator and turbine efficiencies of 78.96 and 50% respectively [21] and a boiler feed-water temperature and pressure of 90°C and 2.5 bar gauge respectively.

We determined the economic feasibility of cogeneration project at the three selected wood processing mills, using the payback period method:

$$\text{Payback} = \text{Total installation cost} / \text{Annual net benefit} \quad (1)$$

This method gives basic measure of the financial attractiveness of a project. It gives the length of time required for a project to return its investment through the net income derived or net savings realized. It disregards salvage value and time value of money.

We used the Combined Heat and Power (CHP) Emissions Software which compares the anticipated carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NO_x) emissions from a CHP system to those of a separate heat and power system to estimate the CO_2 emissions reductions.

We used sawdust collected from industrial sawmills at no cost and made them into sawdust briquettes by screw extrusion. We then carbonized the briquetted sawdust into charcoal in a steel carbonizer at a temperature of 500°C. We also carbonized wood cut from the forest into charcoal.

We determined charcoal yield from the briquetted sawdust as a ratio of the weight of charcoal made to the weight of un-carbonized briquette. We similarly obtained charcoal yield from wood. The average percentage charcoal yield from wood and the amount of charcoal produced from sawdust were used to estimate the quantity of trees that would have been cut from the forest to produce the same amount of charcoal as obtained from the sawdust.

$$W_{sbc} = W_w \text{ x \% yield of charcoal from wood} \quad (2)$$

where: W_{sbc}= weight of sawdust briquette charcoal, W_w= weight of wood cut from forest for charcoal production.

3. Results

Annual wood residues generated in the three mills studied ranged from 19,230 m^3 to 32,610 m^3. Heating values of the wood species ranged from 8.2 to 20.3 MJ/kg. The annual load curves plotted from monthly demand (kW) derived from the electricity bills as well as monthly energy consumptions (kWh) for a period of one year by the three mills were different, increasing from Mill A through Mill B to Mill C (Figure 1). For annual working hours of 7320, 7512 and 7512 with fuel consumption of 12590, 41694 and 46695 tonnes/year respectively for Mill A, Mill B and Mill C, power ratings for co-generation units were specified as 363 kWe, 1759 kWe and 1194 kWe. The heat to power ratios for the specified cogeneration units were 19, 19 and 21 respectively for Mill A, Mill B and Mill C. The initial appraisal of cogeneration potential at the three selected mills gave simple payback period of 7, 11 and 6.6 years respectively. The potential CO_2 emissions reduction resulting from the sized cogeneration units increased with increasing capacity of the unit (Table 1). Carbonization of the sawdust briquette and wood yielded on the average 25% charcoal and 30% charcoal respectively. Annual output of carbonized and semi-carbonized sawdust briquette from the briquette factory was 1400 tonnes.

