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Water-Energy-Food-Ecosystem Nexus in Western Africa

Small-scale sustainable solutions and energy from agricultural organic waste

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1 Executive summary

The present report outlines the findings of a scientific workshop organized by the Joint Research Centre of the European Commission in cooperation with two academic institutions of Senegal: the Université Cheikh Anta Diop de Dakar and the Université Assane Seck de Ziguinchor. The event took place in mid-November 2017 in Dakar and was titled "WEFE Nexus approach for small-scale sustainable resources' management and energy from agriculture organic waste in Western Africa". The objective of this Workshop was to exchange expertise and information, showcase experiences and to collect, discuss and analyse data on the role played by agricultural residues in satisfying local energy needs in a Water-Energy-Food-Ecosystem approach and in the African context. Discussions covered a wide range of scientific topics and challenges, aiming at exploring the full range of the water-energy-food-ecosystem (WEFE) complex interactions.

Accordingly, the following topics have been discussed and are analysed in the report:

- Water resources availability, management and uses;
- The water footprint of bioenergy in Africa;
- Renewable energy sources (RES) and their role in supporting energy access;
- Fuel wood and impacts (e.g. deforestation, soil);
- Energy use of residues (e.g. agriculture);
- Small scale biogas for household use;
- Analysis of technologies and feedstocks;
- Resource assessment (e.g. waste, residues etc.);
- Competitive uses of crop residues;
- Waste management and energy production;
- Waste-water treatment and energy production;
- Environmental impacts and water resources, water quality;
- Case studies;
- Support mechanisms, policy context.

This executive summary provides the reader with a brief outline of the main findings of the workshop and the participants' views on the topics. It also provides the output of related research activities, conducted by the contributors. Each of the following paragraphs is related to one section of the report. Accordingly, the reader can find a detailed description for each analysed topic in the main body of the report.

Water use and water footprint

Freshwater is essential for bioenergy. Biomass production needs large amounts of water. More than 70% of our planet is covered by water, but most of the world's water is saltwater and less than 3% of that is fresh. Of this, 2.5% is frozen in glaciers and not available, and only 0.5% is available in aquifers, lakes and rivers. In particular, the geographical distribution of water resources is highly uneven and in many parts of Africa, water is a scarce resource.

Water Footprint (WF) is a tool to quantify and show the consumption of freshwater and the impact on water scarcity. This tool is an indicator of freshwater use and defines direct and indirect water use along product supply chains. The tool distinguishes between green, blue and grey water and in this way gives a comprehensive and complete overview of the freshwater use and pollution. It can be assumed that if bioenergy production increases according to various predictions, also the use of water will go up. The WFs show large differences among different crops and different countries.

In African countries, it is possible to increase the production of a specific crop in Africa using high input irrigated agriculture. There is a potential to increase yield levels in agriculture, through high input irrigated agriculture, but this needs sufficient water. In the northern African countries, the blue WFs are already relatively large, in the Sub Saharan countries irrigation would be needed to increase maize yields. However, irrigated agriculture requires the availability of sufficient freshwater. Global population will continue to grow. The majority of population growth will occur in emerging and developing economies already experiencing water and energy challenges (see section §2 for detailed information).

Water resources

Created on March 11, 1972, the Organization for the Development of the Senegal River (OMVS) has the following goals: i) achieve food self-sufficiency for the populations of the Senegal River Basin; ii) reduce the vulnerability of the economies of its states to climate hazards; iii) accelerate the economic development of its member states; iv) preserve the balance of ecosystems in the Senegal Region and particularly in the BFS; v) secure and improve the income of the people of the Basin. The Signatory states adopted the Water Charter on May 28, 2002, a legal instrument that assists in the decision-making of water resources management. The Water Charter establishes the principles and methods of water allocation between the sectors of use; defines the procedures for examining and approving new projects; determines the rules relating to the preservation and protection of the environment.

The built infrastructure (dams) helps regulate the flow of the river and satisfy several uses (agriculture, drinking water, industry, etc.) while preserving biodiversity.

Following all the activities that are developing and intensifying in the basin, monitoring the quality of the waters of the Senegal River Basin becomes a concern for the preservation of the health of the population. The control of the water of the Senegal River Basin through the construction of dams and other structures guarantees the availability of water and the development of water uses for irrigated agriculture, hydropower generation, access to drinking water and health, the preservation of ecosystems, sustainable navigation on the river (see section §18 for detailed information).

Access to energy

The demand for energy and freshwater will increase significantly over the next few decades in the context of population increase, increase in wealth and change in the diet. This growth will pose major challenges and place a great deal of pressure on the resources of almost all regions, particularly in developing and emerging economies.

Benin's energy situation is characterized by a strong dependence on the outside world; local energy production estimated at 20% and more than 80% dependent on wood energy. Rural electrification levels are especially low. In Senegal, the rural electrification rate is 24% against 2% in Mauritania. The low level of electrification in these areas represents a real barrier for socio-economic development. No viable and sustainable development is possible without sustainable access to energy. The use of renewable energy sources is an alternative for the development of the energy sector in rural areas (see section §3 for detailed information).

Renewable energy

Renewable energy has been an important component of the African electricity mix. Large hydro is still the main renewable power source, but its share is down to 76% out of a total renewable capacity in Africa. Solar and wind are experiencing a very rapid increase and there is a trend in the continent and globally towards more decentralised generation. Wind and solar have experienced a rapid increase over the last few years.

Biomass potential of the organic waste available appears to be important. Access to these wastes seems easy and the cost would be very low. This study offers us two possible and sustainable solutions, to facilitate access to energy for this population by rural electrification oriented toward the available resources such as solar and biomass and to train the younger generations for a sustainable management of these resources (see section §4 for detailed information).

Bioenergy

Bioenergy has been an important part of the African energy mix for many years and has continued growing and expanding. Capacity from bioenergy has grown slower but at a steady pace, reaching 1.2 GW in 2016, which accounts for 3.1% of renewable capacity in Africa. Electricity generation from bioenergy in Africa reached 2779 GWh in 2015. The majority of bioelectricity generation (91%) originates from bagasse. At least 18 African countries are generating electricity from bagasse, especially in Sudan, South Africa, Swaziland and Zimbabwe. The rest was mostly biogas; particularly landfill gas (4%) and other biogases from fermentation (2%). Electricity from solid biofuels accounted for the rest, being mostly wood waste (62 GWh) and small contributions from wood fuel, palm oil residue and rice husks.

Over the last 10 years, South Africa has developed a well-established biogas-to-electricity sector with more than 22 MW installed in 2016. These include power from landfill gas, biodigesters using farm waste and, to a lesser extent, sewage sludge gas. A number of biogas programmes are in progress in various African countries (Mauritius, Kenya, Morocco, Burkina Faso, Senegal, Tanzania, Benin etc.). Electricity generation from liquid biofuels is still very limited, but small projects to generate electricity from Jatropha oil and biodiesel are emerging.

Small-scale bioenergy projects are becoming a viable option for rural communities and utilities alike, particularly for biogas. There is still a huge wasted potential on agro-industries using bioenergy as a fuel including from sugar cane and palm oil industry.

Traditional biomass use

Globally, traditional biomass has a large contribution to renewable energy supply, in particular in Low-income countries and in Africa. The global primary energy supply from biomass, in traditional biomass use and modern bioenergy, has reached about 56 EJ in 2015, representing a share of the total global primary energy consumption of about 10%. Traditional use of biomass plays a significant role for cooking and heating in developing and emerging countries with about 2.7 billion people relying on the traditional use of biomass for energy. The share of global modern biomass production to total energy supply is still small, but it is expected that the production of modern bioenergy will increase.

Traditional biomass comprises wood, charcoal, crop residues and animal manure mainly used for heating, mainly in developing countries, primarily for cooking, heating and lighting. In many cases, biomass is used in open fires and small stoves with very low efficiency, sometimes causing health problems and leading to the overexploitation of forest resources. Modern biomass for energy includes food crops, energy crops, crop residues, or algae, for example. The supply of traditional biomass to total bioenergy supply is around 75% and modern biomass contributes an additional 25%.

In West Africa, and particularly in Senegal, Mali, Burkina Faso and Niger, wood energy is the main fuel used by 90% of households and is also the basic essential energy consumed. Demographic pressure, particularly urban, and poverty intensify this use and contribute to forest degradation. The use of forest-based fuels as a source of energy for households has an impact on the vegetation cover and leads to deforestation and other environmental impacts. In Burkina Faso, more than 250,000 hectares of forest are cleared each year to meet this need.

The use of wood for cooking makes a large contribution to energy supply. Therefore it is important to quantify the consumption of biomass in different cooking stoves. The tests have been carried out at the Solar Energy Laboratory of the University of Lomé and allow, in the long term, to a) establish the average specific fuel consumption of each cooking stove; b) establish the average time required to prepare a certain type of meal for each cooking stove; c) establish the overall thermal efficiency of each cooking stove. From this study, it appears that improved stoves are a solution for lower energy consumption compared to traditional stoves.

Impacts of traditional biomass use

The widespread uncontrolled collection of wood as for direct burning in cooking stoves or charcoal production for domestic uses in Africa by a large share of the population put an increased pressure on forests and biomass resources. Deforestation ultimately impacts the water cycle directly, especially at the local level: forests, retaining tropical rainfall, provide a natural regulation of floods and droughts. The loss of forest cover leads to increased runoff and flooding risk, especially during the rainy season, while downstream areas are more prone to long droughts in the dry season. Deforestation may also contribute to desertification and severe soil erosion, with loss of agricultural (productive) soils and cascade effects.

In rural areas, wood harvesting takes up a lot of women's time in rural areas, and the biodigester releases women from the gathering of wood and cooking. The time saved allows the woman to develop income-generating activities thus increasing their financial autonomy. The use of improved cooking stoves or the use of biogas for cooking leads to improvements in indoor air quality through the avoidance of smoke from burning wood and improvements and health. The deployment of biodigesters could greatly contribute to the development of rural households by creating jobs in rural areas, achieving food security, restoring farmland, strengthening women's empowerment in rural areas and improvement in girls' education.

Population growth and urbanization, going along with changes in lifestyle and consumption, lead to large quantities of solid and liquid organic waste resulting from agricultural, agro-industrial and urban activities. In the absence of an adequate or deficient waste management system, these wastes can cause harm to human health and the environment. Mobilising various biowastes e.g. from municipal solid waste and sewage sludge to produce biogas in one or more semi-industrial or industrial units to substitute coal and wood are a viable alternative to generate energy for urban populations.

Contribution to sustainable development

Energy poverty also limits the development of the agriculture sector, including the valorisation of milk. The livestock has a major contribution to the rural economy, including Senegal and Mauritania. In areas with high milk production, access to energy is very low and the possibilities of conservation almost non-existent. The low electrification rates of the target production basins, of 20% in Senegal and 2% in Mauritania, limit the means of conservation of the milk and thus the valorisation of the production.

In Senegal, the few village associations that set up mini-dairies use diesel for generators or cold rooms to store milk, and butane gas for pasteurization. The high costs of these energies (60% of operating expenses) limit the profitability of their activity. Millions of litres of milk are thrown away in many villages and this translates into a loss of income for farmers. The "PROGRES-Lait" programme aims at the development of the rural economy through the extension of the horizon of opportunities for the valorisation of the milk value chain by improving access to sustainable energy services. The expected results are to establish 100 entrepreneurial solar mini-platforms (capacity of 200 to 400 l) for more than 2000 small suppliers; 20 solar dairies for conservation and pasteurization in industrial processing companies with more than 1,000 suppliers.

Agricultural residues and waste

There is a large amount of biomass agricultural residues potentially available in African countries. Dry residues, such as cereal straw or corn cob, is commonly left or burnt on the field, or also stored and used for animal feeding. Similarly, wet waste, like the cow or sheep manure, is either simply left on site or it may also be recovered through anaerobic digestion or composting. The food industry generates large quantities of waste; their valorisation, for energy or materials, is a promising way to make the production chains more profitable. Some unexploited biomass residues, such as palm hulls, cashew shells, olive kernels and jatropha and shea cake, etc. are often removed by open-air combustion.

Large amounts of agricultural residues could be recovered from cotton, pineapple, and cashew nut production. A project from Benin aims at the decentralized production of electrical energy by the gasification or direct combustion of post-harvest stems to provide electrical energy to small isolated communities. Another project focus on the energy valorisation of post-harvest waste, peelings and cakes from pineapple processing units through bio-methanisation of waste and drying and carbonization of waste.

The cashew nut production industries produce large quantities of waste (hulls, cakes, shells) that can be used for energy recovery. In these industries, raw cashew shells are used in direct combustion to fuel steam boilers. Converting agricultural waste into briquettes will reduce the use of natural gas or oil as fuel. Briquettes from biomass offer many benefits and are a substitute for charcoal, firewood and lignite. The main raw material needed for the production of briquettes is the cake from hull pressing. The results have shown the possibility of producing briquettes from the cashew industry waste, and more particularly from cakes from the pressing of cashew nuts.

The banks of the Senegal River and the waters of Lake Guiers are infested with invasive aquatic plants. There is of paramount importance to contribute to the fight against the proliferation of aquatic plants on the Senegal River and its effluents that are common to several villages in the lower delta and to minimize the effects of Typha plant proliferation. Integrated management of the invasive aquatic plants includes a combination of physical (manual, mechanical removal and physical barriers) and biological control methods. The use of invasive aquatic plant Typha for energy production (as charcoal of for electricity generation) answers to ecological concerns, provides an energy resource provides opportunities for sustainable development and contributes to the creation of jobs.

One option is the conversion of agricultural waste through thermal processes into a carbon-rich material, called char, and that may be used in various applications. Char can help to substitute wood charcoal used for cooking and constitute a solution to the critical issue of deforestation in Western Africa and of environmental issues related to greenhouse gas emissions and ecosystem disturbance. A process has been developed to produce carbonaceous materials (biochar and activated carbon) from agricultural by-products. These chars are widely used in many fields, including water treatment (de-pollution) and soil amendment (fertilisers). Char can also be used as a catalyst in anaerobic digestion, as a soil improving material to increase crop yield, to increase water retention, to increase soil stability and contribute to carbon sequestration.

Biogas production

The biogas market in Europe developed quite significantly over the last decade. It currently consists of more than 17,000 biogas plants, whereas the majority of the plants are agricultural biogas plants of an installed electrical capacity between 500 kW and 1 MW. The biogas is mainly used for combined heat and power generation. More than 400 biogas plants in Europe upgrade the biogas to biomethane quality. Besides the support for biogas as renewable energy, the objective of the legislation was also to support the agricultural sector, which was suffering from surplus food production in Europe with low prices for agricultural products.

Many African countries have installed large numbers of small-scale, household biogas plants. Most biogas plants in Africa are household digesters of a few cubic metres of digester volume. The main purpose of these family systems is to provide energy for clean cooking and lighting, as well as for the production of high-quality fertiliser for (subsistence) farming. Although the absolute numbers of household biogas systems in Africa appear quite impressive, it represents a small fraction of the existing biogas potential in Africa. Various international development agencies and programmes have supported the roll-out of household biogas systems in Africa, such as the GIZ, SNV, Africa Biogas Partnership Programme, and HIVOS.

In general, biogas systems could be applied in Africa in any scale, ranging from household systems for cooking to large-scale systems for combined heat and power generation or even for the upgrading of biomethane. The use of biowaste as feedstock for biogas production has a very high potential in many regions in Africa, but a key challenge is the collection and management of the biowaste. Household biogas systems in Africa could be widely implemented among the rural poor communities if suitable support of capacity building as well as access to suitable and adapted technologies is provided.

Biogas, along with other types of renewable energy, is part of the policy of diversification of cooking fuels to contribute to the access of 100% of the population to modern cooking services. Biodigesters produce both gas (biogas) for cooking and lighting and organic fertiliser (compost) for improved agricultural yields.

The small individual biodigester can play a role in contributing to the well-being of people, especially women and young people, to a better lifestyle by access to a mean of clean cooking and lighting. Large biogas units require large investments, but they also allow economies of scale and they can consider all possible recovery routes for biogas and digestates (§13).

Biogas plants larger than household scale have a high potential in Africa, too. Several examples in Africa have demonstrated good success, however, also several larger scale biogas projects have failed. Usually, biogas plant failures, both in Europe and in Africa, are due to the human factor and not due to technologies which are in general mature. One problem is certainly the underestimation of the complex microbiological process of anaerobic digestion. The lack of capacity building and the related low technical and management skills of the responsible operators can be reasons for system failures. A key challenge for larger systems is the high initial investment costs.

Biogas projects

The demonstration plant installed by THECOGAS SENEGAL within the Dakar slaughterhouse managed by SOGAS, as well as the factories in Ghana and Burkina, demonstrate part of the sustainable development sector from the waste of a slaughterhouse. This same work could be done from agricultural waste (cow manure, pig slurry, poultry manure, etc.) but also in household waste, market waste and local industries. Every day between 250/300 cattle and 1500/2000 small ruminants are slaughtered at the Dakar slaughterhouse. The slaughterhouse consumes more than 250 m^3 of water each day and between 1500 and 2200 kWh of electricity. The operation of the plant produces more than 220 tonnes of waste (liquid or solid) that poses both environmentally and health risks. Other biogas projects have been implemented in several African countries, such as the 250 kW installed power FA-SOGAZ project in Burkina Faso, that will increase to 500 kW. SAFI SANA in Ghana installed a 50 kW biogas unit that treated sewage sludge.

The experiments conducted in Senegal on pilot sites have shown that the production of biogas from animal waste (cow dung, pig manure, horse manure) and human waste and its use as a source of energy in houses in a rural area could be a sustainable alternative to the use of wood and charcoal. In Senegal a household of 10 people consumed every day more than 5 kg of firewood in rural areas, the installation of a biodigester of 10 m^3 makes it possible to fully satisfy the energy needs for cooking. It was estimated that each m^3 of biogas can replace the equivalent of 5 kg of wood or 3 kg of coal. A 10 m^3 biogas plant installed in a household produces 2.5 m^3 of biogas daily. Its use would, therefore, avoid a consumption of 12.5 kg of wood energy or 7.5 kg of charcoal per day per household.

The medium-term goal of the Biogas Programme in Senegal is to install on short-term 10 thousand biodigesters. And to install by 2030 more than 60,000 biodigesters. This will reduce the use of wood and coal by 30%, and thus more than 15,000 ha of forest will be preserved each year. Senegal's potential for biodigesters is 450 thousand households this will help protect more than 100 thousand ha of forest per year.

Tools for improving knowledge

A key constraint in using biomass for sustainable bioenergy development is the lack of a biomass value chain that would enable a constant supply of feedstock.

To achieve sustainable development of Africa through biogas production from various biowaste it is necessary to improve the knowledge on the resources of biowastes and the existing technologies, to have tools adapted to support reasoned choices of techniques of mechanisation, to offer ready-to-use knowledge for decision-makers and practitioners to formulate an approach and support the development policies of anaerobic digestion techniques. To address this objective, it is necessary to improve the knowledge of organic waste resources and existing technologies, to have tools adapted to direct reasonable choices of anaerobic digestion techniques.

A study proposed a mathematical model for dimensioning small-scale biogas plants, for a household of 6 members (Kane). The evaluation of the biogas energy demand was done on a household of 6 members and on the basis of the energy data indicated on the devices and their daily time of operation (200 l/h per as burner with biogas and 140 l/h per biogas lamp). The results obtained show that the biogas plant for this household includes a digester with a volume of 7 m^3, a substrate mass of 44 kg and a daily production of 1.68 m^3. The conditions for success are mainly based on the availability of the raw material and the acceptability of the population for the technology.

The Energy Smart Food Programme (ESF) of FAO is a multi-partner initiative to move towards energy-smart agri-food systems that are less dependent on fossil fuels and includes four pillars: access to modern energy services in rural areas; energy efficiency in agri-food systems; renewable energy in agri-food systems; application of a water-energy-food approach. A key element of FAO's support to countries aims to ensure sustainable development of bioenergy that supports food security and mitigates the impact on the environment at large.

The Bioenergy and Food Security (BEFS) developed by FAO consists of tools and guidance to support countries in designing and implementing sustainable bioenergy policies and strategies, to promotes food and energy security and contributes to agricultural and rural development. The BEFS analysis covers Natural Resources (biomass potential assessment to identify potential biomass available), Techno-economic Analysis (technology requirements, production costs, smallholder inclusion, job creation and investment requirements) and Socio-economic Analysis (economic and financial viability of the various biofuel pathways, smallholder inclusion and job creation).

2 The water footprint of biomass use for energy production in Africa

Author: P.W. Gerbens-Leenes

Abstract:

Globally, traditional biomass has a large contribution to renewable energy supply, but it is expected that modern bioenergy production will increase. In Africa, there is potential to increase agricultural yields, applying high input and irrigation. This case study uses maize grown for ethanol to show that modern biomass contributes little to total energy demand and has a large impact on freshwater resources. The study showed that if the surplus yield would be used for energy for transport, the contribution to energy demand would be small. In Morocco and Egypt, the contribution would only be 5% of total energy demand in the transport sector, in South Africa and Namibia 12%. To produce this additional amount of maize, large efforts are needed to provide sufficient water. In the northern African countries, the blue WFs are already relatively large, in the Sub Saharan countries irrigation would be needed to increase maize yields. Both regions suffer from water scarcity during at least half of the year. Since the contribution to total energy needs is small and much freshwater is needed that is probably not available, it might be better to search for other solutions. The use of agricultural residues for energy purposes might be one of those solutions but requires further research.

2.1 Introduction

Globally, there is a lot of attention for biomass to replace fossil fuels. In 2014, world energy demand was 13684 Mtoe, of which biomass provided 1421 Mtoe and other renewables, i.e. hydropower, wind, geothermal and solar energy another 516 Mtoe (International Energy Agency, 2016). With a contribution of 10% to total energy demand, biomass provides the largest share of all renewables. There are two categories of biomass for energy, traditional biomass and modern biomass. Traditional biomass comprises wood, charcoal, crop residues and animal dung mainly used for heating (International Energy Agency, 2012). This type of biomass is applied in traditional ways, mainly in developing countries, primarily for cooking and heating. In many cases, people use biomass in open fires and small stoves with very low efficiency, sometimes causing health problems and leading to the overexploitation of forest resources (Fritsche and Iriarte, 2014). Modern biomass for energy includes food crops, energy crops, crop residues, or algae, for example. The supply of traditional biomass to total bioenergy supply is around 75% and modern biomass contributes another 25% (Fritsche and Iriarte, 2014). Energy scenarios indicate a larger contribution of bioenergy to total energy supply in the future (International Energy Agency, 2016). It is likely that modern biomass will increase its share to bioenergy supply.

Modern bioenergy includes the so-termed first, second and third generation bioenergy (Gerbens-Leenes et al., 2014). First generation bioenergy is energy from food crops. For example, bioethanol from maize or sugar cane. There is an ongoing debate about the competition between crops for energy and crops for food. Second generation bioenergy is energy from either energy crops or from agricultural residues. Energy crops are, for example, switchgrass, jatropha, but also trees like poplar. When energy crops are applied for energy, there is no direct competition with food, but an indirect one over the natural resource input, like water. Crop residues, leftovers from agriculture, seem a good alternative for food or energy crops. Third generation bioenergy includes energy from algae. The most recent World Energy Outlook energy scenarios show an increase of total energy use, in combination with an increase of the share of renewables, especially of bioenergy (International Energy Agency, 2016). The IEA has developed three different energy scenarios for 2040 that all show an increase of total energy demand, but are based on different energy mixes (International Energy Agency, 2016). These scenarios are the current policies scenario (annual bioenergy use 77 EJ), the new policies scenario (annual bioenergy use 79 EJ) and the 450 scenario (annual bioenergy use 97 EJ).

Freshwater is essential for bioenergy (Gerbens-Leenes et al., 2009, International Energy Agency, 2012). Bioenergy that derives from biomass needs large amounts of water in agriculture and forestry. Freshwater is a scarce resource because most of the world's water is saltwater, only 2.6% is freshwater of which the largest part is stored in ice (Speidel et al., 1988). Agriculture, industry and domestic supply, with different quality standards for freshwater, are the main users. In 2000, agriculture accounted for 70% of total water withdrawals, industry for 20% and domestic withdrawals for 10% (Shiklomanov, 2000). Humans influence surface water distribution, for example by building large dams (Pekel et al., 2016) for hydropower, water storage for irrigation in agriculture, or flood control. The impacts of agriculture on freshwater availability are very large because that sector uses large amounts of freshwater. A tool to quantify and show the consumption of freshwater and the impact on water scarcity is the water footprint (WF) (Aldaya et al., 2012). The tool is an indicator of freshwater use and defines direct and indirect water use along product supply chains. The WF is a multi-dimensional indicator, giving water consumption volumes by source and polluted volumes by type of pollution. The tool distinguishes between green, blue and grey water and in this way gives a comprehensive and complete overview of the freshwater use and pollution. The blue WF refers to the surface and groundwater volumes consumed (evaporated or incorporated into the product) as a result of the production of a good; the green WF refers to the rainwater consumed. The grey WF of a product refers to the volume of freshwater required to assimilate the load of pollutants based on existing ambient water quality standards (Aldaya et al., 2012).

There are three ways of increasing biomass production, (i) increase the production per unit of land, (ii) increase the area dedicated to bioenergy, e.g. grow energy crops on degraded land, or (iii) use residues. It can be assumed that if bioenergy production increases according to the IEA scenarios, also the use of water will go up. In many African countries, yields are relatively low and have potential to increase, for example, maize, a crop grown for food and also for ethanol, a biofuel used for transport (Fischer et al., 2002). The aim of this paper is to give an indication of agricultural potential in Africa to increase biomass output for energy demand. The study uses the production of maize for ethanol, a biofuel for transportation, as a case study. It gives an overview of water footprints (WFs) of maize for ethanol in Africa, compares this with WFs of maize in Europe and shows potentials and constraints for ethanol production for transport from maize.

2.2 Method and data

In Europe, there are three countries that have a large contribution to total maize production. These are France (18,343,420 tons in 2014), Germany (5,142,100 tons in 2014) and Spain (4,776,190 tons in 2014). Together, they contribute 22% to total European maize production. In Northern Africa, 99% of the maize is produced in Egypt (8,059,906 tons in 2014) and in Morocco (97,379 tons in 2014), in Sub Saharan Africa 99% is produced in South Africa (14,250,000 tons in 2014) and in Namibia (14,250,000 tons in 2014). To compare WFs of maize in Europe and in Africa, the study selected France, Germany, Spain, South Africa, Namibia, Egypt and Morocco. Data on WFs were derived from (Mekonnen and Hoekstra, 2011a).

The FAO gives information on a national scale about actual yield levels for a large number of crops, total production and crop areas (Food and Agriculture Organization of the United Nations, 2017). Also, the FAO has a database using global agro-ecological zones (GAEZ database) on yield levels in different agricultural systems for a specific crop in a specific country, giving information on high input irrigated yields, intermediate and low input yields and actual yields. To have an indication of potential yields in Africa, the study calculated the yield gap between actual yields in the selected countries and potential yields. Data were derived from the GAEZ database of the (Food and Agriculture Organization of the United Nations, 2017). The FAO also indicates the share of a crop production applied for food, feed or for other uses. The study assumed that another use is the use of the crop for energy. The study assumed that increased production is applied for energy and calculated the possible production of maize for energy, $P_{Maize-energy}$ (tons), as follows:

$$P_{Maize-energy} = (Area \times Y_{pot}) - P_{present} + P_{other} \tag{1}$$

In which $Area$ (ha) is the present area used for maize production, Y_{pot} (tons/ha) is the potential yield of maize, $P_{present}$ is the maize production in 2014 (tons) and Pother (tons) is the use of maize in 2014 for other purposes, i.e. bioenergy. Next, the study calculated the energy quantity of ethanol (MJ), $Q_{ethanol}$, that can be produced in Europe, Northern Africa and Sub Saharan Africa based on the possible maize production:

$$Q_{ethanol} = P + Maize - energy \times p \times g \tag{2}$$

In which p is the product fraction of ethanol from maize and q is the energy content of ethanol. The product fraction of 0.15 was taken from (Gerbens-Leenes and Hoekstra, 2012) and the energy content of 30.95 MJ/kg from (International Energy Agency, 2017). To compare the possible ethanol production (MJ) with demand for transport, the study calculated the contribution of ethanol, $Contribution_{ethanol}$, to transport energy demand (%) as follows:

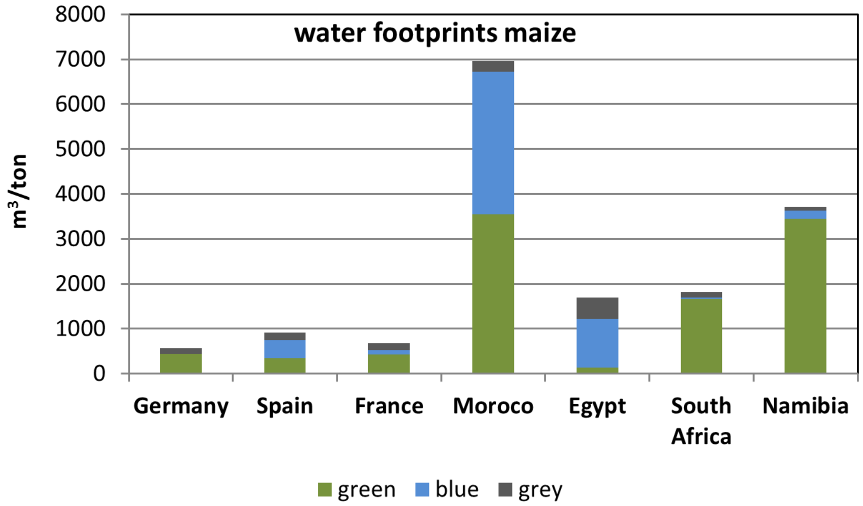
$$Contribution_{ethanol} = E/Q_{ethanol} \times 100\% \tag{3}$$

in which E is the energy demand of transport. Data on energy for transport were derived from the (International Energy Agency, 2017).

2.3 Results

Figure 1 shows the WFs of maize for the seven countries included in this study. There are large differences among the countries. Spain, Morocco and Egypt, countries with a relatively dry climate, have large blue WFs, and maize production depends on irrigation. Germany, France, South Africa and Namibia have relatively large green WFs.

Figure 1: WFs of maize for the seven countries included in this study: Germany, Spain, France, Morocco, Egypt, South Africa and Namibia, source: (Mekonnen and Hoekstra, 2011b).



However, also large differences within countries occur. For example, Figure 2 shows the large differences among WFs of ethanol from maize produced in South Africa. Some provinces do not irrigate, e.g. KwaZulu-Natal and Gauteng, while other provinces have large irrigation requirements, e.g. Transvaal and Limpopo.

Figure 2: WFs of ethanol from maize produced in South Africa for eight provinces including the country average, source: (Mekonnen and Hoekstra, 2011b).

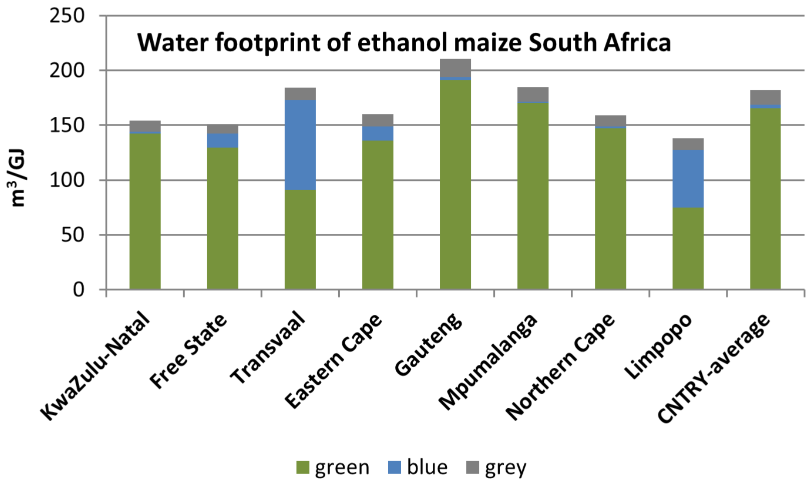


Figure 3 shows actual yields of maize in 2014 and the different yield levels for maize based on the GAEZ database of the (Food and Agriculture Organization of the United Nations, 2017) for three different agricultural systems for three regions. Maize yields in Europe in 2014 do not differ much from yields in Northern and West Asia, 6.9 versus 6.7 tons/ha. Actual yields in Sub Saharan Africa, however, are much smaller, 4.8 tons/ha. There is a large yield gap in Europe and Northern Africa and West Asia, where yields can double. Also in Sub Saharan Africa, there are large potentials and yields can go up to 11.2 tons/ha under high input irrigated conditions.

Figure 3: Actual yields of maize in 2014 and the different yield levels for maize in Europe, Northern Africa and West Asia and Sub Saharan Africa, source: (Food and Agriculture Organization of the United Nations, 2017).

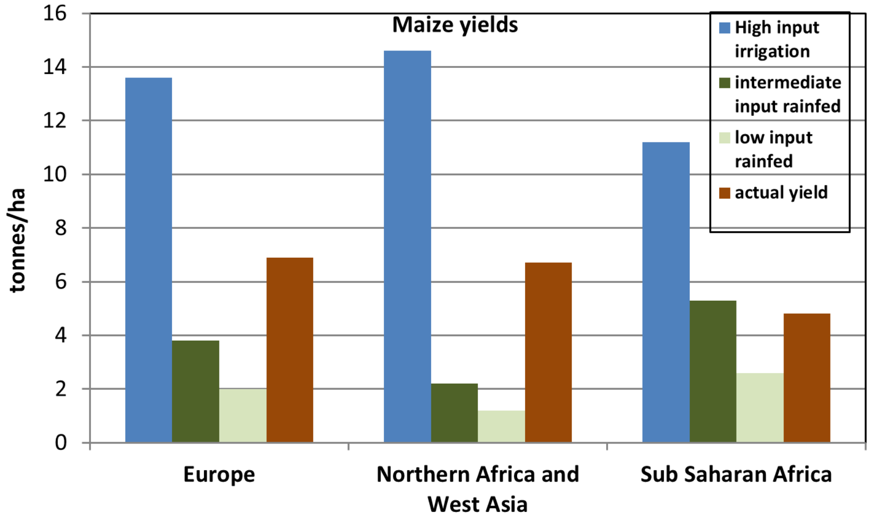


Figure 4 shows the total maize production (tons) in 2014 in Europe, Northern Africa and West Asia and Sub Saharan Africa based on (Food and Agriculture Organization of the United Nations, 2017) data. Especially Northern Africa and West Asia and Sub Saharan Africa have small productions compared to Europe. In Europe the largest share of production is applied for animal feed, in Northern Africa, there is also a large share for food, while in Sub Saharan Africa most of the maize is used for human consumption. In Europe, a small share is applied for other purposes. The study assumed for ethanol, in Northern and Sub Saharan Africa that share is negligible.

Figure 4: Maize production in 2014 in Europe, Northern Africa and West Asia and Sub Saharan Africa, source: (Food and Agriculture Organization of the United Nations, 2017).

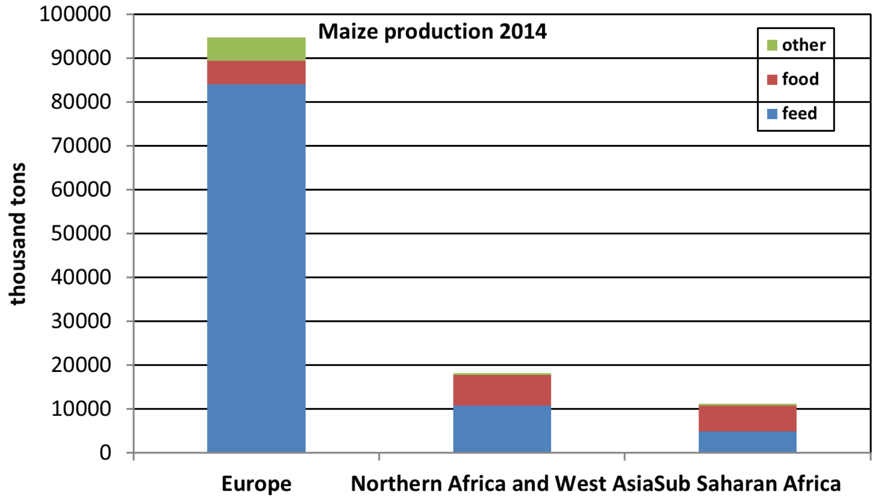


Figure 5 shows the possible production of maize using best agricultural practices, i.e. high input irrigated production on existing land. Especially in Europe, there is a large absolute increase in maize production.

