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Original article

# The carbon footprints of alternative value chains for biomass energy for cooking in Kenya and Tanzania

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ABSTRACT

Due to its availability and affordability for poorer populations, wood-based biomass energy remains vital in meeting local energy demands – especially for cooking fuel – in many regions of the developing world. However, increasing feedstock scarcity (e.g. due to deforestation) coupled with the negative socio-economic and environmental outcomes of inefficient production and consumption technologies make it imperative to identify alternative energy solutions that benefit people without harming the environment. Indeed, tackling energy poverty is crucial to efforts aimed at meeting sustainable development goals at the household level. However, interventions aimed at reducing energy poverty must simultaneously seek solutions that might reduce people's carbon footprint. Carbon footprints, or the amounts of greenhouse gas emissions linked to particular activities, are associated with climate change and its impacts. Globally, calls have intensified to reduce the carbon footprint of energy use, including use of biomass fuels. Locally, climate change issues are increasingly seen as posing particular threats to already vulnerable communities. The present paper evaluates the carbon footprints of alternative biomass energy solutions for cooking, as one key aspect of their environmental performance. It compares the carbon footprints of firewood, charcoal, biogas, jatropha oil, and crop residue briquettes. The research focuses on selected technologies for biomass energy production and consumption in two case study sites in rural and urban contexts of Kenya and Tanzania. Carbon footprinting is applied as a methodological approach to evaluating technological options for sustainable development in developing economies undergoing rapid population growth, urbanization, and industrial development. Results indicate that the unimproved charcoal value chain has a big carbon footprint. The value chain for jatropha oil appears to hold the greatest potential for carbon footprint reductions, as long as the feedstock is grown in the form of hedges around plots. However, the limited yield potential of hedges calls into question the economic viability of this solution. Results further show that carbon footprinting can help to raise awareness and inform stakeholders and decision-makers about alternative, environmentally more suitable biomass energy value chains. However, any assessment of the overall sustainability of these value chains should also integrate socio-economic aspects and factors influencing adoption.



## Background and objectives

Biomass energy continues to play a vital role in meeting household energy demands, especially in developing countries, where it remains easily accessible and affordable [1–3]. About 94% of Africa's rural population and 73% of its urban population use wood-based fuels as their primary energy source. Urban dwellers rely heavily on charcoal, while communities in rural areas tend to depend more on firewood [4]. In Kenya, biomass energy covers 69% of the population's overall energy needs, petroleum about 22%, and electricity as little as 9% [5]. In Tanzania, more than 90% of the population depend on wood-based energy for cooking [3,6]. This reliance on biomass energy in its many forms is likely to continue in the foreseeable future, especially in light of population growth, urbanization [2,7,8], and delays in providing access to modern

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energy sources. Only 17% of Kenya's population and 3% of Tanzania's population have access to modern fuels [9].

In both countries, there is growing concern about the negative environmental and socio-economic impacts of this dependence on wood-based energy. Pressure on forests, land and water degradation, greenhouse gas emissions, and adverse effects on human health because of indoor air pollution are the main arguments raised against continued use of wood-based energy carriers. Accordingly, energy policies in Kenya and Tanzania emphasize the need for a shift towards modern energy sources [5]. However, despite widespread views that biomass energy production and consumption technologies are backward, inefficient, and harmful [8,10], alternative biomass energy value chains may still represent viable options capable of simultaneously alleviating poverty through income generation and being environmentally sustainable if properly implemented [11].

Biomass energy can be produced in an environmentally friendly way if raw materials and production technologies are adequately selected [12], and biomass energy supply chains can be sustainable if carbon emissions and economic efficiency are properly addressed [13]. A systematic review conducted by Robledo-Abad et al. [14] indicates that knowledge about the impacts of bioenergy production on sustainable development is primarily concentrated in developed countries. They recommend increasing such knowledge in developing countries. At the same time, assessing the sustainability of biomass energy supply chains is often complicated by data scarcity. Many developing countries lack up-to-date information that can be used in decision-making. For example, up-to-date forest inventories, needed for sustainable wood fuel production, are often unavailable [15].

