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Climate benefits from alternative energy uses of biomass plantations in Uganda

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ABSTRACT

The establishment of tree plantations in rural areas in Uganda could provide renewable energy to rural communities, while decreasing greenhouse gas emissions from conventional electricity sources and unsustainable forest use. The study evaluates the greenhouse gas benefits that could be produced by biomass based energy systems in Anaka, a rural settlement in the Amuru district in northern Uganda. Two alternative energy uses are explored: a) electricity production through wood gasification and b) traditional fuelwood use. It is estimated that a small-scale wood gasifier could provide electricity for basic community services by planting less than 10 ha of new short rotation coppices (SRCs). The gasification system could save 50–67% of the GHG emissions produced by traditional diesel based electricity generators in terms of CO_2-eq. (0.61–0.83 t MWh^{-1} or 7.1 t y^{-1} per hectare of SRCs). It was also estimated that traditional use of fuelwood in households is currently unsustainable, i.e. the consumption of wood is higher than the annual growth from natural wood resources in the study area. It is estimated that 0.02–0.06 ha per capita of plantations could render the current consumption of wood sustainable. In this way, the CO_2 emissions produced through unsustainable extraction of wood could be avoided (2.0–7.3 t per capita per year or 50–130 t y^{-1} per hectare of SRCs).

1. Introduction

Biomass is the main source of energy in Uganda. National statistics report that 91.5% of energy consumption is derived from the combustion of biomass sources such as fuelwood, charcoal and residues. A very limited share of energy use is covered by electricity (1.1%) and the remaining 7.4% is produced by fossil fuels [1].

Wood biomass will likely remain the dominant household energy source for cooking and heating for several decades in Uganda due to low accessibility to alternative energy sources [2]. In addition, biomass is seen as an option to provide electricity to rural areas where only 1% of the population has access to the grid. High electricity prices, frequent power outages, and high line losses pose hurdles to increasing access to the grid over the short to medium term.

At the same time, forest statistics report that wood resources in Uganda are constantly decreasing [3]. Consequently, biomass based electricity generation or traditional energy from fuelwood can be expected to be constrained by a decreasing availability of wood from forests and other wooded lands. By contributing to the degradation of natural wood resources, biomass based energy

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also contributes to increase greenhouse gas (GHG) emissions in the atmosphere and to climate change.

The establishment of new plantations in developing countries could guarantee wood availability for the future, supply feedstock to renewable energy systems that are accessible to rural communities and produce GHG benefits as compared to fossil fuel based systems and unsustainable wood extraction.

This study assesses the climate mitigation benefits produced by alternative uses of wood plantations, when new Short Rotation Coppices (SRCs) are established on non-forested, low carbon stock land in Uganda. The comparison of GHG benefits from alternative uses of a certain bioenergy source is important to support the most efficient strategies to achieve GHG emission reductions [4,5]. To the knowledge of the authors, this is the first attempt to make such an assessment from wood plantations in Uganda.

Two alternative energy uses of wood plantations in a rural area in Uganda are considered:

a) Electricity from wood gasification; and
b) Firewood for traditional use in households.

The climate mitigation benefits of wood gasification are assessed by applying a GHG balance based on a Life Cycle Assessment methodology. The balance compares the GHG impacts of the gasifier to the impacts of a typical fossil fuel based electricity generation.

In parallel, we assessed the area of SRC plantations needed to supply fuelwood to the rural community. The plantations would avoid degradation of natural biomass resources and thus avoid increasing GHG in the atmosphere. An estimate of the avoided emissions is provided.

2. Methods

2.1. *Study area*

The study area is located in the Amuru district in the Northern part of Uganda (02°36′0″N, 31°57′0″E). The CLIMWAT database [6] reports an annual precipitation of about 1500 mm y^{-1} and an average annual temperature of 23 °C for the meteorological station in Gulu. Climatic measurements taken in 2005–2007 in Aswa-Lolim, Amuru suggest that the average rainfall could be lower in certain areas of the Amuru district, around 900 to 1000 mm per annum [7].

The Anaka refugee camp in Amuru is the settlement chosen for the installation of the gasifier and the assessment of the impacts of traditional use of fuelwood. The Anaka internally displaced people camp (IDP camp) hosts about 22,450 people. Main electricity users in the camp are the hospital and shops. Anaka is located in the north-western part of a water catchment in which the main land uses are grasslands (727 km^2), followed by agricultural land (214 km^2) and forests (192 km^2) [8]. Currently, grasslands are used for hunting. Most likely, in the near future land will return to small holder agriculture and cattle ranching, as they were before the civil war.

2.2. *Biomass for electricity*

Previous investigations showed that small-scale wood gasifiers could be an economically and socially feasible energy system to produce electricity in rural Uganda [9]. This study integrates previous analysis by assessing the mitigation potential of wood gasifiers in Uganda. The GHG benefits of electricity generation by wood gasification as compared to electricity originating from diesel generators in the IDP camp of Anaka are evaluated through a GHG balance based on a Life Cycle Assessment methodology.

2.2.1. *GHG balance*

A GHG balance, based on a Life Cycle Assessment (LCA) methodology, includes all processes, which influence GHG emissions from *cradle to grave* [10]. The GHGs included in the study are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Global Warming Potentials (GWP) on a 100 year time horizon are used to express the contribution of CO_2, CH_4 and N_2O to global warming in terms of equivalent amount of CO_2 (CO_2-eq.) [11].

The GHG balance is performed with the Global Emission Model of Integrated Systems (GEMIS), version 4.5 [12] and project specific data are added to the GEMIS standard data set version 4.5. Two different systems for electricity production are analysed:

- "Electricity wood gasifier – E-WG": Production of electricity with a centralized wood gasification system. The biomass used is supplied from Short Rotation Coppices (SRCs) of *Eucalyptus grandis* Hill ex Maiden.
- "Electricity diesel generator – E-DG": Production of the electricity with decentralized diesel generators.

The GHG balance is based on process chains which are designed for each investigated system: the wood gasification and the reference fossil fuel system (diesel generator). A process chain describes the complete life cycle, starting with the production of raw materials and ending with the supply of energy to the end user (Fig. 1). Emissions or removals from the conversion of grassland to SRCs are also included.

2.2.2. *Input data*

The electricity demand for the Anaka camp is estimated based on a study conducted in the refugee camp of Kyangwali, Uganda within the project BIOSYRCA [13]. Electricity is used by the hospital and the trading centre of the Anaka camp. In Kyangwali, the electricity demand is estimated to be 25.5 MWh y^{-1}. In this study, a demand of 30 MWh y^{-1} is assumed as a conservative estimate to include a possible increase of demand in the near future and higher electricity needs for the hospital.

The data on the electricity generators are reported in Table 1. The gasifier powers a modified diesel engine that runs on a dual fuel mode. The fuel gas provides 75% of the primary energy input. Diesel is required for start-up operations and to support the systems. A small power grid must be constructed to supply electricity from the gasifier to the main buildings of the refugee camp. The length of transmission lines is assumed to be 2 km to connect the hospital and shops of the trading centre. In the case of diesel generators each of the buildings