Chapter 15
Biogas from Organic Waste in African Cities

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Abstract In comparison to bioenergy systems that are based on dedicated energy crops or parts of it, the use of waste materials and residues has received considerably less attention to date, especially with a view to sustainability concerns. This, however, may change in the future, as the competition for organic materials increases. Nevertheless, today one of the main challenges for the twenty-first century is the sustainable management and reuse of waste. This applies to developing, emerging, and developed countries. The focus of using waste for bioenergy production is usually on sustainable waste management, whereas the energy production is seen as a positive side effect. This chapter provides an overview on the different waste treatment options for bioenergy production in Africa and more specifically in three cities in Africa: Addis Ababa (Ethiopia), Arusha (Tanzania), and Johannesburg (South Africa). It shows the urgent need to invest in technologies in urban areas of Africa in order to improve especially health issues. The production of bioenergy is the most promising option to stimulate this investment, as it creates new business and job opportunities.

Keywords Biogas · Anaerobic digestion · Africa · Cities · Composting

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15.1 Introduction

One of the main large challenges for the twenty-first century is the sustainable management and reuse of waste. This applies to developing, emerging, and developed countries. Due to its important developments and legal framework conditions, some general aspects of waste management in Europe are described in the following sections, before the focus of this chapter is placed on Africa.

Although considerable achievements were made in several European countries, a major environmental challenge in Europe still remains in the field of sustainable waste management. Several policies and legislations were introduced in Europe in order to set the rules for sustainable waste management, such as the Landfill Directive 1999/31/EC (EC 1999) and the Waste Framework Directive 2008/98/EC (EC 2008).

The objective of the Landfill Directive is to prevent or reduce as far as possible negative effects on the environment from the landfilling of waste, by introducing stringent technical requirements for waste and landfills. The Directive is intended to prevent or reduce the adverse effects of the landfill of waste on the environment, in particular on surface water, groundwater, soil, air, and human health. It defines "biodegradable waste" as "any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard." It obliges Member States to reduce the amount of biodegradable landfilled waste to 35 % of 1995 levels by 2016.

The Waste Framework Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use. A core content of the directive is the application of the following waste hierarchy as a priority order in waste prevention and management legislation and policy:

- Prevention
- Preparing for reuse
- Recycling
- Other recovery, e.g., energy recovery
- Disposal

The directive defines "biowaste" as "biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants." Article 22 on biowaste of the directive asks Member States to take measures to encourage:

- The separate collection of biowaste with a view to the composting and digestion of biowaste
- The treatment of biowaste in a way that fulfills a high level of environmental protection
- The use of environmentally safe materials produced from biowaste

The directive highlights the importance in accordance with the waste hierarchy, and for the purpose of reduction of greenhouse gas emissions originating from waste disposal on landfills, to facilitate the separate collection and proper treatment of biowaste in order to produce environmentally safe compost and other biowaste based materials.

The problem of many European countries is that still much waste is landfilled and not recycled, nor used for energy production. More details about the European legislation and an approach on how to overcome the waste problem with biogas/biomethane production in five European cities is described by Rutz et al. (2013).

In contrast to the waste management and policies in many European countries, which calls for urgent improvements, the waste management in many African countries is less well managed. Suitable policies are only partially in place or not enforced. Often, informal practices characterize the sector and the waste is dumped on uncontrolled, open dumping sites. Even proper landfilling, that shall be phased out in Europe in the coming years, is rarely applied in African countries. According to the UNIDO review report on waste management, poor waste management practices, in particular the widespread dumping of wastes in water bodies and uncontrolled dump sites, aggravates the problems of generally low sanitation levels across the African continent (Mwesigye et al. 2009).

This poses a large potential for using waste for different purposes. The methane generation potential, derived from MSW (Municipal Solid Waste) produced by African urban areas (403 million inhabitants in 2010), has been calculated by Motola et al. (2013 draft version) and is estimated as 22.560 M m^3/year in volume and 807.641 TJ/year in energy. If all the potential calculated in this study is exploited and converted to power and assuming an efficiency of 40 % of the conversion *process*, the theoretical electricity potential is 92 TW_{el}/year, which is about 14 % of Africa's power production in 2010.

