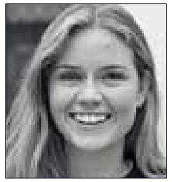
Solid Waste Management and Biogas Feasibility in Kigali, Rwanda

Avfallshantering och potential för biogas i Kigali, Rwanda

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Abstract

Rwanda's capital Kigali has a reputation for being the cleanest city in Africa. Despite Kigali outperforming its neighboring capitals over the last decade with significant progress in waste collection coverage, Solid Waste Management (SWM) remains a key focus area for improvement. Exploring a Waste-to-Energy solution with the aim to contribute to sustainable urban development, transforming biowaste into biogas could help reduce the capital's waste deposition at Nduba Landfill. This is achieved by addressing three main objects: the current state of SWM in Kigali, the suitable operational parameters for a community-based biogas digester in Rwanda, and the biogas potential and investment costs for a village-scale fixed dome biogas digester in the ongoing pilot project Mpazi Rehousing Project in Mpazi neighborhood. The methodology encompasses a comprehensive approach involving literature review, data analysis, field observations and stakeholder interviews. The results indicate significant potential for biogas production, estimating daily outputs of 42 m³ for maximum resident capacity in Mpazi, titled Scenario I, and 36 m³ at 85% resident capacity, titled Scenario II. The investment costs are projected to be approximately $10,100 for a 70 m³ reactor and $8,600 for a 59 m³ reactor. Implementing small-scale investments, such as the community-based biogas digester, does not only present a more feasible and immediate solution for mitigating waste at Nduba Landfill, but also paves the way for scaling up projects in the capital.

Keywords: Solid Waste Management; Waste-to-energy; Biogas production; Fixed Dome Digester

Sammanfattning

Rwandas huvudstad Kigali har ryktet att vara den renaste staden i Afrika. Trots att Kigali har överträffat huvudstäderna i grannländerna de senaste årtiondena med sin märkbara förbättring i avfallsinsamling, är avfallshanteringen fortfarande bristfällig. Genom att utforska en "Waste-to-Energy"-lösning i form av att omvandla bioavfall till biogas med avsikt att bidra till hållbar stadsutveckling, kan huvudstadens avfallsinsamling och deponering till Nduba-deponin reduceras. Tre huvudsakliga frågor studeras: den nuvarande situationen för avfallshantering i Kigali, lämpliga driftsparametrar för en biogasanläggning i Rwanda och biogaspotentialen samt investeringskostnaderna för en fast kupolbiogasanläggning (fixed dome digester) i pilotprojektet Mpazi

Rehousing Project i stadsdelen Mpazi. Studien består av en litteraturundersökning, dataanalys, fältobservationer och intervjuer med aktörer. Resultaten visar att det finns betydande potential för biogasproduktion, med en uppskattad daglig produktion på 42 m³ vid maximal kapacitet för invånare i Mpazi, benämnt Scenario I, och 36 m³ vid 85% kapacitet, benämnt Scenario II. Investeringskostnaderna beräknas vara cirka $10 100 för en reaktor på 70 m³ och $8 600 för en reaktor på 59 m³. Genom att genomföra småskaliga investeringar inom stadsutveckling och hållbarhet såsom en småskalig biogasanläggning, öppnar det upp för möjligheten att våga satsa på större projekt i Kigali.

Introduction

Solid waste generation poses a significant global challenge today, affecting local environments, ecosystems, public health and socioeconomic well-being on a worldwide scale. According to the World Bank, approximately 2,01 billion tons of waste were generated in 2018, and is expected to rise to 3,40 billion tons by 2050 (Kaza et al. 2018). Addressing this issue with sustainable solutions is a top priority globally. A country with successes in collection of solid waste is Rwanda, with its capital Kigali recognized as the cleanest city of Africa.

Despite being one of the continent's smallest countries in terms of area, its population of roughly 13 million ranks Rwanda the most densely populated country on the continent. Often referred to as the Singapore of Africa, Rwanda is praised for its efficient governance, rapid economic growth and successfully urban planning. Specifically, its reputation of cleanliness is the most prominent reason for this comparison. Initiatives such as plastic bag ban, the national cleaning day called Umuganda, strict regulations, awareness campaigns and green investments have earned Kigali this reputation. With the formulation of national strategies and policies, the Government of Rwanda places greatly emphasis on developing SWM. Despite Kigali outperforming its neighboring capitals over the last decade with significant progress in waste collection coverage, SWM remains a key focus area for improvement.

