# Biogas production from biowaste in Kenya and its contribution to environmental sustainability

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The inspiration of utilising biowaste to provide a sustainable alternative energy source was the motivation behind this work. The evaluation of biowaste energy potential and the development of a simple methodology to assess its sustainability were the main challenges undertaken as part of this research. In this work objectives were therefore set to gain insight in the biogas value chain from the perspective of biowaste energy. The research also sought to formulate and operationalize a sustainability assessment framework for biowaste energy production. In addition, the research analysed the potential contribution of biowaste-based biogas energy to environmental sustainability from a case study perspective.

Pursuance to the research objectives, in **chapters 1** and **2** an introduction and analysis of the biogas value chain is given. Chapter 1 presents the motivation of the study and the scope of the work whereas chapter 2 focuses on the biogas value chain (BVC) integrating the BVC production oriented advances with targeted valorisation from the life cycle analysis perspective. Three different categories of advances and system-wide challenges and opportunities are evaluated. It is shown that while the BVC system presents virtually unlimited opportunities for the valorisation of biowaste, it suffers from apparent disconnect in most of the advances. Consequently it is observed that substantial sustainability insight of the BVC is eminent for it to incontrovertibly remain competitively vital to the sustainable energy matrix.

An overview and development of the sustainability assessment framework for the assessment of biowaste-based biogas energy is given in **chapter 3**. Innovative aspects of the proposed framework are the development of a multi-dimensional assessment system with a typology of multi-criteria indicators relevant for biogas energy. In addition two main sustainability issues that could potentially undermine the sustainability of Biowaste-based Biogas Energy (BBE) and hence the assessment framework are defined highlighting the associated opportunities and risks.

First, land use, opportunities and risks are to be taken into account. However, since BBE relies on residues such as agro-based residues, it therefore follows that BBE systems do not have stringent land quality requirements. This implies that technically all the land under agricultural production can be deemed to be available for BBE production. Consequently it can be accentuated that BBE production does not compete with agricultural land and avoids conversion of land with high carbon stocks. In addition since biowaste energy relies on biowaste such as agro residues, it suffices to say that there are no inherent land use risks specific to BBE production.

The second sustainability issue of major concern is resource use, opportunities and risks. While BBE offers possibilities for improving efficient utilization of raw materials, there are concerns on how to tackle potential risks such as soil organic carbon stocks. Nevertheless, the possibilities for closed loop biomass resource cascade configurations are deemed to sufficiently address the forgoing concerns.

In **chapters 4 – 7** of this thesis, different aspects of the sustainability framework are expounded further. In **chapter 4**, two main features related to sustainable application of biowaste in biogas production are defined and tackled by means of characterisation in terms of biogas quality and the key plant nutrients. The results demonstrate the suitability of agricultural residues and segregated textile effluents for biogas and nutrient recovery. Since the valorisation of biogas as a sustainable energy carrier especially for domestic applications precludes the need for specialised biogas cleaning, the results further corroborate the need to explore increased use of the feedstock devoid of gas contaminant precursors as highlighted earlier in chapter 2.

**Chapter 5** elucidates on biowaste energy potential in Kenya and concomitant electricity gains which amount to about 73% of the country's annual power production of 5307 GWh. The evaluation is executed for agricultural residues from five of the major crops produced in the country and takes cognisance of other competing uses of the residues. The results demonstrate that the exploitation of the potential presented by the biowaste residues in biogas production can have a major economic impact in the country. Building on the framework introduced in chapter 3, in **chapter 6**, a multi-criteria sustainability assessment method is developed and applied to screen three different alternatives of biogas production when linking biogas energy with infrastructures of production. The assessment couples integrated life cycle concepts to comparatively analyse the technical, economic and environmental performance of the floating drum, fixed dome and tubular biogas digester systems commonly promoted in Kenya. From the study, it is shown that the three different biogas production systems demonstrate significantly different sustainability behaviours. Furthermore, it is shown that to produce biogas from waste in Kenya, energy inputs are limited to 1.89 MJ/$m^3$biogas while the total energy invested in biogas production for 20 years can be recouped within 26 months of digester operation. In addition, replacement of kerosene by biogas from waste is observed to yield direct global warming reduction of up to 1.09 kg $CO_2$ eq/$m^3$ biogas. On the other hand, the energy autonomy due to biogas production yields a fossil energy replacement saving ranging from 30 to 37 \$Cents/$m^3$ biogas. In general, the tubular biogas digester life cycle scores significantly better in six of the nine impact criteria considered. In **chapter 7**, a case study is presented on the added value of biowaste valorisation to the environmental profile of the African Kitenge. The environmental profile of the production of 1kg Kitenge is evaluated comparing the scenario without biowaste valorisation to the scenario where biowaste is valorised in biogas production and nutrient recovery. The case study employs some of the principles presented in chapter 5 and 6. This study revealed that the production of Kitenge is currently associated with a carbon footprint of 15.58 kg $CO_2$ eq/kg and a corresponding energy demand of 120.5 MJ eq/kg. However it was observed that biowaste valorisation, especially for biogas and nutrient recovery, could yield up to 25% and 37% reduction in carbon foot print and energy demand respectively. These findings underscore the added value of biowaste valorisation to the environmental sustainability of the African Kitenge.

**Chapter 8** is a general discussion of this dissertation while positioning it in the scientific literature and outlining the perspectives.