Despite being currently insufficiently exploited in Africa, urban organic waste (MSW and Agro-Industrial waste) is a potential feedstock for many value-added products for local economies. Organic wastes can be used for anaerobic digestion and related biotechnological processes, such as composting and vermiculture. Thereby, biodegradable wastes are converted into useful bioproducts, including biofuels, fertilizer (e.g., for urban farming), and animal feed. The core challenge of African countries in the waste sector is the management and valorization of biowaste in urban areas. This is an increasing concern in rapidly expanding urban areas in Africa due to rural exodus and migration to cities. While addressing this problem, a contribution to the fulfillment of the following Millennium Development Goals (MDG) can be made:

- MDG 1) Eradicating extreme poverty and hunger
- MDG 6) Combating HIV/AIDS, malaria, and other diseases
- MDG 7) Ensuring environmental sustainability

By improving the management of biowastes in developing countries, their potential adverse impacts on human and animal health can be reduced, the environment protected, and the economy stimulated. In order to demonstrate the impacts, examples of three rapidly expanding African cities are described in Sect. 15.3: Addis Ababa (Ethiopia), Arusha (Tanzania), and Johannesburg (South Africa). The differences of the three cities in climate, social framework, waste management, and different poverty/income levels allow for a comparative analysis.

15.2 Technical Solutions for Waste Management in African Cities

The simultaneous energetic use of organic urban waste, such as municipal solid waste (MSW) and catering/food waste (FW), and the creation of a closed nutrient cycle are only possible in anaerobic digestion (AD) biogas plants. The setup of AD waste treatment plants is developing very rapidly in many countries, such as in Europe (e.g., Germany). These plants are usually technically very sophisticated due to strict legal framework conditions and high profitability expectations. Therefore, these AD plants are usually larger plants of in average about 450 kW_{el}.

In Africa, AD is far less developed, especially for waste treatment (Rutz and Janssen 2012). The framework conditions are very different, technologies are available only to a limited extent, there exists a lack of capacity and financing resources, and project developers are confronted with many other technical and nontechnical barriers. However, AD for treating urban organic waste has many advantages and could be readily implemented in African cities, if the process is adapted to local framework conditions and nontechnical issues are considered.

AD facilities may be much smaller in African cities and need to involve a rather simple technology. Maintenance needs to be easy and special equipment that is not available on African markets has to be avoided. AD facilities must also be affordable by individuals, city communities, NGOs, or by the African waste management sector. Some issues are even easier to address in African cities, such as lower legal requirements. Furthermore, higher temperatures in African favor the AD process without additional heating system (in Europe climate is too cold for AD without heating systems).

Table 15.1 demonstrates in a simplified way the different use and treatment methods of organic urban waste in Africa. It includes some details on the current status of the application/technology as well as the advantages and disadvantages.

The table, highlighting the negative health and environmental impacts of the current waste system in most African cities, clearly stresses the advantages of AD, composting, and vermiculture. The following sections provide short definitions on these advanced processes:

- **Anaerobic digestion** (AD) is a series of processes in which several microorganisms break down biodegradable (organic) material in the absence of oxygen. The resulting output is biogas (mixture of different gases: 50–75 % CH_4, 25–50 % CO_2, 0–10 % N_2, 0–3 % H_2S, 0–2 % O_2) which can be used for heating, cooling, light, electricity, and transport. The other important output is digestate which can be used as fertilizer, e.g., for urban farming.

Table 15.1 Comparison of different waste applications and technologies in Africa and their (dis-)advantages