The municipality City of Kigali commissioned a feasibility study for the development of SWM in Kigali, which was sponsored by Swedfund and conducted by the consulting company COWI in 2019. The study investigates the possibilities of upgrading the currently semi-controlled SWM system, Nduba Landfill, into a sanitary landfill. Currently, City of Kigali is searching for funding to launch the project (Nyiraburanga 2024). As a result of the feasibility study, our study is not intended to develop the collection, transport or management of the SWM in Kigali. Instead, it aims to focus on mitigating the waste transported to the landfill.

As urbanization in Kigali continues to increase, issues regarding inadequate infrastructure and informal settlements arise. An unplanned settlement upgrade launched by the Government of Rwanda is the pilot project Mpazi Rehousing Project. It extends beyond a rehousing project; investments are also targeting critical areas such as stormwater management and environmental resilience. Upon being introduced to this sustainable and modern approach to urban development, the Mpazi Rehousing Project serves as an ideal case study for investigating potential Waste-to-Energy solutions.

This article is based on the master's thesis completing our Master of Science in Environmental Engineering at the Faculty of Engineering at Lund University: Solid Waste Management and Waste-to-Energy Feasibility in Kigali - A Case Study of the Mpazi Rehousing Project (Ahlbin & Olofsson 2024). The specific intent of the master's thesis is to formulate a feasible Waste-to-Energy solution for Kigali, with the purpose of conducting an in-depth examination of the achievements and challenges of the capital's SWM practices. This solution will align with City of Kigali's aspiration of sustainable urban development along with mitigating the volume of solid waste currently deposited at the Nduba Landfill. This is achieved through a collaboration with the company Skat Consulting Rwanda and their ongoing Mpazi Rehousing Project, serving as a case study. The

Figure 1. Weekly waste collection in Kacyiru, Kigali.

solution assessed is the possibility of transforming biowaste to biogas through the implementation of a village-scale biogas digester. In order to accomplish the aim, the following research questions will be answered:

1. How is the solid waste from households collected and transported in Kigali, and how is the waste currently managed at Nduba Landfill?

2. a) What operational parameters and design are suitable for an urban community based biogas digester in Rwanda?

b) How have national initiatives contributed to the biogas development?

3. Considering the ongoing urban upgrade project in Mpazi, what are the estimated biogas potential and its investment costs?

Methodology

The master's thesis was developed using a mix-method approach, consisting of both qualitative and quantitative research to gather and analyze data. Nine interviews with stakeholders were conducted, site observations were performed and relevant literature was reviewed to gain an understanding of the current practices, technologies and challenges in solid waste collection, transportation and management. A site visit to Nduba Landfill, guided by WASAC, served as the primary data collection method for the SWM. A feasible design for a community-based biogas digester suited for the urban setting in Kigali was chosen through a literature review and studying case studies, examining successful small-scale biogas projects in similar conditions to identify best practices and key success factors. A literature review of biogas development initiatives in Rwanda was conducted, complemented by an interview with experts at Rwanda Energy Group. Through a site visit to Mpazi neighborhood, interviews with Skat and residents in Mpazi along with a literature review, the production and investment cost for a biogas digester could be estimated.

Result

Solid Waste Management in Kigali

The growing population of Kigali is reflected in the ascent of the total daily solid waste generation. The generation per capita has been stable while the total daily generation has increased. Kigali generates 640 tons of waste daily, with 70–80% classified as biowaste (Kabera et al. 2019). Despite public awareness initiatives like Umuganda, waste generation remains high. However, a significant change has been observed in the collected waste – over the past decade the collection coverage of solid waste has doubled, even though the generated amount of waste has increased. Although collection rates have improved to 88%, with waste managed by 13 collection companies contracted by the City of Kigali, the vast majority of the

Figure 2. Manual waste collection at Nduba Landfill.

waste is mixed at the source due to insufficient regulations and single-compartment collection trucks, see Figure 1 (Bosco 2024).

At Nduba Landfill, operational improvements since 2020 have transitioned the open dumpsite to a semi-controlled facility. A contracting company is responsible for managing recycling efforts and mitigating environmental impacts, although large-scale waste separation and treatment remain limited. During 2024, a pilot project has been initiated to assess the value of recyclables, with employees sorting plastics, metals and cartons into large bags for transport to small-scale recycling facilities in the city. After manual sorting (seen in Figure 2), employees apply insecticide to the waste to control odors and insects. The waste is then deposited in designated areas, spread, and compacted into layers, each covered with soil from a nearby site. This process takes about two weeks per layer, with the accumulated layers reaching up to six meters high. To further improve waste management, the ongoing Waste-to-Resources project led by the Global Green Growth Institute (GGGI) has introduced a weighing bridge, sorting machines and composting facilities (Mukurarinda 2024).

