

Comprehensive Feasibility Study for the Construction of an Integrated Sustainable Waste Management Facility in Kajiado County, Kenya



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Abstract The work focuses on the feasibility study relating to the design of a new integrated sustainable waste management facility in Ngong town (Kenya), within the Kajiado County; the County borders Nairobi and extends to the Tanzanian border further south. Currently, the waste generated in Ngong town is sent to an illegal dumping site, which must be closed as soon as possible since it is causing serious environmental and social impacts. Specifically, the purpose of the study was to carefully analyze the context, taking into consideration environmental, economic and social aspects, providing technical–economic solutions which must be robust, easy to build, operate and maintain, be cost-effective and self-sustaining from an economic standpoint, and be environmentally and socially sustainable. This chapter focuses on the assessment carried out in view of designing a new integrated sustainable waste management facility. An estimation of the mass and energy balance and of the system design and sizing is also provided, together with an assessment of the overall economic sustainability of the proposed intervention.

Keywords Integrated waste management · Renewable energies · Developing countries

1 Introduction to Proper Waste Treatment Strategies

The present chapter focuses on the feasibility study relating to the design of a new integrated sustainable waste management facility in Ngong town (Kenya), within the Kajiado County; the County borders Nairobi and extends to the Tanzanian border further south. Currently, the waste generated in Ngong town is sent to an illegal dumping site, which must be closed as soon as possible since it is causing serious environmental and social impacts.

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The first stage of the project was a decision-making process carried out to identify the most suitable solution for the construction of a waste management facility in Ngong town (Kenya) and subsequently to provide the main design details. First, different modern waste treatment strategies were analyzed, in order to determine the best option, taking into account the peculiarities of application in developing countries (UNEP 2013; UN-HABITAT 2010; USAID 2009; UNEP II 2013; Mohammed et al. 2013). The results of the assessment are summarized in Table 1.

Table 1 Pros and cons of the main usable waste treatment strategies

PROS	CONS
<i>(1) Thermo-chemical technologies</i>	
<ul style="list-style-type: none"> • Robust technology • Maximum reduction in waste mass and volume • Recovery of electricity and/or thermal energy • Waste is sanitized and sterilized • Possibility of recovering materials such as metals during the process 	<ul style="list-style-type: none"> • Very expensive (construction) • Requires high technical skills for operating • Expensive operation because it requires chemicals for flue gas cleaning • Some solid residues generated are hazardous waste (i.e. filter ash) • Heavy maintenance required to guarantee adequate environmental standards • Requires waste with high low-heating value (i.e. with low organic fraction content) as input • In developing countries, it requires auxiliary fuel (i.e. coal) to support combustion • Pyrolysis and gasification are possible only if these thermal treatments are coupled with integrated waste management systems of small regions • Does not allow material recovery by manual operators in proper hygienic conditions
<i>Preferred application</i> Big cities in developed countries with relatively cold climate, where combined heat and power (CHP) can be implemented and heat can be used for district heating purposes	
<i>(2) Sanitary landfill</i>	
<ul style="list-style-type: none"> • Relatively cheap solution, if post-closure costs are not considered • Some energy recovery can take place by exploiting the landfill gas 	<ul style="list-style-type: none"> • Requires large spaces • Does not allow material recovery by manual operators in proper hygienic conditions • Potential release of methane in the atmosphere (greenhouse gas) • Expensive if post-closure costs are considered (at least 30 years of maintenance and monitoring after the useful life) • Risk of open dump sites around the sanitary landfill
<i>Preferred application</i> Sanitary landfill is not an advisable solution, but it can be an option for very low-income countries as a basic alternative to open dumps	

(continued)

Table 1 (continued)