Increasing feedstock scarcity (e.g. due to deforestation) coupled with the negative socio-economic and environmental outcomes of inefficient production and consumption technologies [8] make it imperative to identify alternative energy solutions that benefit people without harming the environment. One major environmental concern is climate change. Energy use affects the climate by causing emissions of greenhouse gases. The amount of greenhouse gas emissions linked to a particular activity is also referred to as the activity's carbon footprint. Globally calls have intensified to reduce the carbon footprint of energy use, including use of biomass fuels. Locally climate change issues are increasingly seen as posing particular threats to already vulnerable communities. Interventions aimed at reducing energy poverty must therefore simultaneously seek solutions that might reduce the carbon footprint of energy use.

The main objective of the present research is to evaluate the carbon footprints of various biomass energy value chains in two rural and urban contexts in Kenya and Tanzania. We focus on firewood, charcoal, biogas, jatropha oil, and crop residue briquettes, and on selected technologies for the production and consumption of these fuels. We consider biogas, jatropha oil, and crop residue briquettes to be possible alternative energy sources for household cooking. The aim of our research is to help identify less environmentally harmful biomass energy value chains for households that cannot access modern fuels.

## Methodology

### *Study sites*

The research was carried out in two case study sites: Kitui County (Kenya) and Moshi (Tanzania). The two sites lie in different agro-ecological zones and provide a good sample of East African ecological conditions. Furthermore, both sites are in the vicinity of medium-sized towns that represent substantial, but still assessable consumer markets for locally produced biomass fuels.

Kitui County in Kenya has a population of about one million [16], 90% of which lives in rural areas. Population growth, estimated at 2.1%, is expected to increase pressure on natural resources [17] and to aggravate land degradation. An estimated 96.9% of people in Kitui County use solid biofuels for cooking [16]. Of these people, 89% use firewood as their main source of energy, while 8% rely mainly on charcoal [18]. Firewood use dominates in rural areas, while charcoal use dominates in urban areas. Nearly 300,000 bags of charcoal are produced in the county annually, causing severe land degradation in an already fragile ecosystem [19].

Moshi, located in Kilimanjaro Region in Tanzania, has a population of about 700,000. Between 2002 and 2012, population growth in Kilimanjaro Region was 1.8%. This is lower than the national average of 2.7% [20], but still high enough to cause increasing pressure on natural resources, including wood for energy production. Similar to Kitui County in Kenya, firewood and charcoal are the dominant sources of energy for cooking for about 90% of rural and urban populations in Moshi [21].

### *Carbon footprinting*

We applied the Life Cycle Assessment (LCA) technique to calculate and compare the carbon footprint of five different biomass energy value chains (see Table 1 and Section "Selected value chains and assumptions"), focusing on selected production and consumption technologies. The international ISO 14040 standard defines LCA as a technique used to quantify the environmental impacts of a product over its whole life cycle, from raw material acquisition through production, use, end of life treatment, recycling, and disposal [22]. It analyses the material flows and energy flows, quantifies environmental impacts, identifies opportunities for environmental improvement, and helps decision-makers understand the sources and sizes of impacts throughout the life cycle. It is used for product development and improvement, strategic planning, public policymaking, and marketing.

Our analysis is based on data from the literature and background data from version 3.1 of the *ecoinvent* database [23]. As the global warming potential is a key indicator from a climate perspective, and as this indicator, in the case of energy use, is also strongly related to energy efficiency and land use change, we decided to focus on calculating the carbon footprint, which is considered a key aspect of a full LCA. The data basis for LCA in East Africa is scarce. To date, bioenergy LCAs have mostly focused on developed countries [14]. For this reason, we calculated feedstock amounts and biomass fuel yields based on the specific technology's efficiency (see Table 1) and data from the literature (biogas). Emission data for the different life cycle stages were obtained from secondary sources and through calculation based on the guidelines for combustion of stationery sources of the Intergovernmental Panel on Climate Change (IPCC) [24], especially where we found no emission data in the literature (see Table 1). An analysis was done for potential environmental impacts using the global warming potential (GWP 100a) indicator for climate change of the IPCC [25], expressed in terms of kilograms of carbon dioxide equivalents, which we refer to as carbon dioxide equivalents ($CO_2$eq) below. Data were analysed using Simapro software [26].

### *Selected value chains and assumptions*

We evaluated the five biomass fuels in combination with several specific production and consumption technologies, which were selected by stakeholders in participatory workshops in Kitui and Moshi, in June 2014. Participatory selection was done with