Waste application/ technology	Current status in Africa	Advantages	Disadvantages
Uncontrolled dumping/ combustion	Applied in many African cities by individuals	Simple, cheap	Serious negative health impacts through pathogens, air pollution, and water pollution; no valorization possible
Open landfill/dumping	The overwhelming majority of landfills in Africa are open dumps/landfills without leachate or gas recovery systems. Several are located in ecological or hydrological sensitive areas	Simple, cheap	Serious negative health impacts through pathogens and water pollution; landfills are often sited based on considerations of access to collection vehicles rather than hydrological or public health considerations. Waste collecting system is needed
Covered landfill (with landfill gas recovery)	In the last years some countries, including e.g., Egypt and South Africa, have considered policy changes to promote upgraded landfills for their major cities	Environmental impacts can be considerably reduced; valorization only possible if landfill gas is recovered	Sophisticated waste management is needed; it is related to higher costs
Controlled incineration in power plants	Only very few plants are in operation in Africa	Energy recovery possible	Very high investments needed. No nutrient recovery possible
Composting and vermiculture	Composting is made for agricultural wastes in rural areas. Industrial composting activities are very little. Vermiculture is also only applied in some very few examples	Rather simple process. Only low investment costs are needed. Can be also applied at small-scale and decentralized. Creation of microenterprises possible. Closed nutrient cycle	Only applicable to the organic fraction. Source separated collection system is needed. No energy recovery possible
Anaerobic digestion	AD is so far mainly applied on household level in rural areas or related to dedicated waste streams of the agro-industry	Only low investment costs are needed. Can also be applied at small-scale and decentralized. Creation of microenterprises possible. Closed nutrient cycle. Energy production possible for cooking, light, electricity, or transport. Contributes to improve environmental and health issues	Only applicable to the organic fraction. Source separated collection system is needed. Not implemented yet at large-scale due to the lack of processes adapted to local African framework conditions

- **Composting** is the decomposition of biodegradable (organic) material by aerobic bacteria. They decompose the inputs by using oxygen into heat, carbon dioxide, and ammonium. The ammonium is further converted by bacteria into plant-nourishing nitrites and nitrates through the process of nitrification. Also fungi and macro organisms like worms contribute to the decomposition of the material.
- **Vermiculture** is a special form of composting by utilizing various species of worms, usually red wigglers, white worms, and earthworms to create high quality bedding materials, and vermicast. Vermicast, also known as worm castings, worm humus or worm manure, is the end-product of the breakdown of organic matter by a species of earthworm. Containing water-soluble nutrients, vermicompost is an excellent, nutrient-rich organic fertilizer and soil conditioner.

The application of these technologies have impacts on socio-economic aspects on a local level, including on working conditions, local revenues, job creation (especially low skilled jobs), human and environmental health issues, and on micro-scale waste collectors (i.e., scavengers).

15.3 The Situation in African Cities

The treatment of urban organic wastes constitutes one of the largest environmental and social problems of expanding African cities in the twenty-first century. African cities are characterized by rapid expansions due to rural exodus and migration to urban areas. In many cases, this creates serious threats and pressure to the urban infrastructure, which has difficulties to keep pace with the growth. One of the major infrastructural challenges is sustainable waste management.

The infrastructure and land-use planning in African cities (including for waste management) is not coping with the growth of urban areas (around 3.5 % annually, highest in the world) and this is particularly problematic in the slum areas which constitute a large part of many cities and towns in Africa (Mwesigye et al. 2009).

Large fractions of urban wastes are characterized by very high amounts of organic material, including household waste, agricultural waste (due to urban farming), industrial waste, and wastewaters. Organic urban wastes have considerable potential as a source of renewable bioenergy, but currently only constitute serious environmental pollution problems affecting human health in many African cities. These organic wastes are generally suitable as feedstock for biotechnological processes and specifically for AD which could contribute as technology to:

- Manage organic waste streams in cities
- Avoid urban pollution and reduce pathogens constituting a major health risk
- Recycle highly valuable nutrients which are often lacking in African agriculture
- Generate renewable energy
- Increase new business and job creation opportunities

However, the AD process is complex and requires dedicated technology and knowledge to keep it stable and efficient. A large advantage is that biogas can be produced at different scales, from small/simple scale to large/sophisticated scale, depending on the main objectives (e.g., energy production, waste treatment), feedstock material, and available financial resources. The use of urban waste for AD, especially urban household waste, is a large challenge for African cities, due to for instance, weak waste treatment infrastructure, inhomogeneity of feedstock, and impurities in the waste.

So far, most African biogas projects and programs have focused on dedicated wastes from agriculture or on biogas production at household level in rural areas (e.g., Biogas for Better Life Africa[1], Africa Biogas Partnership Programme-ABPP[2], Tanzania Domestic Biogas Programme[3]). Progress is needed in order to develop AD and related biotechnological processes for converting biodegradable wastes in urban areas of Africa into useful bioproducts, including biofuels, and animal feed through the improvement of urban farming by high-quality digestate as fertilizer.