PROS	CONS
<i>(3) Bio-drying with landfill bioreactor</i>	
<ul style="list-style-type: none"> • Reasonable construction costs • Important reduction in water content in the waste, significantly reducing the amount of waste to be landfilled • It allows material recovery by manual operators in better hygienic conditions compared to open dumps and incineration • Very simple operation, not requiring high technical skills • Reasonable maintenance costs and efforts • It allows energy recovery in the landfill bioreactor • It can be converted into a composting plant in case source separation of food waste is established • Very suitable for waste with high water and organic content 	<ul style="list-style-type: none"> • It requires careful management of the landfill bioreactor, to avoid risks of fires and explosions
<i>Preferred application</i> Very flexible technology, which can be applied in a wide range of contexts	
<i>(4) Anaerobic digestion</i>	
<ul style="list-style-type: none"> • Anaerobic digestion allows the production of fertilizers to be used in agriculture • Anaerobic digestion produces biogas to be used in several ways and generate income 	<ul style="list-style-type: none"> • An adequate separation stage for the organic fraction is needed. • Material recovery by manual operators in proper hygienic conditions is not possible. • Potential release of methane in the atmosphere (greenhouse gas)
<i>Preferred application</i> When a high amount of controllable organic waste is available and the digestate has a good local market	
<i>(5) Composting</i>	
<ul style="list-style-type: none"> • Simple and inexpensive technology • Composting allows for the production of high-quality fertilizer (compost) • Small-, medium- and large-scale schemes are available 	<ul style="list-style-type: none"> • Accurate source separation for the organic fraction is needed • The downstream market for compost is not always available, especially if the compost is of low quality • Intense odors might be generated if the exhaust air is not properly treated
<i>Preferred application</i> When a high amount of controllable organic waste is available and the compost has a good downstream local market	

2 Identification of the Most Suitable Solution for the Waste Management Facility

The choice of the most appropriate technology for waste treatment depends on several factors; of these, waste composition is the first aspect to be considered. Within the present collection system in Ngong, mixed waste is collected without any source separation. Consequently, the waste delivered to the facility has a very high moisture content (about 70%), directly connected to the prevalence of organic matter in the waste.

As a consequence, the application of all thermo–chemical technologies is clearly precluded. Moreover, they are expensive and difficult to operate in developing countries, thus were not considered feasible. Regarding the capital cost, it was estimated that an incinerator with the required size for the Ngong project will need an investment of around 50,000,000 €, which is double the cost of the other analyzed technologies. Finally, the technology would hardly allow the re-employment of all the people currently working in the dumpsite.

On the other hand, a sanitary landfill, even if built in compliance with modern standards, has not been considered to be a valid alternative in the long term. In fact, as mentioned previously, this solution will preclude the separation of the recyclable fraction of waste. In this sense, it must be noted that the manual separation of waste as-is was not considered feasible since it cannot be managed in proper hygienic conditions. Food waste being the most relevant fraction (roughly 70% of the overall weight), priority should be given to processes capable of reducing its putrescence and water content. The latter is in the range of 70–80% in weight of food waste.

Having considered all these factors, bio-drying represents the most suitable technology for waste treatment in Kajiado. The suitability of this technology for waste with a high water content has been discussed by several authors throughout scientific literature, as reported, e.g. in He et al. (2013), Tambone et al. (2011), Rada et al. (2007), Tom et al. (2016), Rada et al. (2009), Velis et al. (2009). Mixed waste is processed in a plant that will reduce its putrescence and water content before being delivered to a sorting stage aimed at recovering potentially recyclable materials. An effort toward separate collection would be much more challenging in such a context (also requiring a proper distribution of information and training to the public), but can deliver long-term benefits, such as allowing the recovery of food waste (for animal feed production and for use in agriculture following a composting process) and a better recovery of recyclable materials.

The remaining waste after bio-drying and sorting can be finally disposed of in an engineered landfill bioreactor¹ for biogas production or used as a refuse-derived fuel (RDF) in industrial thermal processes (e.g. cement production), depending on its chemical and physical properties. For the time being, the first option has been taken into consideration, and the conceptual framework of the proposed waste-to-energy strategy is represented in Fig. 1.

¹<https://www.epa.gov/landfills/bioreactor-landfills>.



Fig. 1 Diagram of the proposed waste-to-energy strategy

Non-technological issues also need to be taken into account in the final decision-making stages. Specifically, economic sustainability is a key issue. Daily operational and management costs of the facility should be covered by the budget of the Department of Environment and Natural Resources of the Kajiado County. These costs will be in addition to the existing costs relating to waste collection and public hygiene. Bio-drying is among the most affordable and flexible technological options (in comparison with anaerobic digestion or incineration), and it has been proposed in combination with biogas production so that partial self-sustainability may be achieved.