Figure 5: Possible production of maize using best agricultural practices, i.e. high input irrigated production on existing land.

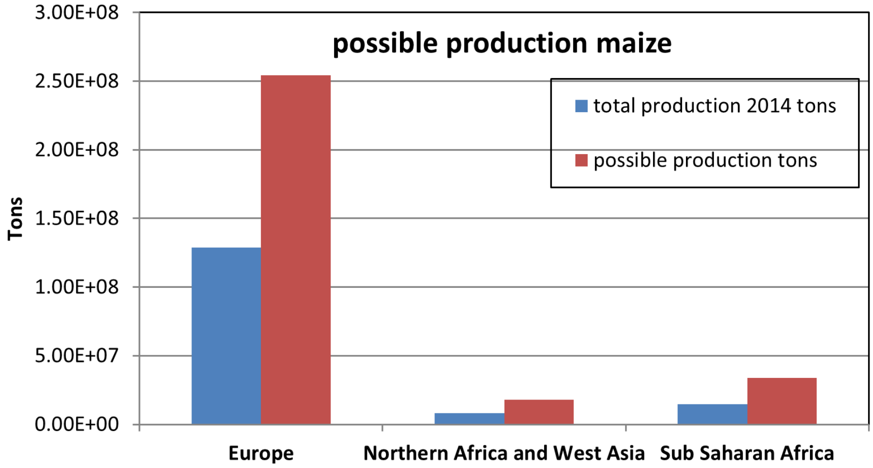
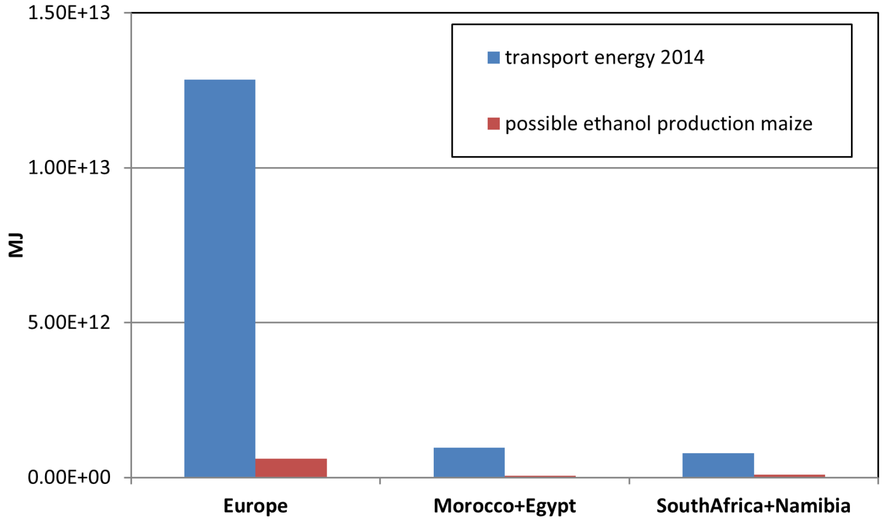


Figure 6 shows the contribution of existing and additional maize production to total transport energy requirements based on demand in 2014. The figure shows that the contribution is very small, in Europe Morocco and Egypt about 5%, in South Africa and Namibia about 12%.

Figure 6: Contribution of existing and additional maize production to total transport energy requirements based on demand in 2014.

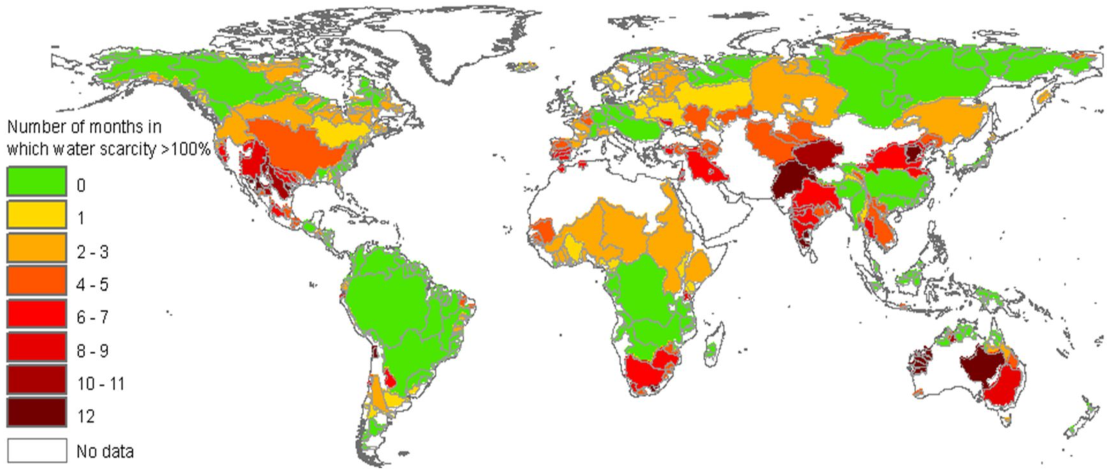


2.4 Discussion

The study showed that it is possible to increase the production of a specific crop in Africa using high input irrigated agriculture. However, irrigated agriculture requires the availability of sufficient freshwater. In many parts of Africa, water is a scarce resource. Blue water scarcity can be defined as the ratio of the blue water footprint and blue water availability in a specific catchment taking the environmental flow requirements of 80% of the available water into account (Mekonnen and Hoekstra, 2011a). Figure 7, taken from (Mekonnen and Hoekstra, 2011a), shows that in Africa the countries where maize is grown suffer from water scarcity during a number of months per year. Therefore it might be difficult to increase agricultural production using irrigation.

Another issue is that additional maize production only contributes a small share to total energy demand for transportation, in Northern Africa (5%) and in Sub Saharan Africa (12%). Given the growth of the population and changes in food consumption patterns towards more western diets with more meat (Food and Agriculture Organization of the United Nations, 2017), the question arises whether the increased production should be applied for food and animal feed or for bioenergy. Moreover, when high input irrigated agriculture is applied, more energy input is needed for fertilisers, machinery, pesticides and irrigation itself, decreasing the energy balance, expressed as the Energy Output-Input ratio (EOI-ratio). However, if additional maize production is applied for food and feed, the amount of additionally produced residues is also large. Residues are a feedstock for bioenergy too and there are many ways to convert them into second generation bioenergy. Moreover, they have smaller WFs than food crops and energy crops (Mathioudakis et al., 2017).

Figure 7: Number of months with blue water scarcity above 100%, source: (Mekonnen and Hoekstra, 2011a).



2.5 Conclusions

At present, the share of global modern biomass production to total energy supply is still small, but to decrease carbon dioxide emissions, it is expected that the production of modern bioenergy will increase. In African countries, there is potential to increase yield levels in agriculture, applying high input irrigated agricultural systems. The case study for maize grown to produce ethanol for transportation showed that if the surplus yield produced would be used for energy for transport, i.e. for ethanol, the contribution to energy demand in the transport sector would be small. In Morocco and Egypt, the contribution would only be 5% of total energy demand in the transport sector, in South Africa and Namibia 12%. To produce this additional amount of maize, large efforts are needed to provide sufficient water. In the northern African countries, the blue WFs are already relatively large, in the Sub Saharan countries irrigation would be needed to increase maize yields. Both regions suffer from water scarcity during at least half of the year. Since the contribution to total energy needs are small and much freshwater is needed that is probably not available, it might be better to search for other solutions. Moreover, it can be argued that it is better to use the production for food, rather than for energy. The use of agricultural residues for energy purposes might be one of those solutions, but requires further research.

Bibliography used in this section:

(Fischer et al., 2002, Fritsche and Iriarte, 2014, Gerbens-Leenes et al., 2009, Gerbens-Leenes and Hoekstra, 2012, Gerbens-Leenes et al., 2014, Mekonnen and Hoekstra, 2011b, Mekonnen and Hoekstra, 2011a, Aldaya et al., 2012, International Energy Agency, 2012, International Energy Agency (IEA), 2014, International Energy Agency, 2016, International Energy Agency, 2017, Food and Agriculture Organization of the United Nations, 2017, Mathioudakis et al., 2017, Pekel et al., 2016, Shiklomanov, 2000, Speidel et al., 1988)

3 Evaluation of the rate of access to energy and the potentialities of renewable energies (agricultural waste) in the region of Casamance

Author: Diouma Kobor
Keywords: Solar energy; Biomass; Sustainable development; Waste recovery; Rate of access to energy.

3.1 Introduction

The electricity sector in Senegal faces significant challenges. In urban areas, blackouts are common. In rural areas the context is different, characterized by a configuration of dispersed potential users having only limited financial resources while the costs of connection to the network are very high and thus prohibitive. The low level of electrification in these areas represents a real handicap for socio-economic development with a marked absence of income-generating activities.

According to the United Nations World Water Development Report 2014:

1. The demand for energy and freshwater will increase significantly over the next few decades. This growth will pose major challenges and place a great deal of pressure on the resources of almost all regions, particularly in developing and emerging economies.

2. The supply and supply of water and energy are intimately linked. Decisions made in one area affect the other, for better or for worse.

3. Water and energy are two key elements of sustainable development and must be recognized as such.

4. Decisions on the sharing, allocation, production and distribution of water resources have important implications for society and gender equality. The management of water and energy must, therefore, be more sensitive to the issue of gender equality. Access to energy is often put on the background while no viable and sustainable development is possible without sustainable access to energy.

The use of renewable energy sources is an alternative for the development of the energy sector in rural areas. On the other hand, the setting up of these sources must meet technical, socio-economic and environmental criteria and require in-depth technical-economic and social studies on access to energy but also to identify the most cost-effective electrification solution for the use of renewable energies and to size appropriately and efficiently these sources of energy.

This paper is the result of surveys and field measurements on the access to energy and renewable energy potential and the valorisation of biomass in Casamance, Senegal.

The analysis of the different survey results showed a low schooling enrolment rate compared to the national average. This result is very revealing of the impact of the conflict in rural areas and made it possible to understand the disparity between rural and urban areas. The results also showed a low rate of access to energy of the rural population compared to the urban population where this rate is close to 90% while it is sometimes less than 10% or even non-existent in some communities.

Finally, a study on the solar potential of these communities was realized with a study on the solar radiation and the dimensioning of the villages to provide solutions for energy supply in these areas. This work on the energy potential of the region has shown a real paradox: when access to energy is non-existent in some localities, the biomass potential for energy is sometimes up to 10 times higher than the energy needs in these localities.

3.2 Description of the project and results

3.2.1 Description of the concept: state of the art, methods and approaches

This work is divided into three main studies:

- Study of the rate of access to energy of rural areas: It was to carry out a survey on the number of the population having access to energy.
- For biomass resources, it consisted of an investigation of agricultural waste (rice balls, millet stalks), cashew shells, oil palms, etc. in these selected control areas. The planned duration is one week per rural community, which lasts a total of 5 weeks.
- Finally the data processing was the last part where the work was done under the Excel software then a comment on the results and recommendations were made.

The criteria for the selection of the localities: We based on the work carried out by the project PROCAS (Development Project for Casamance) in its capitalization document between 2007 and 2010. Internet research was also conducted for the exact location of different areas and localities of Casamance. In these documents, a classification on the different zones of Casamance was made according to the following criteria:

First-ranking according to 3 degrees of impact: Zone strongly impacted by the Casamance conflict, zone moderately impacted by the conflict and zone not impacted by the conflict.

Second-ranking according to the rate of return by zone of the refugees of the conflict: A cartography of the zones according to the number of displaced persons, the number of return thus of the rate of return with a percentage ranging from 60 to 100%.

Third-ranking according to the level of poverty: indices $<$150 and between 150 and 250 were given to each rural community.

3.2.2 Main results, main results and achievements

Access to Energy: Table 1 gives us the results of the energy needs of each locality visited. This gives us an idea of the rate of access to energy in this area.

Access to Energy:
Table 1 gives us the results of the energy needs of each locality visited. This gives us an idea of the rate of access to energy in this area.

Table 1: Composition of the population and access to energy rate.

Cities	Men %	Women %	Schooling rate %	Boys %	Girls %	Share boys enrol. %	Share girls enrol. %	Access to energy %	Students access to elec. %
Niafor	56.93	43.07	54.95	60.36	39.64	58.26	50.57	13.61	14.86
Assoumoul	46.48	53.52	39.44	61.43	38.57	52.12	28.42	17.32	15.00
Bading	24.84*	22.15*	45.70	48.72	51.28	x	x	20.70	6.84
Bissassou	x	x	57.11	58.84	41.16	x	x	10.53	11.55
Kaguitte	55.91	44.09	50.91	63.39	36.61	57.72	42.27	10.45	13.39
Oukout	43.39	57.44	53.31	44.96	55.04	55.24	51.08	21.49	25.58
Djibelor	45.93	57.44	54.07	52.17	47.83	60.76	47.31	83.14	88.04
Gouraf (Niaguis)	41.67	29.89	62.25	58.06	41.94	62.07	62.50	9.77	14.19
Bourofaye	54.49	45.51	81.01	57.93	42.07	82.35	79.22	41.32	31.74
Tobor	50.45	49.24	63.07	53.28	46.72	66.60	59.84	54.88	60.00
Suelle	52.20	47.80	83.22	55.24	44.76	77.84	90.98	76.94	75.00
Kawaguire (Mlomp)	52.72	47.55	79.56	55.31	44.69	77.95	80.81	12.77	8.94
Kabatagua (Dianki)	43.98	56.02	86.52	42.86	57.14	94.29	81.48	16.87	22.08
Mampalago	52.36	47.64	80.04	56.84	43.16	80.61	79.31	13.72	16.09
Average	60.01	57.48	70.23	69.89	55.11	82.52	70.20	35.40	35.15

*Here the percentage did not include boys and girls out of school

Energy Potential of Biomass

In this part estimated the amount of biomass waste coming from biomass from such as rice fields, peanut fields, millet fields, etc. The survey was often conducted with the help of the village chief or the mayor of the commune or the president of the agricultural cooperative if it exists. The results were obtained sometimes by estimation because of the lack of knowledge on the quantitative evaluation of the population. Tables 2-5 give the results of these studies.

Table 2: Biomass energy potential of localities by estimation following the survey, part 1

City	Type of waste	LHV (MJ/kg)	Quantity harvest (t)	Avail. period	On the spot or forest	Free or Paid	Energy Potential	Total (MJ)
Niafor	Rice Ball	14.894	60	Dec-Jan	OTS	P	893640	
	Peanut hull	14.483		Feb-Jun	OTS	P	0	
	Cashew Hull	21.92	500	Apr-Aug	OTS	P	10960000	14846070
	Cashew Apple		1250	Apr-Aug	FP	P	0	
	Millet stalk	18.126		Dec-Jan	FP	P	0	
	Corn stalk	14.935	186	Oct-Nov	FP	P	2777910	
	Hull of Palm	21.452	10	May-Jul	OTS	P	214520	
Assoumoul	Rice Ball	14.894	10	Dec-Jan	OTS	P	148940	
	Peanut hull	14.483	15	Jan-Jun	OTS	P	217245	5295315
	Cashew Hull	21.92	200	Jan-Jun	OTS	P	4384000	
	Cashew Apple		500	Apr-Aug	FP	P	0	
	Millet stalk	18.126	10	Dec-Jan	FP	P	181260	
	Corn stalk	14.935	10	Oct-Nov	FP	P	149350	
	Hull of Palm	21.452	10	Jan-Jun	OTS	P	214520	
Bading	Rice Ball	14.894	10.5	Nov-Dec	OTS	F	156387	
	Peanut hull	14.483	1	Jan-Jun	OTS	F	14483	5295315
	Cashew Hull	21.92	1	Apr-Aug	OTS	F	21920	
	Cashew Apple		2	Apr-Aug	OTS	F	0	
	Millet stalk	18.126	1	Nov-Dec	OTS	F	18126	
	Corn stalk	14.935	3	Oct-Dec	OTS	F	44805	
	Hull of Palm	21.452	1	Always	OTS	F	21452	
Bissassou	Rice Ball	14.894	0.75	Nov-Dec	OTS	F	11170.5	
	Peanut hull	14.483	1	Jan-Jun	OTS	F	14483	110504.5
	Cashew Hull	21.92	1	Mar-Jun	OTS	F	21920	
	Cashew Apple		2	Mar-Jun	OTS	F	0	
	Millet stalk	18.126	1	Nov-Jan	OTS	F	18126	
	Corn stalk	14.935	3	Nov-Jan	OTS	F	44805	
	Hull of Palm	21.452	1	Always	OTS	F	21452	

Table 3: Biomass energy potential of localities by estimation following the survey, part 2

City	Type of waste	LHV (MJ/kg)	Quantity harvest (t)	Avail. period	On the spot or forest	Free or Paid	Energy Potential	Total (MJ)
Kaguitte	Rice Ball	14.894	1	Dec-Jan	F	F	14894	
	Peanut hull	14.483	147	Dec-Jun	OTS	F	2129001	
	Cashew Hull	21.92	40	Apr-Aug	OTS	F	876800	
	Cashew Apple		100	Apr-Aug	OTS	F	0	4222007
	Millet stalk	18.126					0	
	Corn stalk	14.935					0	
	Hull of Palm	21.452	56	Always	OTS	F	1201312	
Oukout	Rice Ball	14.894	5	Dec-Jan	OTS	P	74470	
	Peanut hull	14.483	3	Feb-Apr	OTS	P	43449	
	Cashew Hull	21.92	3	Mar-Apr	OTS	P	65760	
	Cashew Apple		5	Mar-Jul			0	2328879
	Millet stalk	18.126					0	
	Corn stalk	14.935					0	
	Hull of Palm	21.452	100	Always	OTS	P	2145200	
Djibélor	Rice Ball	14.894	1	Nov-Dec	F	F	14894	
	Peanut hull	14.483					0	
	Cashew Hull	21.92	2	Apr-May	F	F	43840	
	Cashew Apple		3				0	58734
	Millet stalk	18.126					0	
	Corn stalk	14.935					0	
	Hull of Palm	21.452	1	Always	OTS	P	21452	
Tobor	Rice Ball	14.894	100	Dec-Feb	OTS	F	1489400	
	Peanut hull	14.483	1	Feb-Jun	OTS	F	14483	
	Cashew Hull	21.92	200	Apr-Jul	OTS	F	4384000	
	Cashew Apple		100			F	0	5942396
	Millet stalk	18.126	1	Nov-Dec	OTS	F	18126	
	Corn stalk	14.935	1	Dec-Jan	OTS	F	14935	
	Hull of Palm	21.452	1	Always	OTS	P	21452	
	Cow dung			Always	OTS	F	21452	

Table 4: Biomass energy potential of localities by estimation following the survey, part 3

City	Type of waste	LHV (MJ/kg)	Quantity harvest (t)	Avail. period	On the spot or forest	Free or Paid	Energy Potential	Total (MJ)
Suelle	Rice Ball	14.894	100	Dec-Feb	OTS	P	1489400	
	Peanut hull	14.483	150	Feb-Jun	OTS	P	2772450	
	Cashew Hull	21.92	60	Mar-Jul	OTS	P	1315200	5577050
	Cashew Apple		40	Mar-Jul	F	P	0	
	Cow dung		90	Always	OTS	P	0	
Kawaguire (Mlomp)	Rice Ball	14.894	1	Dec-Jan	OTS	P	14894	
	Peanut hull	14.483	1	Feb-Jun	OTS	P	14483	
	Cashew Hull	21.92	1	Mar-Jul	F	P	21920	55297
	Cashew Apple		2	Mar-Jul	F	P	0	
	Hull of Palm	21.452	1	Always			21452	
	Cow dung			Always	OTS	F	0	
Kabatagua (Dianki)	Rice Ball	14.894	1	Dec-Mar	OTS	F	14894	
	Peanut hull	14.483	1	Feb-Jun	OTS	F	14483	
	Cashew Hull	21.92	1	Mar-Jul	OTS	F	0	88358
	Cashew Apple		2	Mar-Jul	OTS	F	0	
	Millet stalk	18.126	1	Dec-Jul	OTS	F	18126	
	Corn stalk	14.935	1	Dec-Jul	OTS	F	14935	
	Cow dung			Always	OTS	F	0	
Gouraf (Niaguis)	Rice Ball	14.894	52	Dec-Feb	OTS	F	774488	
	Peanut hull	14.483	20	Jan-	OTS	F	369660	
	Cashew Hull	21.92	26	Apr-Aug	OTS	F	569920	3192092
	Cashew Apple		52	Apr-	F	P	0	
	Millet stalk	18.126		Dec-Jan	F	F	362520	
	Corn stalk	14.935	20	Oct-Dec	F	P		
	Hull of Palm	21.452	52	Always	OTS	P	1115504	

3.2.3 Benefits of a successful application, prerequisites and limitations

Relationship between needs and exploitable energy resources

The results of the measurements and surveys of the energy potential of each locality allowed us to make a study of the needs and the possibilities of solving in a sustainable way the problem of access to the energy of these populations. Table 6 below contains all the results of the study proposed in this context.

Table 5: Biomass energy potential of localities by estimation following the survey, part 4.

City	Type of waste	LHV (MJ/kg)	Quan. harv. (t)	Avail. period	On the spot or forest	Free or Paid	Energy Potential	Total (MJ)
Bourofaye (Boutoupa-Camaracounda Niaguis)	Rice Ball	14.894	24	Dec-Jan	OTS	P	357456	
	Peanut hull	14.483	1	Feb-Jun	OTS	P	194155	
	Cashew Hull	21.92	153.6	Mar-Jul	OTS	P	3366912	4112678
	Cashew Apple		307.2	Mar-Jul		P	0	
	Corn stalk	14.935	13	Always	OTS	P	194155	
Mampalago	Rice Ball	14.894	0.5	Dec-Jan	OTS	P	7447	
	Peanut hull	14.483	1.5	Feb-Jun	OTS	P	27724.5	
	Cashew Hull	21.92	3	Mar-Jul	OTS	P	65760	165287.5
	Cashew Apple		9	Mar-Jul	F	P	0	
	Hull of Palm	21.452	3	Always	OTS	P	64356	
Total							46,357,469	46,250,389

3.3 Discussion and conclusions

Access to Energy
In Table 1, we notice that this population is almost the same as in the whole country with percentages on the gender almost at around 50% that can switch from one side to the other according to the zone and also according to the survey. What is striking is also the low enrolment rate in these areas compared to the average of the Ziguinchor region which is among the most, if not the highest in Senegal (close to 90%). In these data, it is important to highlight the disparity between the percentage of boys in school which is always higher than that of girls. This situation is indicative of the problem caused by this crisis, which shows that the first victims are children and women in particular. This gender ratio (rate of girls enrolled in relation to the rate of boys attending school) is almost 106% in the country at primary level and 91.8% in the secondary school in 2012, whereas it has been inverted in these villages.

For the access to the energy of the population, all the villages having undergone a strong impact of the conflict with the exception of Bourofaye and Oukout (Bissassou, Kaguitte, Gouraf, etc.) have the weakest access rate to energy, with values below 20%. What should be noted overall is the poor access to energy of the population in all surveyed areas except Djibelor, Tobor and Suelle who are on the main roads and near Ziguinchor and big community respectively. In fact, this rate is less than 20%. This means that only one-fifth of the population at best has access to energy. Regarding the percentage of students with access to energy, it is even more alarming with peaks almost none at 7% and 9% in the villages of Bading and Kawaguire. It is important to note this low percentage, which does not exceed 15% in most of the areas surveyed, with the exception once again of Djibelor, Tobor and Suelle for which the values go up to 88% in Djibelor.

Table 6: Energy and biomass needs and potential.

City	Energy req. (Wh)	Total Needs (Wh)	Energy Req. (MJ)	Solar Potential (Wh/d)	Biomass Potential (MJ)	Desired system
Niafor	8.07E+04	2.69E+05	3.53E+05	3461	1.48E+07	PV+GE or PV+Biomass
Ass or m or l	1.20E+05	1.71E+05	2.25E+05	3461	5.30E+06	PV+GE or PV+Biomass
Bading	8.34E+04	8.34E+04	1.10E+05	3461	2.56E+05	PV+GE or PV+Biomass
Bissass	2.52E+05	2.80E+05	3.68E+05	3461	1.11E+05	PV+GE or PV+Biomass
Kaguitte	8.82E+04	1.76E+05	2.32E+05	3461	4.22E+06	PV+GE or PV+Biomass
or k or t	9.78E+04	3.26E+05	4.28E+05	3461	2.33E+06	PV+GE or PV+Biomass
Djibelor	1.43E+05	1.43E+05	1.88E+05	3461	5.87E+04	National Grid
G or raf (Niaguis)	1.17E+05	1.17E+05	1.53E+05	3461	3.19E+06	PV+GE or PV+Biomass
B or rofaye (Camarac or nda-Niaguis)	7.65E+04	7.65E+04	1.01E+05	3461	4.11E+06	PV+GE or PV+Biomass
Tobor	3.08E+05	7.69E+05	1.01E+06	3461	5.94E+06	National Grid
Suelle	2.78E+05	9.28E+05	1.22E+06	3461	5.58E+06	National Grid
Kawaguire (Mlomp)	1.93E+05	2.15E+05	2.82E+05	3461	5.53E+04	PV+GE or PV+Biomass
Kabatagua (Dianki)	6.29E+04	6.99E+04	9.18E+04	3461	8.84E+04	PV+GE or PV+Biomass
Mampalago	2.66E+05	5.32E+05	6.99E+05	3461	1.65E+05	PV+GE or PV+Biomass
Averagetotal	1.55E+05	2.97E+05	3.90E+05	3461	3.30E+06	PV+GE or PV+Biomass

In a word, we must distinguish on this table two main categories according to the rate of access to energy, localities where the rate of access to energy is quite low or sometimes non-existent ($<$22% in general) which are mainly areas where the conflict has had a strong impact but also very rural areas. On the other hand, quite sparse localities (Suelle, Djibelor and Tobor) have access rates to energy as important sometimes as in the city centres. The particularity of these localities is especially their proximity to the big cities or being rather densely populated communes. These solutions could come from natural resources that abound in this southern region of the country both in renewable energy than in Biomass.

Energy Potential of Biomass

This study consisted of an estimate of the organic waste available in each area surveyed. According to the results of the survey (example tables 2-5), biomass potential in all areas is very important. Access to these wastes seems easy and the cost would be very low. The identified and calculated needs took into account both household and industrial and institutional needs. For all calculation made, it can be noticed that the energy resources available in these areas cover by far their needs.

The main question is what would be the best and sustainable solutions for the population. For that purpose, we made a study on renewable energy systems combined with a generator that can run on biogas or diesel. The availability of biomass resources alone covers most of the energy needs of these localities except for certain localities such as Mampalago, Kawaguire and Kabatagua for which our estimates were difficult to obtain. It should also be noted that estimates have been made with sometimes a very clear underestimation of the organic resources available for reasons of security.

The numbers are very relevant (Table 6). Indeed, with an energy requirement of 5.461.000 MJ these localities alone produce about 9 times their needs (46.250.000 MJ) of organic waste. It seems therefore clear to us that, in order to provide sustainable and viable support to these populations and to support a sustainable peace dynamic in this region of the country, we cannot avoid to give value to these resources and facilitate their access to this population. Helping people to become independent of aid is the best thing that can be for a country.

Recommendations and perspectives

This study offers us two possible and sustainable solutions, to facilitate access to energy for this population by rural electrification oriented toward the available resources such as solar and biomass and to train the younger generations for a sustainable management of these resources. To find a lasting solution to this conflict, radical solutions are necessary and will necessarily pass through several of the most important actions:

- drastic decrease in unemployment
- introduction of security
- youth education
- the creation of businesses at community level, at local level
- access to health and public facilities

All these actions are related to something that is unavoidable; it is access to energy and water.

Bibliography used in this section:

(Water UN, 2014, Ott, 2011, Carbonnier and Grinevald, 2011, Rudolf, 2013)

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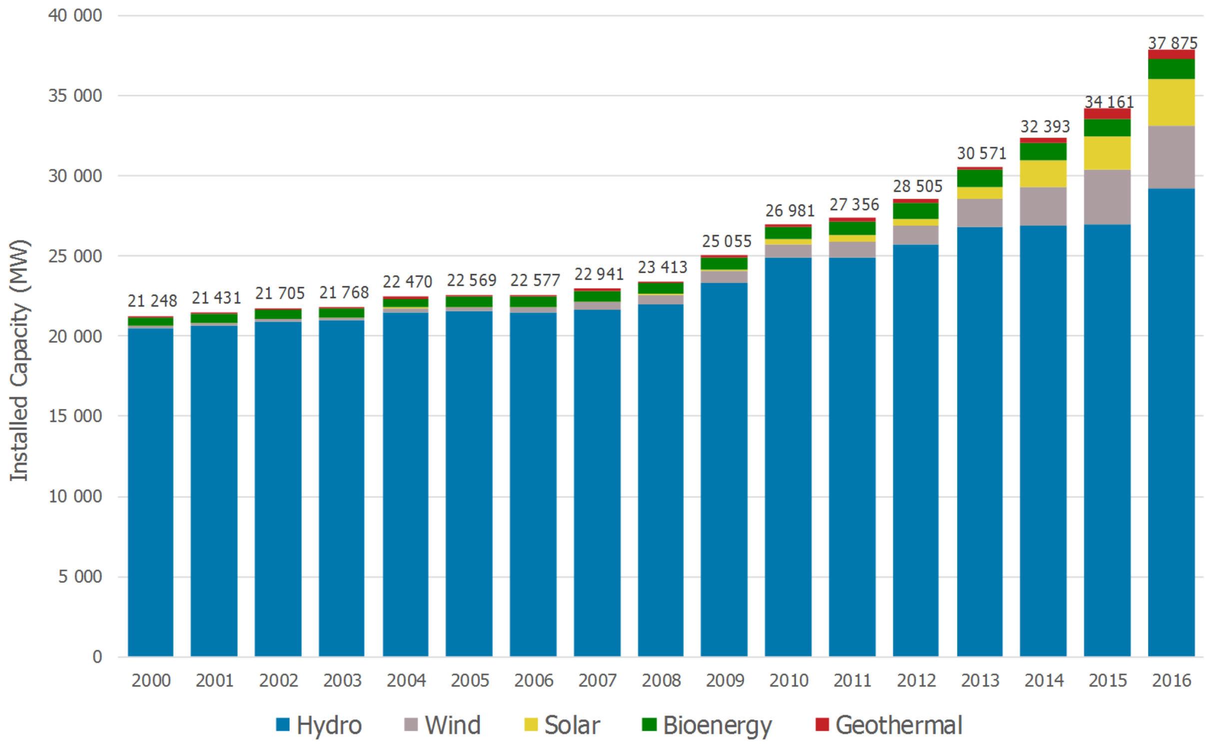
4 Current status of electricity from bioenergy in Africa

Author: Javier Esparrago

4.1 Overview of Renewable Electricity Generation in Africa

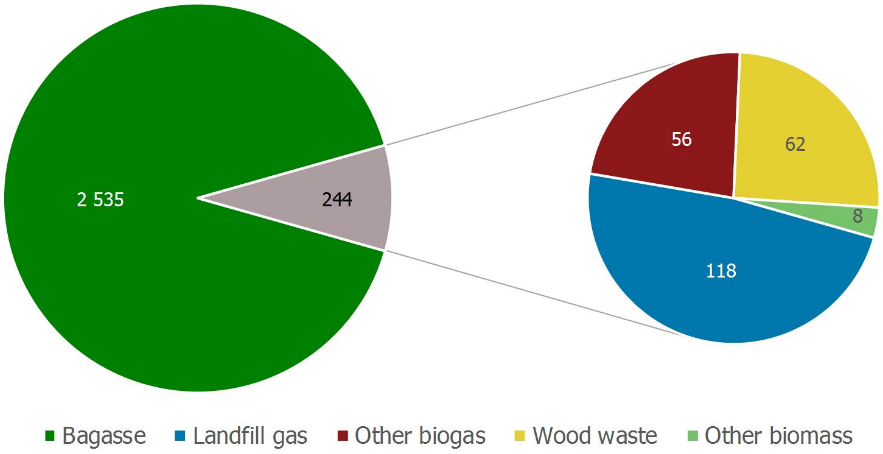
Renewable energy has historically been an important component of the African electricity mix. However, the renewable contribution was mostly limited to large hydropower facilities. According to IRENA latest statistics (International Renewable Energy Agency (IRENA), 2017), in 2006, large hydro plants (>10 MW) represented 94% of the total renewable installed capacity in the continent, with most of the rest being split between generation from bagasse, smaller hydro plants and an incipient wind sector. A decade later, the picture is substantially different. Large hydro is still the main renewable power source, but its share is down to 76% out of a total renewable capacity of 37.9 GW. As illustrated in Figure 8, wind and solar have experienced a rapid increase over the last few years, accounting now for 3.9 GW and 3 GW respectively. Capacity from bioenergy has grown slower but at a steady pace, reaching 1.2 GW in 2016, which accounts for 3.1% of renewable capacity in Africa. Geothermal (0.64 GW) and small and medium hydro (0.57 GW) complete the picture.

Figure 8: Renewable power installed capacity in Africa.



Electricity generation from bioenergy in Africa amounted to 2779 GWh in 2015, the most recent year covered by IRENA generation statistics (Figure 9). The vast majority of it (91%) corresponded to electricity generation from bagasse. The rest was mostly biogas; particularly landfill gas (4%) and other biogases from fermentation (2%). Electricity from solid biofuels accounted for the rest, being mostly wood waste (62 GWh) and small contributions from wood fuel, palm oil residue and rice husks.

Figure 9: Electricity generation from bioenergy in Africa in 2015 (GWh).



In terms of geographical distribution, sugar-producing countries lead on installed capacity from bioenergy. At least 18 African countries are generating electricity from bagasse according to IRENA statistics; with Sudan, South Africa, Swaziland and Zimbabwe having more than 100 MW of installed capacity. In terms of generation, however, Mauritius leads the table with 530 GWh due to improved efficiency in electricity generation from sugar mills.

Excluding bagasse, South Africa and Tanzania are the two countries with the highest installed bioenergy capacity. Over the last 10 years, South Africa has developed a well-established biogas-to-electricity sector with more than 22 MW installed in 2016. These includes power from landfill gas, biodigesters using farm waste and, to a lesser extent, sewage sludge gas. Mauritius, Kenya and Morocco are also starting to unveil their biogas potential and have installed more than 2 MW to date. Other interesting biogas power developments already running are Fasobiogaz in Burkina Faso and pilot gasification projects in Tanzania and Benin. Electricity generation from liquid biofuels is still very limited, but small projects to generate electricity from Jatropha oil and biodiesel are already occurring in various locations of the continent.

4.2 Data limitations

The figures described in previous paragraphs are based on the latest IRENA Statistics (International Renewable Energy Agency (IRENA), 2017). These statistics are provided directly by the countries using the IRENA Questionnaire or are collected from different sources including national official statistics, reports from industry and academia, and other unofficial sources. While every effort is put to build an accurate and comprehensive dataset, we suspect that some power generation from renewables may be unaccounted for in traditional statistics.

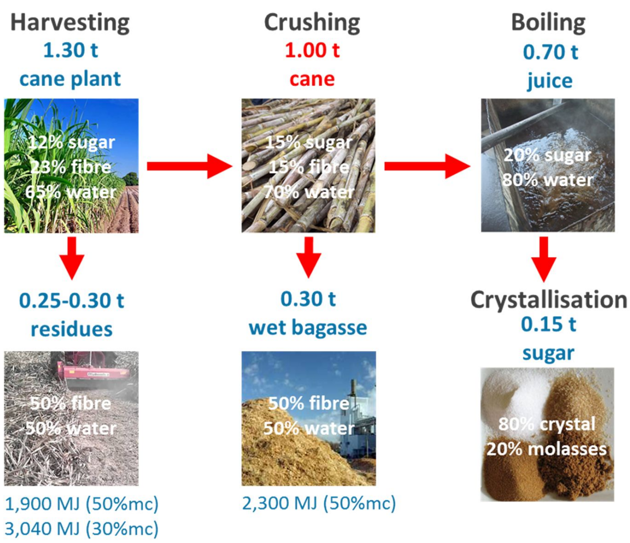
The reasons for this shortage of data are varied and depend on the source of energy and the country. In some cases, national officers lack appropriate funding for data collection activities. Another common problem is the lack of an institutional framework and its enforcement for the collection of statistics, centralisation of data and sharing arrangements between different governmental units. In the case of power from bioenergy, it often occurs in a decentralised manner and sometimes off-grid, making the collection of data more difficult. Furthermore, many countries currently do not collect any information about the electricity produced by enterprises for their own use (auto-production), which is remarkable in African industries usually powered by biomass such as the sugar and palm oil industry. IRENA's statistics include some estimates of this and are, therefore, higher than the figures presented by many other agencies. However, it is quite likely that a lot of off-grid and small-scale bioenergy generation (auto-production) is still missing from these estimates.

