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Household energy economics in rural Ethiopia: A cost-benefit analysis of biogas energy

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ABSTRACT

Limited success in promoting improved energy sources, such as biogas, in rural areas of developing countries has been partly blamed on insufficient understanding of household energy use patterns. In this study, we assess the costs of energy generation from major energy sources (firewood and dung) in rural Ethiopia, as well as the economic potential of biogas as an alternative in addressing both energy and food security challenges. Results show that households in rural areas largely collect their own fuel, with female household members being mainly responsible for the chore. By investing in biogas plants, households could save time and energy, and have a supply of slurry that can be used as fertilizer in agricultural production. A cost-benefit analysis of biogas plants yields positive net present values for households collecting their own energy sources. Even higher net present values are obtained for households purchasing all of their energy needs; these households stand to gain significantly from the financial benefits of energy cost savings with biogas technology. Results are highly dependent on slurry being effectively used as a source of fertilizer and on the price of the replaced energy source. Thus the promotion of slurry use as fertilizer must be an integral part of a successful biogas programme. Another important issue is that at present, biogas plants are highly subsidized and thus the above conditions hold under the assumptions of subsidies. When analysed without subsidies, indicators are still positive, yet amortisation periods are significantly longer and close to the depreciation point, so that investment risks increase.

1. Introduction

Africa's energy challenges have been described as major and severe despite the existence of great energy potentials on the continent [1–4]. Access to modern energy systems remains a challenge in Sub-Saharan Africa despite reserves of petroleum, natural gas and coal, which in 1990 accounted for nearly 2%, 3% and 1% of world reserves respectively, and the potential of hydro-, solar and geothermal energy sources [4]. Consequently, biomass, consisting of firewood, charcoal, dung and crop residues, remains the main source of energy in Sub-Saharan Africa [1–3].

The current widespread and inefficient use of biomass energy has implications on the environment, human health and food security [5–7]. Deaths from acute respiratory infections as a result of indoor air pollution have been estimated at around 1.3 million annually, which is higher than malaria deaths and almost half of HIV/AIDS deaths [8]. Women and children are the most affected as their exposure to indoor air pollution is higher than that of men [2,5]. Air pollution also contributes to greenhouse gases (GHGs) leading to climate change [5]. High demand for firewood (and its charcoal form) in urban areas has been linked to increased deforestation [9]. Household productivity is affected by the reallocation of time and labour from yield bearing activities to the collection of biomass energy [10]. Households also lose productive time due to ill health [5]. Biomass combustion in general and dung and crop residue combustion in particular amount to nutrient export from agricultural land [11].

Like other Sub-Saharan countries, Ethiopia is highly dependent on biomass for energy; households in rural areas are almost completely dependent on biomass for their energy needs [12]. Firewood is becoming scarce in Ethiopia where increasing population pressure, land degradation, deforestation and loss of soil nutrients continue to worsen both food security and the energy crisis [13,14]. With the increasing shortage of firewood, households are turning to dung and crop residues for energy. This new reliance

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further contributes to environmental, human health and food security problems. Consequently, there is a need to jointly address energy and food security challenges [15,16].

The lack of success in promoting cleaner and improved energy sources in Sub-Saharan Africa is partly due to the limited understanding of household energy use patterns [17]. Relatively few studies have focused on household energy use in Africa [18]. Biogas offers a technically feasible energy alternative in rural areas and helps mitigate some of the consequences of extensive biomass energy use [19,20]. Ethiopia, where the technology has been promoted since 1979 to kerb the energy crisis, has, according to the UNDP/World Bank Energy Management Assistance Program (ESMAP), a biogas potential of up to two million family units [21]. A feasibility study carried out by Eshete et al. (2006) revealed that of Ethiopia's 600–700 domestic biogas plants, about 60% have stopped functioning due to water and dung shortages, technical problems, abandonment and loss of interest [12]. A similar trend was observed by Ethiopian Energy Authority (EEA) [21]. Despite past failures the country has recently set up a multiple stakeholder driven biogas programme implemented by the National Biogas Programme Ethiopia (NBPE) to develop a viable and sustainable commercial biogas sector [22]. One of the earlier studies on biogas in Ethiopia has been conducted by Seyoum (1988) [23]. A more recent study undertaken by Renwick et al. in 2007 also deals with the financial performance of biogas plants in Sub-Saharan Africa as a whole, including, but not solely focused on, Ethiopia [24]. We follow the conclusions of their research which propose further studies examining market segmentation with respect to different potential target household types. Therefore, the main objective of the study is to provide a detailed analysis across different segments of the potential target groups and plant types. In particular, we segment the potential demand situations for biogas plants in three energy source scenarios, namely for households purchasing firewood, collecting firewood, and collecting dung. In a sensitivity analysis, we differentiate households according to their income. We also discuss two different sizes of biogas plants with 4 m^3 and 6 m^3 fermenter volume. As the majority of potential target households live in rural areas with agriculture as their main economic activity, we have a closer look at the potential linkages between agriculture and biogas plants by computing the fertilizer value of slurry as a by-product in the process.