Another aspect that needs to be considered is the organization of the waste management system. Bio-drying is appropriate for the current system, and it can also be adapted for a gradual shift toward separate collection (for example the bio-drying reactor can be used for composting the source-separated food waste). Nonetheless, other management options would require different technologies, along with significant involvement on behalf of public bodies. This is a governance issue which should also be discussed with local institutions and other pertinent stakeholders.

In the short- and medium-term, a bio-drying plant followed by manual sorting and by a landfill bioreactor has been chosen since it presents the following key strong points:

- it allows for the manual separation of mixed waste under more hygienic conditions, enabling the employment of people from the informal sector currently working on the dumpsite;
- it minimizes odor emissions and their relevant social impacts;
- it is a flexible solution which will also be suitable for the future source-separated waste, when a proper separate collection system will have been implemented;
- the capital cost is affordable, especially compared to alternatives such as waste incineration;
- it is a robust technology, without the need for complex high-tech equipment and skills.

3 Description of the New Facility

As already highlighted, bio-drying is particularly suited for processing waste with a high moisture content, since it allows for the partial evaporation of water by using the heat released by the aerobic biological degradation of the organic matter. The only technological interventions required for the process are a preliminary light shredding (aimed at opening the bags in which waste is contained) and forced air intake achieved through the use of simple air blowers, for a duration that can range between 10 and 20 days. This process can be simply operated by non-specialist staff and must be as automated as possible. The staff will only be required to oversee the activity based on a simple and intuitive interface and a few controls. Bio-drying results in a significant reduction in weight and moisture of the waste entering the process (in the range of 25–35%). The exhaust air needs to be treated before being released into the atmosphere. This can be done by using a bio-filter installed on the roof or on the side of the bio-drying building.

In the current case-study, since a solar photovoltaic (PV) plant will be installed on the roof, the bio-filter will be placed on the ground close to the bio-drying building. The bio-filter allows air to pass through retaining and bio-degrading pollutants. The bio-filter will be composed of organic filtering material, such as wood chips or coconut shell fragments, depending on the local availability of suitable materials. The filtering material needs to be periodically integrated and replaced: its life span depends on several parameters that must be considered in the final detailed design of the system, depending on the selected commercial technology (Fig. 2).



Fig. 2 View of a bio-drying system located in Italy, similar to the one described

By reducing the putrescence and humidity of waste, the following sorting operations aimed at recovering potentially recyclable materials (plastic, glass, metals) are simplified and can be carried out with simple mechanical devices (sieves, magnets) or even by hand sorting, thus ensuring the involvement of the existing informal sector. The last option appears particularly suitable for the re-integration of the people currently employed at the dumpsite.

After sorting, residual waste can finally be disposed of in the engineered bioreactor for biogas production or used as a refuse-derived fuel (RDF) in industrial thermal processes (e.g. cement production), depending on its chemical and physical properties.

The bioreactor will take the place of the conventional engineered landfill, receiving residues from previous stages. This must be accurately designed in order to avoid groundwater and soil contamination and requires a drainage system for the leachate (the liquid part leaching from the waste) as well as a collection system for the biogas produced by anaerobic processes. State-of-the-art technologies for achieving such purposes are those in compliance with current European Union legislation on landfilling (Directive 1999/31). Since leachate and biogas production are mainly influenced by the presence of the organic fraction, bio-drying can affect both of these aspects positively by achieving a partial degradation of the organic fraction.

By considering an estimated daily production of 130 tons of waste in the area under study, and an annual 6% increase in waste generation (mainly due to the projected population increase), the new bioreactor will need to accommodate an annual range of 30,000–62,000 tons of bio-dried material (estimated quantities, respectively, for the first and twentieth year). Assuming a typical level of compaction (0.8 t/m^3) and adding the daily coverage material, the total volume in a 20 years' time-span will be about $1,200,000 \text{ m}^3$. This volume may change (hopefully by decreasing) if and when new waste management strategies are put in place, namely the introduction of source separation of food waste. The surface area occupied by the bioreactor will be around $60,000 \text{ m}^2$.

Generation of biogas will start after 1–2 years, since a minimum amount of waste is needed before enhancing its generation by means of leachate recirculation. The amount of biogas produced will be burned in a co-generator unit producing heat and power. The electric energy will be enough to power the bio-drying facility, and the excess generation can be fed to the grid, helping to ensure the economic self-sustainability of the system as a whole.