4.3 Estimating theoretical current and potential generation from agro-industrial processes

In order to overcome some of the limitations described above, IRENA is developing a series of estimation methods aimed at quantifying the theoretical current and potential electricity generation from agro-industries based on reported agricultural production. In the case of Africa, palm oil and sugar cane processing industries have been identified as the most relevant for this analysis. The objective of these estimations is to provide theoretical reference points that can be then compared with existing statistics. This will help to identify data gaps, prioritise data collection efforts, assess existing calculation methods and provide an overview of the accuracy of current statistics on bioenergy. In addition, by modelling existing best practices in the estimations, a theoretical potential can be estimated offering some insights on the role that bioenergy can play in the future energy mix by using readily available technology.

A literature review was conducted analysing the different processes involved in the sugar cane (Lavarack et al., 2004, Ogden et al., 1990, Deepchand, 2005, Pippo and Luengo, 2013) and palm oil industry (Ani and Mohamad Nor, 2010, Nasution et al., 2014, Ohimain and Izah, 2015, Aziz et al., 2015). Typical energy and mass flows for an average installation were elaborated. Similarly, typical energy consumption for each of the processes were analysed. Current best available techniques for energy generation on these industries were also identified. At the time of writing this paper, the methodology is still in a preliminary stage and results should be taken as indicative. However, we believe this approach can be very useful to understand the current context of electricity from agro-industrial waste.

Figure 10: Mass and energy flows in the sugar cane processing industry.



4.3.1 Sugar cane processing

For the sugar cane industry, it is calculated that 0.3 tonnes of bagasse with an approximate energy content of 2300 MJ are generated for every tonne of processed sugar cane (Figure 10).

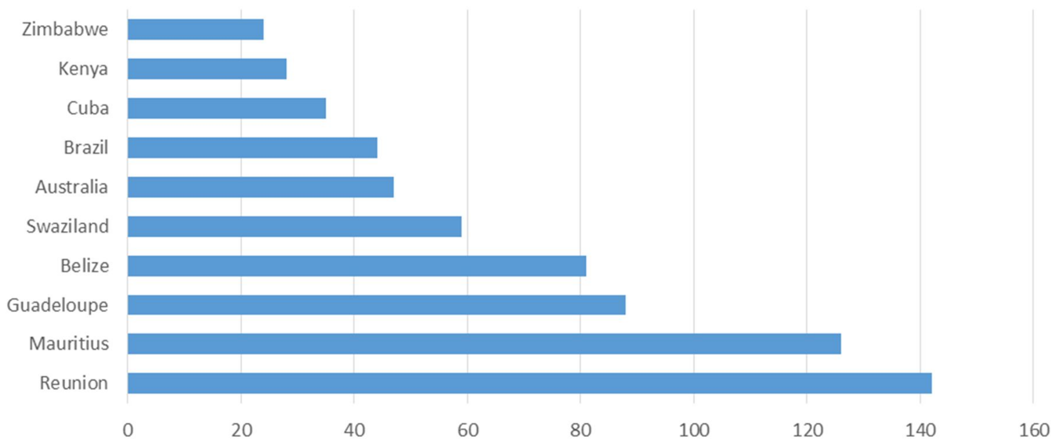
Mill energy needs are usually covered using bagasse as a source of energy. Table 7 summarizes energy use per tonne of sugar cane for each of the processes. This includes the use of auto-produced electricity necessary to meet the electricity demands of the mill (around 25 kWh per tonne of processed sugar cane). The vast majority of energy used in the sugar cane industry is in the form of heat for boiling and crystallisation.

Table 7: Energy use for each process per tonne of cane.

Process	Energy (MJ/t)
Crusher (steam-driven)	110
Boiling + crystallisation	800
Electricity (25 kWh/t)	90
Total	1,000

The figures above refer to a typical low-technology mill, fitted with low pressure steam engines which are used for driving machinery as well as producing electricity. By upgrading to modern high-pressure steam systems for power generation and electrification of the machinery, it is possible to generate 120 kWh of electricity per tonne of cane, of which 30 kWh would be for self-consumption and 90kWh to be exported to the grid. There are successful examples in countries like Mauritius, which went through a modernisation process of its sugar industry, being energy generation one of the main drivers for this change. Figure 11 illustrates this difference in power production per tonne of cane between several countries.

Figure 11: Power generation from bagasse (kWh per tonne of cane).



According to (Food and Agriculture Organization of the United Nations, 2017) the total production of sugar cane in Africa was over 95 Mt in 2014. Although found in West Africa, the majority of sugar cane is produced in South and East African countries with suitable climatic conditions for this crop, such as South Africa, Egypt, Kenya and Sudan. Using the production figure as an input and applying the typical values calculated above, we estimated that around 95 PJ of energy from bagasse could be being generated in Africa. This includes around over 2 TWh of electricity just for self-consumption, excluding exports to the grid. By modernising mills and applying best available techniques, over 11 TWh could be generated with the same yields. Table 8 details the estimated energy use and potential generation by the sugar cane industry in West Africa based on agricultural production.

Table 8: Estimated current & potential energy use from bagasse (sugar cane production, 2014).

Country	Sugar cane production (tonnes)	Electricity own-use (GWh)	Heat use (TJ)	Total energy use (TJ)	Electricity potential (GWh)
Côte d'Ivoire	1,998,426	50	1,819	1,998	240
Nigeria	1,057,324	26	962	1,057	127
Senegal	702,891	18	640	703	84
Burkina Faso	478,842	12	436	479	57
Mali	354,461	9	323	354	43
Guinea	301,012	8	274	301	36
Liberia	266,213	7	242	266	32
Niger	226,928	6	207	227	27
Ghana	149,000	4	136	149	18
Sierra Leone	77,254	2	70	77	9
Cabo Verde	28,000	0.7	25	28	3
Benin	20,398	0.5	19	20	2
Guinea-Bissau	6,416	0.2	6	6	1
Rest of Africa	89,864,214	2,247	81,776	89,864	10,784
Total Africa	95,531,379	2,388	86,934	95,531	11,464

4.3.2 Palm oil processing

The palm oil industry generates four main types of waste (Figure 12). Empty fruit bunches are the largest type of residue from palm oil processing (0.22t per tonne of fruit bunches). Due to their bulkiness and high moisture content, they are usually returned to the fields for mulching, although they may also be used for energy purposes. Press fibre and kernel shells are commonly used as fuel to power the palm oil mills due to their lower water content, easier handling and improved burning characteristics. Palm oil mill effluent (POME) is a liquid waste produced in large quantities by palm oil mills. In many cases, this effluent is kept in pools for biological treatment releasing GHGs and sometimes being inappropriately disposed. There is a huge energy potential for POME through gasification, reaching 25 m^3 (550 MJ) of biogas per tonne of fresh fruit bunch. Successful projects have been implemented in South East Asia and many others are in the pipeline, and a similar technology could be applied in Africa.

Energy use in palm oil processing is detailed in Table 9. A total of 1245 MJ of energy are used for processing one tonne of fresh fruit bunches, half of it corresponding to heat used in the clarification and refining process. Around 20 kWh of electricity are used to move machinery. In larger plants, this electricity is generated using press fibres and kernel shells as fuel. However, in smaller plants a large proportion of the mechanical force is done by hand with the help of a diesel generator for heavy loads.

Figure 12: Mass and energy flows in the palm oil processing industry.

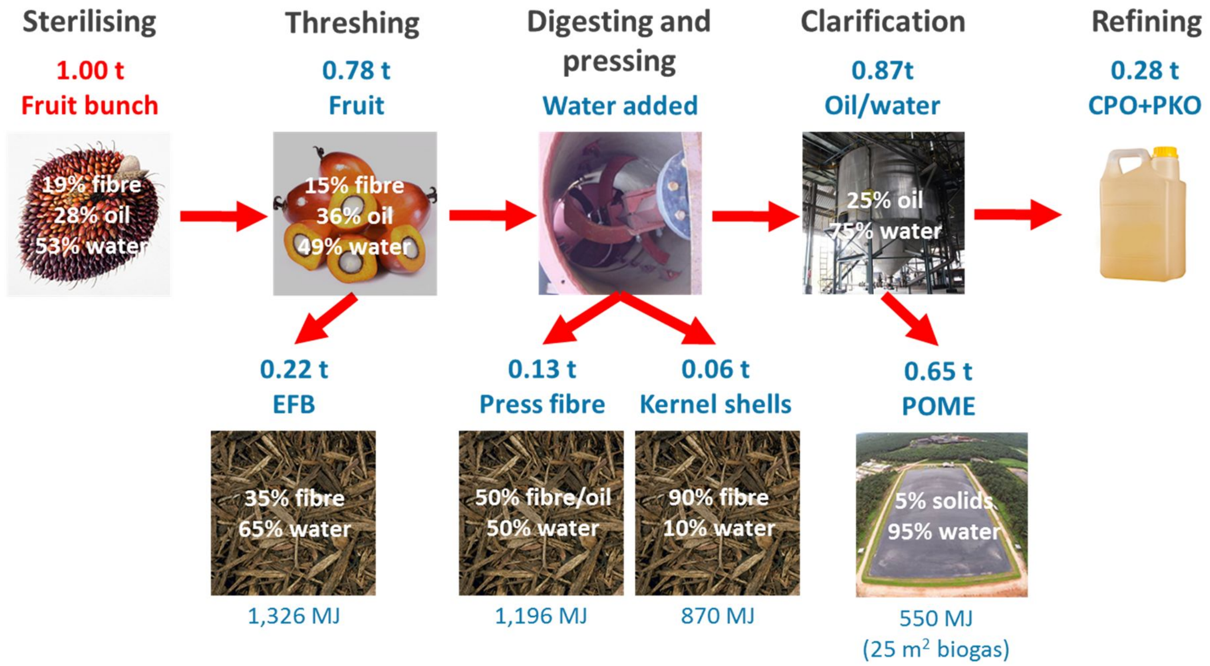


Table 9: Energy use in each process per tonne of fresh bunch.

Process	Energy (MJ/t)
Sterilising	350
Digesting	200
Clarification/refining	620
Electricity (20 kWh/t)	75
Total	1245

Oil palm fruit production reached 18.7 Mt in Africa in 2014 (Food and Agriculture Organization of the United Nations, 2017), the majority of it in West Africa. Nigeria was the largest producer in oil palm fruit in the continent, followed by Ghana and Côte d'Ivoire. Using the production figure as an input and applying the typical values calculated above, we estimated that around 22 PJ of energy from palm oil residue could be being generated in Africa. This includes around over 75 GWh of electricity for self-consumption. The reason for this low electricity figure is because the majority of palm oil in Africa is processed in small and medium-size mills, where much of the work is manual or aided by small diesel generators.

Only around 20% of Africa's palm oil is processed in large mechanized mills with capacity for self-generation of electricity from residues (Yombouno, 2014). However, it was assumed that palm oil residues are used to heat generation in both small and large facilities. At current yields, the potential for electricity generation in Africa from palm oil residues could be over 3.5 TWh, assuming that all the remaining fibres, shells and POME biogas is used for co-generation of heat and power. Table 10 details the estimated energy use and potential generation by the palm oil industry in West Africa based on agricultural production.

Table 10: Estimated current & potential energy use from palm oil residues (based on oil palm fruit production, 2014).

Country	Oil palm fruit production (tonnes)	Electricity own-use (GWh)	Heat use (TJ)	Total energy use (TJ)	Max electricity potential (GWh)
Nigeria	7,962,213	32	9,316	9,430	1,513
Ghana	2,443,270	10	2,859	2,894	464
Côte d'Ivoire	1,672,877	7	1,957	1,981	318
Guinea	833,458	3	975	987	158
Benin	586,975	2	687	695	112
Sierra Leone	209,819	>1	245	249	40
Liberia	175,153	>1	205	207	33
Togo	144,687	>1	169	171	27
Senegal	120,181	>1	141	142	23
Guinea-Bissau	80,780	>1	95	96	15
Gambia	35,071	>1	41	42	7
Rest of Africa	4,438,292	18	5,193	5,257	843
Total Africa	95,531,379	2,388	86,934	95,531	11,464

4.4 Conclusions

Bioenergy has been an important part of the African electricity mix for many years and, in recent times, it has continued growing and expanding. However, the renewable power scenario in Africa is changing. Solar and wind are experiencing a very rapid increase and there is a trend in the continent and globally towards more decentralised generation. Electricity from bioenergy is also showing a similar trend. Small-scale bioenergy projects are becoming a viable option for rural communities and utilities alike, particularly for biogas.

However, there is still a huge wasted potential on agro-industries using bioenergy as a fuel. This paper covered the sugar cane and palm oil industry. Both are well established technologies with high energy requirements and which generate large amounts of biological waste. In many cases, auto-generation in these industries is not reported and not included in national statistics. This lack of data may have a negative impact on several policy aspects and may overlook the potential of these sources for the current and future energy mix in Africa. This paper also offers some initial estimations of the amount of electricity and heat from bioenergy on these industries and the theoretical potentials that could be achieved with current best available techniques and existing levels of agricultural output.

Bibliography used in this section:
(International Renewable Energy Agency (IRENA), 2017, Lavarack et al., 2004, Ogden et al., 1990, Deepchand, 2005, Pippo and Luengo, 2013, Ani and Mohamad Nor, 2010, Nasution et al., 2014, Ohimain and Izah, 2015, Aziz et al., 2015, Food and Agriculture Organization of the United Nations, 2017)

5 Importance of evidence-based bioenergy policy development.

Author: Manas Puri
Keywords: Cashew; energy recovery; cashew waste; briquettes; bioenergy.

Over the past century, the global capacity to produce food has increased tremendously. Countries have been able to increase volume of food production due to both agricultural area expansion as well as increase yields of major crops. However, the global human population surpassed seven billion during 2011 and is predicted to reach 10 billion by 2050 (FAO, 2017). Estimates are projecting a 50 percent increase in food demand by 2050 compared to 2013 levels (FAO, 2017) to satisfy the growing population. At the same time, 795 million people are chronically hungry and 2 billion suffer micro-nutrient deficiencies (FAO, 2017).

Expanding agricultural are looks unlikely due to already stressed land and water resources. Additionally, the rapid increases in yields in the past was partly due to the availability inexpensive fossil fuel which allowed for increased availability of inputs and practices such as fertilisers, pesticides, expansion of irrigated agriculture etc. While this did increase food production, it also resulted in food systems becoming a major source of greenhouse gas (GHG) emissions, with significant contributions to global climate change. At the same time, agriculture is also severely affected by the changing climate through increases incidence of extreme climatic events such as droughts or floods, and changes in water availability and soil quality, which may have a significant impact on agri-food systems.

Therefore, the global community needs to find ways for countries to transition to a food system that can ensure food security for all while mitigating and adapting to climate change. FAO has supporting countries to achieve this transition through its Energy Smart Food Programme (ESF) which is a multi-partner initiative that works with member countries helping them move towards energy-smart agri-food systems that are less dependent on fossil fuels. The four pillars of the ESF programme form the overall framework of FAO's work on Energy:

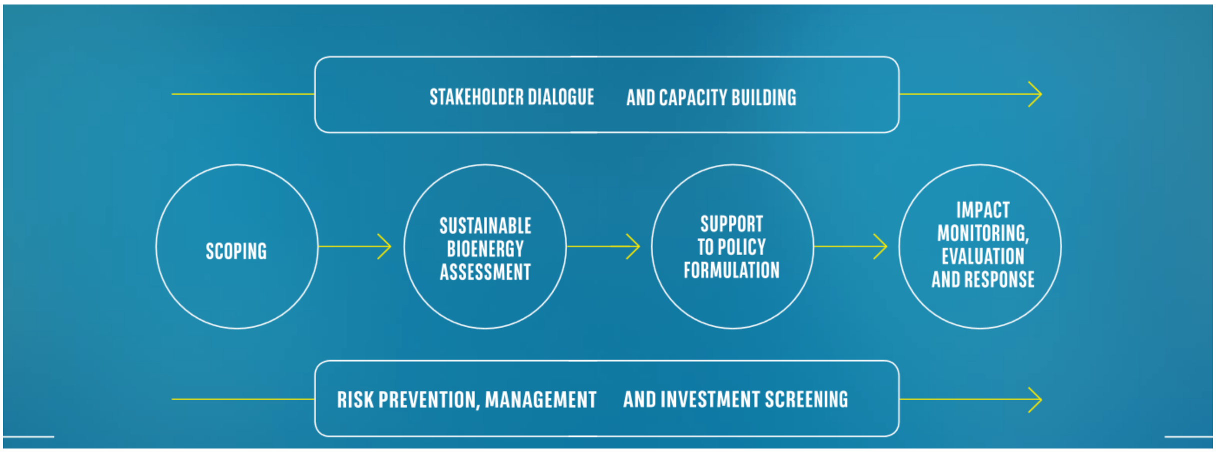
- Access to modern energy services in rural areas;
- Energy efficiency in agri-food systems;
- Renewable energy in agri-food systems;
- Application of a water-energy-food approach.

A key element of FAO's support to countries is in the Bioenergy sector to ensure sustainable development of bioenergy that supports food security and mitigates impact on the environment at large. In large parts of Africa and Asia, traditional use of bioenergy is the largest source of for energy domestic and industrial purposes. In 2014, the total primary energy supply of biomass was 59.2 EJ which is 10.3 percent of all the supply of energy globally of 573 EJ (WBE, 2017). In Asia and Africa, almost all the supply is in the form of solid biofuels, most of which is harvested unsustainable. This has had significant impact on biomass resources in these regions such as deforestation. Many countries have developed specific bioenergy policies and targets that fit into their broader renewable energy targets. However, it is also imperative to develop these targets based on sound analysis and evidence. Bioenergy as a renewable energy source cross cuts many ministries by it nature. While generally, Ministry of energy is in-charge of developing energy policy, bioenergy policies should be developed in consultation with other ministries, specifically Ministries of Agriculture, Ministry of Forestry etc., all of which are key stakeholders in the bioenergy sector. Additionally, to truly usher a sustainable bioenergy development, investments would need to be made, specifically from the private sector so that there is a stable and affordable supply of sustainable bioenergy.

The Bioenergy and Food Security (BEFS) Approach has been developed by FAO to support countries in designing and implementing sustainable bioenergy policies and strategies. The approach promotes food and energy security and contributes to agricultural and rural development. It consists of tools and guidance to support countries through the main stages of the bioenergy policy development and implementation process.

The BEFS analysis starts with the definition of the country context which identifies the policy structure in the country, key economic indicators and the state of energy and agriculture sector in the country. This is followed by three areas of analysis for the whole biofuel supply chain, namely Natural Resources, Techno-economic Analysis and Socio-economic Analysis. The Natural Resource analysis includes a Biomass Potential Assessment to identify potential biomass available in the country to be used for modern bioenergy technologies. The Techno-economic and Socio-economic analyses address technology requirements, production costs, smallholder inclusion, job creation and investment requirements. Food security considerations and sustainability dimensions are interwoven throughout the BEFS analysis. With regards to food security, current and planned uses of biomass for non-bioenergy purposes are subtracted from the amount of feedstock potentially available for bioenergy production as well as any other use, such as the use of crop residues as a soil amendment or for feeding animals. Economic and social sustainability cover issues related to the economic and financial viability of the various biofuel pathways, smallholder inclusion and job creation, among others.

Figure 13: Bioenergy and Food Security (BEFS) approach developed by FAO.



The BEFS analysis has been used in many countries across the world to support bioenergy policy development at country level. The methodology was most recently used in Turkey and Egypt to understand the potential of bioenergy development in the country. The results in Turkey identified the main types of residues available for bioenergy production as well as their geographical distribution within Turkey. Two main agricultural residue types were considered: crop residues (collected or spread) and livestock residues (cattle, buffalo and chicken manure). Collected residues (those residues that are either collected in the field after harvest or at the processing plant after the processing and packaging of the final product) that show larger availability include sunflower head, maize cob, maize husk, rice husk and hazelnut husk and there are more than 100,000 tonnes of each available per year.

The natural resource assessment identified that the province of Edirne (Marmara Region), Adana (Mediterranean Region), Tekirdağ (Marmara Region), Konya (Central Anatolia Region) and Kirklareli (Marmara Region) have the largest amount of collected residues. The highest share in the total available residues consisted of sunflower head and maize cob. Concerning those residues that are spread in the fields, cotton stalk, maize stalk and sunflower stalk seemed to have the highest availability with each exceeding 1.8 million tonnes available per year in Turkey. The provinces of Sanliurfa (Southeast Anatolia Region), Adana (Mediterranean Region), Aydin (Aegean Region), Hatay (Mediterranean Region) and Diyarbakir (Southeast Anatolia Region) provinces were estimated to have the largest amount of spread residues, with cotton stalk and maize stalk having the largest shares in the total.

Based on the identified residues a techno-economic analysis was done to understand how much energy and using which technology can be most economically viable in the country. The analysis considered two distinct bioenergy pathways:

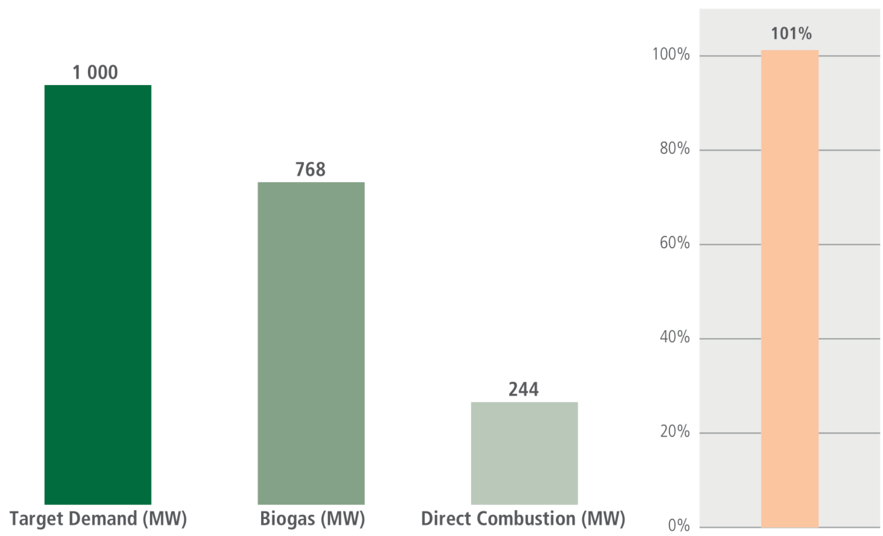
1. Residues burnt directly in CHP plants (crop residues mainly), and;
2. Residues that first need to be converted into biogas (manures mainly).

To be profitable, these plants need to operate under certain constraints, specifically the current feed-in tariff, ranges of biomass energy potential and their price. Based on these constraints, a subset of biomass feed stock was identified form the result of the natural resource assessment. Feedstock that were deemed available for bioenergy production in the natural resource assessment and that that met these criteria were:

1. For direct residue combustion: groundnut husk, pistachio shell, hazelnut husk, rice husk and potentially from maize cob and maize husk;
2. For biogas to CHP: cattle manure, poultry manure and sunflower heads.

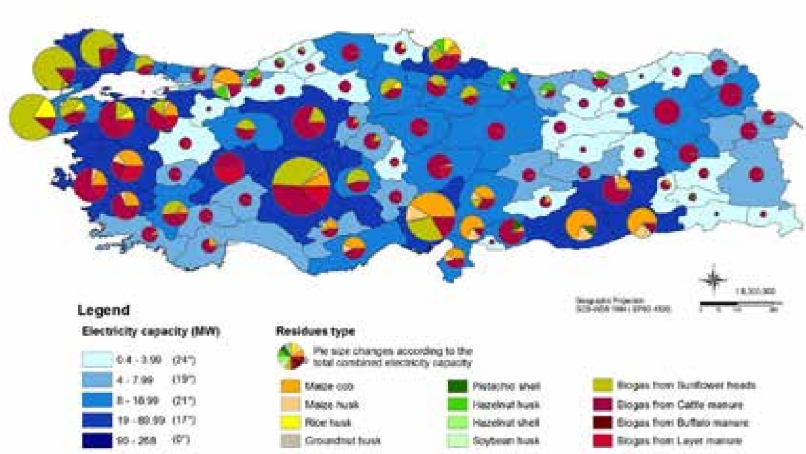
The analysis concludes that it would be possible to reach a combined production capacity of 1012 MW using the above-mentioned residues and technologies This production potential is around 101 per cent of the target 1000 MW of energy to be produced by biomass by 2023 as defined in the Turkish renewable energy target.

Figure 14: Comparison of combined production capacity of CHP alternatives and Turkish renewable energy target for electricity from biomass.



Furthermore, the use of residues as a feedstock for briquetting and pelleting was also analysed. Many parts in Turkey uses, coal and fuel-wood that could be replaced by biomass briquettes and pellets. However, to be truly commercially viable, it is important to consider the minimum required energy potential and the price ceiling for both briquettes and pellets compared to the region's charcoal and fuel-wood consumption and to what extent the competing industry has been established.

Figure 15: Electricity capacity generation (MW) from crop residues (excluding cotton stalk) and livestock manure biogas.



Based on these conditions, the top 10 most promising crop residues identified as potentially available and profitable were: hazelnut shell and husk, groundnut husk, cotton stalk, maize cob and husk, pistachio shell, soy-bean husk, sunflower heads and rice husk. However, the accessibility of residues that (proportion of the available residues that can be mobilized for energy production) are spread in the field can have a major impact on their final use. To see the effect of accessibility issues in the country, cotton stalk was further examined as an example. This residue was chosen for this analysis as it is abundantly available in the country. Given this, if 20 percent of cotton stalk were to be accessed or collected, would result in producing 1033 ktoe of energy. Given the Turkish renewable energy target for biomass heating and cooling is set at 3537 ktoe, the 1033 ktoe would be equivalent to almost 30 percent of the target. If collection and mobilization were to be improved for cotton stalk, then there could be potential to fulfil an even larger share the target.

From a policy point of view, a key constraint in using biomass for sustainable bioenergy development is the lack of a biomass value chain that would enable a constant supply of feedstock. In the medium to long-term, efforts should be made to develop appropriate policies and mechanisms, as outlined above, to put in place an agricultural residue value chain that ensures a uniform and dependable supply of residues. This should involve cooperatives, intermediaries and a mechanism to encourage information exchange between energy producers and biomass owners as well as policies to introduce mechanization equipment for the collection and pre-treatment of residues and storage facilities.

Smart energy use and policy development should stem from a clear identification of the specific energy forms and demand required by consumers (e.g. communities and industries). And supply options that may exist in the country. Based on this, the most promising and interesting markets can be determined, and sustainable bioenergy can effectively replace non-sustainable energy forms.

Bibliography used in this section:
(WBE, 2017, FAO, 2017, FAO, 2016)

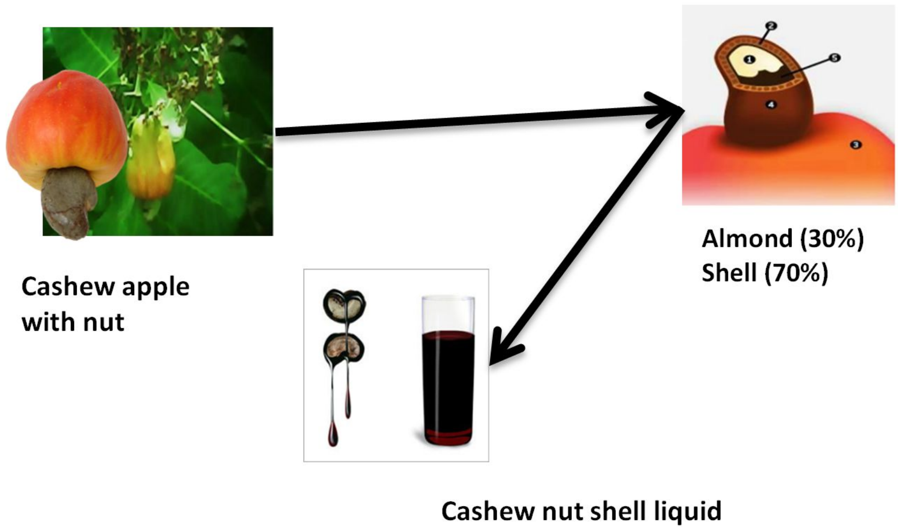
6 Energy recovery of cashew waste: production of combustible briquettes

Author: Marie Sawadogo
Keywords: Cashew; energy recovery; cashew waste; briquettes; bioenergy.

6.1 Introduction

The use of biomass for energy production is one of the means to ensure energy security and solve the environmental problems associated with the use of fossil fuels in developing countries. Small and Medium-sized Enterprises (SMEs) need electrical and thermal energy for carrying out their activities. In Burkina Faso, this thermal energy is usually produced from firewood or charcoal.

Figure 16: Cashew apple with nut.



In addition, the cashew nut production industries produce large quantities of waste (hulls, cakes, shells) that can be used for energy recovery. In these industries, raw cashew shells are used in direct combustion to fuel steam boilers. This method leads to the production of flue gas that contains anacardic acid that is irritating and may even be carcinogenic, due to the presence of CNSL (Cashew Nuts Shell).

This article presents the results of a study on energy production from cashew waste; indeed, fuel briquettes were produced from the cashew cake. The process consists in a first step in the carbonization of the cake at a temperature of 350°C, the resulting char is then milled to a particle size of 0.5 mm. The resulting charcoal powder is then mixed with water and cassava starch, used as a binder. Cassava starch is used because of its physiochemical properties, its availability on the local market and its low price. The mixture obtained is then densified in a screw press to obtain briquettes 5.5 cm in diameter and 10 cm long.

Several proportions of water and cassava starch were tested. The briquettes were then characterized. This paper presents the results of physiochemical and mechanical tests of briquettes made. The results of the combustion tests are also presented.

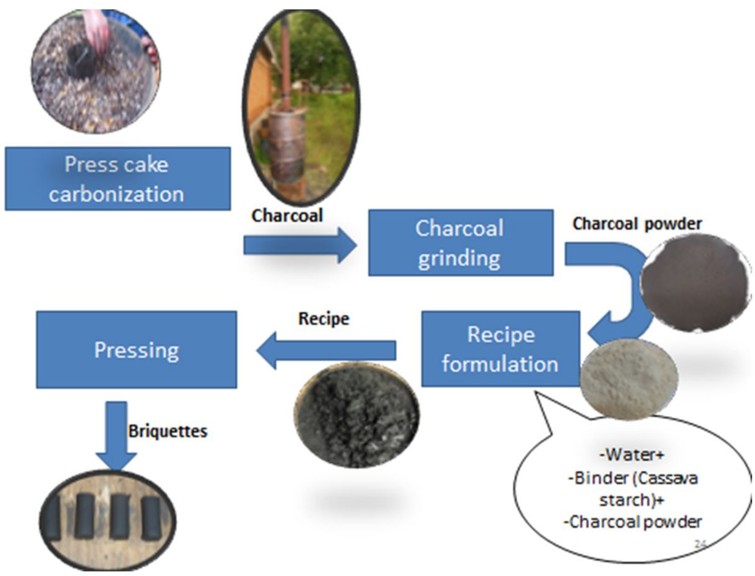
6.2 Description of the project and results

Burkina Faso is a landlocked country located in West Africa. Burkina Faso's energy situation is characterized by low access to energy services. According to the report on Sustainable Energy for All (Sustainable Energy for All, 2014), over 90% of the country's population does not have access to modern cooking fuels. The main source of energy remains biomass (wood and charcoal) for more than 80% of the population, or more than 2,424 ktoe in 2008 (Sustainable Energy for All, 2014). The thermal energy needed by small and medium-sized enterprises (SMEs) is generated from firewood. This intensive use of wood has an impact on the vegetation cover, leading to advanced deforestation; in Burkina Faso, more than 250,000 hectares of forest are cleared each year to meet this need (Bensch et al., 2013).

The agri-food industry is facing energy supply challenges; converting agricultural waste into briquettes will reduce the use of natural gas or oil as fuel (Nurhayati et al., 2016, Pasquiou et al., 2012). Briquettes from biomass offer many benefits and are a substitute for charcoal, lignite and firewood. Briquettes have environmental qualities and benefits superior to charcoal because they are derived from renewable resources (Kathuria and Grover, 2012). In addition, the use of briquettes will help reduce deforestation by partially replacing charcoal and help reduce the use of fossil fuels (de Oliveira et al., 2017).

The valorization of the cashew nut necessarily implies the valorisation of the hull and the CNSL, which until now had been little exploited and which result in large amounts in the production zones in Burkina Faso. Hence the interest of finding a means of recovery that is more adapted to the nature of the raw material. One of the possible solutions is the densification of the cake which could solve the problems associated with the low density of the raw hulls. As for the problems associated with the presence of the CNSL, they could be solved by a thermochemical treatment of the cake before any conventional combustion operation.

Figure 17: Briquette production process.



The main raw material needed for the production of briquettes is the cake from hull pressing; the pressing process makes it possible to extract the CNSL which can be valorised in the industry. The briquettes obtained are then dried in the open air. Main ingredients used for the production of briquettes are cakes from the pressing of hulls, binder and water. The briquette production process is shown in Figure 17.

The cake is carbonized at a temperature of 350 °C and milled to a particle size of 0.5 mm. The resulting charcoal powder is mixed with water and the binder in well-defined proportions (Table 11).

Table 11: Biomass energy potential of localities by estimation following the survey, part 4.

Recipe	**Water** %	**Binder** %	**Charcoal powder %**
B30.5	30%	5	65
B30.10		10	60
B30.15		15	55
B30.20		20	50
B35.5	35%	5	60
B35.10		10	55
B35.15		15	50
B35.20		20	45

The mixture of these ingredients is called ”recipe”. Fifteen (15) recipes were formulated by varying the amounts of water and binder in the mix. The quantities of water selected for the blank tests on the press are 25%, 30% and 35% relative to the total mass (coal + starch + water). For each quantity of water selected, a different amount of binder (starch) was applied, namely 5%, 10%, 15%, 20% and 25% starch to the total mass (Table 11). These different proportions of starch were chosen based on the work of (Kaliyan and Morey, 2009); for example. B.30.5 denotes a briquette containing 30% water and 5% binder.

6.3 Results and discussion

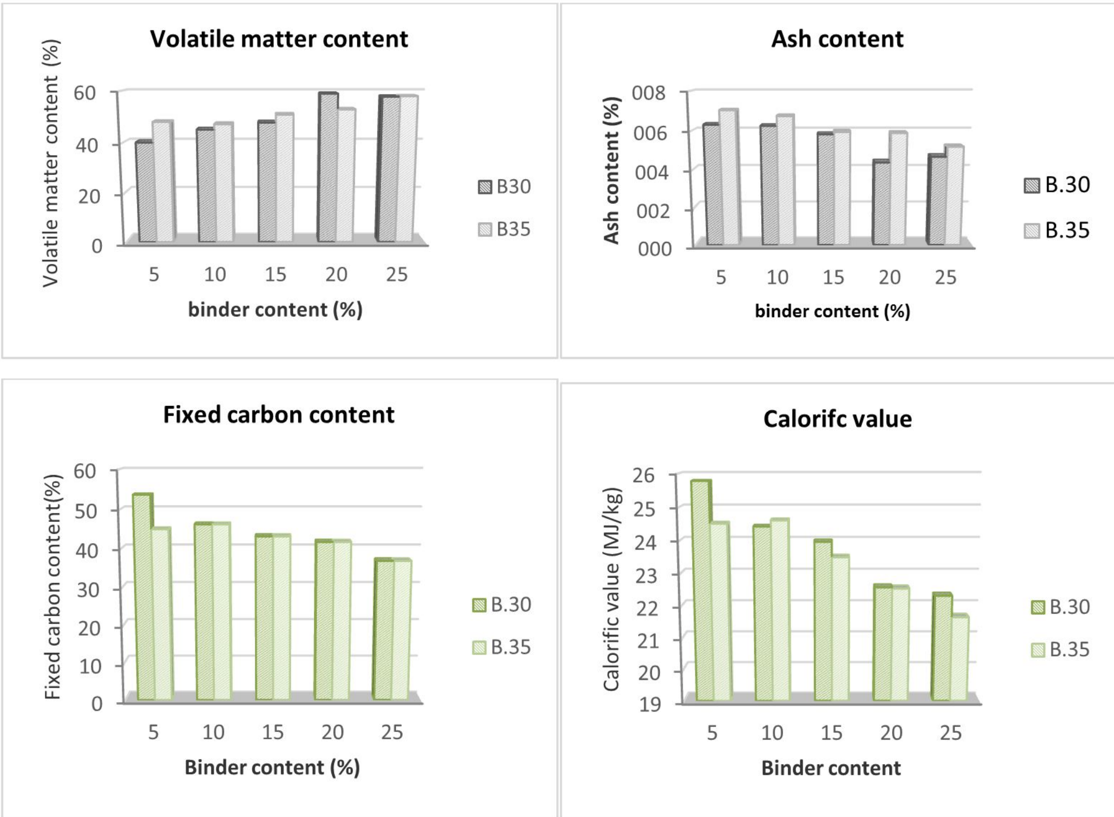
This section presents the results of the tests performed on the briquettes obtained. The results presented are for briquettes with 30% and 35% water (Figure 18(b)). Briquettes with 25% water showed cracks (Figure 18(a)) and are therefore excluded from testing.