Thus, in most African countries there is urgent need to improve waste management and sustainable energy supply in urban areas. In the following section, the situations of three African cities are described: Addis Ababa (Ethiopia), Arusha (Tanzania), and Johannesburg (South Africa).

The differences of the three cities in climate, social framework, waste management, and different poverty/income levels allow for an interesting comparative analysis. For instance, in Johannesburg waste management systems are more sophisticated and AD technology and financing sources more abundant than in Addis Ababa or Arusha. This has some impact on technology selection. Currently, the use of biogas in Addis Ababa and Arusha is more feasible for smaller systems such as for cooking and small applications whereas in Johannesburg it may be as sophisticated as upgrading to biomethane quality for transport use.

15.3.1 Addis Ababa, Ethiopia

Addis Ababa was established in 1887. It is a rapidly growing city with a total land area of about 546 km^2 and a population of over 2.9 million. Poor solid waste management is an issue of major concern of the city. According to the Addis Ababa Sanitation, Beautification and Park Development Sectoral Plan (SBPDA 2004), about 65 % of the solid waste generated by the city is collected and disposed at the dumping site. Hence, this dumping site, with an area of 36 ha, has been filled so far with about 10 million t of waste in the past 46 years. The volume of solid waste generated in the city is increasing drastically as a result of the rapid population growth. The city has no dedicated plan for solid waste management, and it lacks necessary

[1] http://www.biogasafrica.org

[2] http://www.snvworld.org/en/ourwork/Pages/Africa_Biogas_Partnership_Programme.aspx

[3] www.biogas-tanzania.org

Fig. 15.1 Waste collectors in Addis Ababa. (Source: D. Rutz, WIP)

infrastructure. The primary and secondary collection schemes for solid waste are not well organized and are characterized by poor efficiency (Fig 15.1).

According to Addis Ababa Health Bureau (1997), the major sources of solid waste were residential (76 %), commercial (15 %), street sweepings (6 %) and the remaining 3 % from other sources. Food left over, kitchen waste, and spoiled vegetables constitute the major residential and commercial waste. The official solid waste generation rate data generated from Gordon dating back to 1995, being about 15 years old (SBPDA 2004). According to this reference, it was about 252 g/capita/day. Recently, the IGNIS project investigated the waste generation rate for different sources and has obtained very close figures to the data from Gordon (IGNIS 2010). Hence, the daily generation rate is estimated to be about 730 t. The biodegradable component is estimated to be higher than 70 %. It is characterized by very high moisture content (Tsegaye 2007).

Hence, the organic fraction of the city waste has a very high potential for anaerobic digestion and for composting. However, there are limited experiences for biotechnical treatment in the city. Some individuals, NGOs, and the city's Environmental Protection Authority have been constructing biogas plants and composting facilities. The biogas production is thus currently very limited and only includes the treatment of human and animal wastes. The practices are lacking efficiency, experience, and knowledge about biogas production and utilization. In the IGNIS project, small-scale research was carried out to investigate biogas potential of food left-over and other organic waste mixtures in a 15 m^3 digester. However, experience is not yet mature to optimize the biogas plant.

Key challenges in Addis Ababa

- The increasing volume of waste, which is attributed to the large growth of the city population, is a major concern since current waste disposal sites are not capable to accommodate these wastes properly. The existing open disposal site is an open dumping field overflowing to the nearby highway. Due to land scarcity in the city, a sanitary landfill will be set up in the neighboring administrative regional state which is about 30 km away from the city. However, also this landfill also will not be large enough to dump all waste.

- There is neither appropriate treatment nor disposal methods regarding the solid wastes being dumped on the dumping sites, particularly considering the adverse GHG impact of dumped waste.
- Waste collection does not include waste separation. The characteristics and composition of the (organic) waste is not very well investigated. There is only knowledge and awareness to sustainably manage the waste (skilled personnel, technology, and others).
- A large portion (70 %) of the waste in Addis Ababa is biodegradable and would be suitable for AD, but is currently disposed uncontrolled.
- Some experience on AD exists. However, biogas production is largely limited to the treatment of animal and toilet wastes. Slight changes of the feedstock characteristics usually result in rapid changes in gas production and disturbances in AD. There is currently lack of research on the use of MSW in AD processes in Addis Ababa.