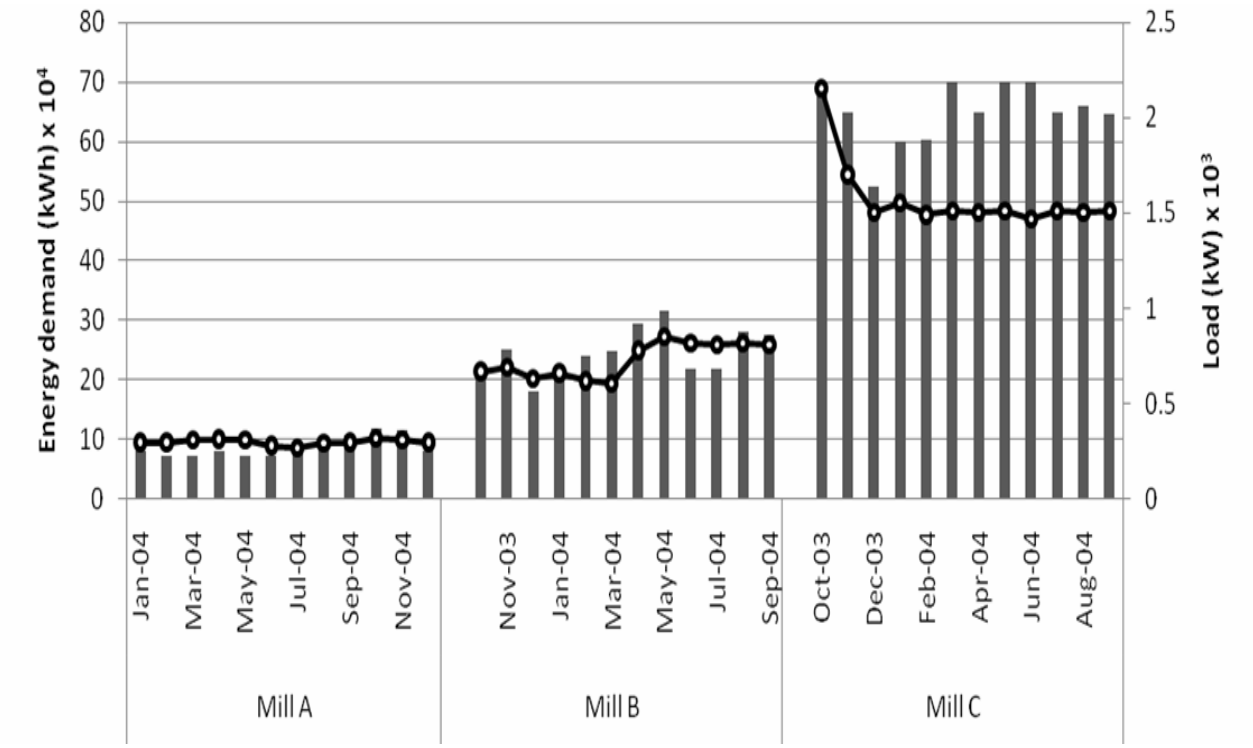

Figure 1. Electricity demand and consumption paterns of the three sawmills. Bars represent energy demand whilst lines represent load

Table 1. Potential emission reduction resulting from sized cogeneration (CHP) unit.

	Mill A	Mill B	Mill C
Unit Capacity (kW)	363	1759	1194
Operation (hr)	7320	7512	7512
CO_2 Emission Rate (lb CO_2/MMBtu)	117	117	117
Heat Content of Wood Biomass (Btu/lb), HHV	7395	7395	7395
CO_2 Emission Reduction (tonnes/year)	2777	13809	9373
Metric tons of carbon equivalent/year	687	3414	2318
Forest area absorbing carbon equivalent/year (acres)	572	2845	1931

4. Discussion

The energy sources for Ghana are oil products, electricity and biomass. The country imports all her oil requirements. Electricity is obtained primarily from two hydro stations and two light-crude-oil fired thermal plants. Urban residential areas consume virtually all the total household electricity produced in the country. Power from the national grid is not reliable and many high income urban household in the country use diesel/petrol generator set as standby in the event of power failure. Biomass-fired cogeneration plant could be used instead.

Many rural communities far from the national grid offer good prospects for biomass-fired cogeneration. These communities depend on biomass for energy particularly charcoal and fuel wood. Smaller modular cogeneration plants using internal combustion and sterling engines technologies could be most useful in these remote areas where biomass is abundant and electricity is scarce.

The estimated load profiles (Figure 1) and power-to-heat ratios were used to investigate the applicability of various types of prime mover technologies for a site. The wood processing mills in Ghana use onsite boilers to generate steam or hot water to meet all their thermal demand. Hence the cogeneration plants for the three selected mills were sized for thermal load matching. As the steam consumption in the mills was high, the backpressure steam turbine was selected.

Several turbine inlet pressures and temperatures were considered for the sizing of the cogeneration plants and from results of the study, the inlet temperature was specified as 400°C at all the three sites and the inlet pressure was taken as 30 bars at both Mill A and Mill B and 40 bars at Mill C. These led to power ratings of 363 kWe, 1759 kWe and 1194 kWe and heat to power ratios of about 19, 19 and 21 at Mil A, Mill B and Mill C respectively. The corresponding fuel consumptions were about 17,000m³/year, 80,000m³/year and 32,000m³/year. The fuel requirement for the plants at Mill A and Mill C compared favorably with the annual volume of residue generated which was estimated as 27,360m³ 32,610m³, at Mill A and Mill C respectively. Thus the mills generate enough wood residues which can be used to fire cogeneration plant to produce all or part of their electricity and thermal needs instead of relying solely on power from the national grid which is gradually becoming expensive as the country moves towards full recovery economic tariff. The wood processing mills however, have lower power to heat ratio and require cogeneration plants in the power range of 1 to 2 MWe.