Despite the fact that managing the bioreactor is aimed at maximizing the recirculation of leachate in order to enhance biogas generation, a certain amount of leachate will be produced and will need to be disposed of. It is very difficult to estimate the exact amount of leachate produced, since it depends on many factors, particularly on the local climatic conditions as well as on the actual management of the bioreactor itself (proper daily coverage, extent of recirculation, etc.). Although some experiences demonstrate the possibility of achieving a very low production of leachate, the literature data is more variable, ranging from 0.02 to 0.26 m^3 per ton of waste disposal. In our estimate, we have conservatively assumed an initial generation of

0.1 m³/t, targeting a progressive decrease thanks to continuously improved management of the bioreactor.

Following the above-described preliminary sizing of the system, an indicative layout of the plant was developed, as shown in Fig. 3.

Because of the relatively low amount of leachate, and of its possible reduction, it is not advisable to build a dedicated treatment plant at the site considering the complex management of such systems and the lack of rivers or water basins in which to convey the treated water. The excess leachate will be periodically evacuated by means of tank trucks and properly disposed of at wastewater treatment plants in the

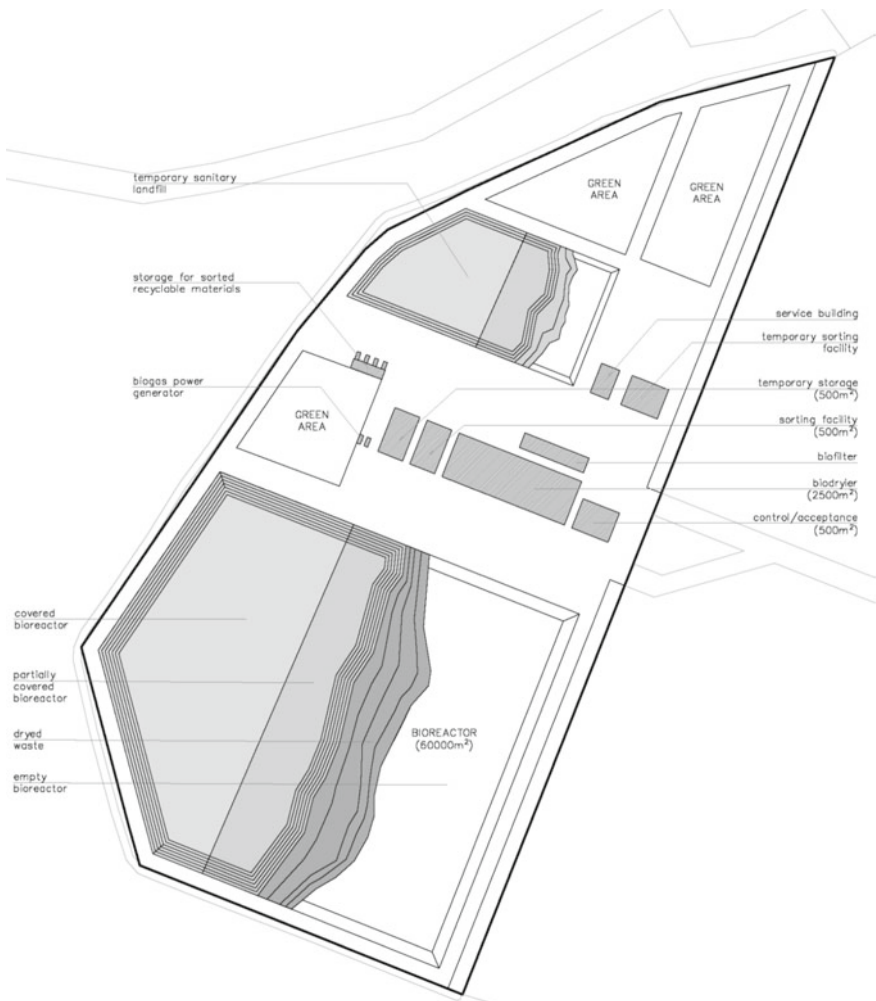


Fig. 3 Indicative system layout (elaboration by the authors)

Nairobi area. A feasibility analysis was carried out and some private companies that are potentially suitable for the purpose were identified.

