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# Overview of holistic application of biogas for small scale farmers in Sub-Saharan Africa

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ABSTRACT

Holistic farming systems provide designs for the whole farm that make long term sustainable use of nutrients, water, labour, finances and energy. In using organic residues to produce energy, and safely recycling the digested residues back into the farming system, a biogas digester could be a central component of many holistic systems. This paper discusses the influence of environmental, socioeconomic and cultural constraints on the use of biogas digesters in holistic farming systems in Sub-Saharan Africa. In higher altitude areas where maintenance of optimal temperature can constrain anaerobic digestion, floating drum or fixed dome digesters are a better option than flexible balloon digesters because they are less susceptible to temperature changes. If water is a key constraint, rainwater harvesting could be used to reduce the additional labour needed to collect water. If energy is the most limiting resource in the farming system, the optimum use of organic residues might be as a fuel for anaerobic digestion, whereas, if water is limiting, energy production by burning or pyrolysis might be a better option. The bioslurry from anaerobic digestion can be used in fish ponds to produce plankton to feed fish, and can be applied to fertile fields and fields of intermediate fertility, while biochar from pyrolysis is better used to improve the soil in infertile fields. If labour is limiting, it is particularly important that the system design minimises any additional labour needed to process the organic residues on a daily basis, considering trade-offs between labour and other resources.



## 1. Introduction

All farming systems, whether holistic or not, are structured around the availability of the resources; water, energy, nutrients, carbon, labour and finance. Holistic farming systems attempt to maximize re-use of resources so as to maximize efficiency and long term sustainability, incorporating financial, land and grazing planning, as well as biological monitoring [1]. Biogas digesters can form a central component of a holistic farming system, allowing the efficiency of many aspects of the system to be optimized by providing energy for household use, cleaning and recycling of waste water and producing an organic fertilizer that can be used in aquaculture or can be used to return carbon and nutrients to the soil to improve crop productivity [2]. There is a significant move within many countries in Sub-Saharan Africa (SSA) to increase the implementation of zero grazing systems. This provides a timely

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incentive for biogas development in order to fully utilise the increased animal excreta captured at the household level. The number of biogas installations across Africa is increasing, largely in the domestic energy sector, due to national domestic biogas programmes, such as supported by the African Biogas Partnership Programme, aiming at constructing 70,000 biogas plants in Rwanda, Tanzania, Kenya, Uganda, Ethiopia, Cameroon, Benin and Burkina Faso by the year 2013 [3]. Success of these systems depends on them being fully integrated into the farming system so that the multiple potential benefits of biogas digesters can be realized.

As for many issues related to rural development with small scale farmers in Africa, there is never only one solution [4]. Rural areas, in most cases, are characterized by heterogeneity in physiographic, climatic and socio-economic conditions [5]. A range of different approaches is required to cater for the technological demands of different areas. The same applies to production of biogas. In principle, anaerobic digestion is a conversion of organic materials into methane, carbon dioxide and bio slurry [6]. While the principles are the same, there are many different methods that can be used, depending on the climate, soils, organic residues and water availability at different times of the year. Methods of anaerobic digestion are classified by critical operating parameters including continuity (batch or continuous), operating temperature (psychrophilic, mesophilic or thermophilic), reactor design (plug-flow, complete-mix or covered lagoons), and solid content (wet or dry) [7]. Designs most commonly used by small scale farmers in Africa and Asia are continuous, mesophilic (30–38 °C [8]), plug-flow, wet processes and include flexible balloon [9], fixed dome [10,11] and floating drum digesters [10]. The design of the digester has implications for the conditions that must be supplied by the farming system to achieve optimum biogas production (amount and quality of feedstock, water, temperature etc), and so profoundly influences the nature of other operations that can be included on the farm. Choice of method is also dependent on the culture and tradition of the people. For instance, in some cultures human excreta can be incorporated; in other cultures not so [12]. This impacts the nature of the feedstock available for digestion.

Different authors have attempted to formalise methods used in farming system design. De Jager et al. [13,14] presented the NUTMON concept (Nutrient Modelling for Tropical Farming Systems – now rebranded at farm scale as MONQI – Monitoring for Quality Improvement), which integrates agronomic, economic and social objectives to arrive at specific nutrient management practices, using a questionnaire to produce a farm inventory of nutrient and economic flows to and from all farm units. The NUANCES approach (Nutrient Use in Animal and Cropping Systems: Efficiencies and Scales [14]) uses dynamic simulation models to maximise the use efficiency of all inputs at farm level; this allows modelling techniques, such as inverse modelling [15], to be used to suggest farming strategies that would result in the best possible trade-offs between different farming objectives. These approaches have not yet included biogas digesters; here we review the information that is needed to use such methods to design a farming system around a biogas digester.

By carefully planning the holistic farming system around the recycling of resources provided by a biogas digester, improved returns for the input of labour and the investment needed for the installation and operation could be achieved. This article discusses how the elements of such a holistic farming system can be brought together and designed to suit the particular environmental, socioeconomic and cultural constraints of operation. By bringing together, in one paper, a review of the impact of different constraints on the design of a farming system centred on a biogas unit, the potential impacts on resource flows and feedbacks are considered. This provides a new emphasis on the design of biogas digester based farming systems in SSA that has not yet been considered in previous work.

## 2. Environmental constraints

### 2.1. *Temperature*

The optimal temperature for anaerobic digestion is between 35 and 40 °C [16]. In an investigation of the impact of temperature on methane production capacity and energy output, Wei et al. [17] observed that the optimum temperature for anaerobic digestion was 35 °C, producing the largest amount of methane in only 31 days. At lower temperatures, total methane production was reduced and required a longer period for complete fermentation. However, methane production continued at temperatures as low as 20 °C. Bohn et al. [18] investigated methane production in a laboratory-scale reactor, inoculated with mesophilic bacteria and operated at temperatures as low as 12 °C. Hydrolysis was observed to decrease below 25 °C, and below 16 °C, acidogenesis and methanogenesis became rate limiting steps; this was accompanied by adaptation of the microbial population in the digester.

If the temperature is much lower than the optimum, other means may be required to raise the temperature in the digester. Kumar and Bai [19] used a greenhouse canopy to raise the temperature in a plastic digester, allowing gas production to continue during the winter period when temperatures ranged from a maximum of 16–21 °C to a minimum of 2 °C. Hong [20] reported the use of compost to insulate and heat an anaerobic digester. The biogas produced can also be used to generate the heat required to raise the slurry temperature to the optimum for anaerobic digestion [21].

The heat lost during anaerobic digestion is a function of the surface area and the insulation of the digestion vessel. Therefore, small scale anaerobic digesters lose a higher proportion of their heat than larger digesters. This is one reason why small scale biogas units are found in Asia and Africa but are not common in more temperate climates. Even in Asia and Africa, biogas technology is not popular in high altitude areas due to low temperatures. Biogas units in temperate zones are generally very large and not used by small scale farmers, and even in sub-tropical zones, part of the year may be too cold to maintain efficient small scale biogas production. This suggests that small scale biogas units are more suitable for tropical and sub-tropical than for temperate regions.

Digester design affects the temperature profile that can be maintained in the digester; in cold, hilly conditions, a fixed dome digester was observed to maintain a lower temperature