Figure 18: The briquettes as produced from the press.

6.4 Results of the proximate analysis

These results show the volatile matter content, the ash content, the fixed carbon content and the lower heating value (LHV) of the briquettes. The results show that the level of volatiles increases with increasing the proportion of starch. On the contrary, the increase in the starch content leads to the reduction of the other three parameters (LVH, fixed carbon, ash content). The average LHV of the briquettes is 24 MJ/kg.

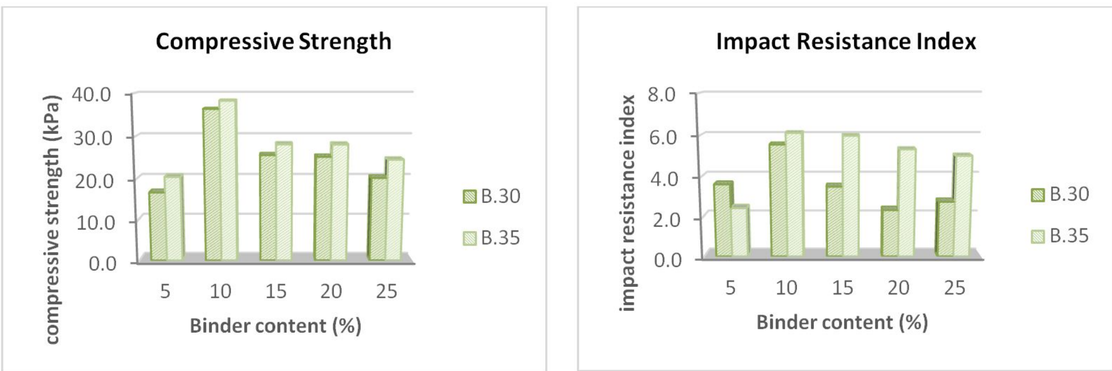
Figure 19: Results of the proximate analysis.



6.4.1 Mechanical properties

This section presents the results obtained for the mechanical tests. The indices of resistance to impact and compression have been calculated.

Figure 20: Results of the mechanical tests.



The analysis of the results shows that the determining parameters are the LHV of the briquettes and their mechanical properties. Considering these characteristics, B.30 and B.35 with 10% binder have the best properties. Before Briquettes being transported, those with the best mechanical characteristics will be preferred; therefore, the briquette selected for this study is the B.35 10% binder. It represents the best compromise between physiochemical characteristics and mechanical properties.

6.5 Results of the combustion tests

The B35.10 briquette has been tested in a charcoal furnace. The protocol used for this test is the "water boiling test" or boiling test (Bailis et al., 2007). The results obtained (Table 12) are compared with those of the boiling test carried out on the same furnace, under the same conditions but with charcoal.

Figure 21: Water Boiling test performed.

Figure 22: Cook stoves assessment platform.

The combustion tests with briquette B 35.10 show results similar to those using charcoal. Charcoal has an ash content of 2.7% and a heating value of 29.9 MJ/kg. The low specific consumption of the briquette representing the amount of energy per litre of water consumed per minute is lower than that of charcoal.

Table 12: Result of the Water Boiling Test.

	Boiling duration (min)	Firepower (kW)	Thermal effic. (%)	Spec.fuel consumption (kJ/l/min)
with briquette	47	1.34	33.9	131.09
with wood charcoal	45	1.5	33.7	144.56

6.6 Conclusions

The results of this study have shown the possibility of producing briquettes from the cashew industry waste, and more particularly from cakes from the pressing of cashew nuts. Briquettes of good quality were obtained (mechanical strength, compressive strength, good quality of combustion). These results showed that the hulls can have a double valorisation; on the one hand through the CNSL that is extracted there and on the other hand through the production of fuel briquettes. An economic study will be conducted to show the viability of the project and to promote its dissemination. This project is carried out in a logic of industrial ecology, and surveys conducted with several industrials show that they are ready to use the briquettes for their energy needs.

Acknowledgements

This work was done within the framework of the Switch Africa Green project (GRANT-CFP-KEOH-2015-002 ”Switch Africa Green Component B”). With the support of the European Union and the United Nations Environment Program [BFA / UNEP / 00091206/2015/023] and UNOPS.

Bibliography used in this section:
(Bailis et al., 2007, Bensch et al., 2013, Kaliyan and Morey, 2009, Kathuria and Grover, 2012, Nurhayati et al., 2016, de Oliveira et al., 2017, Pasquiou et al., 2012)

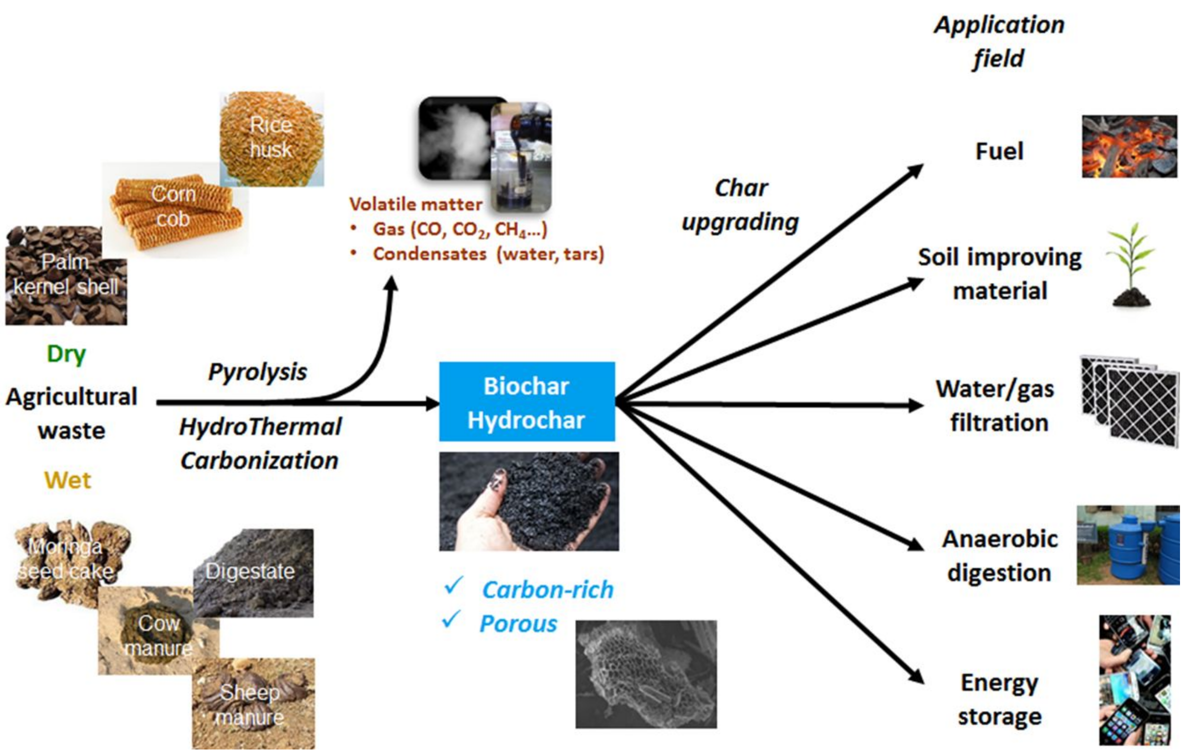
7 The potential of biomass agricultural waste recovery as char in Western Africa

Author: Capucine Dupont, Eric van Hullebusch

7.1 Introduction

There is a large amount of biomass agricultural waste potentially available in Western African countries (Food and Agriculture Organization of the United Nations, 2017). Dry waste, such as cereal straw or corn cob, is commonly left or burnt on field, or also stored and used for animal feeding. Similarly, wet waste, like cow or sheep manure, is either simply left on site or it may also be recovered through anaerobic digestion or composting. This situation induces several major issues, in particular fast release of carbon in atmosphere, air pollution due to toxic emissions in the case of uncontrolled burning, risk of insect infestation in the case of storage, risk of pathogens in the case of wet waste disposal and also biological recovery, as well as production of waste difficult to handle during anaerobic digestion.

Figure 23: Overview of char value chain based on agricultural waste.



To cope with these issues, one option is the conversion of agricultural waste through thermal processes into a carbon-rich material, called char, and that may be used in various applications, as illustrated in Figure 23. This paper aims at giving an overview of i) the main steps of this value chain, ii) the remaining issues towards its large-scale implementation and iii) related recommendations.

7.2 Char value chain

7.2.1 Char production

When heated in absence of oxygen, agricultural waste, including digestate, releases some volatile matter, including gas, such as CO or CH_4, and condensates, namely water and tars. It also gives rise to a carbon-rich, porous solid. This solid, whose properties are closer to coal, is usually called “biochar” when the thermal process used is slow pyrolysis and “hydrochar” in the case of hydrothermal carbonization (HTC). The main characteristics of these processes are summarized in Table 13. It is important to note that pyrolysis is suitable with dry waste only since it requires heating between 350 and 600 °C under inert atmosphere.

Table 13: Main characteristics of char production processes.

	Pyrolysis	**HTC**
Waste type	Dry	Wet
T (°C)	350-600	180-250
Gaseous atmosphere	1 bar inert	Water above saturated P
Heating rate (°C .min-1)	#10	#10
Residence time (hour)	1-5	1-10
Char yield (w% dry biomass)	20-30	45-70
Maturity level	Commercial	Demonstration

Pyrolysis is usually performed at atmospheric pressure, and is associated to slow heating rate in the range of a °C/min as well as to long residence time of several hours. Such conditions enable to reach char yields up to 35 w% of dry biomass (Libra et al., 2011). In the case of HTC, char yield is even higher and lies in the range of 50-80 w% of dry biomass (Libra et al., 2011). Contrary to pyrolysis, this process has the major advantage of being suitable with wet waste, since it is typically operated between 180 and 250 °C in water above saturated pressure. However, while pyrolysis is well-mastered on different scales, from very small and robust reactors to larger and more advanced ones (see an example of unit implemented in Senegal in Figure 24), HTC is still at demonstration stage (see an example of pilot specifically designed for use in developing countries in Figure 25). Noteworthy is the major influence of process conditions, as well as of feedstock used, on char physicochemical properties such as adsorption capacity or pH (Libra et al., 2011).

7.2.2 Char upgrading

The bio/hydrochar properties may be upgraded in order to fulfil specifications required by the different applications. The main process types are thermal and chemical processes, usually referred to as activation, as well as mechanical processes. Here only mechanical processes are considered since they are the most mentioned and/or developed in Western Africa. Mechanical processes include pelletising and briquetting. Both of them are well-established processes and consist in applying pressure to char, possibly mixed with binding agent like clay. The product obtained

Figure 24: Example of slow pyrolysis units: on the left, small unit implemented in Uganda, source: (Paing, 2015); on the right, large unit implemented in Senegal, source: (Reinaud, 2017).

Figure 25: HTC pilot unit, source: (Riu Lohri et al., 2013).

has a defined shape, either of cylindrical pellet with a few cm height and several mm diameter, or of cylindrical, cubic or spherical briquette with characteristic dimension ranging from 1 to more than 10 cm (see the example of briquetting in Figure 26). This upgraded char has the advantage of being denser and uniform, which makes it more convenient than raw char for transport, storage and further applications like combustion. However, these processes require energy, which significantly increases the final product price. Noteworthy briquetting seems to be more developed at the moment in Africa than pelletising, certainly because of the low cost of this process and its suitability with small-scale units.

7.2.3 Char applications

Below is given a brief overview of the principle, advantages and drawbacks as well as of the status of the different char applications. Note that only the short to medium term applications in the African context are addressed here. No description is therefore given of the very high added value applications in electro-chemistry, for instance as electrodes in battery.

Figure 26: Production of char briquettes in Uganda, source: (Moses, 2017).

7.2.4 Solid biofuel

Char can be used as solid biofuel, mainly in stoves for cooking in household and also possibly in larger boilers for further combined heat and electricity production. Char can therefore help to substitute wood charcoal used for cooking and constitute a solution to the critical issue of deforestation in Western Africa, and of environmental issues related like greenhouse gas emissions and ecosystem disturbance. Moreover, when this solid biofuel is burnt, especially in modern stoves, such as gasification ones, toxic emissions are reduced during conversion and thus the dramatic issue of household air pollution can be partly solved. Nevertheless, the high ash amount in agricultural waste compared with that in wood decreases the efficiency of such solid fuel and the high concentration in species like K and Si may lead, mostly in the case of large units, to agglomeration during burning or corrosion of the unit (Vassilev et al., 2013).

7.2.5 Soil improving material

Char can also be used in agricultural fields as soil improving material. This application is the most popular and mature one. Adding char to soil has been found to increase crop yield, to increase water retention and to increase soil stability. Moreover, it releases carbon much more slowly than biomass left on field and thus contributes to carbon sequestration. However, at the moment, the link remains unclear between feedstock used, production process conditions and resulting char performance. Moreover, depending on crop and soil, results obtained with the same char may be either positive or negative (Jeffery et al., 2011). Another issue to be mentioned is the char amount that is said to be required per soil volume. For instance, as illustrated in Figure 27, laboratory scale tests led to excellent results when comparing crops grown with and without biochar, but with 40 v% of char mixed with soil (Biogrow, 2017).

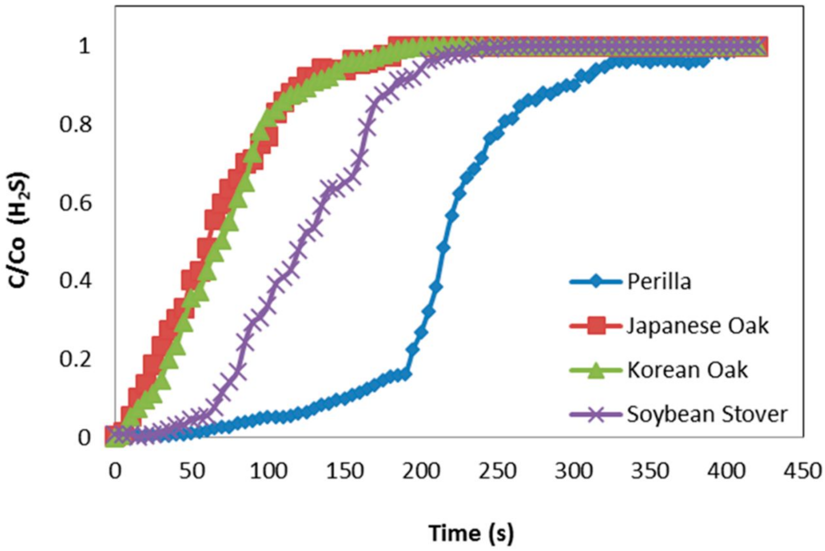
Water/gas filtration

Another type of application is the treatment of waste water or gas, like Volatile Organic Compounds (VOC) or H2S found in biogas from anaerobic digestor. Char may indeed be used as adsorbent in filter or as adsorbent and medium for bioconversion when mixed with compost in biofilter. This technique has proven its efficiency while

Figure 27: Result of growth test led on lettuce with and without biochar in soil, source: (Biogrow, 2017).

being relatively cheap (Kanjanarong et al., 2017). However, as previously, the link remains unclear between feedstock used for char production, process conditions and performance. This is for instance shown in Figure 28, where three profiles of breakthrough curves can be observed for four biomass types. Moreover, the process of filtration itself still requires optimization and the issue of char regeneration should also be considered.

Figure 28: Breakthrough curve obtained with chars from different biomass types (Sethupathi et al., 2017).

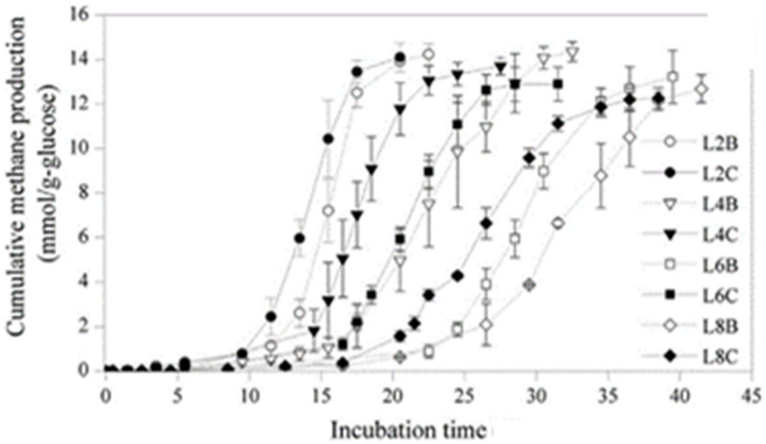


Anaerobic digestion

A new field of application has also been recently raising interest. The idea is to use char as additive or "catalyst" in anaerobic digestor so as to enhance process efficiency. More precisely, char could increase kinetics of CH_4 production, as evidenced in Figure 29, and could also increase CH_4 yield. Such application, which is fully in line with the biorefinery concept, could be of great interest in developing countries where anaerobic digestors tend to become widespread.

However, this application is still at an early stage of research, and, even more than for the applications mentioned above, the link is unclear between feedstock used to produce char, process conditions and resulting performance of char in an anaerobic digester. Indeed, missing knowledge is not only on the link between feedstock/process conditions and char properties required but also on the char properties required themselves, because mechanisms involving char in anaerobic digestion are poorly known.

Figure 29: Kinetics of CH_4 production obtained using different conditions without (white) and with (black) char added, source: (Luo et al., 2015).



7.3 Issues to be solved towards large-scale implementation

There have been several research studies and project initiatives aiming at moving towards implementation of char value chain in Western Africa – always for production of solid fuel or soil improving material. For instance, one can cite two joint European-African projects, namely Bebi (EUROPEAID - BEBI project, 2017), that ended in 2013, and Biocharplus, which led to the creation the Africa Biochar Partnership in 2016 (ECREEE: Biocharplus, 2016). Despite these initiatives, wider implementation of char value chain in Western Africa is still limited by several technical and non-technical issues.

7.3.1 Technical issues

First, as highlighted above, there is a major need to understand the link between feedstock properties, process conditions, char properties and resulting performance in the different applications. Systematic studies are missing that would test the various feedstock available in the main applications. Such studies would draw out correlations and thus enable i) optimization of process conditions versus feedstock and application as well as ii) use of difficult waste through feedstock blending. In parallel, technological work should be considered in order to develop technologies suitable with the Western African context, i.e. technologies that would be in priority robust and cheap, while remaining efficient.

7.3.2 Non-technical issues

Besides technical issues, one crucial aspect towards char value chain implementation is the business model. Two main questions should be addressed:

- First, the question of the actors on the whole value chain, from feedstock to product, and of the actor that is willing to invest on char production and upgrading, that could be either the feedstock producer or the char end-user.
- Then, the question of the scale and market associated: a priori the local micro and small scales, i.e. those of household and farmer respectively, appear to

be the favourable ones in Western Africa. However, large-scale may also be of interest when feedstock like agroindustry residues and applications like power generation are considered.

Another non-technical aspect that should be taken in consideration for successful implementation is social acceptance, especially since households are targeted end-users. A striking illustration is the failure of some trials of wood charcoal replacement by biogas cookstoves because of the poor taste of food cooked according to users. It is of great importance to adopt multifactor approach in projects and to strengthen training activities in order to raise awareness of stakeholders and more generally of population, notably regarding air pollution risks linked with cooking, pathogens associated to waste and opportunities of char use in this context.

Lastly, the issue of governance and role of public authorities should be taken into account. There is undoubtedly a need for funding to support large research and demonstration projects involving public and private bodies together and federate efforts. Subsidies can also be seen as a tool to initiate spreading of the solution before self-profitability is reached.

7.4 Conclusions

The char value chain appears to be highly promising in the Western African agricultural waste context. One key message is that char must be seen as a plural word: it encompasses various types of materials depending on feedstock and process conditions used and can therefore be suitable with different applications, from very basic to more advanced ones. These different end-uses of char interestingly make this material able to contribute to solve the issues related to the Water Energy Food Ecosystem Nexus in an economically and environmentally sustainable way, provided the remaining technical and non-technical issues are addressed in the future, mainly through efforts in research and development projects, demonstrations and trainings involving all actors along the value chain.

Bibliography used in this section:
(Food and Agriculture Organization of the United Nations, 2017, Paing, 2015, Libra et al., 2011, Reinaud, 2017, Riu Lohri et al., 2013, Moses, 2017, Vassilev et al., 2013, Jeffery et al., 2011, Biogrow, 2017, Kanjanarong et al., 2017, Sethupathi et al., 2017, Luo et al., 2015, EUROPEAID - BEBI project, 2017, ECREEE: Biocharplus, 2016)

8 Valorisation of agricultural by-products available in Africa: production of activated carbon and their applications

Author: Abdelaziz Bacaoui
Keywords: biomass; by-products; activated coal; optimization; adsorption; water treatment.

In order to promote the agricultural by-products available and underused in Africa, we have developed an economical process to produce carbonaceous materials (biochar and activated carbon). These chars are widely used in many fields, including water treatment (de-pollution) and soil amendment (fertilisers).

In Africa, the food industry generates large quantities of waste; their valorisation, for energy or materials, is a promising way to make the production chains more profitable. Some unexploited biomass residues, such as palm hulls, cashew shells, olive kernels and jatropha and shea cake, etc. are often removed by simple combustion (often without the use of energy) for to solve congestion, pollution (leaching, anaerobic digestion, etc.) and safety issues (fire, explosions after methanisation, etc.). In order to better exploit these by-products, several research projects have been conducted to study their valorisation as activated carbon (En-naciri et al., 2014, Rahman et al., 2015, Rachel et al., 2017, Rahman et al., 2017). Activated char is porous carbonaceous material widely used for water purification as well as for the treatment of liquid and gaseous industrial discharges, but also for the gold industry.

The development of the number of agri-food processing units in Africa in recent decades has not only resulted in the production of large quantities of waste but also the use and import of large quantities of activated carbon for the treatment of aqueous effluents, the bleaching and deodorization of fruit or vegetable oils and the extraction of cyanide gold complexes from mining industrial processes.

Despite the availability of raw material (agricultural by-products), and the important local market (high cost of importation), the production units of activated carbon are almost non-existent. The techniques for manufacturing activated carbon use relatively simple processes that are easy to implement on a small scale in the African continent.

The establishment of a local industry, using inexpensive precursors, thus appears as an interesting alternative allowing:

- make profitable the agri-food chains that generate these residues by their transformation into value-added products and thus guarantee the competitiveness of the activities in the long term;
- innovate in order to improve the quality of life of citizens through the use of low-cost de-polluting agents;
- provide users with a local product at a lower cost;
- participate in industrialization and job creation through the installation of small capacity coal production units.

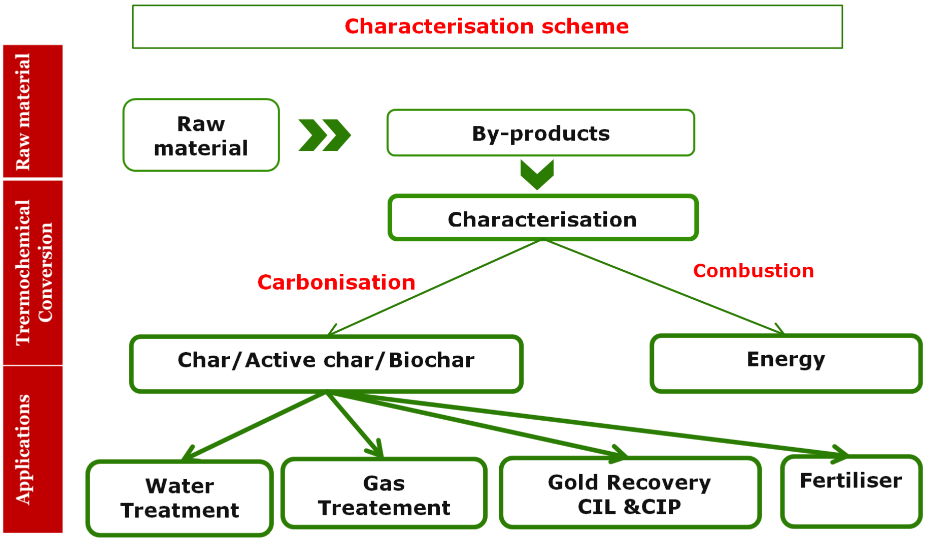
In addition, depending on the uses, the physical-chemical properties of activated carbons (essentially porous texture and mechanical strength) must be adapted to the types of pollutants or adsorbates to be treated in order to guarantee good extraction yields, hence the interest to have a local production so that the producer can offer active carbons answering best to the needs and the specificities of use of the user. Once saturated with adsorbent, active carbon is either eliminated or regenerated; the second option being the most economical to avoid buying and importing coal. However, for lack of units with pyrolysis furnaces operators in Africa are forced, in most cases, to eliminate the coals.

8.1 Description of the project and results

a) Description of the concept: state of the art, methods and approaches.

The quality of the activated carbon obtained is considerably influenced by the precursors used for the preparation.

Figure 30: Description of the methodology.



Although the method of preparation used primarily determines the surface area and surface function nature of the product obtained, the porous structure and the pore size distribution are greatly influenced by the nature of the starting material. The precursor selection criteria are primarily high carbon content, low volatile matter and ash content, availability and cost.

The choice of precursors (raw material)

Conventionally, activated carbon is produced from carbonaceous materials such as wood, peat, mineral coal. In recent years, interest has focused on the search for low-cost adsorbent materials from the recovery of by-products or industrial waste. It is in this sense that we have carried out several studies, which aim to valorise agro-food waste (olive kernels, jatropha cake and shea butter etc.), which are available in Africa, in order to prepare activated carbons likely to be used in several fields.

The precursors used show a high lignin content (with a very high content that could reach of up to 50%), a relatively high amount of carbon, low ash content (<2.5%), and low amounts of mineral matter (<0.5%). Comparison of these characteristics with other biomass wastes shows that they are by far good candidates for the production of activated carbon.

Thermochemical Conversion: Preparation of Charcoals (Char, Biochar, Activated Carbon)

The preparation of char from the by-products has been done according to several processes:

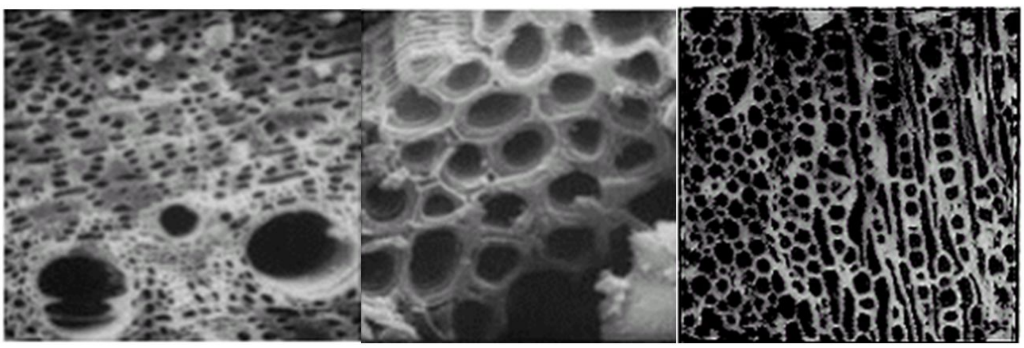
- Direct carbonization under inert atmosphere in the furnace to produce a carbon structure ready for activation;
- Hydrothermal carbonization (HTC) for the wet raw material (70% moisture) to produce biochars;
- Physical activation in the presence of an oxidizing agent (e.g. H_2O, CO_2) or a chemical activation in the presence of an activating agent (e.g. H_2SO_4, H_3PO_4; KOH) to produce active chars with well-developed porous structures.

The factors involved in these processes were optimized using the experimental design method (study of factors, response surfaces and desirability function). The carbons obtained, under optimal conditions, were characterized (quality indices, specific surface area, pHPZC, total surface functions, etc.).

Applications:

The char obtained has specific surfaces ranging from 1050 to 2365 m^2/g, depending on the process and the conditions used, which shows the quality of the precursors and the relevance of the approach pursued. The materials prepared physically in a single step have a mixed porous structure (micro-porous) and basic nature. Those prepared in two stages (carbonization in an inert atmosphere followed by activation by water vapour) have the same character but developed more micro-porosity. On the other hand, the char prepared chemically, have more interesting yields, are of acidic nature and characterized by large specific surfaces with different porous structures, according to the chemical agent used: the impregnation with phosphoric acid favours the formation of large pore size and develops more external surface, while potassium hydroxide promotes the formation of micro-pores and achieves very large specific surfaces (> 2000 m^2/g).

Figure 31: Activated char micropores.



Activated char is characterized by the use of quality indices such as methylthionine chloride, diiodine and phenol (AWWA, 1991), determination of the pH of the zero charge point (pH$_{PZC}$). In fact, the iodine values are greater than 1100 mg/g (standard value is 600 mg/g), the attrition indices are of the order of 0.02% (standard value must be less than 2%), the methylthionine chloride values of 450 mg/g

(standard value is 180 mg/g), the specific surfaces of the order of 2000 m^2/g (standard value 800 m^2/g). These values reflect the quality of the precursors as a raw material for the development of new activated carbons effective for water treatment and in the gold mining industry. The comparison of the coals prepared with coals cited in various research studies made it possible to assess the quality and performance of activated carbons prepared from argan shells.

Bibliography used in this section:
(Ennaciri et al., 2014,Rahman et al., 2015,Rahman et al., 2017,Rachel et al., 2017)

9 Research of ways and means of adaptation to climate change in the culinary arts in Togo

Author: Kossi Napo

9.1 Introduction

The LES lab (Laboratoire sur l'Energie Solaire de la Faculté des Sciences de l'Université de Lomé, Togo) has undertaken for a long time (since the 90s) research work aimed at bringing solutions approaches by the development of so-called improved stoves. In this context, it has made aware, developed and trained craftsmen for the manufacture of these improved cooking stoves aiming to consume less charcoal and thus less destroy the forests. Following the development of cooking stoves, the research activity performed had to establish the performance of wood or charcoal stoves developed by NGOs and individuals. In this context, certain structures (Togolese State, UEMOA, NGO, etc.) have benefited from the skills of the LES for their work aiming to reduce the consumption of charcoal or wood.

9.2 Objectives

The purpose of the work carried out is to provide information on the technical operating characteristics of the wood stoves. The tests have been carried out at the Solar Energy Laboratory of the University of Lomé and allow, in the long term, to:

- Establish the average specific fuel consumption of each cooking stove;
- Establish the average time required to prepare a certain type of meal for each cooking stove;
- Establish the overall thermal efficiency of each cooking stove.

9.3 Cooking stoves tests

The tests were carried out on several cooking stoves and we present here only the results obtained on twelve (12) cooking stoves:

- Five different sizes of "Toyola Coalpot" charcoal cooking stoves and five equivalent sizes of traditional "Malagache" cooking stoves;
- An "Envirofit G 3300" wood cooking stove and a traditional "3 Pierres" wood cooking stoves of equivalent size.

The "Toyola Coalpot" and "Envirofit G 3300" cooking stove were delivered to the Laboratory, while the traditional "Malagasy" and "3 Stones" fireplaces were ordered and purchased from the artisans from the market by the Laboratory. Figures 32, 33 show the images of the "Toyola Coalpot", "Malagasy", "Envirofit G 3300" and "3 Pierres" cooking stoves, respectively. The characteristics of the different stoves tested are summarized in Tables 14, 15, 16.

Figure 32: "Toyola Coalpot" and "Malagasy" fireplaces.

Figure 33: "Envirofit G 3300" and "3 Pierres" fireplaces.

Table 14: Characteristics of Toyola coalpot biomass cooking stove.

Characteristics (cm)	Toyola 1	Toyola 2	Toyola 3	Toyola 4	Toyola 5
Height	21.00	25.00	30.00	36.00	42.00
Length of combustion chamber	6.00	6.00	6.50	9.00	10.50
External diameter	27.00	30.50	33.00	40.50	50.00
Internal diameter	19.00	23.00	23.00	28.50	34.00
Thickness of ceramics	3.50	3.50	5.50	6.5.	9.00
Air inlet	9.00×5.50	10.00×6.50	10.00×6.00	17.00×9.00	19.00×11.00

Table 15: Characteristics of Toyola coalpot biomass cooking stove.

Characteristics (cm)	Malgache 1	Malgache 2	Malgache 3	Malgache 4	Malgache 5
Height	21.00	25.00	30.00	36.00	42.00
Length of combustion chamber	6.00	6.00	6.50	9.00	10.50
Side measure	19.00	23.00	23.00	28.50	34.00
Air inlet	14.00×12.00	16.00×12.00	21.00×12.00	26.50×13.50	28.00×13.00

Table 16: Characteristics of Envirofit G 3300 and 3-Pierres cooking stove.

Characteristics (cm)	Envirofit G 3300	3-Pierres
Height	27.00	27.00
Length of combustion chamber	6.00	6.00
External diameter	19.00	
Internal diameter	15.00	
Air inlet	16.00×10.50	

9.4 Procedure of testing

The procedure used by the laboratory is that proposed by a group of experts for the "Household Energy and Health Program" of "Shell Foundation". The procedure has three stages: the Boiling Water Test (TEE), the Controlled Kitchen Test (CCT) and the Kitchen Performance Test (TPC).

However, the kitchen performance test, which measures the relative rate of consumption of charcoal for different types of cooking stoves in an ordinary family environment, did not take into account the real difficulties of tests and measurements in households. Simultaneous testing of different households under the same conditions of household use has proved difficult to achieve; instead, we opted to recruit three women (actresses of the kitchen in general in Togo) who performed in the laboratory the tests of controlled kitchen, but in more or less ordinary household conditions.

During testing and for each type of fireplace, the following equipment, elements and conditions:

- Marmite (we used aluminium pans)
- Quantity of water
- Amount of charcoal
- Wind direction
- Experience time

In order to find a relevant energy efficiency of the stoves, several series of boiling water and controlled kitchen tests were carried out under the same conditions of temperature, humidity and air flow rate for each type of cooking stove.

9.4.1 Water Boiling Test Procedure (WBT)

Water Boiling Tests (WBT) are simple, short simulations of procedures normally followed during the cooking of a meal. These tests measure the fuel consumed and the time required. TEEs are used to quickly compare the performance of different stoves or the performance of the same stove in different operational situations. WBTs are carried out by stove designers, researchers and field operators.

During water boiling tests, a stopwatch is used to measure the time required for each stove to bring the temperature of a quantity of water to the boiling point.

The test consists of two phases:

A "high power" phase consisting in boiling a specific amount of water. This high-power phase is itself divided into two stages: a first cold start stage (well-cooled stoves), followed by a second hot start stage (hot stoves).

A "low power" phase during which the boiling is allowed to continue for 45 minutes.

9.4.2 Controlled Kitchen Test

The Controlled Kitchen Test (CKT) is intended to be an intermediate step between the Water Boiling Test and the Kitchen Performance Test. The main objectives of the CKT are:

- Compare the fuel consumed and the time needed to cook a meal in different households;
- Determine if the home can actually cook the range of meals normally prepared in the area where it is to be used.