2. Materials and methods

2.1. Study area and data

Household surveys for the study were conducted in two *woredas* (districts), Dale in the Southern Nations Nationalities and Peoples Region (SNNPR) and Arsi Negele in Oromiya Region, both of which are located around Awassa, the regional capital of SNNPR. Awassa is approximately 280 km south of the Ethiopian capital Addis Ababa. The SNNPR and Oromiya regions are two of the four regions targeted by the NBPE. The two *woredas*, one from each region, were selected because of their different dung usage habits: In Arsi Negele dung is commonly used as both fertilizer and a source of energy for cooking, while in Dale it is primarily used as fertilizer.

2.2. Data collection

The rural farm household, defined in this study as a group of people sharing the same hearth and depending mainly on agriculture for their livelihood in a rural area [25], is the sampling unit. A multistage stratified sampling method was used to obtain study *kebeles* (villages). A complete list of *kebeles* was constructed with the help of local authorities at *woreda* level taking into consideration different regions for consideration of agro-ecological and climatic factors as availability of firewood varies by climatic region. Four *kebeles* were randomly selected for the study. Probability proportional to size (PPS) sampling method was used to select 80 households at *kebele* level. At each *kebele*, a list of households was obtained from the *kebele* office and systematic random sampling was used to select study households.

A standard household questionnaire applied in a survey in April and May of 2010 was used for primary data collection. The questionnaire at household level covered demography, income sources (on- and off-farm), resource and asset endowment, land cultivation, agricultural input use and crop yields, food availability and access, food security status, and labour and energy management. A total of four key informant interviews, one at each *kebele*, were also conducted to obtain information on land ownership, livestock ownership and energy sources usage. Key informants included administrative officials and developmental extension officers. Additionally, selected markets in survey areas were visited to check on available energy sources and their respective prices.

2.3. Conceptual framework

We assume that households maximize their utility subject to constraints like resources and budgets. Energy sources are intermediate consumption goods that carry a cost to the household and are used for different purposes, chief among them household food preparation [26]. According to Newman et al. (1996), energy consumption leads to both (positive) utility but also to (negative) waste and other effects [27]. These costs and benefits are pivotal in this study to the comparison of main energy sources for rural Ethiopia. Households make decisions on energy collection and use based on a shadow price [28,29]. Shadow prices of energy sources are determined by the economic value of alternative uses of the resources committed for energy generation. Households have an option to either purchase or collect energy sources and the shadow price also depends on the trade-off between household budget and time constraints.

2.4. Shadow price of energy sources

For a functioning market, the market price of an energy source reflects the cost of its use. For energy sources that are not purchased on markets, opportunity costs or shadow prices are determined by time spent collecting the energy source [10]. Following the work of Kanagawa and Nakata (2007) the following formula was used for calculating opportunity costs of energy sources [30].

$$\mathrm{OCE}_i = \frac{\mathrm{OCL}}{\mathrm{DE}_i} \times T_i, \quad (1)$$

where OCE is the shadow price per unit of energy (ETB/GJ),[1] OCL are the opportunity costs of labour (ETB/hour), DE is the energy (GJ/year) for energy source i and T is the time spent (hours/year) for collection.

Dung has an additional opportunity cost in its alternative use as fertilizer. Tests for determining the fertilizer values were conducted on dried dung samples collected concurrently with the household survey. Elementary analysis (dry combustion according Dumas) was performed for nitrogen content. The results indicate that on average 16 kg of dung is equivalent to 1 kg of diammoniumphosphate (DAP), a common fertilizer in Ethiopia,

[1] At the time of the study, the exchange rate ETB/US $ was 13.4.