15.3.2 Arusha, Tanzania

Arusha is a city in northern Tanzania. It is the capital of the Arusha Region, which claims a population of 1,288,088, including 281,608 for the Arusha District (2002 census). Refuse generated is estimated at an average of 410 t/day and an average daily rate of 0.8 kg/capita. The amount of *solid* waste currently generated from household source only in Arusha city is 254 t/day or 0.48 kg/capita/day, which is within the range of 0.4–0.64 kg/capita/day for developing countries as reported by the World Bank. The refuse generation in Arusha City comes from different sources as follows: commercials/trade activities 39 %, markets 18 %, households (domestic) 18 %, industries 2 %, street vendors/pedestrians 2 %, institutions 0.5 %, and construction waste materials 3.5 %. Only 160–220 t, which counts for approximately 40 %, are collected and disposed. The remaining 60 % is not collected due to limited financial resources required for purchasing enough refuse collection trucks and other equipment resulting in serious environmental pollution especially at garbage collection centers (Fig. 15.2).

Solid wastes from households consist of degradable food wastes, leaves, and dead animals as well as nondegradable wastes such as plastics, bottles, nylon, medical/hospital wastes, industries and commercial waste. The most visible wastes produced by urban dwellers in Arusha are organic domestic waste, plastics, and general packaging materials. About 70 % of the household waste is organic. A large quantity of organic waste is littering the town and surrounding water streams, or is put on cumulative refuse piles in collection points and along road ditches. Much of the non-collected waste consists predominantly of plastics and comes directly from commercial centers and households.

Arusha has favorable climatic and weather conditions which favor urban farming, especially dairy livestock keeping that produces large amounts of cow dung which could be potentially used as energy source. Solid waste collection and disposal in

Fig. 15.2 Waste collection at the central market in Arusha. (Source: D. Rutz, WIP)

Arusha is involving franchises (private firms) and community based organizations (CBOs). Collection includes street sweeping, refuse bins, plastic bags, communal and other household containers.

Key challenges in Arusha

- A key challenge regarding waste management for the city of Arusha is mainly the volume of waste being generated, which increases at a faster rate than the ability of the agencies to improve waste collecting infrastructures. There is a lack of financial and technical resources to manage this growth. Therefore, waste management in the city of Arusha is characterized by lack of source sorting, inefficient collection methods, insufficient coverage of the collection system, insufficient storage, and improper disposal of waste. There is no proper landfill operation. This is evidenced by the accumulating wastes and illegal dumps that can be observed in the streets. Thus, these wastes create major public health problems as well as cause water pollution and greenhouse gas emissions.
- Arusha city has very few trucks to remove waste from communal bins and other public generation and collection points to Muriet dump site. Only about 40% of waste is collected. The rest, mostly cow dung, is either being burnt in-situ, left along the road, or disposed in rivers. Open dumping is common practice in Arusha City. Communal waste collection bins are not enough and where available, people are not trained to use them. Scavengers put fire on communal waste bins to extract metals from waste.
- Most cow dung of urban farming is dumped, wasting valuable nutrients. It is common practice in Arusha that residents practice urban farming through keeping dairy cattle in their household, which produces large amounts of cow dung. This is not managed by solid waste management systems, presenting a huge potential for AD.
- The composition of the waste is characterized by high levels of impurities, large moisture content, large amount of organic waste (70%) in the urban waste fraction, as well as large quantities of dust and dirt (street sweepings, etc.).

Fig. 15.3 Biogas cooking stove supplying a canteen close to Arusha (Diligent biogas plant). (Source: D. Rutz, WIP)

- Traditional AD processes which exist in developing countries have several drawbacks. Depending on the technology, the drawbacks include extremely low treatment efficiency, problems of odor, health issues, and long retention time, as well as other operational and technical problems. Furthermore, the biogas technologies of existing plants concentrate mainly on energy production and less consideration is given to waste reduction. In the greater Arusha area, only very few AD plants exist. A major application of biogas is the use as cooking fuel (Fig. 15.3).