You can also use the Controlled Kitchen Test for:

- Compare different culinary practices on the same household;
- Give a cook an opportunity to learn how to use the cooking stove;
- Follow up on the Boiling Water Test and use the cooling stoves in more realistic but still controlled conditions.

To better appreciate the performance of the stoves, a series of actual cooking tests is essential. It is performed by several users under the control of Laboratory Technicians. The main dishes (with different cooking times) most commonly prepared in households have been chosen in our case and are:

- Corn hominy with fast cooking time;
- Read rice with average cooking time;
- White beans with longer cooking time.

All the ingredients necessary for the preparation of each dish are weighed and therefore the quantity used in known; it was only necessary to evaluate the energy required to cook each meal in order to calculate the relative gain of the hearth.

9.5 Material and conditions of testing

Pans and Fuels

For the sake of convenience of the tests, it was purchased, instead of cast iron pots, aluminium pans (commonly used). The charcoal used was the one commonly used by households, ordinary charcoal purchased from the same supplier for all tests. The moisture content of this coal, determined on a wet basis.

Measuring devices

The protocol used to measure the energy efficiency of improved stoves has required a number of high-precision measuring devices: thermometers for temperature measurement, sample weigh scales, hygrometer and hot-wire anemometer for measuring the humidity and air velocity and a stopwatch.

Elements for controlled cooking

The controlled kitchen tests (TCC) concerned the preparation of usually consumed meals and to do this, the raw materials were acquired at the local market.

Test conditions

All the tests took place at the Solar Energy Laboratory of the University of Lomé, under a covered and fenced shed at 3/4 and the physical conditions of the tests were the normal cooking of the Togolese households: in open air with the cooking stoves directly placed on the ground where the average rate of humidity is around 75%.

9.6 Results

9.6.1 Results of boiling tests (TEE)

The results presented after these different observations show that:

- The burning rate (burned fuel mass per unit of time) of the stove "Malagasy" is greater than that of the stove "Toyola coalpot" up to 39%;
- The thermal efficiency (heat transfer rate at the pot) of the stove "Toyola coalpot" is better than that of the stove "Malagasy", the difference ranging between 13.04% and 22.22% depending on the size of the stoves;
- The specific consumption (mass of fuel required to bring a litre of water to a boil) of the "Toyola coalpot" is lower than that of the Malagasy stoves, the difference of up to 48.55% depending on the size of the stoves;
- The burning rate of the "3 Stones" stove is greater than that of the "Envirofit G 3300" stove, reaching 14% depending on the test conditions;
- The thermal efficiency of the "Envirofit G 3300" stove is better than that of the "3 Stones" stove by approximately 12.24%;
- The specific consumption of the "Envirofit G 3300" stove is lower than that of the "3 Stones" stove by approximately 14.93%.

9.6.2 Results of the controlled kitchen tests (TCC)

Using the described methods, materials and working conditions, the results allow us the following analyzes:

- The low specific consumption (mass of fuel required for cooking a unit of meal) of “Toyola coalpot” stoves;
- For short-time cooking dishes (rice and maize paste), the tests make it possible to confirm that the ”ceramic” wall of the “Toyola coalpot” stoves does not imply a very great saving. (neither in cooking time nor in fuel used);
- On the other hand, the series of tests with the ”bean” dish with a longer preparation time shows that for this cooking time, the walls of the “Toyola coalpot” stoves play their role in reducing heat loss (by compared to a metal wall of Malagasy stoves), so these types of stoves confirm their good adaptability for long-term cooking activities;
- The same observations can be made for the ”Envirofit G 3300” stoves, that confirm their performance in terms of specific consumption for all 3 dishes;

9.7 Conclusions

From these studies It appears that improved stoves are a solution for lower energy consumption compared to traditional stoves. In order for its use to be effective, it is necessary not only to be aware of their use but also of the material to be used.

An important perspective to consider in this study is the essence of wood used to produce charcoal. It will be necessary in a future study to use for these tests all the wood species used in Togo for the production of charcoal. This study will determine the type of wood that will produce a more combustible charcoal. Thus, in their policies for the plantation of wood or forestation, the competent authorities will advise this or that species of wood to be planted or developed for the production of the charcoal.

10 Analysis of technologies and feedstocks : case of PROGRES-LAIT

Authors: Ndèye Fatou Faye Cissé, Mame Bousso Faye

10.1 Introduction

The PROGRES-LAIT is a regional program for the development of the milk value chain, which puts at the heart of its approach: 1) rural entrepreneurship, by making available to the actors especially the women at the base, 2) energy platforms for the conservation of milk followed by 3) a Public Private Partnership (PPP) approach at community level as a market development instrument in seven production basins in Senegal and Mauritania. The dynamic of professionalisation of the system of collection, conservation and commercialisation will be supported by bringing together small producers at the organisational, managerial and financial levels, as well as the implementation of a social communication strategy to encourage membership and development of entrepreneurship.

Moreover, in large villages with potential for craft development, energy platforms will provide access to energy for lighting, milling, welding, etc.

The PROGRES-Lait project is a contribution to reducing the vulnerability of the populations concerned and, as such, responds to several major challenges: the fight against poverty, the fight against the effects of climate change and access to energy. Finally, it is resolutely entrepreneurial and as such it is also part of the transition to a green economy creating value for all actors and countries concerned.

In both countries, livestock sector planning, like other sectors of economic and social development, takes very little into account the energy dimension, effectively reducing the impacts of sectoral interventions on the fight against poverty. Energy is not an end in itself but rather a tool for the services of other development sectors. As such, energy poverty inevitably leads to economic and social poverty.

10.2 Issues

In terms of energy, particularly rural electrification levels are very low. In Senegal, the rural electrification rate is 24% against 2% in Mauritania. The lack of energy response by sectoral planners is reflected in a weak development of energy services with other strategic sectors of development. Thus, energy poverty limits the horizon of valorisation of the development potential of the milk value chain, while the sector has an important capacity of contribution to the economic growth of the two countries. In Senegal, livestock is the second most important activity in the agricultural sector and the milk sector affects more than 350,000 families and contributes to 35% of GDP in the primary sector and 4.8% of the national GDP. In Mauritania, livestock is an activity that dominates the rural economy with 13.6% of GDP and 77.2% of the value added of the rural sector (in 2013, CSLP). However, this sector is marked by a first paradox: - High production in front of strong imports of dairy products in both countries. Local production of milk is estimated at 166 million litres in 2009, of which 139 million litres of cow milk (84%) and 27 million for small ruminant milk (16%) (in DIREL, 2010). With the particular support granted to this sector, local production is experiencing an encouraging steady increase. Over the period 2006 to 2009, it recorded a leap of 38.8% in milk production, with an average annual growth of 15.5 million litres. However, only 40% of demand was covered by domestic production and the rest by imports valued at 65 billion against 54 billion in 2007, an increase of 15% in two years. This similar situation of poverty in abundance is noticed in Mauritania which, with a large livestock estimated at $\simeq$8,159,263 of heads and a potential milk production of about 817.828 t/year in 2007, the country remains dependent on imports to cover its internal consumption. Milk powder imports alone experienced a spectacular evolution, changing from 8174.1 tons in 2003 to 9891 tons in 2007, i.e. 21 percent during the period considered.

An analysis of the various problems highlighted above shows that in areas with high milk production, access to energy is very low and the possibilities of conservation almost null, because of the highly perishable nature of milk. Indeed, the low electrification rates of the target production basins, of 20% in Senegal and 2% in Mauritania, limit the means of conservation of the milk and thus the valorisation of the production. The pyramid that follows reveals this second paradox among actors: women in villages that produce milk do not have access to energy for its conservation and industrial dairies that have access to energy for processing have difficulties to have access to milk.

Millions of litres of milk are thrown away in many villages and this translates into a loss of income for farmers, thus favouring the mechanisms of poverty creation in rural areas.

The absence of energy and conservation equipment explain the discharge of milk in production ponds during certain periods of the year (rainy season), particularly in Mauritania where there are no village mini-dairies.

Women at the base are forced to sell the production daily and throw away leftovers, thus confining them to a trajectory of self-consumption and not the development of entrepreneurship culture.

In Senegal, the few village associations that set up mini-dairies use diesel for generators or cold rooms to store milk, and butane gas for pasteurization. The high costs of these energies (60% of operating expenses) limit the profitability of their activity. However, the trends of the oil costs (more than 150% in 10 years between 2000 and 2010) show that these burdens will increase further.

Moreover, this problem analysis also highlights a poor organization of the collection linked to a lack of articulation between the different value chains, which disadvantage the links between suppliers and distributors of milk. The weak structure of the sector explains that the farmers do not find buyers of their production and surprisingly the industrial dairies which assure the transformation and the distribution of milk, are in constant disruption of supply. This commercial constraint partly explains the over-abundance of raw milk on the market during the rainy season and the high logistical costs for processing units (dairies) to the detriment of consumers. For example, a company in the processes of valorisation of milk processing in Senegal, in order to supply itself in sufficient quantity is forced to collect the production at the base, through daily rotations with its own 4$\times$4 vehicles in villages that cause too high production costs thus limiting competitiveness.

10.3 Objectives

The objectives of PROGRES-Milk are: The overall objective of the program is the development of the rural economy through the extension of the horizon of opportunities for valorisation of the milk value chain by improving access to sustainable energy services.

Specific objectives:

1. Strengthening access to sustainable and stable energy;
2. Promoting entrepreneurship, especially women's entrepreneurship, to strengthen the economic power of women through access to solar milk preservation platforms;
3. Establishment of efficient organizational models for small producers and innovative partnerships that could stimulate the development of an autonomous market for the collection and marketing of milk through the professionalisation of the value chain.

10.4 Expected results

1. 100 entrepreneurial solar mini-platforms (capacity of 200 to 400 L) are installed at the village level for more than 2000 small producers supplying the dairies in the villages in focus;
2. 20 solar dairies for conservation and pasteurization are installed and supply industrial processing companies. They also connect more than 1,000 households (10,000 people) and 20 community infrastructures (20,000 people) for lighting, telephone charging, milling and welding;
3. An innovative financing mechanism is put in place to ensure the sustainability of the programme;
4. Professionalisation of small producers and community-based organizations.

Communication, information and awareness of all stakeholders (decision-makers, private, base-organizations and producers)

Figure 34: Social engineering.

10.5 Achievements between 2016 and 2017

Social engineering

- Diagnosis of OCB: degrees of organization in the areas of intervention;
- Surveys to establish the baseline situation in pilot areas;
  - Senegal: 851 Households;
  - Mauritania: 760 households;
- Final choice of targeted PTFM implementation areas;
- COOPEL:
  - 11 set up / Senegal: AG selected villages / formalization;
  - 12 accompaniment / Mauritania (HODH);

  Contribution from local authorities: Deliberation of the installation sites of the platforms;
  - Senegal: Diambanouta: 2500 m^2; Tatki/Podor: 3600 m^2; Lodé: / Podor: 400 m^2; Teminto: 10000 m^2;
  - Mauritania: Timbedra: 1200 m^2, Amourj: 1600 m^2 and Aweinat Zbil 1200 m^2; Blessed Naji 1600 m^2; Barick DIAW 2500 m^2; Tékèche 1600 m^2.

Formations

- 4 formation sessions for trainers on milk production;
- 80 participants in Mauritanie;
- Formation: 150 farmers et 7 collectors;
- 1 session on Entrepreneurship dynamic organisational and financial management COOPEL (17);
- Development and production tools: Formation guide and notebook with translation in Arabic and Poular.

Figure 35: Training sessions.

Energy infrastructures

- 2 solar mini-grids installed (Tatki, Diambanouta): Connection of households, community infrastructure, and workshops of welding and welding, hairdressing, etc.;
- Establishment of storage tanks and milk processing (2000 litres in Tatki (8000 Wp of photovoltaic panels), 200 litres in Lodde (3000 Wp photovoltaic panels), 600 litres in Diamanouta (Cooling tanks: N. 2 of 300 Lt each, cooling Time: in 3 hours from 37 °C to 4 °C, 2000 litres at Néma (10 kW cabinet, with solar field of 15 kWp).

Figure 36: Energy infrastructure.

Figure 37: Energy infrastructure.

Participation/sharing

- Launch Communities of Practice: Livestock Feed;
- Exchange visits basic actors and technical services;
- Dairy units;
- Exchange visit to Mali and Burkina;
- Study of the operation of the DIRFEL dairy and the BOULAL cooling centre;
- Cross-border collection centres (Senegal: Gambia and Guinea Bissau) / FODDE;
- Boungkiling solar lantern distribution platform;
- Berger Dairy.

Next steps

- Establishment of an economic model;
- Database development: Livestock and milk production;
- Social entrepreneurship development in energy / COOPEL;
- Professionalisation breeders / champions;
- Securing the local milk market: strengthening the partnership with the industrial / purchasing protocols;
- Securing production: A strategy of production and access to fodder to sustain milk production in the dry season and secure supply platforms;
- An information and awareness campaign for farmers to strengthen the network of basic collection.

11 Energy recovery of waste from the lake Nokoué in Benin

Authors: Basile Kounouhewa

11.1 Introduction

The energy issue is a global development issue. Benin's energy situation is characterized by a strong dependence on the outside world; local energy production estimated at 20% and more than 80% dependent on wood energy. Benin's economy depends mainly on agriculture today. The priority agricultural sectors in the country are cotton and pineapple, which has been added in recent years to the cashew nut sector. Cotton production in Benin in 2016 is about 451,000 tonnes of fibber corresponding to 1 804,000 tonnes of waste which is mostly burned in the fields (for a ratio of 4.0) and that of pineapple In 2013, nearly 35% of pineapple production was processed into juice, which resulted in 40 to 80% of post-harvest waste.

Figure 38: Use of wood for cooking.

On the other hand, given the quality of tourist sites in Benin, the economy could also rely on the tourism sector. The lacustrine cities of Lake Nokoué, the best known is Ganvié (affectionately called the Venice of Africa) have not yet delivered their full potential tourism. Several causes justify this situation among which two deserve to be mentioned here:

- The unavailability of electrical energy to attract the establishment of true structures of reception, attraction and lodging;
- Increasing levels of anthropogenic pollution of the water body due to the use of a technique of trapping fish with branches ("Akadja") and the discharge into this lake of organic household waste.

11.2 Description of the projects

This is to provide energy to isolated agglomerations through a solar photovoltaic energy mix - generator.

11.2.1 Energy valorisation of agricultural waste:

Gasification of cotton stems:
This project aims at the decentralized production of electrical energy by the gasification of post-harvest stems in the cotton basin of North Benin (communes of Banikoara, Kandi, Gogounou, S'égbana and Kérou). It aims to provide electrical energy to small isolated localities of the conventional network in order to partially or completely cover their needs by energy recovery of locally available waste. It will be installed in each locality, a unit of a few kilowatts (depending on the size of the population), the collection of stems will be organized to recover about 50% of the cotton stems in the locality concerned. Here the generator is not powered by fuel; one of the following technologies will power the generator:

- The gasification of cotton stems;
- Direct burning of cotton stems

Figure 39: Cotton harvesting and collection.

The main benefits of this project are the availability of biomass and the cancellation of the fuel cost.

Methanisation of waste resulting from pineapple harvesting-processing:
This project will make it possible to energetically valorise post-harvest waste and peelings and cakes from pineapple processing units in Benin. Two ways seem a priori possible:

- Bio-methanisation of waste;
- Drying and carbonization of waste.

The benefits of this project relate to the abundance of waste during the harvest and processing periods of pineapple. At the end of these projects, the following results are expected:

- Availability of energy;
- Reduction of pollution;
- Job creation.

Figure 40: Processing pineapple.

11.2.2 Energy valorisation of anthropogenic organic waste from Lake Nokoué in Benin

Household waste in lakeside cities contributes enormously to the pollution of Lake Nokoué; they are essentially of organic origin and therefore are potential sources of energy. This project will make it possible to energetically valorise household organic waste that pollutes the lake and hampers the development of the tourist site of Ganvié in Benin.

The project focuses on biogeneration of organic household waste through the installation of a biodigester in each household; the gas produced will be used for cooking; biodigesters will be sized to provide at least three hours of cooking per day to each household. The sludge will be collected and transferred to a treatment and drying site to obtain fertilisers for the soil. Expected results

- Reduction of pollution of the lake;
- Improvement of cooking techniques in households;
- Better management of household waste in lakeside towns.

Bibliography used in this section:
(French Environment and Energy Management Agency, 2001, Adrien Bio Yatokpa et al., 2010, Carme, 2010, Clokoun, 2017)

12 Domestic biodigester: A solution for the preservation of ecosystems and resilient agricultural households

Author: Matar Sylla, Bassirou Sarr
Keywords: Biodigester; resilience; reinforcement; ecosystem; agricultural.

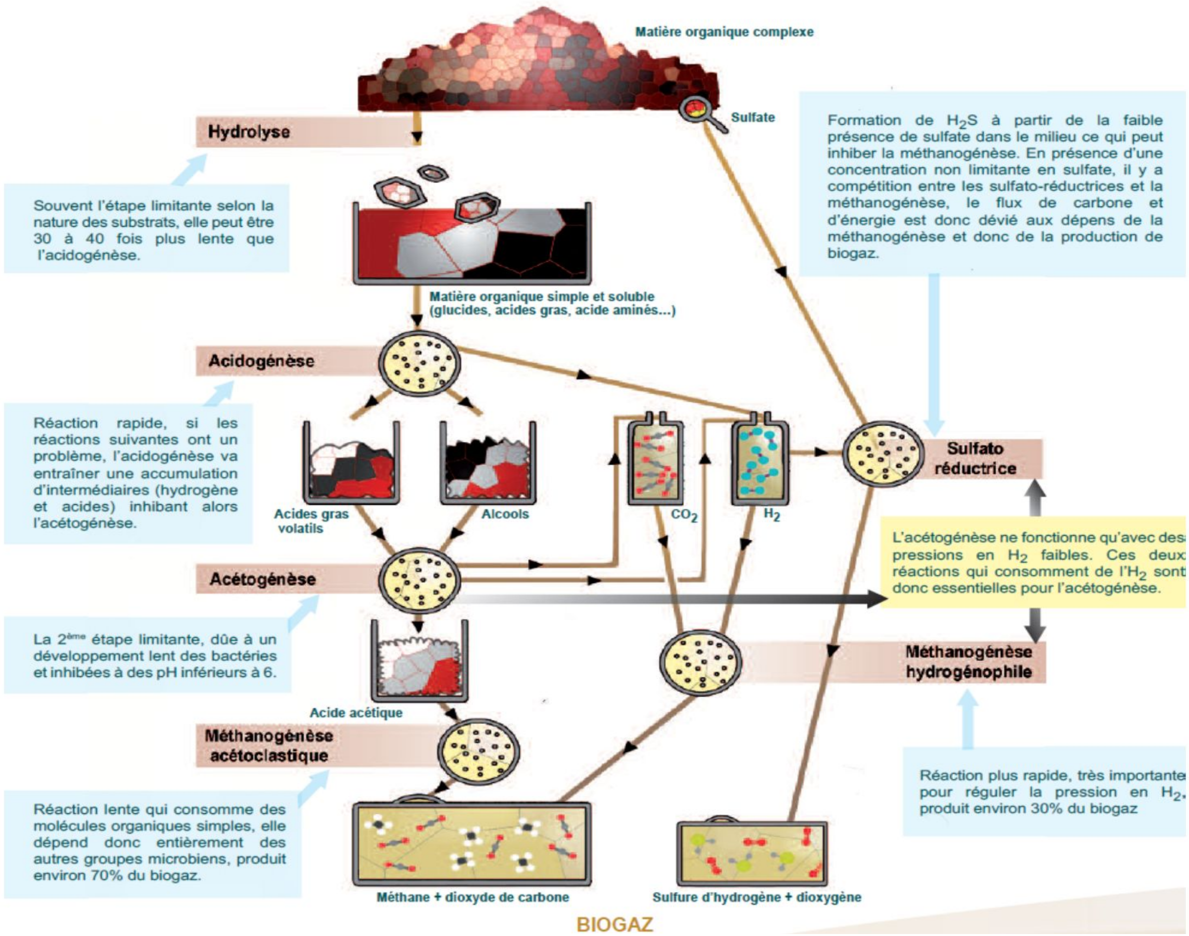
12.1 Introduction

Biogas, along with other types of renewable energy, is part of the policy of diversification of cooking fuels to contribute to the access of 100% of the population to modern cooking services in accordance with objectives of the White Book of the Economic Community of West African States (ECOWAS).

Biogas is produced in installations called biodigesters from, among others, manure from domestic livestock (cattle and pigs). Biodigesters produce both gas (biogas) for cooking and lighting and organic fertiliser (compost) for improved agricultural yields.

The effluent that results from the production of biogas is an organic fertiliser richer than manure whose use for fertilisation of fields reduces the consumption of chemical fertilisers while increasing crop yields. This has a positive impact on the balance of payments (fertiliser imports), on the improvement of agricultural yields and the quality of products (organic).

Figure 41: The conditions for the methanisation reaction.



12.2 Description of the project and results

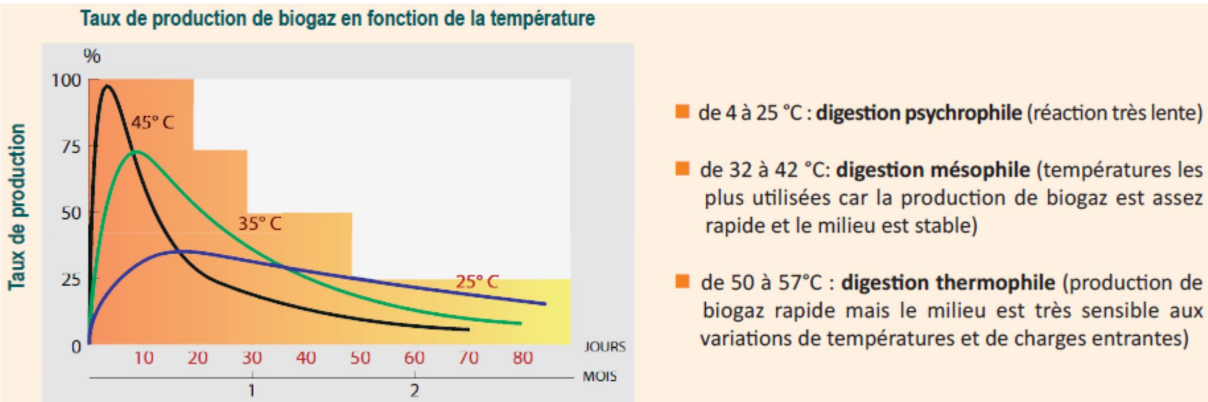
Methanisation represents a complex set of reactions carried out with the help of different groups of anaerobic bacteria. The process is illustrated in Figure 41.

The balance of the environment is essential to ensure satisfactory living conditions for each bacteria group. If a group of bacteria no longer works, the whole chain of reactions is blocked. This is why the operation of an anaerobic digestion plant is important and precise rules must be observed in the supply of substrates and in the maintenance of the physiochemical conditions of the digester.

12.2.1 The conditions for the methanisation reaction

Temperature
The methanisation reaction is generally accelerated by heat but, in detail, this mechanism is more complex. Each group of bacteria has a different comfort temperature and, outside of these temperature ranges, an inhibition of the reactions might appear. There are three temperature zones for anaerobic digestion: the psychrophilic, mesophilic and thermophilic zones (see curve below). Daily variations of 1 °C can disturb thermophilic digestion while mesophilic digestion is resistant to variations of 2 to 3 °C. In any case, changes in temperature are to be avoided, because the hydrolytic and acidogenic bacteria are more resistant to variations than other groups of bacteria. Accordingly, there is a risk of acid accumulation in the digester that stops the reaction.

Figure 42: The role of temperature.



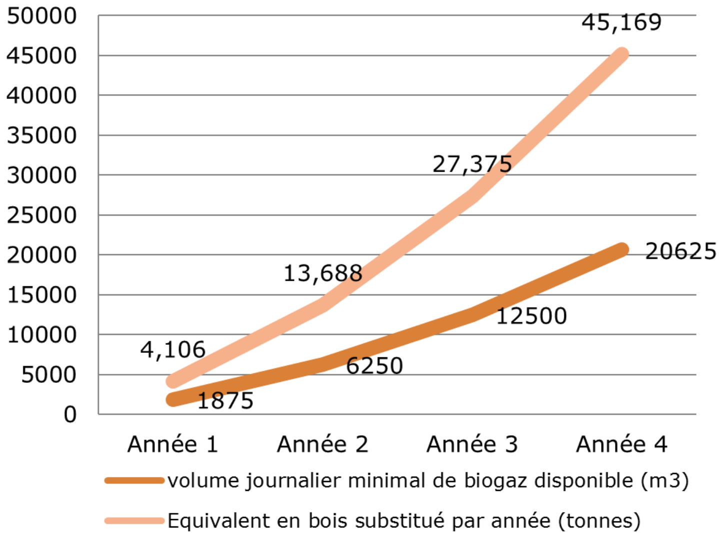
pH
The production rate of biogas decreases very rapidly outside a pH range between 6 and 8. As with temperature, the bacterial groups have different optimum growth pH domains. The pH in the digester is between 7 and 7.5, which corresponds to the favourable ranges for acetogenesis and methanogenesis.

Raportul Carbon / Nitrogen
The C / N ratio is important for the stability of the process. If this ratio is too high, carbon cannot be completely degraded. Conversely, a ratio too low can lead to a large production of ammonia which inhibits bacteria at low concentrations. To have a good stability, the C / N ratio must be between 20 and 30, approximately.

12.2.2 Biodigester's impact on forestry ecosystems

The experiments conducted in Senegal on pilot sites have shown that the production of biogas from animal waste (cow dung, pig manure, horse manure) and humans and its use as a source of energy in houses in rural area could be a sustainable alternative to the use of wood and charcoal. It has been estimated that each m^3 of biogas (65% methane) can replace the equivalent of 5 kg of wood or 3 kg of coal. For example, a 10 m^3 biogas plant installed in a household produces 2.5 m^3 of biogas daily. Its use would therefore prevent a consumption of 12.5 kg of wood energy or 7.5 kg of charcoal per day per household.

Figure 43: Substituted wood equivalent quantities.



The medium-term goal of the program is to install 10 thousand biodigesters:

- By 2030 the goal of the program is to install more than 60,000 biodigesters;
- This will reduce the use of wood and coal by 30%, and thus more than 15,000 ha of forest will be preserved each year;
- Senegal's potential for biodigesters is 450 thousand households this will help protect more than 100 thousand ha of forest per year.

12.2.3 Impact of the biodigester on strengthening the resilience of agricultural households

Definition 1: Resilience is considered to be the ability of a person, community, or system to rebound or even reborn as a result of a shock and resulting disruption having destroyed some of its integrity. This rebound capacity makes it possible to overcome the consequences of a shock, a break-up and the resulting crisis, in order to set out on a sustainable path.

Definition 2: Applied to the current context of Senegalese rural households marked by climate change, declining land fertility, shrinking arable land, resilience is the ability of rural households to cope with these changes, to produce their food in quantity and quality, and to be able to address their health, school and social needs, while being part of sustainability.

a) Improving food security through increased yields

Rural households that use effluent on their crop land have seen an increase in agricultural yields on major crops. For millet, there is an increase in the average yield of 102.46% compared to the average of the DAPSA of the last 5 years. Compared with the performance of control households in the same areas, there is an increase of 109.11%. For peanut, beneficiaries registered an increase of 64.69% compared to the average of DAPSA and 105.73% compared to neighbouring households.

Figure 44: Productivity with and without biodigester fertiliser.

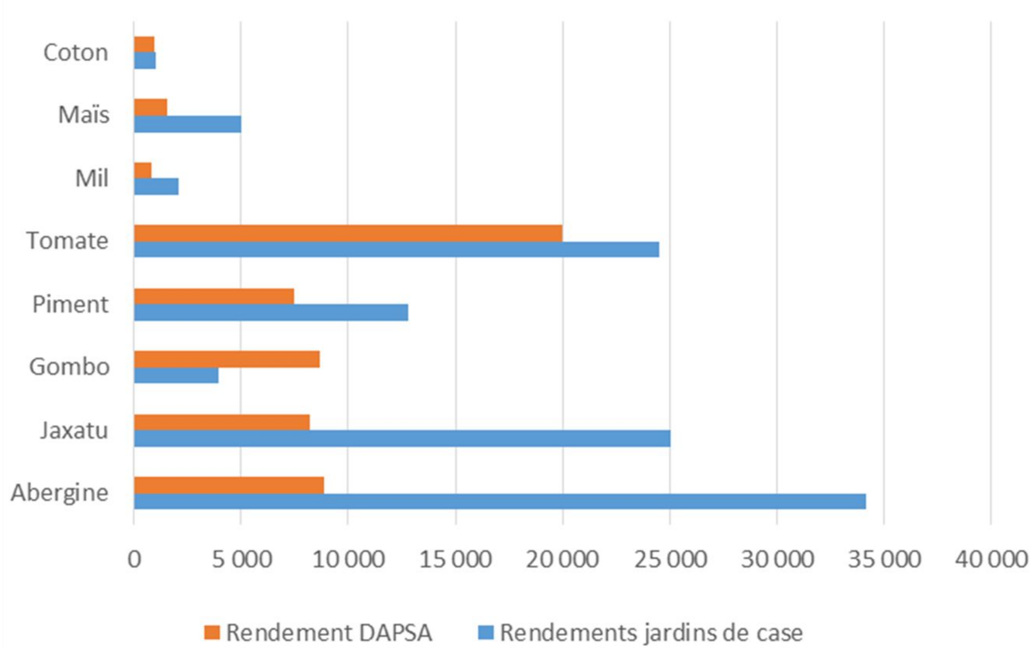
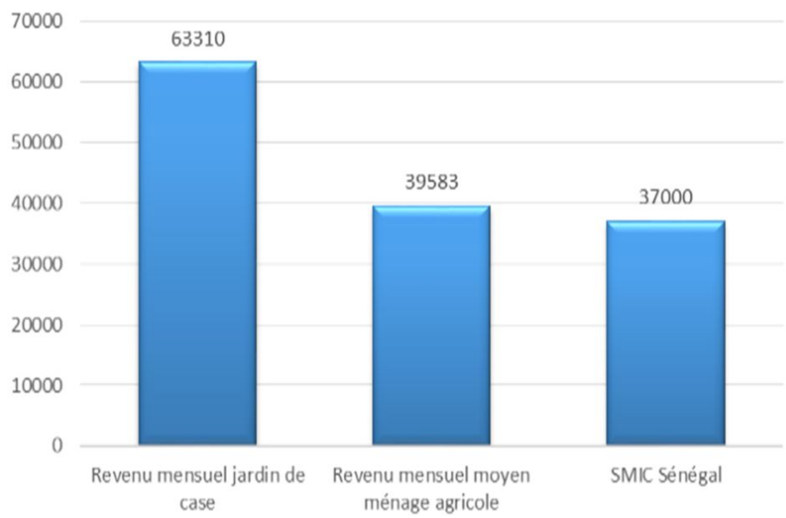


Figure 45: a. Rice plot with biodigester fertiliser; b.Rice plot without biodigester fertiliser.

b) Improving food security by increasing animal productivity

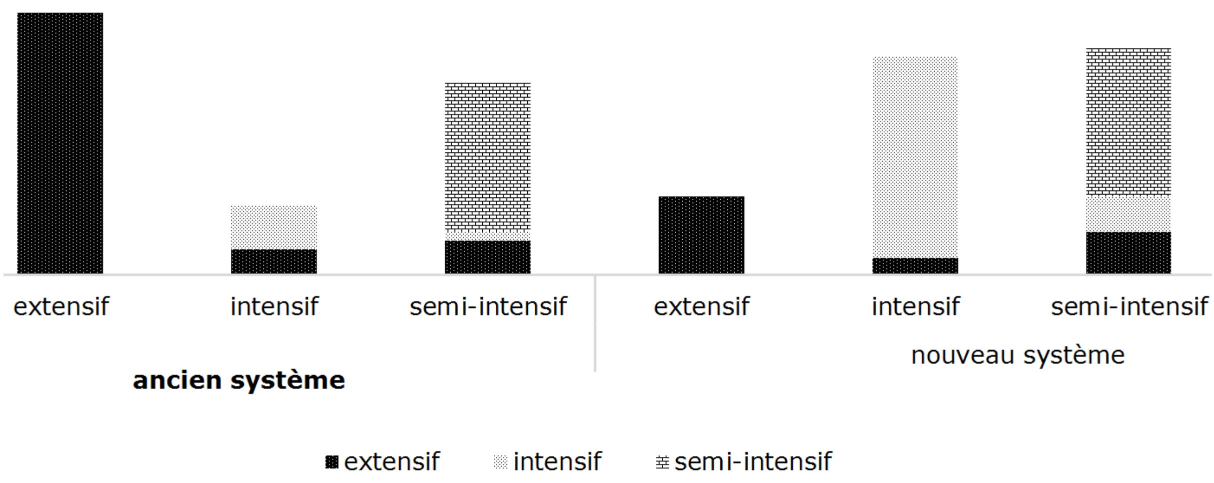
The increase in annual household income, according to this study, the new activities created by the biodigester combined generate an average income of 326,482 FCFA/year/household with a functional biodigester. The use of biogas provides savings to households for the purchase of cooking fuel and chemical fertiliser. These average savings on the purchase of cooking fuel are 44,736 FCFA/year/household. For the chemical fertiliser, the average saving per household is 24,891 FCFA/ha (source PNB-SN).

Figure 46: Estimated created revenue.



Improvement of herd management allowing an increase in milk production but also births. The figure below shows the impact of the biodigester on herd management;

Figure 47: Comparison of breeding systems.

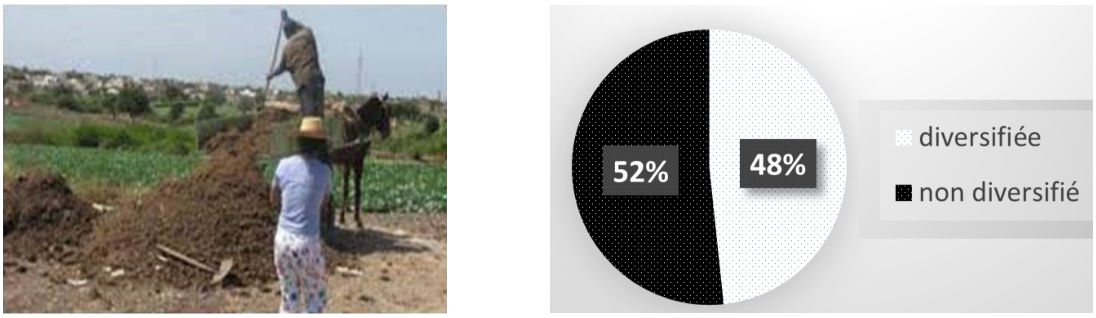


Improvement of knowledge on livestock manure management

Producers traditionally farm animals in plots for organic fertilisation, which results in low availability of mineral elements after application, weed and disease proliferation (non degradable organic matter) and loss of ammonia nitrogen. The anaerobic digestion allows a degradation of the organic matter with the availability of the NPK, for the interest of this fertiliser it was noted an improvement of the storage conditions of the organic fertiliser resulting from the biodigesters.

With the installation of the biodigester, activities in households have diversified. The level of diversification of these activities is given in Figure 48b.

Figure 48: Improvement of livestock management.



(a) Traditional manure management. **(b)** Level of diversification of activities.

Reduction of women's work

The installation of a biodigester makes it possible to free the women from the work for wood collection, depending on the area the wood collection requiring from women between 2 hours and 4 hours of time per days.

In addition, cooking with methane takes less time than cooking with wood and charcoal. The figures below show the time saved by a woman in a household with a biodigester for collecting wood and cooking.

Figure 49: Cooking fuel searching time.

Table 17: Improvement of women' health and children education (mins of cooking time).

	Before the project			With the project		
Diourbel	65	123	92	28	68	57
Fatick	55	123	148	19	64	92
Louga	31	103	106	13	57	71
Ziguinchor	78	148	75	23	59	37
Average	57	124	105	21	62	64
Range	20	18	31	6	5	23

Health: biogas as a household fuel prevents women and children in rural and peri-urban areas from breathing carbon monoxide fumes released during the burning of firewood;

Education: In non-electrified areas, biogas can be an effective alternative for lighting with biogas lamps.