In addition, in order to ensure economic sustainability, the exploitation of renewable energy sources, specifically PV technology, is recommended in the new facility; This will allow for the generation of electricity to cover the energy demand before the biogas production starts and to minimize the running costs during the entire system’s lifetime. All the roofs of the facility’s buildings will be covered in a PV system generating a total estimated power around 800 kW_p. It was assumed to have around 5800 m² of roof surface and that 1 kW_p of PV modules needs around 7 m² of useful surface. Such a PV plant is expected to generate approximately 1,300,000 kWh/year of electricity. Thus, this project also represents an interesting case of effective matching between two renewable and local energy sources.

The biogas collected from the bioreactor will be burned in specific biogas CHP units generating both thermal energy and electricity. Stable biogas production will start 18–24 months after the first operation of the plant. Since the production of electricity from the combustion of biogas is expected to be about 180 kWh per ton of waste entering the bioreactor, a potential production of about 5000 MWh is expected from the third year of plant operation. In 20 years, considering the increase of the daily waste production, it will be possible to reach a potential production of about 10,000 MWh per year.

A flow chart detailing the rounded mass balance of the system in the third year of its operation is shown in Fig. 4.

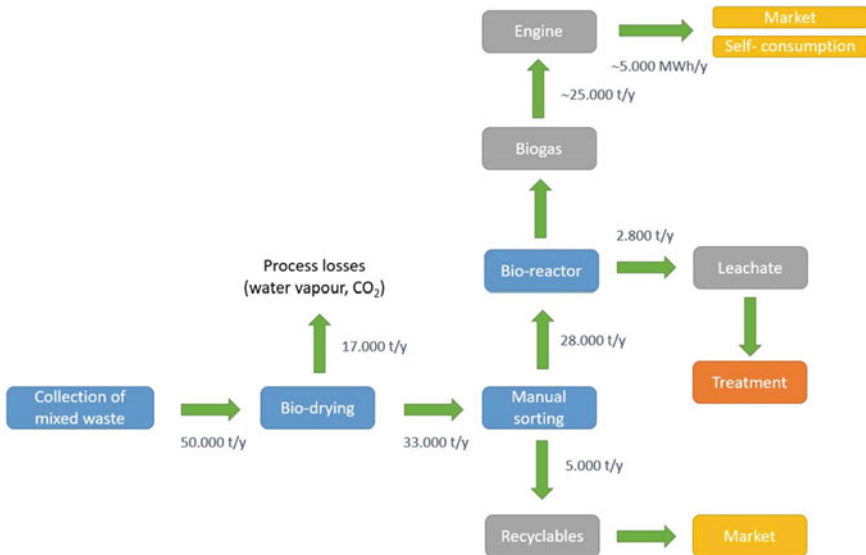


Fig. 4 Overall mass balance of the system at year 3 (rounded figures)

4 Final Evaluations and Conclusions

By considering the information collected during the feasibility study, it was possible to state that the implementation of the new integrated sustainable waste management facility is feasible with the use of robust technologies composed of a bio-drying unit coupled with a bioreactor for the production of biogas. This was assumed as the best technological option for the Kajiado County's context.

The total budget required for the entire intervention (construction of the integrated waste management facility, including the closure of the existing dumpsite and capacity building/training activities) is approximately equal to 20,000,000 €. It must be noted that such an amount must be considered as an average educated guess, pending the huge uncertainties associated with these types of activities, where unexpected events can arise at any time. The new facility (waste-to-energy system), together with the rooftop solar energy system, will be able to generate more than 5,000,000 kWh/year at full power (at around the third year of operation), which is equivalent to an economic counter value ranging from 350,000 to 450,000 €/year. Part of this energy will be used for the operation of the facility, while the excess will be sold to the national grid to generate income. In this way, before the tenth year of operation, the system will begin to generate positive incomes compared to the running costs. The project herein described represents an interesting case of technological transfer from Europe to Africa, taking into account the local peculiarities that strongly affect waste management. Several socio-economic issues have been faced, especially in relation to local population and environment. By monitoring the developments of this experience, future studies will potentially be able to contribute also in terms of technical replicability.

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