15.3.3 Johannesburg, South Africa

The Gauteng Province (including the cities Johannesburg, Pretoria, and Ekurhuleni) in South Africa is the largest mega-city in Africa as measured in terms of economic activity, and generates most waste per person in South Africa (2.44 m^3/year/person). This waste is disposed to 25 landfill sites across the province. In addition, a large number of closed landfill sites exist. Separation of municipal waste is limited. A number of landfill gas capturing projects at some of the landfill sites have started since 2005. These projects, for the most part, flare landfill gas with the intention of earning income through Clean Development Mechanism (CDM) credits. No biogas generation through anaerobic digestion is currently conducted at any of the landfill sites in Gauteng.

The City of Johannesburg, one of the largest metropolitan municipalities within the province, generates municipal waste which requires the equivalent of 1.7 M m^3/year. This waste is primarily disposed at five landfill sites, including Robinson Deep, Limbro Park (full and closed in 2010), Goudkoppies, Marie Louise, and Ennerdale. The City of Johannesburg is the leading Metropolitan Municipality in the province with respect to waste separation and landfill gas beneficiation. At one closed landfill site in the province, the Sebenza site at the Ekurhuleni Metropolitan Municipality,

Fig. 15.4 Filling station of NOVO for upgrades landfill gas plant at the Sebenza landfill site. (Source: Hugo A., NOVO)

landfill gas is captured, cleaned, and compressed and used to refill vehicles belonging to the Ekurhuleni Metropolitan Municipality and minibus taxis (Fig. 15.4). This project has been developed as a pilot project by the private company Novo Energy (Pty) Ltd, in cooperation with the Ekurhuleni Metropolitan Municipality.

Key challenges in Johannesburg

- Waste collection in Johannesburg is relatively advanced in comparison to Addis Ababa and Arusha. However, source separation is still insufficient. This is required to ensure that sufficient quantities of the suitable feedstock are available.
- Appropriate biogas generation equipment needs to be identified, which can produce biogas with a defined quality for various applications, such as upgrading and use in the transport sector.
- The AD technology needs to be demonstrated in order to generate credibility in South Africa and to phase out landfilling in the long term.
- The economic and financial feasibility of the biogas generation technology, and it applications, needs to be assessed under South African policy, legal, and economic conditions.

15.4 Socio-Economic Impacts

In general, proper waste management has many positive impacts on the environment and on humans. In addition, biogas production from waste generates energy and high quality fertilizer. Due to the positive impacts of the “feedstock” production step, biogas from waste is very different to the use of dedicated energy crops, which are presented elsewhere in this book. Although there are many positive impacts during the feedstock production step of energy crops, there are several negative impacts and challenges to be overcome. In contrast to this, the use of waste for bioenergy production can be regarded per se as positive. The positive impacts of using waste for bioenergy are also recognized, e.g., by European policies (EC 2012).

Despite the positive impacts, changes of systems such as from poorly managed waste systems to well-managed systems, may also have spontaneous negative impacts for some individuals. Waste pickers, also called scavengers, are person who collect reusable or recyclable materials thrown away by others to sell or for personal consumption. Waste picking is a phenomenon of mainly developing countries due to urbanization. It is usually an informal sector. People living from the informal waste sector may lose their basis for income, shelter, and food. However, these impacts are minor in comparison to the overall positive impacts of well managed waste systems, and solutions to avoid these negative impacts can be easily identified, such as the set-up of social programs, in which employment is generated for the people of the informal sector.

15.5 Conclusion

Although biogas production from waste has multiple positive impacts, the realization of good waste management practices in Africa is rarely in place. This is due to the fact that the gap between waste management policy and legislation and actual waste management practices is widening, due to ongoing capacity constraints or nonexistence of waste management facilities for the different waste streams (Mwesigye et al. 2009). Furthermore, there are gaps in know-how and capacity and finally of investment.

The existing waste management structures in Europe often pose a barrier to the introduction of new technologies as stakeholders in the waste sector tend to use the “old” technologies as long as possible. In contrast, the low level of waste management structures in Africa presents a large opportunity to streamline investments in the direction of creating sustainable waste management practices, such as anaerobic digestion. However, there is an urgent need to enable large amounts of investment in waste management in Africa.

The examples and comparisons of the three cities in Ethiopia, Tanzania, and South Africa have shown differences in development of the waste sector. This highlights the need for individual approaches.

Due to the positive impacts of using waste for energy (biogas) production, nowadays heavily criticized bioenergy, especially in developing countries, could get a new and very positive image.

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