12.3 Discussion and conclusions

The biodigester technology with methane produced, can effectively protect forest ecosystems, indeed in Senegal a household of 10 people consumed every day more than 5 kg of firewood in rural areas, the installation of a biodigester of 10 m^3 makes it possible to fully satisfy the needs for cooking energy.

In addition to the energy produced, the effluent resulting from the degradation of organic matter is a powerful organic fertiliser that strongly contributes to strengthening the resilience of agricultural households by:

- An increase in yields of all cultures (gardening, winter crops),
- A diversification of household economic activities: more than 48% of households with a biodigester have confirmed that they have diversified their income-generating activities after the installation of the biodigester, 52 have strengthened their income activities (through an extension or modernization of production systems).
- Significant time savings for women: in rural areas, wood harvesting takes up a lot of women's time in rural areas, and the biodigester releases women from the gathering of wood and cooking. The time saved allows the woman to develop income-generating activities thus increasing their financial autonomy.
- Reduction in diseases related to the release of smoke from burning wood and an improvement in the education of girls who are often forced to support their mothers in collecting wood.

Thus the popularization of biodigester technology could greatly contribute to the development of rural households by creating jobs in rural areas, achieving food security, restoring farmland, strengthening women's empowerment in rural areas.

Bibliography used in this section:
(French Environment and Energy Management Agency, 2009, Amigun et al., 2012, Provitolo, 2009, Dauphiné and Provitolo, 2007)

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13 WABEF, a toolkit to promote anaerobic digestion of biowastes in West Africa

Author: J.-M. Médoc, S. Niang, M. Ba, M. Kamaté, J. Lekoto, R. Van Veenhuizen
Keywords: biowastes; anaerobic digestion; biogas; fertiliser; West Africa.

13.1 Introduction

Population growth and urbanization, going along with changes in lifestyle and consumption, lead to large quantities of solid and liquid organic waste resulting from agricultural, agro-industrial and urban activities. In the absence of an adequate or deficient waste management system, these wastes can cause harm to human health and the environment. Biogas technologies are unique compared to other renewable energy forms, in that they address several challenges in sub-Saharan Africa in an integrated manner, enhancing the connections and potential synergies between sectors. WABEF - Western Africa Biowastes for Energy and fertiliser - promoted anaerobic digestion to recycle biowastes to produce energy and fertilisers, and as such closing the organic matter loop.

13.2 Description of the project and results

WABEF is a research and development and capacity building project that aims to promote anaerobic digestion at a semi-industrial, industrial (i.e. >20 m^3) scale from organic residues in West Africa. WABEF involves six partners: CIRAD (France) at the coordination, the University Cheikh Anta Diop and the African Institute of Urban Management of Senegal, the AEDR-Teriya Bugu in Mali, the Songhai Center in Benin and the RUAF Foundation of the Netherlands.

WABEF aims to contribute to the sustainable development of Africa through the promotion of anaerobic digestion to recycle biowastes (i.e. organic wastes in the broad sense) issued from agricultural, agro-industrial and municipal activities. Biogas technology is unique compare to other renewable energy sources and promoting its development in West Africa will support the environmental, energy and agricultural sectors (Figure 50). How?

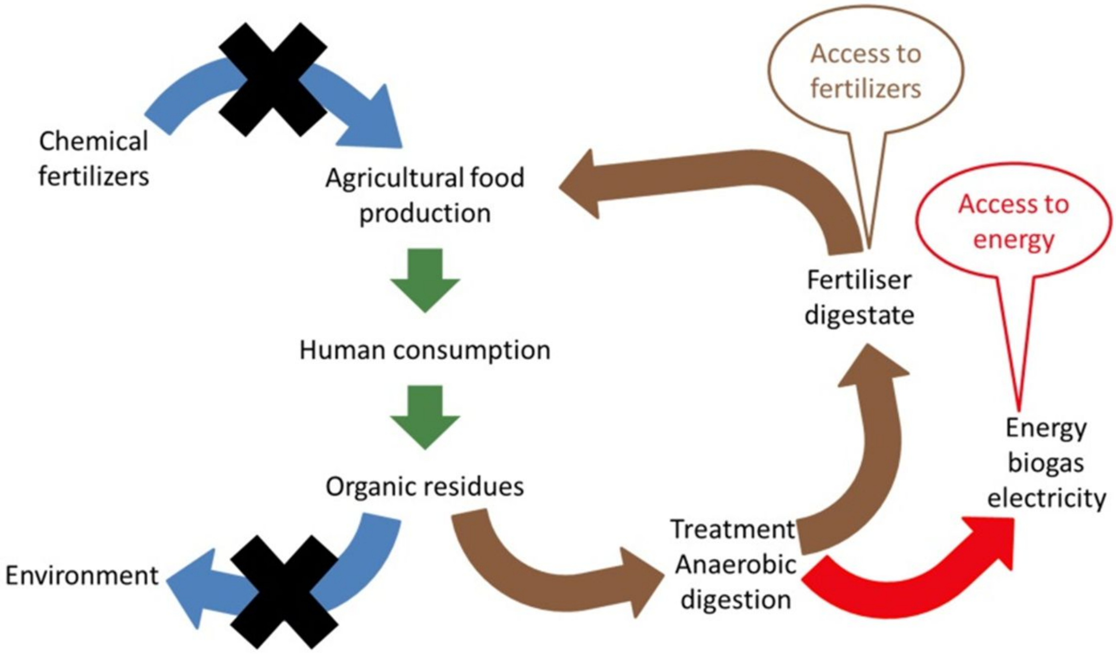
- By reducing the pressure of biowastes on the environment while recycling them into biogas plants to produce energy for cities and by reducing the deforestation while breaking the supply of wood and coal from rural areas;

- By contributing to the satisfaction of energy needs in a complementary mix with other sources of conventional and renewable energies;

- By closing the organic matter loop through the production of bioslurries, as fertilisers returned to the agricultural production areas, to address agricultural productivity and food security issues.

In the industrialized countries and in many countries of the South, an anaerobic digestion boom has been observed since 10 years, or even more for some, so why not in the countries of the Sudano-Sahelian area where the climate is favourable?

Figure 50: Anaerobic digestion as an opportunity for closing the loop in the food, energy and agricultural systems.

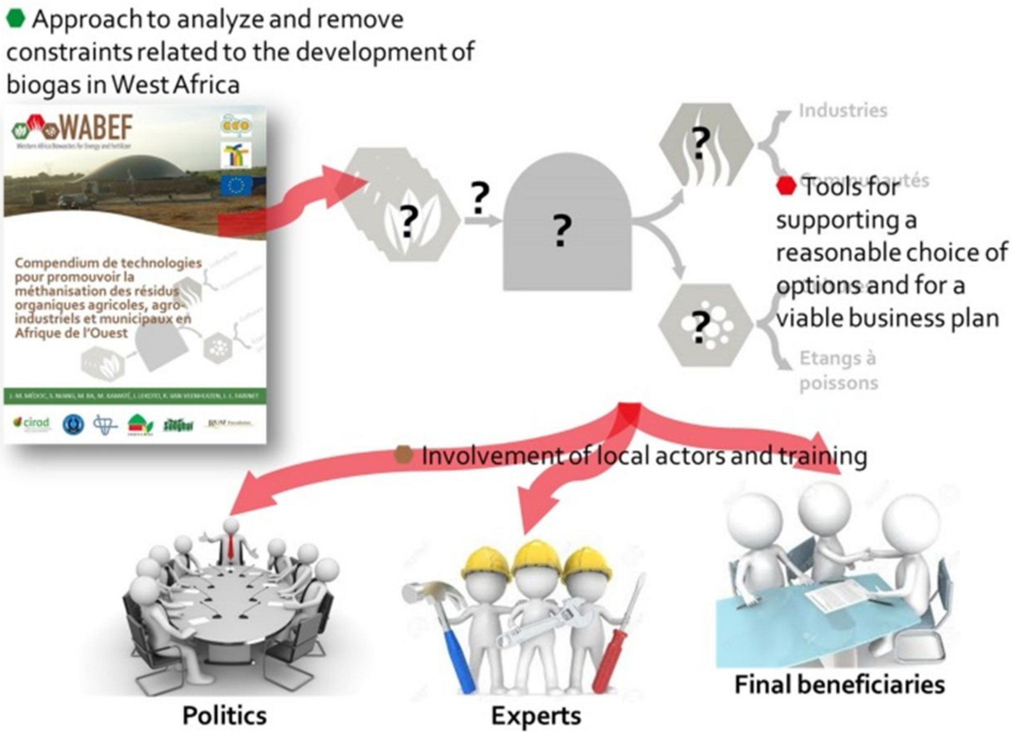


To address the above objective, it was necessary to improve the knowledge on the resources of biowastes and the existing technologies, to have tools adapted to support reasoned choices of techniques of mechanisation, to offer ready-to-use knowledge for decision-makers and practitioners. The objective is to use scientific data, industrial references and existing tools to formulate an approach and support the development policies of anaerobic digestion techniques. To address this objective, it is necessary to improve the knowledge of organic waste resources and existing technologies, to have tools adapted to direct reasonable choices of anaerobic digestion techniques. And for this, WABEF implemented a 3-step approach (Figure 51):

13.2.1 Lessons and challenges

The first step allowed analysing and learning from biogas experiments in Europe and in Africa to remove the constraints linked to the development of biogas in West Africa. Thirty-four visits of anaerobic digestion experiences in Europe (14) and Africa (20) have been carried out to learn about technological and managerial successes and failures, but also political and regulatory incentives and disincentives. Three main lessons have emerged. The first lesson is the need to secure the biowastes supply of the technology to ensure its smooth operation and durability. The second is to have policy and regulatory frameworks that provide incentives for attractive tariffs for the purchase of by-products, in particular biogas and electricity, and that promotes technologies consuming these by-products. The third lesson, symmetrical to the first one, is to secure the flow and recovery of bioslurries produced in order to minimize the risks of environmental pollution, to avoid loss of income for the unit and to maintain a good reputation.

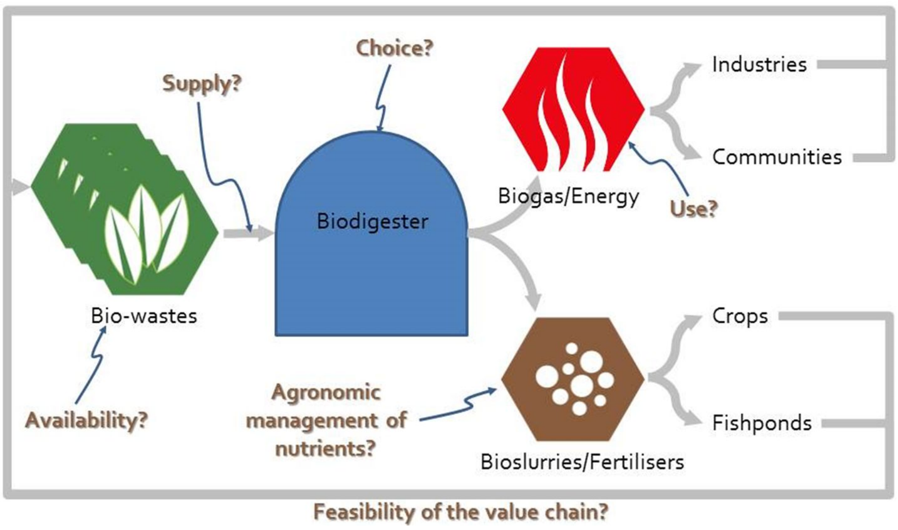
Figure 51: WABEF's 3-step approach.



A toolkit to promote anaerobic digestion of biowastes in West Africa

In the second step, relying on the operation of the value chain we have by reusing, adapting existing tools tried to provide a toolkit composed of a specific tool to characterize or evaluate each step of the value chain and its feasibility (Figure 52). In other words, the aim was to identify and evaluate the elements for developing a business model supported by the demand for biogas and fertilisers.

Figure 52: Questions to be answered to support decision-making and a viable business plan.



Thus, for each step of the value chain, WABEF proposes an operational tool allowing answering the questions: What availability of biowastes? What supply for which biogas system? What valorisation for biogas? What agronomic management for bioslurries? What feasibility for the whole value chain? And what ready-to-use knowledge for decision makers and practitioners?

As an example, the answer to the question "What availability of the biowastes?" is introduced:

In West Africa, little information on biowaste deposits and their quality are available and their relevance raises questions. A methodology to identify, quantify and assess their potentialities in term of fertilisation and production of biogas is developed in the form of three databases (MS Excel spreadsheet) to estimate the deposit of biowastes from agricultural activities (crops and livestock), the deposit of biowastes from municipal activities and the deposit of biowastes from agro-industrial activities.

The frame of the database for agricultural biowastes is organized around the livestock and the cultivated areas censuses at the District level. Animal dejections or crop residues production ratios are included according to the literature. Combining this two information allow reaching the raw deposit. And those data on raw deposits are those often found in the literature, which are not relevant enough for securing the supply of a biogas project. Applying on the raw deposit the agricultural practices, like the duration of production cycle, the number of cycles per year, the time of presence of animals, allows reaching the controllable deposit of a biowaste. Then applying on this controllable deposit the valorisation rate of the controllable biowastes, constituted by the quantities of biowaste directly applied on soil, sold, used for construction or combustion, etc. to avoid competition, allows calculating the mobilisable deposit for biogas.

The database for the municipal biowastes uses national census of the population at the District level divided into urban population and rural population and projections. Production ratio of organic fraction of household solid wastes (from the Municipal Solid Wastes Management National Programme in Sénégal), of faecal sludge are obtained from literature.

Combining population distribution with the production ratios allows reaching the deposits of organic fraction of household solid wastes. The same combination with the estimates on use of sanitation facilities (data from the Joint Monitoring Programme for Water supply and Sanitation of the WHO and UNICEF) allows calculating the faecal sludge deposits from piped sewer systems, from septic tanks, from dry latrines and also from unimproved sanitation facilities that are not controllable. In Sénégal, WABEF calculated the potential availability of agricultural and municipal biowastes based on the national census of 2013 (Table 18).

Table 18: Agricultural and municipal deposits of biowastes in Sénégal.

	Biowaste (mil tonnes DM/year)
Controllable animal dejections	2.311
Production of crop residues (cereals and legumes only)	2.426 billion
Production of biowastes (organic fraction of household wastes)	0.216
Controllable faecal sludge	8.713

All the data necessary for the implementation of such calculations are dispersed, often difficult to access, and generally poorly organized. The re-use of biowastes as agricultural fertilisers and energy using biogas technologies, requires proper management of these resources. Governments should introduce a systematic approach to the collection and dissemination of statistics on biowastes at various levels and sectors, with an identified focal point.

13.2.2 Capacity building

In the third step WABEF targeted the involvement of local actors for the appropriation of the results, in particular through the dissemination of knowledge and know-how. The results were disseminated in July 2017 in a regional school at Songhaï (Bénin) gathering selected high-level actors from Bénin, Cape Verde, Mali and Sénégal. They have been trained in the use of the WABEF toolkit and are responsible for further uptake and dissemination. One policy brief describing and illustrating why the use of biowaste in anaerobic digestion should be promoted, how and what policy and financial incentives are needed to promote wider use of biogas was disseminated to local executives. A curriculum scenario for practitioners and university training is proposed for dissemination in specific Master programs in West Africa.

Development of a critical mass of specialists in biogas and related topics is key in the development in West Africa. This requires the development and dissemination of curricula including decision-making tools for the training of technicians at all levels (vocational schools, technological institutes, universities, etc.).

13.3 Discussion and Conclusions

Promoting the integrated development of anaerobic digestion is not equal to promoting a single technology or one existing model, but to offer to the stakeholders the key elements to support reasoned choices for developing an integrated and a viable biogas value chain. The successful fixed domestic dome biodigester cannot be up-scaled to all localities, especially in urban and peri-urban areas, for reasons of space, safety and public hygiene. But it triggers the start of the sector, and is part of a mix of renewable energy.

In West Africa, in particular in Senegal, Mali, Burkina Faso and Niger, wood energy is the main fuel used by 90% of households and is also the basic essential energy consumed. Demographic pressure, particularly urban, and poverty intensify this use and contribute to forest degradation. The city of Bamako, 5.4 million inhabitants, consumes 884,491 tons of wood-fired equivalents annually. Reducing deforestation goes through the desire for the emergence of a new sector that could be gas. Mobilising municipal biowastes e.g. from municipal solid waste, faecal sludge and sewage sludge in municipalities to produce biogas in one or more semi-industrial or industrial units to substitute coal and wood seems to be a viable alternative to generate energy for urban populations; Such as the anaerobic lagoon of territorial interest of Ashaiman Slum, Greater Accra, Ghana.

In more isolated rural, domestic and agricultural situations, the small individual biodigester can play a role in contributing to the well-being of people, especially women and young people, to a better lifestyle by access to a mean of clean cooking and lighting; but the supply of biowastes must be secured year-round. At the scale of a rural community or groups of farmers, biogas of semi-industrial size could bring economic development by the production of energy supplying the motive force and the heat for the transformation of food.

Large biogas units require large investments, but they also allow economies of scale and they can consider all possible recovery routes for biogas and digestates. But the technology, economic, environmental, social and political sectors must be on the same level of technology readiness.

At local level access to information on the availability of organic resources and the use of by-products as well as access to various sources of financing and appropriate technologies should be facilitated through local incubator centres. The establishment of these decentralized support structures will bring together local authorities, technical services and communities. The development of biogas in West Africa requires a favourable political climate and strong government support; that includes proper financial support for businesses and households' investment.

An integrated approach must also enable proper management of information and waste resources as described above. Furthermore, innovative information and capacity building approaches are needed to support the private sector, governments and civil society to enable wider adoption and dissemination of biogas as part of a further increase in its proportion of renewable energy in Africa.

13.3.1 Policy Recommendations

1. Taken in its own right as part of an energy mix, biogas (anaerobic digestion) would contribute to the energy coverage of West African countries. It is essential to develop integrated planning and coordination processes that overcome sectoral approaches.
2. The recycling of organic residues as agricultural fertilisers and for energy through anaerobic digestion requires the control of these resources. The public authorities must establish, at the level of all sectors generating organic residues, a systematization of the collection of statistics.
3. The development of anaerobic digestion cannot be achieved without institutional support at national and local level. Today, subsidies focus on the installation of the anaerobic digestion units. A rational distribution of the subsidy for the investments in equipment and disposal of treatment by-products (fertiliser and biogas) as well could support this development and its long term deployment.
4. Having a critical mass of specialists is one of the key factors in the development of anaerobic digestion in West Africa. The development and dissemination of know how including decision support tools for the training of technicians at all levels (vocational schools, technological institutes, universities, etc.) should be encouraged.
5. Access to information on the availability of organic resources at the local level, the valorization of by-products, sources of financing and appropriate technologies should be facilitated to project promoters, practitioners through local incubators. For this goal, it is necessary to support the establishment of decentralized support structures that bring together local authorities, technical services and local communities.

Bibliography used in this section:
(ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), 2015, International Renewable Energy Agency (IRENA), 2015, ACP-EU Cooperation Programme for Science and Technology, 2014-2017, Ahmim-Richard, 2017, Danielle and Don, 2004)

Acknowledgement

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14 Performance Evaluation of Ferrocement Downdraft Gasifier System

Author: Francis Kemausuor, Michael Kwaku Commey, Edwin Nii Badger, Isaac Osei
Keywords: Ferrocement, Downdraft, Gasifier, Biomass
Abstract:

The ability to generate energy from biomass on a larger scale is limited by technology and availability of biomass feedstock. Nonetheless, these constraints can be overcome when gasification technology combined with high-efficiency conversion and end-use strategies are employed. In this study, biomass gasification was undertaken in a 20 kW capacity Ferrocement Downdraft Gasifier (FDG). Feed-stocks used were kane charcoal, bamboo charcoal, teak charcoal and wood pellets. The effects of several parameters including operating moisture content, temperature, gasifying agents, biomass residence time on producer gas flow-rate and yield were assessed. The gas generated was used to run a gas engine system. Analysis of the experimental results showed maximum producer gas output from FDG to be 55 Nm^3/h for teak and bamboo, with bamboo generating more stable engine runs. Highest engine speed on producer gas was determined to be 2,300 rpm, at bamboo charcoal consumption rate of 8 kg/h. Stable temperature range of 38-50 °C was recorded across the various cylinders in the system with a maximum gasifier temperature of 1045 °C.

14.1 Introduction

Globally, energy demand has been increasing at a fast pace, and this is especially in developing countries where efforts are being made to increase access to clean and modern energy. Due to continuous reduction in fossil fuel quantity and associated environmental problems, renewable energy can be used as an alternative to produce electricity and generate heat (Garg and Sharma, 2013).

Among the renewable energy sources, biomass stands superior in developing countries, being evenly spread across each country. Biomass, in the form of firewood and charcoal mainly for cooking and other heat applications, is the most consumed fuel in Ghana, accounting for close to 40% of total energy consumption in the country (Energy Commission Ghana, 2015). Each year nearly 600,000 premature deaths in Africa is attributed to household air pollution resulting from the inefficient traditional use of solid fuels, such as fuel wood and charcoal (International Energy Agency (IEA), 2014). One effective of use of biomass for power generation is through gasification (Demirbas, 2008, Naik et al., 2010, Deublein and Steinhauser, 2011)].

Biomass gasification is a unique form of renewable energy technology suitable for rural and urban electrification. Gasification systems have been commercially established in China, India and South-East Asia successfully for various industrial and domestic applications (Ramamurthi et al., 2015). Developing countries including Ghana can therefore tap into her plentiful biomass resources for sustainable and affordable energy to extend electricity to rural communities. The aim of this study was to conduct a performance evaluation of a 20 kW Ferrocement downdraft gasifier engine system using local charcoal feedstocks.

14.2 Materials and Methods

14.2.1 Experimental Setup

A 20kW, 1500 °C maximum temperature, Ferrocement down-draft gasifier and an engine system installed at the Technology Consultancy Centre (TCC) of the Kwame Nkrumah University of Science and Technology (KNUST), Ghana was used for the study (Figure 53).

Figure 53: The 20 kW gasifier.

A four-stroke, four-cylinder, sixteen valve Benz 1500 cc petrol engine reorganized to operate on producer gas was coupled to the gasifier system for the experiment. Figure 54 presents a schematic diagram of the experimental set up.

14.2.2 Procedure

For the study, 7 kg each of charcoal from Anogeissus Leiocarpus (kane), Bambusoideae (bamboo), Tectona grandis (teak) and wood pellets, characterized into sizes ranging from 2.5×2.5 to 3×3 mm were used. A torch was used to ignite the charcoal and allowed to burn for 10 minutes. A blower was used to suck the gas from the burning charcoal at the outlet of the gasifier tube for about 10 minutes and then directed towards a flaming paper. The blower was removed and the valve to the blower was closed to allow gas flow into the engine. The cooling of the gas took place immediately after the gas leaves the reactor and continued as the gas passed the filtering train. The heat from the gas was rejected to the cooling water in which all ferrocement cylinders were submerged. A bunker which acted as a charcoal reservoir was placed over the gasifier. The engine was started with a lean gas-air mixture and operating parameters including producer gas flow rate, temperature at different points in the gasifier etc. were measured at intervals of 5 minutes for 180 minutes.

14.3 Results and Discussion

14.3.1 Calorific Values of Feedstocks

Teak charcoal and wood pellets had the highest and lowest specific kinetic energy of 29.1 and 20.4 MJ/kg respectively as shown in Table 19. It has been reported that, biomass with high energy content has high quantity of producer gas and better gas quality (Atnaw et al., 2014).

Table 19: Calorific Values of Biomass Feedstocks.

Biomass Type	Energy Density (Cal/g)	Heat Capacity (J/K)	Specific Kinetic Energy (MJ/Kg)
Teak	**6951.1**	5790.3	**29.1**
Kane	6447.9	5966.7	27.0
Bamboo	6817.5	5945.8	28.5
Wood Pellets	4868.3	**7326.6**	20.4

Table 20: Laboratory Analysis of Biomass Feedstock.

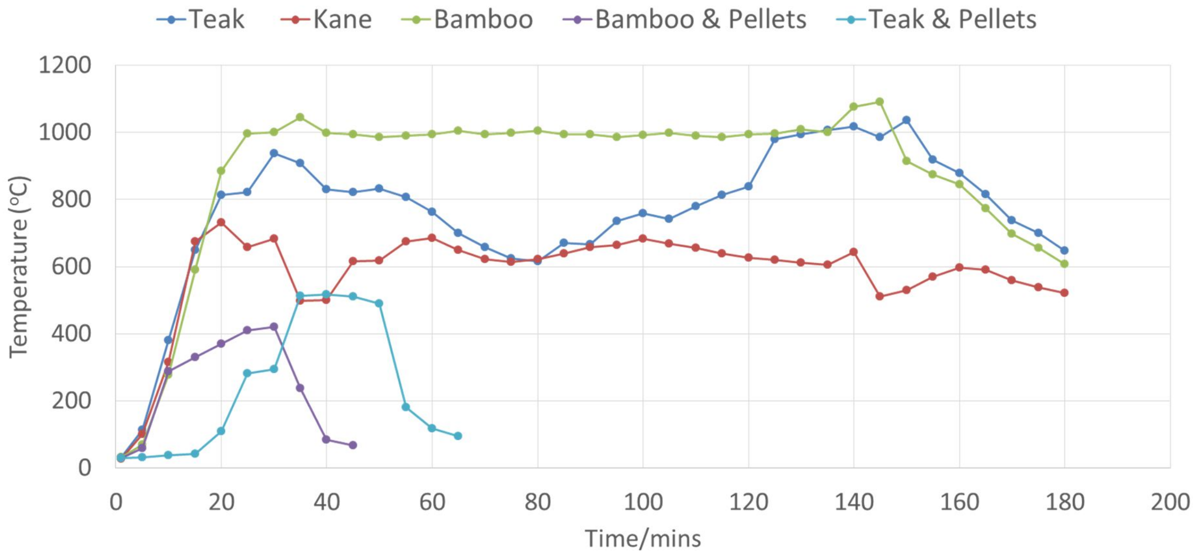
Parameters	Teak	Kane	Bamboo	Wood pellets
Proximate analysis				
Ash content (% of T.S.)	5.3	**6.76**	6.18	0.37
Moisture content (%)	6.77	**8.56**	7.8	7
Volatile matter content (%of T.S.)	12.15	15.32	13.98	**82.77**
Fixed carbon (%)	**75.78**	69.32	73.04	9.86
Ultimate analysis (%)				
Carbon content	**88.1**	79.83	85.3	44.5
Hydrogen content	1.91	2.91	2.72	4.64
Oxygen content	9.64	17.05	11.66	**50.72**
Sulphur content	**0.03**	0.01	0.01	0.005
Nitrogen content	**0.32**	0.2	0.22	0.14

Proximate and ultimate analysis of teak, kane, bamboo charcoal and wood pellets are presented in Table 3. Moisture component (dry basis) for the various charcoal types was measured to be teak (6.77%), kane (8.56%), bamboo (7.8%) and finally wood pellets (7%). Ash content for teak, kane, bamboo and wood pellets were determined to be 5.3%, 6.76%, 6.18% and wood pellets 7.27% respectively. Volatile Matter was found to be between 12-14% for teak and bamboo, wood pellets (82.77%) and kane (15.32%). It was observed that the fixed carbon for teak, kane and bamboo are 75.78%, 69.32% and 73.04% respectively and 9.86% for wood pellets. It was found out that the weight percent on dry basis for carbon in teak, kane and bamboo ranges between 79.83-88.1% and 44.5% for wood pellets. The ultimate analysis of the feedstocks shows a negligible amount of nitrogen and sulphur.

14.3.2 Temperature profile in the Reactor

It can be observed that temperature increases with time and reduces at the end of the gasification process (Sengratry, 2006). As indicated in Figure 55, after 20-30 minutes, the system approached stable gasification temperature for bamboo charcoal (900-1050 °C). Temperature profiles for both teak and kane were unstable, at 600-800 °C and 400-750 °C, respectively. The temperature profiles during the gasification of the wood pellets were the lowest as compared to the other feedstocks (250-550 °C).

Figure 54: Temperature profile in the Reactor.



14.3.3 Temperature profiles in Cyclones Cylinders

It can be observed that temperature profiles in both cyclones were stable (32-42 °C), as a result of the cylinders being submerged in cooling water. But in the use of wood pellets, temperature levels in the cyclone cylinders increased sharply (35-52 °C).

14.3.4 Temperature Profiles of Gas Outlet

The temperature of the gas leaving the system was stable and low for bamboo (34-40 °C), teak temperature profile was also between 35-47 °C while temperature profile for kane was unstable and high (34-60 °C).

14.3.5 Temperature in Cooling water

Temperature in the gasifier was maintained by the circulation of water. A constant cooling temperature of 30 °C was observed for the system design (Tuyen and Loof, 1992). The temperature of the cooling water in the system was very low for bamboo (31-37 °C), kane temperature profile was stable (33-38 °C), but the temperature for teak was high (i.e., 31-50 °C). It took approximately 6 hours for the gasifier to be cooled down to ambient temperature again.

14.3.6 Effects of moisture content on the gasification

Moisture content significantly affects both the operation and the quality of the producer gas (Uslu et al., 2008, Antal et al., 1996). It was observed that high moisture content reduced the consumption and feeding rate of the biomass. Ferrocement down-draft gasifier performs very well with about 40% moisture content on dry basis.

14.3.7 Gasifier producer gas flow-rate

Figure 8 presents the producer gas flow rate for the various feedstocks during the test. It can be seen that, the gasifier flow-rate increased steadily in the initial stages and remained relatively constant and decreased at the end of the gasification. As expected, teak charcoal and wood pellets recorded the highest and lowest gas flow-rate based on their corresponding energy potentials as presented in Table 21. Bamboo performed better than all the other fuels as result of its physical and chemical properties as presented in Table 19.

Figure 55: Produced gas flow-rate.

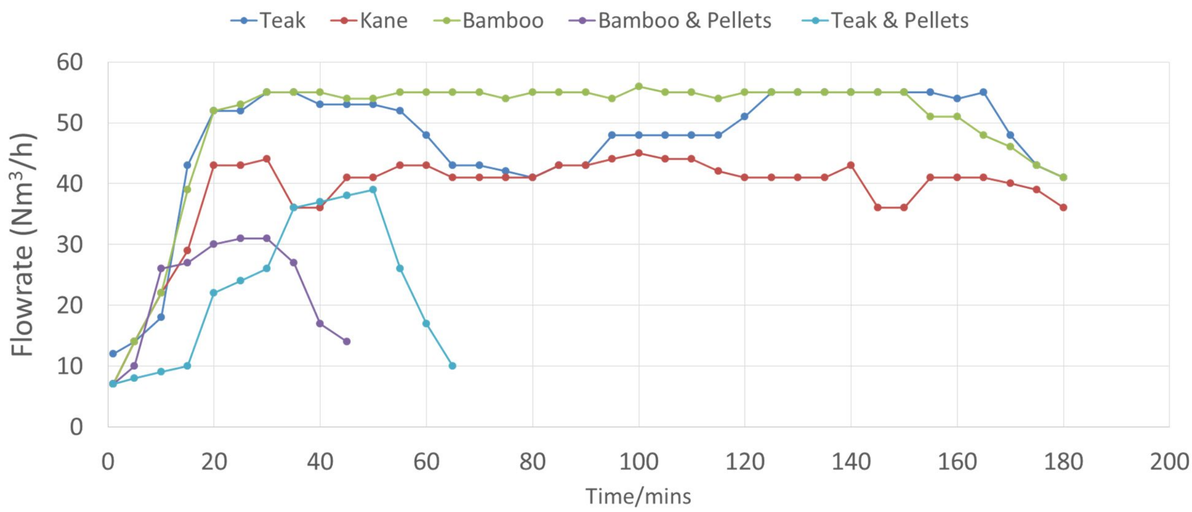


Table 21: Highest Gasifier Readings Observed.

Biomass Feedstock	Reactor Temperature (°C)	Flow-rate (Nm^3/h)	Engine speed (RPM)	Voltage (V)	Frequency (Hz)
Teak	937.4	55	2350	300.25	39
Kane	683.6	45	1881.5	241.5	31.5
Bamboo	1045	55	2312.5	297	37.5
Wood Pellets	655.3	43	1600	204	27

14.3.8 Performance characteristics of engine set and generator

The engine system is found to respond very well to load changes, with generation capacity as high as 8.1 kW at peak performance. The overall Ferrocement downdraft gasifier coupled to the engine system efficiency of generating electricity from biomass feedstock was 55.8%.

The alternator generating the power was integrated with three 10 W bulbs. The bulbs run with power generated from the Ferrocement down-draft gasifier for more than 2 hours of operation with teak and bamboo as fuel, but kane performed lower than 2 hours.

14.4 Conclusions

The main conclusions of the study are:

1. Kane, bamboo and teak were found to be effective sources of fuel for generation of producer gas.

2. Wood pellets is not a suitable option for generation of producer gas in FDG.

3. The reactor grate temperature was nearly 1100 °CC, which is suitable for efficient gasification.

4. The gasification zone temperature was between 500-1000 °C, with average gas flow rate of 48 Nm^3/h. Higher heating value of feedstock has significant effect on gasification rates, as a result bamboo and teak with more than 28 MJ/kg of energy content produced increased temperatures in gasifier reactor. The highest gasification temperature and producer gas flow-rate were 1090.0 °C and 56 Nm^3/h respectively. Lower temperatures increased possibility of producing high tar content in the produced gas.

5. During operation, an increase in moisture content reduced the fuel consumption rate. Moisture content above 10% limits the gasification process in the gasifier reactor.

6. Flow-rate of producer gas and air into the gasifier steadily increase with time.

A disadvantage of the Ferrocement down-draft gasifier as observed during the experiment is the occurrence of cracks in the casted refractory cement armature during use, this reduces the lifespan of the system.

Bibliography used in this section:
(Garg and Sharma, 2013, Energy Commission Ghana, 2015, International Energy Agency (IEA), 2014, Demirbas, 2008, Naik et al., 2010, Deublein and Steinhauser, 2011, Ramamurthi et al., 2015, Atnaw et al., 2014, Sengratry, 2006, Tuyen and Loof, 1992, Uslu et al., 2008, Antal et al., 1996)

15 Biogas production experiences from Europe and Africa

Author: Dominik Rutz and Rainer Janssen
Keywords:

15.1 Introduction: Anaerobic Digestion

Biogas is produced by anaerobic digestion (AD). AD is a biochemical process in which various types of anaerobic micro-organisms (bacteria) decompose complex organic matter (biomass) into smaller compounds, in the absence of oxygen. The process of AD is common to many natural environments such as in marine water sediments, stomach of ruminants or in peat bogs. Also in biogas plants organic input material, which is called feedstock, is anaerobically digested in order to decompose it into the two main products biogas and digestate.

In most biogas plants, several feedstock mixtures are simultaneously used in order to stabilize the process to optimise biogas production. This is called co-digestion. Suitable feedstock for AD includes a large range of biomass materials, preferably consisting of easily decomposable material. This includes fats, oils, sugars, and starch. Furthermore, cellulose is easily decomposable, whereas lignin, a major compound of wood, is difficult to decompose by AD. Typical feedstock for biogas plants can be of plant and animal origin (Rutz et al., 2015).

The type of the feedstock influences the AD process and the final composition of the produced biogas (Al Seadi et al., 2013). Biogas consists mainly of methane (CH_4, 40-80%) and carbon dioxide (CO_2, 15-45%) and of smaller amounts of hydrogen sulphide (H_2S), ammonia (NH_3), nitrogen gas (N_2), and other compounds. Furthermore, biogas is normally saturated with water vapour (H_2O) (Rutz et al., 2015).

The desired compound is energy rich methane since this can be used for energy or material purposes. The methane yield is one of the most important characteristics of the used feedstock in the AD process. The type and the methane yield of feedstock highly influence the profitability of a biogas plant. Besides the feedstock type, also other factors such as the design of the digestion systems, digester temperature, retention time, and organic load influence the composition of the biogas (Rutz et al., 2015).

The AD process is a result of linked process steps, in which the feedstock with complex organic compounds is continuously broken down into smaller compounds. Specific groups of micro-organisms are involved in each individual step. These organisms successively decompose the products of the previous steps. The four main process steps of AD are: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Al Seadi et al., 2008).

The general understanding of this complex biochemical process is important to optimize biogas technologies and projects. It may appear that biogas technologies, especially at household scale systems, are very simple. However, the well functioning of the system with high yields and low safety risks without interruptions for a long period is a challenge and requires good skills of the operator.