The initial appraisal of cogeneration potential at the three selected mills, Mill A, Mill B and mill C gave simple payback period of 6.6, 7 and 11years respectively. These figures show that cogeneration projects in the Ghanaian wood processing mills could be financially attractive. Thus, co-generation using residues of the wood-processing industry is feasible in terms of technology and resource supply and has a great potential for alleviating some of the energy demand in Ghana as observed by Ellsworth [22].

The CO_2 emissions reductions are equal to the emissions attributable to the electricity displaced from the grid based on capacity increases in the current average fuel mix. It is assumed that wood residues would continue to provide the needed process heat for use in the various plants, with the same emissions as would have resulted due to decomposition/disposal of the residues. If no fossil fuel for electricity is consumed, then the overall emission savings is what would have resulted by burning the fossil fuel for electricity generation. Thus from the three mills studied, a total of 25,959 tonnes /year of CO_2 emission reduction could be achieved, with higher plant capacities providing more CO_2 emission reduction (Table 1). Cogeneration saves Europe around 280 million tonnes of CO2 and reduces the dependence on energy resources by 1500 PJ per year [23].

For a CHP system described as reducing emissions equivalent to planting 572 acres of forest (Table 1), it means that the difference in carbon emissions between the CHP system and SHP (single heat and power) is equal to the atmospheric carbon annually sequestered by 572 acres of forest. Thus from the three mills studied, the emission reduction of 25,959 tonnes /year of CO_2 is equal to removing the carbon that would be absorbed by 1848 acres of forest (Table 1).

In Ghana it has been determined that more wood fuels is consumed than any other energy source, followed by petroleum and electricity. It has also been documented that about 1.29 million Ghanaian households use charcoal for cooking, or about 31 % of the total number of households in Ghana [24]. According to the FAO, Ghana has the highest per capita wood energy demand in all of West Africa and is among the top two for charcoal. It has been estimated that about 69% of all urban households in Ghana use charcoal. The total wood fuel consumption in 2000 in Ghana was approximately 18-20 million tonnes of solid wood equivalent, with annual charcoal consumption of about 1.1 million tonnes [25].

The introduction of briquette on the well-established woodfuel market, as can be expected was characterized by suspicion, lack of confidence and unfair comparison with fuelwood in price and with charcoal in quality. The interviews and discussions with bakeries, brick and tile factories and other small scale industries using charcoal indicated that they are interested in briquette anyway. A vigorous publicity campaign is suggested by Cosgrove-Davies [26]. Since the yield of charcoal from wood was 25 %, then the annual production of 1400 tonnes of sawdust briquette charcoal, potentially saves 5,600 tonnes of trees/year in the forest (equation 2).

5. Conclusion

Adoption of cogeneration by the three mills studied potentially contributes CO_2 emission reduction of 25,959 tonnes /year, whilst conversion of sawdust in the briquette factory contributes a saving of 5,600 tonnes of trees/year that would have been cut from the forest. Thus, diffusion of biomass co-generation and sawdust briquetting nationwide could be of immense benefit to the country in terms of climate change mitigation. Cogeneration and sawdust briquetting would not only cut down Ghana’s fuel consumption and CO_2 emissions. It would also improve the reliability of energy supply, avoid important investments in new electricity networks, create jobs in high-tech and high value-added sectors, and strengthen Ghana’s competitiveness in energy efficient technologies.

A suite of potential bioenergy policies including a displacement of fossil fuels with a percentage of biofuels produced from forest and agricultural biomass; a price premium for electricity produced through cogeneration; and incentives for bioenergy producers could ensure minimal use of fossil fuels resulting in climate change mitigation. It is expected that these policies will not only impact the forest sector by creating demand for forest biomass but other sectors of the economy through factor markets. These results may provide valuable information for policy makers in their decision-making.

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