The operation of a biogas plant largely depends on the size and technology of the system. There exist large differences between the different types of biogas plants. They can be classified as follows:

Objective: household level, agricultural, industrial

Size of the plant: household-, small-, medium-, large-scale

Moisture level of substrate: Wet or dry fermentation

Process stages: Single or multi stage process

Material flow: Continuous or discontinuous process

Process temperature: Psychrophilic (25 °C), Mesophilic (37-42 °C), Thermophilic (50-60 °C)

Biogas use: cooking & lighting, CHP, biomethane

15.2 Biogas in Europe

The biogas market in Europe developed quite significantly over the last decade. It currently consists of more than 17,000 biogas plants, whereas the majority of the plants are agricultural biogas plants of an installed electrical capacity between 500 kW and 1 MW. The biogas is mainly used for combined heat and power generation. About 400 of the biogas plants in Europe upgrade the biogas to biomethane quality.

Within Europe, the main growth of the biogas sector happened in Germany with the introduction of Renewable Energy Sources Act (EEG) which included fixed feed-in tariffs for electricity generation from biogas guaranteed for 20 years. Besides the support for biogas as renewable energy, the objective of the legislation was also to support the agricultural sector, which was suffering from surplus food production in Europe with low prices for agricultural products.

With the installation of biogas plants, the role of farmers changed, and many became so called "energy farmers". Due to its high yields, mainly corn silage is used in the agricultural biogas plants, besides manure, slurry, residues and other crops. Due to lobbying and criticism of the public about the often large-scale cultivation of corn monocultures, the legislation has recently changes so that in the last two years only very few biogas plants were newly installed in Germany. At the moment, the sector discusses about options on how to continue the operation of these biogas plants, which are falling out of the fixed feed-in tariff after the 20 years. This is due to the fact that several plants started operation in 2000 and after 20 years, in 2020, the fixed feed-in tariff is closed for them.

All this development in Europe and especially in Germany proofs that the biogas technology is available at commercial scale and mature, although further developments are expected. This applies to all value chain steps, from feedstock collection to biomethane utilisation. The main barriers are the relatively high production costs of biogas in the range of €0.10 to €0.25 per kWh electricity (compared to €0.02 to €0.12 for PV), which makes it necessary to use biogas for special services, such as e.g. for balancing the power grid which is increasingly influenced by fluctuating power generation from e.g. photovoltaics (PV) and wind.

15.3 Biogas in Africa

Similar to Europe, also many African countries have installed large numbers of biogas plants. However, most of them are very different, as their size is much smaller and the purpose of them is very different. Most biogas systems in Africa are household digesters of a few cubic metres of digester volume. The main purpose of these family systems is to provide energy for clean cooking and lighting, as well as for the production of high quality fertiliser for (subsistence) farming. These household systems do not exist in Europe due to cold climates which requires digester heating in winter (household systems are usually not heated), safety issues, and different agricultural structures.

Although the absolute numbers of household biogas systems in Africa appears quite impressive, it is only a tiny fraction of the existing biogas potential in Africa. Many African countries and regions are well-endowed with a huge biomass potential, both in terms of biowaste, but also for crops (Rutz and Janssen, 2012). However, this potential is by far not used. Furthermore, the climatic conditions are usually very favourable not only for biomass production, but also for the digester design, as external digester heating may not be required in most cases. Especially rural regions could benefit from biogas systems due to income generation, energy access and security (Rutz and Janssen, 2014), and high-quality fertiliser production.

However, all these advantages are often not exploited, due to various barriers. These barriers may include the lack of financing of the rural poor, low educational level, lack of skills, local availability of technologies and equipment, water scarcity, and low level of awareness.

In general, biogas systems could be applied in Africa in any scale, ranging from household systems for cooking to large scale systems in the MW range for combined heat and power generation or even for upgrading of biomethane. A key challenge for larger systems is the high initial investment costs.

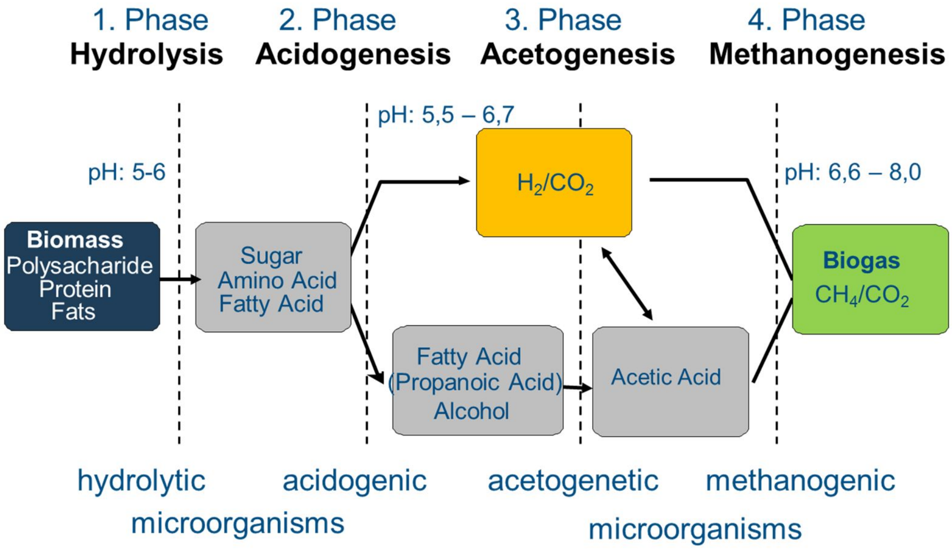
Especially the use of biowaste as feedstock for biogas production has a very high potential in many regions in Africa (Rutz et al., 2014, Ngumah et al., 2013), however, a key challenge is the collection and management of the biowaste. Currently applied waste management practices or waste dumping or landfilling are by far "cheaper", if external costs are not considered, than introducing proper waste logistics and management. For these systems, a clear political will and appropriate and enforced legislation is necessary.

Due to its high relevance for rural development in Africa, household biogas systems are described in more detail below, as well as by (Austin and Morris, 2012). There exist mainly three digester types for household systems (Figure 56):

- Fixed Dome Type (Chinese-, Indian-, Vientan-type, etc.)
- Floating Gas Holder Type
- Plastic Tunnel Type

The selection of the technology for household biogas systems is influenced by several aspects, such as environmental issues (climatic conditions, soil conditions, groundwater level), technological parameters (capacity/system size, construction methods, operation and maintenance, local dissemination level), affordability of potential farmers (availability of construction materials, human resources / skills, cost of installation, operation and maintenance), quality and quantity of available

Figure 56: Process steps of anaerobic digestion.



feeding materials (e.g. cattle dung, pig manure, residues, human excreta), availability of water for mixing, or the size of the household/farm (number persons as well as of cattle/pig per household).

Figure 57: Digester types for household biogas systems in Africa: Fixed Dome Type (underground; Tanzania), Floating Gas Holder Type (underground; Mozambique), Plastic Tunnel Type (aboveground; Mali), source: Dominik Rutz, WIP.

Various international development agencies and programmes have supported the roll-out of household biogas systems in Africa, such as, among others, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (https://www.giz.de), SNV Netherlands Development Organisation SNV (http://www.snv.org), Africa Biogas Partnership Programme and HIVOS (http://www.africabiogas.org/, https://www.hivos.org). Also private companies have set up commercial small-scale biogas programmes, such as the HomeGas programme in Kenya of the German polymer company Rehau (https://www.rehau.com).

15.4 Lessons learned - Recommendations

Household biogas systems in Africa could be widely implemented among the rural poor communities, if suitable support of capacity building as well as access to suitable and adapted technologies is provided. However, systems shall not be donated completely through donation funds, but it is more important to facilitate access to affordable financing so that the families are enabled to buy the systems themselves under good conditions. This creates real ownership and responsibility of the system. Ideally, household biogas systems are introduced to whole villages or regions which facilitates the coordination, capacity building and the experience exchange among the farmers. This could result in various benefits such as income generation, fertiliser production, energy generation for cooking, and reduction of fuel wood consumption which is traditionally used as cooking fuel in many regions.

Biogas plants larger than household scale have a high potential in Africa, too. Several examples in Africa have demonstrated good success, however, also several larger scale biogas projects have failed. The reason of the failures can be manifold. Usually, biogas plant failures, both in Europe and in Africa, are due to the human factor and not due to technologies which are in general mature. One problem is certainly the underestimation of the complex microbiological process of anaerobic digestion. The lack of capacity building and the related low technical and management skills of the responsible operators can be reasons for system failures. This applies especially to the operation and maintenance. Hence, local staff must be highly trained and skilled as larger biogas plants are technically very sophisticated, investment intensive (installation), and operational intensive (maintenance). Under all circumstances safety needs to be ensured.

15.5 Conclusions

For any biogas plant, the key question at the beginning of a new project is question about the objective and purpose of the project. Is the main objective for example energy generation, fertiliser production, waste treatment, or all of them? Thereby, the advantages of biogas systems seem to be very clear:

- Wet / in-homogenous wastes can be treated
- Recycling of nutrients as fertiliser (digestate)
- Biogas can be produced at any scale!
- Local revenue generation
- Continuous job creation during the lifetime of the biogas system
- Multiple use of biogas (e.g. also for cooking)

Ideally, a biogas project responds to several objectives. However, the limits and challenges of biogas projects must be realistically evaluated. For instance, in case that the only (!) objective is power generation, biogas is a very expensive technology. In that case, for instance power generation through photovoltaics is much simpler, cheaper, and less risky. If the objective is, besides energy generation, e.g. also solving waste problems and increasing agricultural productivity through the use of high-quality fertiliser, biogas is an excellent solution.

Bibliography used in this section:
(Al Seadi et al., 2008, Al Seadi et al., 2013, Austin and Morris, 2012, Ngumah et al., 2013, Rutz and Janssen, 2012, Rutz et al., 2014, Rutz and Janssen, 2014, Rutz et al., 2015)

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16 Valorisation of Dakar slaughterhouse waste or the production of clean energy from biogas: an example of sustainable development

Author: Lamine Ndiaye

Abstract:

The scarcity of conventional energy resources, the proliferation of geopolitical conflicts and the increase in demand are all reasons why countries are encouraging the emergence of new energy production sectors. Among these, biogas has many strategic advantages: a variety of recovery routes, continuous production, easy storage and a waste recovery route. Biogas is a response to climate change and a response to the fight against greenhouse gases. This is the end of the "consume-discard" for the entire biodegradable organic material sector, and the beginning of the circular economy; nothing will be lost in this area, everything will be transformed.

The pilot waste recovery industrial unit that we installed in the Dakar slaughterhouse and managed by the company THECOGAS SENEGAL demonstrates part of the sustainable development sector from the waste of a slaughterhouse and a form of circular economy within the same company. This same work could be done from agricultural waste (cow manure, pig slurry, poultry manure, etc.) but also from household waste, market waste and local industries. In this case, we will be in a circular economy within a waste pool, a larger territory, a region or an industrial domain.

The waste is transformed into biogas and subsequently biomethane. The biomethane, resulting from this process, is a gas of composition identical to that of fossil natural gas, but resulting from the gasification of biomass and therefore renewable. Its industrial production is not yet developed in our subregion, but more and more academic and industrial actors seem to be interested in it. Applications are emerging such that the use as fuel for gas vehicles will no longer speak of biomethane but BIOGNV or natural car biogas These actions are operated by companies present on all the sector as it can be managed by youth associations, women, around income-generating activities.

The promotion of industrial biogas would limit all the pollution of the environment caused by certain industries of the place. This is the case of slaughterhouses, but also of fish-processing industries, dairies, etc. All these industries can see their waste recycled into energy and biofertilisers and no longer be discarded either at sea or in wild waste dumps and is a circular economy.

The promotion of sustainable development, inclusive development that respects the environment while allowing nature to renew itself is of great significance here. Using the waste produced by an industry to supply energy to the same plant remains in the field of the circular economy of CSR in short, but especially of climate change.

16.1 General framework

Situation and constraints in the energy sector

The energy balance of the country in 2012 reveals that biomass and petroleum products still represent 95% of total energy consumption. The level of final energy consumption per capita remains very low: 0.206 toe in 2009, well below the African average above 0.500 tonne-oil equivalent (toe) and the world average (above 1.2 toe).

Electricity sector situation

Even today, 45% of Senegalese do not have access to electricity (20% in cities, 60% in rural areas). A delay that Senegal wishes to fill by doubling the country's energy capacity: "From 573 MW in 2011-2012, the total installed capacity of our energy park has now reached 821 MW. The goal is to reach 1,264 MW in 2019".

Renewable Energy; huge potential to exploit

Senegal has great potential for the development of renewable energies. It is there:

- A sunshine very important on practically all the country with an annual irradiation varying from South-East to North-West between 1850 and 2250 kWh/m^2/year;
- Wind regimes averaging 6 m/s (from 50m above sea level) on the west coast of the country, between Dakar and Saint Louis.
- For biomass, according to a study conducted by the firm SEMIS[1] in 2013, its potential annual production is estimated at 25,266,984 tonnes of dry biomass where agricultural waste constituted by manure and crop residues occupy the most important. The theoretical potential for biogas from this dry biomass is 1,417,892,000 Nm^3.

New vision of the State: an all-solar option

"Senegal has chosen to develop the energy mix, with the option of making clean energy to reduce the cost of a kilowatt-hour (kWh) in the near future and provide Senegalese with electricity in quality and quantity [...]. In our option, solar will play an important role with increasingly competitive production costs"[2]. More than 60 MW solar were thus realized between 2016 and 2017, many projects are in expectation. In the field of wind power, a fleet of 150 MW will soon (2019 horizon) operate 50 MW. The target of 20% of renewable energy in the energy mix is thus reached in 2017.

In the new macroeconomic framework in force in Senegal, the Emerging Senegal Plan leaves an important place for energy and agriculture. These two sectors are the result of the operability of the "waste to energy" concept.

[1] Étude sur la situation de référence en matière de biogaz au Sénégal
[2] Available online at: http://www.lemonde.fr/afrique/article/2016/11/30/

Waste to energy as a way of recycling waste.

The generation of electricity by waste is not an immediate option of the state of Senegal. The PNGD in charge of the sector plans to valorise the domestic waste by the production of compost and much later the production of biogas.

ANER, although it has in its objectives the development of project in the field of biomass, its approach has focused in the biofuels sector through jatropha and ethanol projects.

The "waste to energy in West Africa" project, a private initiative

The program we are running is an immediate response to waste management. It's a private initiative. It is at the crossroads between the renewable energy production sector and the electricity sector, but also the waste recovery sector. It is at the heart of the issue of sustainable development and industrial ecology. It is very innovative in Senegal and the sub-region where no meaningful experience has emerged[3]. The only experiment on the generation of electricity from waste is that initiated by THECOGAS in the framework of a pilot project which is stopped today for the needs of strengthening works. It is precisely this latter case that serves as a model to illustrate the "role of waste to energy" in sustainable and inclusive urban development strategies.

16.2 Waste to energy at the Dakar Abattoir

We will briefly recall the concept of "waste to energy" via biogas production before presenting the experience of the Dakar slaughterhouse.

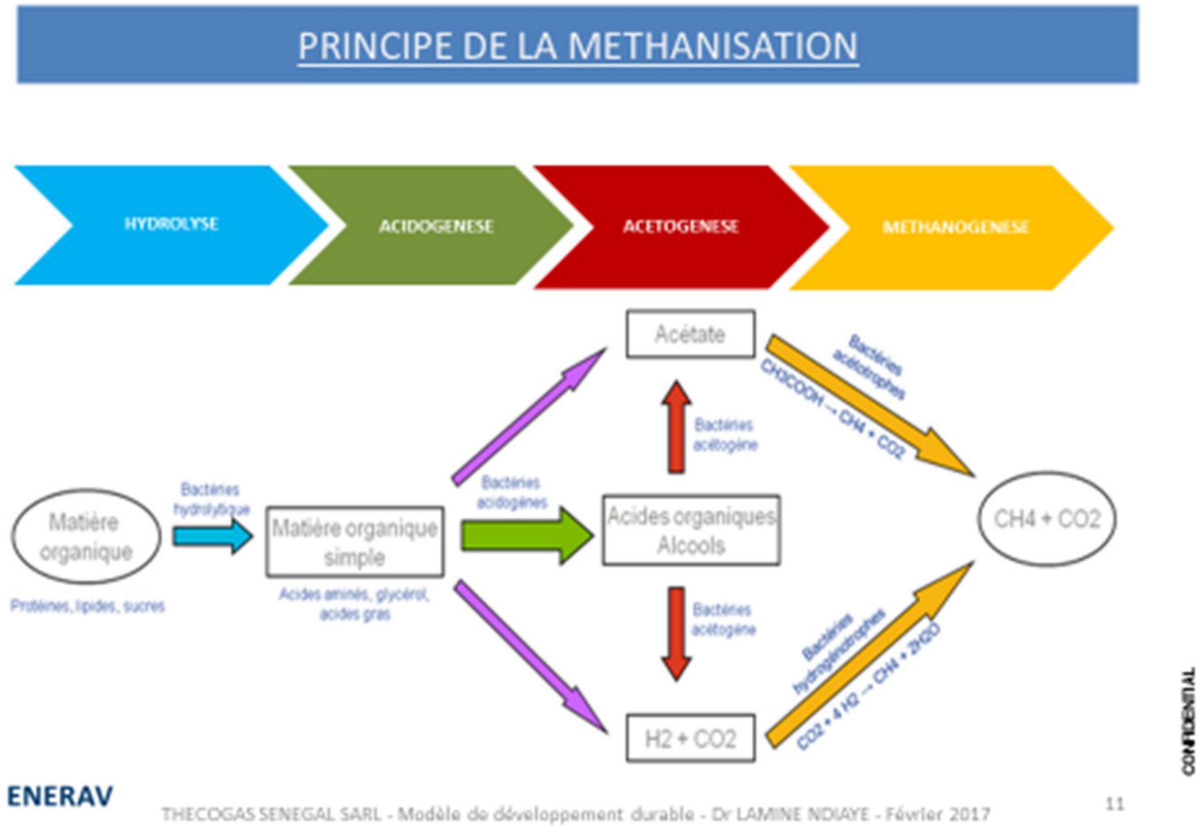
Methanization is the partial degradation of organic matter in the absence of oxygen under the combined action of several types of microorganisms and under well defined conditions of temperature and pH (Hydrogen Potential). A series of biological reactions leads to the formation of biogas (mainly composed of CH_4 and CO_2) and digestate. In the principle of biogas production, organic matter goes through four successive phases as shown in Figure 58.

16.3 The Sogas pilot project

Every day, between 250/300 cattle and 1500/2000 small ruminants are slaughtered at the Dakar slaughterhouse. For the preparation of all these animals and make available to the population of Dakar quality meat, the slaughterhouse consumes more than 250 m^3 of water each day and between 1500 and 2200 kWh of electricity. The operation of the plant produces more than 220 tonnes of waste in any state (liquid or solid) that is experienced as a nuisance both environmentally and health. The objective of the project is to transform these negative effects into favourable factors by removing all the environmental constraints but also the production of energy (electrical and thermal), the production of bio-fertiliser. The immediate expected results are:

[3]ONAS 1989 has developed a project with sludge from STEP, the research centres are interested but it did not progress much.

Figure 58: Principle of Methanisation.



- The reduction of more than 50% of the daily electricity consumption from the national grid (cold rooms);
- The provision of hot water for the sanitary needs of the factory;
- The production of liquid fertiliser;
- The lifting of environmental constraints.

The project: the concept of the four pillars

Four main pillars have been set up to meet the objectives of the project.

- Biology pillar
- Transport and refining pillar
- Pillar of energy production
- Pillar of electricity consumption

The biochemistry pole

It is the biogas production pole by degradation of organic matter from the main biodegradable waste of the plant: rumen contents, waste-water, blood. All of this is happening in an anaerobic environment.

The production of biogas is done in a tarpaulin digester to which are connected various equipment contributing to the production of a gas of quality. The operation being discontinuous and infinitely mixed, the waste is premixed in a pit of the same name equipped with a mixing grinder pump. Two brewers prevent the substrates introduced into the tarpaulin from turning into thick paste. In its composition, the biogas produced contains hydrogen sulphide (H2S) which must be brought back to an infinitely small level (some PPM) so as not to affect the correct functioning of the electrical power pole but also not to poison the users . This is done through the introduction of a few litres of air (6% of the total volume of digester) by means of two compressors operating alternately. This H2S management system is based on oxidation-reduction reactions that convert H2S into sulphate, oxygen and water. To be sure of this result, the gas produced is regularly analysed to ensure that its composition is of quality.

The refining pole

The biogas thus produced is transported by a pipeline network to the refinery pole which is essentially composed of a desulfurization unit. The desulfurizer, consisting of two "filter balloons" based on iron filings and operating alternately, sets the residual H_2S and water. Thus the purified biogas will be used as fuel for the engine of the power generation and heat plant. In the transport circuit, condensation wells are installed which trap the water resulting from the displacement of the biogas.

The energy and heat production sector: CHP

The production of energy and heat is done by means of a generator with biogas driving an alternator for the production of electrical energy and a boiler which makes it possible to transform the gases produced into water vapor and therefore into hot water up to 70 °C. 800 MWh of electricity and more than 1700 MWh of heat will be produced annually to cover a good part of the needs of the plant. Just remember that it takes 70 kwh of heat to raise the temperature of the water by 1 °C.

The energy consumption pole

The generated electrical energy is routed to the end-user's point of consumption to feed the agreed points at the time of the plant's energy assessment.

Biofertilisation: a result of the biochemistry pole operation

The operation of the biochemistry cluster will result in the degradation of substrates introduced into the digester. To ensure the balance of the functioning of the bacteria, the substrates will be introduced every day and 80% of the equivalent of the substrates (in volume) will be released. The products released are called digestate and have a good agronomic value for the fertilisation of the plants The use in agriculture is strongly advised because more economic than the chemical fertilisers, more respectful of the environmental standards and more water-saving because of its consistency. It is actually a liquid fertiliser directly assimilable by the plant because the mineralization is completed and resulting from a process of degradation of organic matter hence the name of biofertilisers. It will just be necessary to make sure of the agronomic quality of this digestate by the determination of the nutrients which composes it and to set up a good plan of spreading. The digestate resulting from methanation has an excellent agronomic quality, better than non-methanised materials: the nutrients are in mineral form more easily assimilated by plants, which improves the yield in most cases.

16.3.1 The investment

From a technical point of view, the pilot unit was constituted by:

- A tarpaulin digester of 4000 m^3 of total capacity with 2500 m^3 of substrate and 1500 m^3 of gasometer,
- A pre-treatment unit called a premix well equipped with a mixing grinder pump
- A combined heat and power station, CHP, with a capacity of 100 kW
- A desulfurization unit with two treatment lines working with granules
- A control cabin that can control all the equipment installed
- Various installations such as mixers, submerged pumps etc.

16.3.2 Some financial elements

- The total investment cost €650,000 HTHD;
- The cost of the kWh produced was around €13 cents (89 CFA francs);
- The selling price of the κWh was around €15 cents, while the price of the SENELEC is €18-21 cents/kWh for the city.

16.3.3 Results

For more than two years of operation, the monitoring system put in place has made it possible to identify all the parameters that go into the production process. From the number of animals slaughtered by the slaughterhouse to the production of electricity and heat. The analysis of the summary tables below shows that energy production from the biogas unit accounted for 12% in 2014 and 14% in 2015 of all energy consumed in the energy sector. For these same periods, the unit collected and valued:

- 40% of rumen contents waste and 13% of waste water produced by the slaughterhouse for the year 2014 and
- 36% of rumen contents and 14% of slaughterhouse liquid effluents in 2015.

It should be noted that the objective of the project was not to replace electricity consumption from the national agency but rather to reduce the electricity consumed by cold rooms whose installed capacity at the time of the feasibility study of the project was 66 kW as shown in the table below.

Table 22: Total energy consumption of the slaughterhouse between 2012-2015 (kWh).

	2012	2013	2014	2015
Total production biogas unit [KWh]			116,994	107,657
Total supply SENELEC [KWh]	932,335	878,225	851,584	678,987
Total consumption SOGAS	932,335	878.225	968,578	786,644
% energie from biogas/total energy			12%	14%

Table 23: Monitoring energy production from biogas in 2014.

slaughter SOGAS				Substrate used			Electricity production	
Period	Cattle (heads)	Sheep/ Goats (heads)	Tallow (tonnes)	Waste water (m^3)	Manure (kg)	Other (kg)	kWh	Operation hours
January	5933	38627						
February	5318	34106	13	279				
March	5692	40096	140	699			9690	158
April	5054	36427	134	699			14222	199
May	5332	38698	143	687			16580	240
June	4768	37552	104	792			15326	211
July	4549	41587	149	735			13895	183
August	5282	41486	124	578			12021	174
September	5352	37921	164	801			10177	129
October	4959	24630	99	423			8606	106
November	4949	28082	137	639			7287	174
December	6030	41468	171	723		550	9190	150
Total	63218	440680	1377	7055			116,994	1724

Table 24: Monitoring energy production from biogas in 2015.

slaughter SOGAS				Substrate used			Electricity production	
Period	Cattle (heads)	Sheep/ Goats (heads)	Tallow (tonnes)	Waste water (m^3)	Manure (kg)	Other (kg)	kWh	Operation hours
January	6376	38667	104	738		1	15457	216
February	5880	36224	125	612	649	750	11606	164
March	6186	39405	150	905	705	250	13396	182
April	5846	40058	69	672	715		4136	90
May	5907	41541	72	762	430		16580	132
June	5818	37372	39	1578			9182	176
July	5257	48580	155	465			12061	172
August	5965	45143	110	330			11451	89
September	5478	36352	88	264			5637	58
October	5388	31062	110	330			3871	106
November	5988	35382	100	300			8606	174
December	6442	45405	125	375		550	7287	69
Total	70531	475191	1247	7331			107,654	1628

Some additional remarks are:

- The production of biogas has always around 800 m^3/d. This was related to the quality of the materials: the blood in the effluents of the slaughterhouse is not mastered, the water of the slaughterhouse is relatively salty. These two elements inhibited the activity of bacteria, and slowed down the transition from acidogenesis to acetogenesis before methane production;
- The low biogas production has negatively influenced the expected electricity production;
- The load power of the biogas group was regularly close to the maximum power allowed, 90% of its capacity while the maximum load limit was to be around 85%;
- The quality of the slaughterhouse facilities did not often allow a correct injection into the internal network. But despite everything and among the lessons learned, let us remember the efficiency of the electricity production with the waste of the slaughterhouse. It is this certainty that prompted the initiators of the project to set up a new, more ambitious project in every respect.

Other projects are emerging in the sub-region:

- In Burkina Faso where FASOGAZ has set up a similar project with the particularity of being able to feed its energy produced into the network of the national agency thanks to a purchase of energy contract. This 250 kW installed power project will increase to 500 kW with the same business model: buy substrates, upgrade them and sell electricity to SONABEL. In its business, the promoter is considered a private electricity producer, IPP. In 5 months, the biogas plant has delivered more than 240,000 kWh to the national grid;
- On the same business model and the same technology; SAFI SANA in Ghana installed a 50 kW unit that treated fecal sludge. SAFI SANA's intention is to widen its range of substrates to be valorised by treating the domestic waste and the waste of the markets. The plant will increase its power generation capacity to one megawatt.

Other projects of medium size are possible:

- Rural electrification is the case of the project we are running with the Village of Doughe in Tambacounda;
- Production energy through UNDP multifunctional platforms;
- Energy for income-generating activities: the case of bakeries but also farms integrated 'agriculture, breeding, fish farming;
- Power of drawing or exhaling water through boreholes equipped with biogas engine (the area of the 7 boreholes in the sylvo pastoral is the ideal model);
- Energy in the Senegal River valley or delta with agricultural biomass and huge energy needs to irrigate rice paddies; All of these activities would be done with community-managed community digesters.

Ten lessons-learnt:

After a few years of operation, we can already identify the lessons learned in the field of waste recovery:

1. Waste recovery: it works perfectly; it is possible to install industrial anaerobic digestion units everywhere. The technology is mature, the substrates are available;
2. Financial profitability depends on the overall operating result: sale of energy and digestate;
3. The impact on the environment is real: less olfactory nuisance, less visual pollution, less rejection on the natural environment;
4. The effect of digestate on agriculture is a reality: biofertiliser deserves to be better known. There is a potential market and a good communication policy to put in place;
5. The methanisation is the project of a terroir managed by a private sector with a strong implication of the local communities and the international community and this within the framework of a PPP;
6. The energy applications are multiple, BIOGNV, bottling etc.;
7. A new interest of the scientific and academic community;
8. Energy for industries but also for the populations;
9. Development of new training streams;
10. Creating green jobs;

16.4 Conclusions

The scarcity of conventional energy resources, the proliferation of geopolitical conflicts and the increase in demand are all reasons why countries are encouraging the emergence of new sectors. Among these, biogas has many strategic advantages: a variety of recovery routes, continuous production, easy storage and a waste recovery route. The demonstration plant installed by THECOGAS SENEGAL within the Dakar slaughterhouse managed by SOGAS, as well as the factories in Ghana and Burkina, demonstrate part of the sustainable development sector from the waste of a slaughterhouse. This same work could be done from agricultural waste (cow manure, pig slurry, poultry manure, etc.) but also from household waste, market waste and local industries. But for a real model of sustainable development to emerge, it would require a certain number of prerequisites:

- Pilot projects must be set up to convince and communicate by example in all the countries of the subregion;
- A national biogas industrial program must be set up in each country with all actors: local authorities, research, the private sector, banks, technical ministries, donors, etc.;
- There is a need for a regional program to attract donors and international organizations. This program could be supported by UEMOA-like organizations;

- Our states must put in place a program to support the sector, just like the domestic biogas program;
- New training courses must be created in schools and universities to support the development of the main sector;
- It is necessary to set up a regulatory framework (law, decrees of application)
- Above all, it is necessary to have a clear will and vision of our states; In rural areas, industrial biogas in its medium size version can be a real alternative to wood energy consumption. Methane waste is enormous and largely invades the villages. Their valorisation would be a real alternative to the fossil fuels generally used and very little accessible. A true endogenous inclusive development strategy could thus emerge;
- The promotion of sustainable development and environmentally friendly development while allowing nature to renew itself is of great significance here.

17 Mathematical approach for dimensioning of a biogas production unit and applications

Author: Cheikh Sidi Ethmane Kane

17.1 Introduction

Mauritania is a totally desert country in its northern part and Sahelian in its southern part. Its climate is characterized by high temperatures exceeding the threshold of 40 °C (except in the northern coastline "Dakhlet Nouadhibou"), and relatively mild winters. The Mauritanian population rises to 3,537,368 inhabitants according to the results of the general census of the populations and habitat, with an annual growth rate of 2.9% (Office National de la Statistique, 2013). More than half of this population (50.52%) resides in urban environment. In 2000, the energy consumption amounted to 481,000 tep (tonne oil equivalent). Energy intensive sectors are: (i) the residential sector (41.2%), (ii) the industrial and mining sector (30,56%), (iii) the transport sector (24.59%) (iv) the tertiary sector (2.43%) and finally (v) the agricultural sector (1.19%). The energy balance of the country shows a change from 80% traditional forest-based fuels in 2000 (Office National de la Statistique, 2008) to less than 50% in 2013 (Office National de la Statistique, 2014). This has been due to a rapid annual growth of 15% in average of fossil fuel demand in the country in recent years. The use of these forest-based fuels as a source of energy for households contributes not only to deforestation but to the multiple problems that are causing climate change today. To overcome these challenges, it will be necessary to move towards the technologies of the anaerobic digestion which constitute today an alternative solution to fight against the poverty and the climatic hazards. This study consists of a dimensioning of a biogas plant. This sizing is based on a solid mathematical model. A technical study is developed to show the interest for families to produce their own biogas. A household of six members was selected as a sample for this study. The overall objective of this work is to encourage rural populations to develop the energy potential of their agro-pastoral area in compliance with environmental standards and to reduce their energy dependence on firewood consumption. To achieve this overall goal, we will conduct a technical study of biomass recovery to obtain biogas, alternative energy that can replace conventional fuels used in households and then evaluate the cost of the installation.

17.2 Description of the project and results

Description of the concept: state of the art, methods and approaches
Several authors have developed empirical design methods in which the estimation of biogas produced is obtained on the basis of laboratory experiments. The literature is not rich on mathematical models for estimating the amount of biogas produced in digesters. Nevertheless, some kinetic models have been developed to describe the process of anaerobic fermentation and then to estimate the amount of biogas produced. The Monod model which presents a hyperbolic relationship between the exponential growth rate of microorganisms and the concentration of substrates. This model can be used to determine the rate of use of the substrate and the volume of cumulative biogas produced through Equations 4, 5 below (Amarante, 2010):

$$U = U_m \frac{S}{K_g + S} \tag{4}$$

Where:
U: the rate of use of the substrate;
U_m: the maximum use rate of the substrate;
S: substrate volume load;
K_S: the substrate concentration when $U = U_m/2$ (half saturation).

$$V(t) = V_m \times \frac{t}{1 + \frac{t}{K_s}} \tag{5}$$

Where:
t: the time elapsed since the last feeding of the fermenter

Another model known as the kinetic model of the first order makes it possible to determine this same volume of biogas through the following mathematical Equation 6 (Al Seadi et al., 2008):

$$G = G_m \times (1 - e^{K_0 \times t}) \tag{6}$$

Where:
G: the accumulated biogas volume for a time t given in days;
G_m: the cumulative maximum volume for an infinite digestion time;
K_0: an apparent kinetic finding expressed in (day-1).

The limitations of these models lie in the fact that the set of kinetic parameters they use are insufficient to describe the process biologically in terms of hydraulic retention time and also that obtaining these kinetic parameters is impossible for certain complex substrates. . The model developed by Hashimoto has solved these limits and makes it possible to calculate the volume production of biogas through Equation 7 below (Al Seadi et al., 2008,Coudure and Castaing, 1997):

$$PV = \frac{B_o \times S}{TRH} \times [1 - \frac{K}{TRH \times \mu m - 1 + K}] \tag{7}$$

Where:
PV: the specific production;
B_0: the methane production potential for the substrate;
TRH: the hydraulic retention time;
S: the substrate volume load;
K: the inhibition constant, specific for a given substrate and bacterial consortium;
μm: the maximum growth rate of micro-organisms.

17.3 Dimensioning of the biogas plant

A biogas plant usually consists of a digester, purification equipment, equipment for use and connection accessories. As part of this project, the facility is intended to produce raw biogas used for cooking and lighting; it will therefore not include purification equipment. Under these conditions, sizing this domestic installation comes down to the sizing of its main element (the biodigester) and the gas pipe. For the biodigester, the approach will consist in first sizing the gasometer, the useful volume of the digester and finally the total volume of the digester (volume of the tank).

17.3.1 Sizing equations of the digester

After evaluating the daily biogas requirements, we will use the Hashimoto model to determine the daily specific production (equation 5) and then from the useful volume V of the digester, we will finally be able to calculate the daily volume production thanks to the Equation 8 [5], [6]. The production of biogas in m^3 of the digester is thus obtained from equation 7. For a useful volume V of the digester, we then obtain a daily volume production of:

$$G = PV \times V = \frac{B_o \times S \times V}{TRH} \times [\frac{K}{TRH \times \mu m - 1 + K}] \tag{8}$$

17.3.2 Equations for dimensioning the tank

The volume of the tank (V_D) which is nothing other than the volume of the digester is the volume of the assembly formed by the gasometer and the volume of the effluent (useful volume V):

$$V_D = V + G \tag{9}$$

Knowing that:

$$V = Q \times TRH \tag{10}$$

And by introducing Equations 8 and 10 in Equation 9, we succeed in expressing VD as a function of Q by the following equation:

$$V_D = Q \times [TRH + B_o \times S \times (1 - \frac{K}{TRH \times \mu m - 1 + K})] \tag{11}$$

We can finalize Equation 11 taking into account that:

$$V = \frac{m}{\rho \times s} \tag{12}$$

the flow rate (Q) is not only a function of the mass (m) of the substrate to be digested, but also of the ratio of its mixture with water ($1 : x$); the volume occupied by this mass of substrate is:

$$Q = v \times (1 + x) = \frac{m(+x)}{\rho s} \tag{13}$$

and

$$V = TRH \times Q = \frac{TRH \times m \times (1 + x)}{\rho s} \tag{14}$$

the volume load (S) is expressed as a function of the mass (m), the concentration (c) and the working volume (V).

$$S = \frac{m \times c}{C} \tag{15}$$

After replacing Equation 13 in 10, and Equation 10 in 14, we obtain:

$$S = \frac{c \times \rho s}{TRH(1 + x)} \tag{16}$$

Substituting Equations 13 and 15 in Equation 11, gives the final design Equation 17 of the project:

$$V_D = \frac{m(1+x)}{\rho s} \times [TRH + \frac{B_o \times c \times \rho \times S}{TRH(1+x)} \times (1 - \frac{K}{TRH \times \mu m - 1 + K})] \tag{17}$$

17.3.3 Dimensioning equations of the pipes for the entry of the substrate and the exit of the effluent

The height of these pipes is decisive for the volume of biogas to be produced. The fluid (substrate) being at rest, there is no loss of charge. The height (h) of the fluid in the pipes is therefore the same as in the digester (law communicating vessels). By approximating the base of the digester to a cylinder, we determine (h) from the Equation 18:

$$V = \frac{\pi \times d^2 \times h}{4} \tag{18}$$

Where V is the useful volume of the digester and (d) its diameter in meter.

17.3.4 Sizing equations for the gas line

The diameter of the pipes is a very important factor for the proper functioning of the biogas devices. The pressure drop and the distance separating the production site and the location of use being known, this diameter is obtained thanks to the equation used in fluid mechanics:

$$J = \nabla H = \frac{\lambda \times \Lambda \times \rho \times u^2}{D \times g} \tag{19}$$

Where V is the useful volume of the digester and (d) its diameter in meter.

17.4 Case study

Assessment of households' need for biogas

- The evaluation of the biogas energy demand will be done on a household of 6 members and on the basis of the energy data indicated on the devices to use and their daily time of operation (200 l/h per hearth of the burner with biogas and 140 l/h per biogas lamp): this assumes that these devices are known in advance;
- A burner with 2 fireplaces is used and the household takes two hot meals daily. According to their eating habits, the cooking time is usually between 11h and 13h; 19h 30 min and 20h 30 min and lasts on average 1h 30 min. Then breakfast between 6h 30 min and 7h the next day and the lamp is used in the evening between 19h and 22h;

The results obtained show that the biogas plant for this household includes a digester with a volume of 7 m^3, a substrate mass m=44 kg and a daily production of 1.68 m^3. The benefits are many, deforestation will be avoided, the digestate product will be used for agricultural needs as organic fertiliser, it also helps to fight against poverty and climate hazards. The conditions for success are mainly based on the availability of the raw material and the acceptability of the population for the technology.

17.4.1 Discussion of results

In this study, we have proposed a physical model of the digester that seems to fit well for family facilities. The fixed combined tank digester was preferred to the separate tank digester or the combined and floating digester in order to use a single tank instead of two, resulting in lower installation costs. It would be desirable at first to test this physical model on small installations in which the volume of the digesters does not exceed 7 m^3. Beyond that, we will study the possibility of burying these reservoirs, even if only partially in the soil. The assessment of household biogas requirements is very complex. This complexity is due to several quantifiable or not quantifiable parameters. The technique used assumed to know in advance the devices and their operating times. Otherwise, this evaluation can be done on a case by case basis. The dimensioning of the useful volume of the digester could be done without any difficulty since the equation used for this purpose ($V = Q \times TRH$) is universal according to the previous works. As for the dimensioning of the digester, equation 8 resulting from the model chosen was used to evaluate the expected specific volume of biogas. This equation was first applied numerically for verification and its result compared to that of the empirical model. It should also be noted that the evaluation of PV by the empirical method is done on a graph for a temperature (T) between 26 °C and 28 °C . Knowing that PV is a function of (T), this slight difference can be justified by this reasoning.

17.5 Conclusions

A production facility was well dimensioned and built for a household of 6 members for cooking and lighting needs. To this end, some equipment to obtain pure methane is needed before the popularization of technology in the areas where the potential is important.

Bibliography used in this section:
(Office National de la Statistique, 2013,Office National de la Statistique, 2008,Office National de la Statistique, 2014,Amarante, 2010,Al Seadi et al., 2008,Coudure and Castaing, 1997)

18 Allocation of water to different uses and objectives

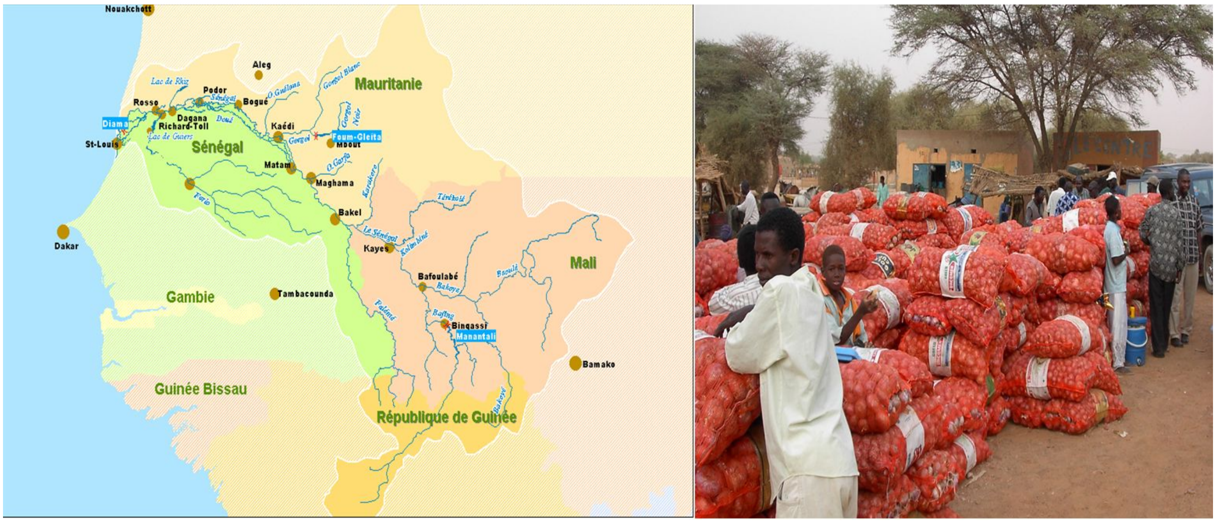
Author: Attaher Mohamed

18.1 Introduction

The Organization for the Development of the Senegal River (OMVS) Created on March 11, 1972, the Organization for the Development of the Senegal River (OMVS) has the following missions:

1. Achieve food self-sufficiency for the populations of the Senegal River Basin;
2. Reduce the vulnerability of the economies of its states to climate hazards;
3. Accelerate the economic development of its member states;
4. Preserve the balance of ecosystems in the Senegal Region and particularly in the BFS;
5. Secure and improve the income of the people of the Basin.

Figure 59: Location of the basin (area: 375,000 ha).



To achieve the objectives mentioned above, the States adopted the Water Charter on May 28, 2002, a legal instrument that assists in the decision-making of water resources management.

The Water Charter:

- Establishes the principles and methods of water allocation between the sectors of use;
- Defines the procedures for examining and approving new projects;
- Determines the rules relating to the preservation and protection of the environment;
- Defines the framework and modalities for the participation of water users in decision-making bodies

The aim is to ensure that the population of riparian states enjoys the full use of the water resource and their fundamental right to good quality water while taking into account the safety concerns of people and uses. It is the Permanent Water Commission (Commission Permanente des Eaux - CPE), an advisory body to the Council of Ministers of the OMVS, which is in charge of the issues of water allocation between the various sectors of use. As such, and in accordance with the provisions of the Convention establishing the OMVS of March 11, 1972, and the provisions of the Convention relating to the status of the Senegal River of March 11, 1972 and the provisions Water Charter of the OMVS of 28 May 2002, it issues opinions and recommendations to the Council of Ministers concerning, inter alia:

- The principles and modalities of the equitable distribution of the waters of the Senegal River between the sectors of water use (energy, irrigation, navigation, drinking water supply, etc.);
- The rules for any project of use of the water or measures likely to modify in a significant way the characteristics of the regime of the Senegal River, its conditions of navigability, of agricultural or industrial exploitation, the sanitary state its waters, the biological characteristics of its fauna and flora, and its water body in particular, projects subject to prior authorization, as referred to in Articles 10 and 25 of the Charter;
- Regulation of fair use of river water;
- Regulation of the quantitative and qualitative conservation of river water.

Manantali Dam:

- Storage of 11.3 billion m^3;
- Energy Production 800 GWh/year;
- Flow regularization of the river at 300m^3/s at Bakel;
- Irrigation capacity of 255,000 ha in combination with the DIAMA dam;
- Artificial dikes (flood-protection crops, environnement, etc.);
- Navigability of the river all year long from Saint-Louis to Ambidédi (Mali).

Figure 60: Manantali Dam.

Diama Dam:

- Availability of fresh water in sufficient quantity and guaranteed all year round;
- Development of agricultural activities;
- Storage capacity: 250–588 m^3.

Figure 61: Diama Dam.

The assessment of any damage caused by a water project is the sole responsibility of the Commission. It is the body most involved in water management. It manages both conflicts, the distribution of water between different uses of water as well as risks and uncertainties related to hydrology and climatology in the watershed of the Senegal River.

The CPE intervenes for all decisions of approval of major projects on the river, of authorization of the collection of the waters of the river, of adoption of the annual programs of management of the common works. The opinion of the Permanent Water Commission is required before the Council of Ministers of the Organization takes a decision.

The CPE prepares annual and / or seasonal plan for the management of the activities and proposes to the Council of Ministers of the OMVS:

- A programme;
- A nomenclature of the authorization and declaration thresholds pursuant to Article 10 of the Charter;

The projects under the authorization regime are sent to the CPE for an assent. The CPE is composed of the representatives of the Member States with three permanent representatives per State. However, each delegation may be assisted, at its convenience, by any competence it deems useful. The representatives of the High Commission, the Diama Management and Exploitation Company (SOGED), the Manantali Energy Management Company (SOGEM), the private operators of OMVS and the Energy Companies States attend the meetings of the EPC. Observer status with the CPE may be granted by the Council of Ministers, on the proposal of the High Commissioner, to certain entities of the Member States. They then participate effectively in the work of the CPE. Observer status may be granted to:

- Users' representatives;
- Representatives of Territorial Communities;
- Representatives of non-governmental organizations;
- Representatives of the decentralized management committees.

The EPC meets in ordinary session at the invitation of the High Commissioner during the following periods: 2^{nd} half of February, 1^{st} half of June, 2^{nd} half of August, 1^{st} half of October, 1^{st} half of December. The assent and recommendations of the CPE are formulated unanimously by the Member States. They are transmitted to the Member States and included in the agenda of the next session of the Council of Ministers. In case of disagreement, the High Commissioner shall refer the matter to the President of the Council of Ministers. More than 85% of the basin's population (about 7 million inhabitants) lives near a tributary stream of the Senegal river. The built infrastructure (dams) help regulate the flow of the river and satisfy several uses (Agriculture, Drinking Water, Industry, etc.) while preserving biodiversity.

Figure 62: Infrastructure and activities in the Senegal River basin.

Following all the activities that are developing and intensifying in the basin, monitoring the quality of the waters of the Senegal River Basin becomes a concern for the preservation of the health of population. In fact, deterioration in the quality of water was noticed from both physical-chemical aspects (alteration of basic parameters relating to organic matter and nutrients, water contamination by micro-pollutants), as bacteriological.

However, in the absence of regular and uniform data, it is difficult to assess the extent of these alterations and the evolution of pollution from upstream to downstream. It should be noted that the main sources of contamination are mainly around mining activities, cities or irrigated areas. There is also the issue of aquatic plants such as Typha. These sources of pollution can also generate disturbances on groundwater.

The Office of the High Commissioner of OMVS commissioned a study in 2012, which defined an optimum network of 59 monitoring stations for water quality. This network is being operational with the assistance of Compagnie Nationale de Rhône (France). The control of the water of the Senegal River Basin through the construction of dams and other structures guarantees the availability of water and the development of water uses for:

- Irrigated agriculture;
- Hydroelectric power generation;
- Access to drinking water and health;
- The preservation of ecosystems;
- Sustainable navigation on the river.

19 From water pollution to energy opportunity

Author: Elhadj Ibrahima

19.1 Introduction

In sub-Saharan Africa, people find it difficult to access good quality water in sufficient quantity to meet their biophysical and socio-economic needs. In these conditions, the banks of the Senegal River and the waters of Lake Guiers are infested with invasive aquatic plants.

This project aims to contribute to the fight against the proliferation of aquatic plants on the Senegal River and its effluents that are common to several villages in the lower delta and to minimize the residual effects of this plant proliferation.

Typha is a real hindrance to both access to water for all purposes, impairs the quality of water for human consumption, is a vector of water-borne diseases, is a refuge for grain-eating birds that constantly threaten grain crops, as well as reptiles that are harmful to humans.

19.1.1 Environmental impact of invasive aquatic plants

There is of paramount importance to contribute to the fight against the proliferation of aquatic plants on the Senegal River and its effluents that are common to several villages in the lower delta and to minimize the residual effects of this plant proliferation.

Figure 63: Senegal river basin.

The extent of the proliferation phenomenon of the aquatic plant Typha, is higher especially upstream of the Diama dam and all along the banks of Lake Guiers. The rate of reproduction of Typha is so high that it annihilates weeding operations carried out periodically on the river, the main axes of circulation of irrigation water, emissaries, adductors, irrigation canals and makes it more difficult the access to the water resources.

The local populations, completely helpless in the face of the invasion of Typha, are trying to find their way to access the resource, in an isolated and disorganized way, in front of a phenomenon of mass production.

19.2 Energetic use of biomass invasive aquatic plants

Integrated management of the invasive aquatic plants include a combination of physical and biological control methods. Physical means include manual and mechanical removal, and the use of physical barriers such as cables and dams of materials. Biological control is the determination of insect or plant species suitable for the eradication of aquatic plants and their release in infested areas.

The use of physical methods for the fight against Typha are preferred for an energy valorisation of harvests resulting from weeding. This include manual cutting by individuals using a complete individual equipment for the manual cutting of typha. They will be complemented by the use of mechanical cutting machines capable of carrying out large-scale weeding operations.

Figure 64: Manual cutting of typha plant.

Only the energy valorisation of Typha seems, at this stage of the knowledge, likely to respond on a large scale to the challenge of the proliferation of this invasive aquatic plant. In addition, this energy valorisation would answer to a double ecological concern by the alternative energies that would be provided to the citizens, and the creation of jobs and sustainable income in the localities concerned, on the other hand. This energetic valorisation of the typha could take two different but complementary aspects, namely the production of charcoal and the production of electrical energy.

Charcoal is the first source of energy consumed in Senegal, far ahead of all other forms of energy. Charcoal is also the first threat for the environment in Senegal. Any alternative measure of charcoal by another form of alternative energy that is moreover renewable and environmentally friendly, such as typha charcoal, would be an exceptional opportunity for the country's sustainable development.

In addition, the production of electrical energy in Senegal is mainly of thermal origin with plants operating with imported petroleum products.

The other value of typha would be its use as a source of energy instead of petroleum products: either through the transformation into biogas or directly as fuel in boilers. It is a common technology in the industry. Rural electrification by these production units would be a decisive step in increasing the rate of electrification and lowering electricity tariffs.

Figure 65: Production of Typha charcoal.

Table 25: Energy use in each process per tonne of fresh bunch.

The results of carbonisation tests:	
Efficiency of carbonisation	20%
Capacity of the facility	80 kg
Number of the necessary facilities	40
Duration of carbonisation (wirH cooling)	4 h
Amount of powder of carbonised per week	637 kg

19.3 Conclusions

The use of invasive aquatic plant Typha for energy production (as charcoal of for electricity generation) has multiple advantages. First of all, this solving a big problem, of natural origin of the access to water of the populations in the Senegal river due to the proliferation of the invading plants of the typha kind. Secondly, this meaning turning this problem into an opportunity for sustainable development with full respect for the environment, through the endogenous and large-scale valorisation of this plant.

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References

ACP-EU Cooperation Programme for Science and Technology, ‘Western Africa Biowastes for Energy and Fertilizer’. 2014-2017. URL https://wabef.cirad.fr.

Adrien Bio Yatokpa et al., ‘Identification et cartographie des potentialités et modalités d’exploitation des sources d’énergies renouvelables sur l’ensemble du territoire national’, Tech. rep., PNUD, Juillet 2010.

Ahmim-Richard, A., ‘Gestion des forêts naturelles et approvisionnement durable en bois-énergie des villes du Sahel. Schéma Directeur d’Approvisionnement en Combustibles Domestiques de Bamako’, *République du Mali Ministère de l’Environnement*, 2017.

Al Seadi, T., Rutz, D., Janssen, R. and Drosg, B., ‘Biomass resources for biogas production’, *Book Chapter in The Biogas Handbook–Science, Production and applications*, 2013, pp. 19–51.

Al Seadi, T., Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T., Volk, S. and Janssen, R., ‘Biogas handbook.–university of southern denmark esbjerg’, Tech. rep., ISBN 978-87-992962-0-0, 2008.

Aldaya, M. M., Chapagain, A. K., Hoekstra, A. Y. and Mekonnen, M. M., ‘The water footprint assessment manual: Setting the global standard’, Routledge, 2012.

Amarante, J. A. L., ‘Biométhanisation des déchets putrescibles municipaux–technologies disponibles et enjeux pour le québec’, *Centre Universitaire de Formation en Environnement (M. Env.), Université de Sherbrooke, Sherbrooke*, 2010.

Amigun, B., Parawira, W., Musango, J., Aboyade, A. and Badmos, A., ‘Anaerobic biogas generation for rural area energy provision in africa’. In ‘Biogas’, InTech, 2012.

Ani, F. N. and Mohamad Nor, N., ‘Energy index for palm oil processing in oil palm mills’, *International Journal of Quality and Innovation*, Vol. 1, No 2, 2010, pp. 112–123.

Antal, M. J., Croiset, E., Dai, X., DeAlmeida, C., Mok, W. S.-L., Norberg, N., Richard, J.-R. and Al Majthoub, M., ‘High-yield biomass charcoal’, *Energy & Fuels*, Vol. 10, No 3, 1996, pp. 652–658.

Atnaw, S. M., Sulaiman, S. A. and Yusup, S., ‘Influence of fuel moisture content and reactor temperature on the calorific value of syngas resulted from gasification of oil palm fronds’, *The Scientific World Journal*, Vol. 2014, 2014.

Austin, G. and Morris, G., ‘Biogas production in africa’. In ‘Bioenergy for sustainable development in Africa’, Springer, 2012. pp. 103–115.

Aziz, M., Oda, T. and Kashiwagi, T., ‘Design and analysis of energy-efficient integrated crude palm oil and palm kernel oil processes’, *Journal of the Japan Institute of Energy*, Vol. 94, No 1, 2015, pp. 143–150.

Bailis, P. R., Ogle, D., Maccarty, N., From, D. S. I., Smith, K. R., Edwards, R., Energy, H. et al., ‘The water boiling test (wbt)’, 2007.

Bensch, G., Grimm, M., Peter, K., Peters, J. and Tasciotti, L., ‘Impact evaluation of improved cooking stoves in burkina faso. iob evaluation no. 388.’, 2013.

Biogrow, 'About Biochar'. 2017. URL http://biogrow.co.nz/biochar/biochar-fertilisers.

Carbonnier, G. and Grinevald, J., 'Energie et développement', Vol. 2. Institut de hautes études internationales et du développement, 2011.

Carme, F., 'Proposition technico-économique de localités à électrifier par systèmes d'énergies renouvelables', Tech. rep., ABERME-GTZ, Mai 2010.

Clokoun, I., 'Estimation et valorisation énergétique des tiges de cotonniers par la gazéification', Tech. rep., Mémoire de Master UAC, Octobre 2017.

Coudure, R. and Castaing, J., 'Bilan de fonctionnement d'une unité de méthanisation de lisier de porc', *Journées de la recherche porcine en France*, Vol. 29, 1997, pp. 335–342.

Danielle, O. and Don, H., 'Social Enterprise Canvas: Organizational design for social ventures'. 2004. URL https://www.blankcanvas.io/canvases/social-enterprise-canvas.

Dauphiné, A. and Provitolo, D., 'La résilience: un concept pour la gestion des risques', In 'Annales de géographie', 2. Armand Colin, pp. 115–125.

de Oliveira, R. S., Palácio, S. M., da Silva, E. A., Mariani, F. Q. and Reinehr, T. O., 'Briquettes production for use as power source for combustion using charcoal thin waste and sanitary sewage sludge', *Environmental Science and Pollution Research*, Vol. 24, No 11, 2017, pp. 10778–10785.

Deepchand, K., 'Sugar cane bagasse energy cogeneration—lessons from mauritius', In 'parliamentarian forum on energy legislation and sustainable development, Cape Town, South Africa', Vol. 10. p. 2005.

Demirbas, A., 'Biofuels sources, biofuel policy, biofuel economy and global biofuel projections', *Energy conversion and management*, Vol. 49, No 8, 2008, pp. 2106–2116.

Deublein, D. and Steinhauser, A., 'Biogas from waste and renewable resources: an introduction', John Wiley & Sons, 2011.

ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), 'Renewable Energy Policy'. 2015. URL http://www.ecreee.org.

ECREEE: Biocharplus, 'ABP: The Africa Biochar Partnership'. 2016. URL http://www.ecreee.org.

Energy Commission Ghana, 'Ghana Energy Outlook'. 2015. URL http://energycom.gov.gh/files/Energy%20Outlook20for%20Ghana%20-%202015.pdf.

Ennaciri, K., Bacaoui, A., Sergent, M. and Yaacoubi, A., 'Application of fractional factorial and doehlert designs for optimizing the preparation of activated carbons from argan shells', *Chemometrics and Intelligent Laboratory Systems*, Vol. 139, 2014, pp. 48–57.

EUROPEAID - BEBI project, 'Agricultural and environmental Benefits from Biochar use in ACP Countries'. 2017. URL https://www.uniud.it/.

Fall, B., 'Recensement général de la population et de l'habitat, de l'agriculture et de l'élevage (rgphae) 2013: rapport provisoire', 2014.

FAO, 'BEFS Assessment for Turkey: Sustainable bioenergy options from crop and livestock residues', Tech. rep., Food and Agriculture Organization of the United Nations, 2016.

FAO, 'The future of food and Agriculture: Trends and Challenges', Tech. rep., Food and Agriculture Organization of the United Nations, 2017.

Fischer, G., Van Velthuizen, H., Shah, M. and Nachtergaele, F. O., 'Global agro-ecological assessment for agriculture in the 21st century: methodology and results', 2002.

Food and Agriculture Organization of the United Nations, 'Food and Agriculture Statistics FAOSTAT'. 2017. URL http://www.fao.org/faostat/en/#home.

French Environment and Energy Management Agency, 'Pyrolyse et gazéification de la biomasse pour la production de l'électricité: Procédés et Acteurs', Tech. rep., ADEME, Month 2001.

French Environment and Energy Management Agency, 'La méthanisation. comment se transforme la matière organique en énergie?', Tech. rep., ADEME, 2009.

Fritsche, U. R. and Iriarte, L., 'Sustainability criteria and indicators for the bio-based economy in europe: State of discussion and way forward', *Energies*, Vol. 7, No 11, 2014, pp. 6825–6836.

Garg, A. and Sharma, M., 'Performance evaluation of gasifier engine system using different feed stocks', *International Journal of Emerging Technology and Advanced Engineering*, Vol. 3, No 6, 2013, pp. 188–199.

Gerbens-Leenes, P., Xu, L., Vries, G. and Hoekstra, A. Y., 'The blue water footprint and land use of biofuels from algae', *Water resources research*, Vol. 50, No 11, 2014, pp. 8549–8563.

Gerbens-Leenes, W. and Hoekstra, A. Y., 'The water footprint of sweeteners and bio-ethanol', *Environment international*, Vol. 40, 2012, pp. 202–211.

Gerbens-Leenes, W., Hoekstra, A. Y. and van der Meer, T. H., 'The water footprint of bioenergy', *Proceedings of the National Academy of Sciences*, Vol. 106, No 25, 2009, pp. 10219–10223.

International Energy Agency, 'World Energy Outlook 2012', *IEA*, 2012. Paris, France.

International Energy Agency, 'World Energy Outlook 2016', *IEA*, 2016. Paris, France.

International Energy Agency, 'World Energy Statistics'. 2017. URL http://www.iea.org/statistics/.

International Energy Agency (IEA), 'Africa Energy Output: A Focus On Energy Prospects In Sub-Saharan Africa'. 2014. URL http://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf.

International Renewable Energy Agency (IRENA), 'Renewable Energy Country Profiles Africa'. 2015. URL http://www.irrena.org.

International Renewable Energy Agency (IRENA), 'Renewable Energy Statistics 2017'. 2017. URL http://www.irrena.org.

Jeffery, S., Verheijen, F. G., van der Velde, M. and Bastos, A. C., 'A quantitative review of the effects of biochar application to soils on crop productivity using metaanalysis', *Agriculture, ecosystems & environment*, Vol. 144, No 1, 2011, pp. 175–187.

Kaliyan, N. and Morey, R. V., 'Factors affecting strength and durability of densified biomass products', *Biomass and bioenergy*, Vol. 33, No 3, 2009, pp. 337–359.

Kanjanarong, J., Giri, B. S., Jaisi, D. P., Oliveira, F. R., Boonsawang, P., Chaiprapat, S., Singh, R., Balakrishna, A. and Khanal, S. K., 'Removal of hydrogen sulfide generated during anaerobic treatment of sulfate-laden wastewater using biochar: evaluation of efficiency and mechanisms', *Bioresource technology*, Vol. 234, 2017, pp. 115–121.

Kathuria, R. and Grover, S., 'Using agricultural residues as a biomass briquetting: an alternative source of energy', 2012.

Lavarack, B., Hodgson, J., Broadfoot, R., Vigh, S., Venning, J. et al., 'Improving the energy efficiency of sugar factories: case study for pioneer mill', In 'PROCEEDINGS-AUSTRALIAN SOCIETY OF SUGAR CANE TECHNOLOGISTS', PK Editorial Services; 1999, pp. 7–11.

Libra, J. A., Ro, K. S., Kammann, C., Funke, A., Berge, N. D., Neubauer, Y., Titirici, M.-M., Fühner, C., Bens, O., Kern, J. et al., 'Hydrothermal carbonization of biomass residuals: a comparative review of the chemistry, processes and applications of wet and dry pyrolysis', *Biofuels*, Vol. 2, No 1, 2011, pp. 71–106.

Luo, C., Lü, F., Shao, L. and He, P., 'Application of eco-compatible biochar in anaerobic digestion to relieve acid stress and promote the selective colonization of functional microbes', *Water research*, Vol. 68, 2015, pp. 710–718.

Mathioudakis, V., Gerbens-Leenes, P., Van der Meer, T. H. and Hoekstra, A. Y., 'The water footprint of second-generation bioenergy: a comparison of biomass feedstocks and conversion techniques', *Journal of cleaner production*, Vol. 148, 2017, pp. 571–582.

Mekonnen, M. and Hoekstra, A., 'Global water scarcity: monthly blue water footprint compared to blue water availability for the world's major river basins', *Value of Water Research Report Series. UNESCO-IHE*, 2011a.

Mekonnen, M. and Hoekstra, A. Y., 'The green, blue and grey water footprint of crops and derived crops products', *Hydrology and earth system sciences discussions*, Vol. 8, No 47, 2011b, pp. 763–809.

Moses, S., 'Inclusive Business Hub. Eco-Fuel Africa: Sustainable charcoal in Uganda'. 2017. URL `http://www.inclusivebusinesshub.org/project/project-profile-eco-fuel-africa-sustainable-charcoal-in-uganda/`.

Naik, S., Goud, V., Rout, P. K. and Dalai, A. K., 'Production of first and second generation biofuels: a comprehensive review', *Renewable and sustainable energy reviews*, Vol. 14, No 2, 2010, pp. 578–597.

Nasution, M. A., Herawan, T. and Rivani, M., 'Analysis of palm biomass as electricity from palm oil mills in north sumatera', *Energy Procedia*, Vol. 47, 2014, pp. 166–172.

Ngumah, C. C., Ogbulie, J. N., Orji, J. C. and Amadi, E. S., 'Biogas potential of organic waste in nigeria', *Journal of Urban and Environmental Engineering*, Vol. 7, No 1, 2013, pp. 110–116.

Nurhayati, A. Y., Hariadi, Y. C. and Hasanah, W., 'Endeavoring to food sustainability by promoting corn cob and rice husk briquetting to fuel energy for small scale industries and household communities', *Agriculture and Agricultural Science Procedia*, Vol. 9, 2016, pp. 386–395.

Office National de la Statistique, 'Enquête permanente sur les conditions des vies de ménage en mauritanie', Tech. rep., 2008.

Office National de la Statistique, 'Ressencement général de la population et de l'habitat en mauritanie', Tech. rep., 2013.

Office National de la Statistique, 'Enquête permanente sur les conditions des vies de ménage en mauritanie', Tech. rep., 2014.

Ogden, J. M., Hochgreb, S. and Hylton, M., 'Steam economy and cogeneration in cane sugar factories', *International sugar journal*, Vol. 92, No 1099, 1990, pp. 131–143.

Ohimain, E. I. and Izah, S. C., 'Energy self-sufficiency of semimechanized oil palm processing: a case study of bayelsa palm mill, elebele, nigeria', *Energy Economics Letter*, Vol. 2, No 3, 2015, pp. 35–45.

Ott, M., 'PROCAS: a reliable partner for the development of Casamance', Tech. rep., Capitalization Document of the second phase (2007 - 2010), 2011.

Paing, H. H., 'Group researches and tests clean cooking products for the developing world', *Phys.org*, 2015. URL `https://phys.org/news/2015-05-group-cooking-products-world.html`.

Pasquiou, V., Randimbivololona, P., Dunod, A. and Lepage, A., 'Etude sur la valorisation des déchets agro-industriels pour la production de chaleur et d'électricité en afrique subsaharienne', *Africa-EU Energy Partnership*, 2012, pp. 1–39.

Pekel, J.-F., Cottam, A., Gorelick, N. and Belward, A. S., 'High-resolution mapping of global surface water and its long-term changes', *Nature*, Vol. 540, No 7633, 2016, p. 418.

Pippo, W. A. and Luengo, C. A., 'Sugarcane energy use: accounting of feedstock energy considering current agro-industrial trends and their feasibility', *International Journal of Energy and Environmental Engineering*, Vol. 4, No 1, 2013, p. 10.

Provitolo, D., 'Vulnérabilité et résilience: géométrie variable des deux concepts', *séminaire résilience de l'ENS*, 2009.

Rachel, N. Y., Abdelaziz, B., Daouda, K., Julius, N. N., Gaelle, D. D. E., Abdelrani, Y., Mehdi, L. and Joseph, K. M., 'Optimization study of the removal of atrazine from aqueous solution on to composite activated carbon-silver using response surface methodology', *Materials Sciences and Applications*, Vol. 8, No 03, 2017, p. 258.

Rahman, A. N., Bacaoui, A., Nongwe, I. B., Mbadcam, K. J. and Yaacoubi, A., 'Composite activated carbon from plastic waste and lignocellulosic waste materials', *International Research Journal of Natural and Applied Sciences*, Vol. 2, No 11, 2015.

Rahman, A. N., Wahabou, A., Mountapmbeme Kouotou, P. and Bacaoui, A., 'Removal of micropollutants from aqueous solution using activated carbons from pet waste', *Canadian Journal of Pure and Applied Sciences*, Vol. 2, No 1, 2017, pp. 4131–4140.

Ramamurthi, P., Fernandes, M., Nielsen, P. and Nunes, C., 'Electricity Production from Rice Husk Gasification for Rural Electrification in Ghana: An Economic and Energetic Perspective', *23rd European Biomass Conference and Exhibition*, 2015, pp. 1656–1663.

Reinaud, G., 'Une technologie agricole innovante grâce au biochar qui augmente les rendements agricoles de manière écologique', *Pro-Natura International*, 2017. URL https://www.pronatura.org/?page_id=521.

Riu Lohri, C., Robbiani, Z. and Zurbrügg, C., 'Hydrothermal Carbonization (HTC): A Pressure Cooker for Biowaste', *Sandec News*, 2013.

Rudolf, M., 'Economic Analysis of Forced Displacement in Casamance, Senegal', Tech. rep., at the request of the World Bank, 2013. Compilation of Notes.

Rutz, D. and Janssen, R., 'Opportunities and risks of bioenergy in africa'. In 'Bioenergy for Sustainable Development in Africa', Springer, 2012. pp. 391–399.

Rutz, D. and Janssen, R., 'Summary: The contribution of bioenergy to energy access and energy security'. In 'Socio-Economic Impacts of Bioenergy Production', Springer, 2014. pp. 285–290.

Rutz, D., Janssen, R., Mergner, R., Demessie, B. A., Manyanga, L. and Crafford, J., 'Biogas from organic waste in african cities'. In 'Socio-Economic Impacts of Bioenergy Production', Springer, 2014. pp. 253–266.

Rutz, D., Mergner, R. and Janssen, R., 'Sustainable heat use of biogas plants', *A Handbook, 2nd Edition, Biogas Heat, WIP Renewable Energies, Munich, Germany*, 2015.

Sengratry, K., 'Promotion of the Efficient Use of Renewable Energies in Developing Countries Chapter VI; Gasification, Promotion of the Efficient Use of Renewable Energies in Developing Countries', Tech. rep., 2006.

Sethupathi, S., Zhang, M., Rajapaksha, A. U., Lee, S. R., Mohamad Nor, N., Mohamed, A. R., Al-Wabel, M., Lee, S. S. and Ok, Y. S., 'Biochars as potential adsorbers of ch4, co2 and h2s', *Sustainability*, Vol. 9, No 1, 2017, p. 121.

Shiklomanov, I., 'World water resources and water use: Present assessment and outlook for 2025', *World Water Scenarios Analyses*, 2000, p. 396.

Speidel, D. H., Ruedisili, L. C. and Agnew, A. F., 'Perspectives on water: uses and abuses', 1988.

Sustainable Energy for All, 'Evaluation rapide et analyse d ' ècart', 2014, pp. 1–41.

Tuyen, B. and Loof, R., 'Ferrocement gasifier: aspects of design and operation', *Journal of Ferrocement*, Vol. 22, No 4, 1992, pp. 353–358.

Uslu, A., Faaij, A. P. and Bergman, P. C., 'Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation', *Energy*, Vol. 33, No 8, 2008, pp. 1206–1223.

Vassilev, S. V., Baxter, D. and Vassileva, C. G., 'An overview of the behaviour of biomass during combustion: Part i. phase-mineral transformations of organic and inorganic matter', *Fuel*, Vol. 112, 2013, pp. 391–449.

Water UN, 'The united nations world water development report 2014: water and energy', *United Nations*, 2014.

WBE, 'Global bioenergy statistics', Tech. rep., World Bioenergy Association, 2017.

Yombouno, A., 'Oil palm production in West and Central Africa'. 2014. URL https://www.grain.org/article/entries/5034-oil-palm-production-in-west-and-central-africa.

List of abbreviations and definitions

AfDB: African Development Bank

CAPEX: Capital Expenditure

EC: European Commission

ECOWAS: Economic Community of West African States

EE: Energy Efficiency

EU: European Union

FAO: Food and Agriculture Organization of the United Nations

FIP: Feed-in-premium

FIT: Feed-in-tariff

FC: Fuel Cost

GHG: Greenhouse gas

GW: Gigawatt

GWh: Gigawatt-hour

INDC: Intended Nationally Determined Contributions

IPCC: Intergovernmental Panel on Climate Change

JRC: EC Joint Research Centre

kW: Kilowatt

LCOE: Levelised Cost of Energy

MW: Megawatt

NDC: Nationally Determined Contributions

O&M: Operation and Maintenance

OMVS: Organization for the Development of the Senegal River

OPEX: Operating Expenditure

PVWPS: Photovoltaic Water Pumping System

R&D: Research and Development

RES: Renewable Energy Sources

RET: Renewable Energy Technologies

SDGs: UN Sustainable Development Goals

SSA: Sub-Saharan Africa

TWh: Terawatt-hour

UN: United Nations

WEF: Water–Energy–Food nexus

WEFE: Water–Energy–Food–Ecosystems nexus

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JRC Mission

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