The water filtering through the waste becomes contaminated with dissolved and suspended substances, forming leachate. This pollutant-rich liquid contains organic and inorganic compounds, heavy metals, pathogens and toxins. Leachate movement depends on precipitation, waste composition and landfill design, making its capture crucial to prevent groundwater and soil contamination. The landfill is strategically located on a hill to minimize the risk of contaminating the groundwater (Bosco 2024). Open channels direct leachate to large ponds, where it is permanently stored without treatment, see Figure 3. Currently, three ponds have been excavated and are being used until full. Regular sampling monitors potential contamination, and the site observations indicated well-maintained ponds with minimal odor and no visible flies (Nyiraburanga 2024).

A Community-Based Biogas Digester System

Charcoal is widely used for cooking in Rwanda due to its accessibility and cost-effectiveness. Its widespread

Figure 3. One of the three ponds designated for the storage of leachate water.

use poses environmental threats including deforestation, soil erosion and biodiversity loss, together with indoor air pollution contributing to respiratory health issues (Kabera et al. 2016). The leading alternative to coal is biogas. It offers a sustainable and cost-effective production of both renewable energy – used for cooking, heating water or gas lamps – and fertilizer, creating a closed cycle of nutrients. Experience worldwide suggests that it is culturally accepted, requiring only basic skills for construction and management (Amigun & Blottnitz 2010). It also addresses Rwanda's goal of reducing biomass dependency from 79% to 42% by 2024 and minimizing greenhouse gas emissions (REG 2023). In sub-Saharan Africa, domestic biogas systems are the most common, but institutionally managed digesters have proven more successful (Amigun & Blottnitz 2010). The history of biogas in Rwanda dates back to the end of 1990 when the Government of Rwanda initiated efforts to promote renewable energy sources and improve access to clean cooking fuel in rural areas. Recognizing the country's vast agricultural sector and the abundance of organic waste, biogas technology emerged as a viable solution to address energy poverty and environmental challenges (Kabera et al. 2016). Since then, various initiatives have been implemented to expand biogas production across the country, targeting rural communities as well as institutions, such as prisons and schools (Musabe 2024).

The operational parameters and design profitable for a biogas digester in Rwanda have been examined, evaluating local conditions based on literature reviews, expert interviews and site visits. For a digester in a tropical climate without supplemental heating, a mesophilic temperature range (30–40°C) was found suitable, which offers stability and resilience to fluctuations in environmental conditions (Vögeli et al. 2014). When comparing different designs of digesters, the low-tech design of a fixed dome biogas digester was found cost-effective and adapted to the climate of Kigali (Rao & Doshi 2018). Typical household food waste in Kigali has a C:N ratio of ~14:1, which has proven appropriate as feedstock for biogas production (Mucyo 2013). Daily maintenance is important to sustain microbial activity. The microbial system operating at this temperature range is robust, but it will slow down the anaerobic digester process somewhat and require a hydraulic retention time of at least 30 days. Maintaining an optimal pH is easy if the digester is well managed – ensuring only food waste is fed, avoiding inhibitors and keeping salt and oil levels low (Vögeli et al. 2014). Therefore, digesters can operate efficiently with minimal pretreatment of feedstock and their byproducts can support clean cooking and farming. Common challenges are methane leakage, pH instability and ensuring high-quality waste input (Amigun & Blottnitz 2010).

Prospects for Biogas in Mpazi Rehousing Project

The Mpazi Rehousing Project spans four hectares, accommodating up to 2,000 residents in informal settlement post-upgrade. These buildings have been removed, new fundaments built and 25 new building blocks are to be constructed (Figure 4). Waste generated in Mpazi is projected at 0.57 kg/day per capita, with 70% as biowaste (Kabera et al. 2019). Two scenarios were modeled: full resident occupancy (42 m^3 daily biogas output) and 85% resident occupancy (36 m^3 daily biogas output). Investment costs for the required 70 m^3 and 59 m^3 reactors are estimated to $10,100 and $8,600, respectively. The proposed biogas system would improve waste management, provide clean cooking alternatives and support Kigali's urban development goals. Moreover, with a calorific value of 6.0–6.5 kWh per cubic meter of biogas, the energy produced could power 40–50 stoves for approximately two hours daily. When compared to LPG, with a cost of $0.071/kWh, biogas offers a more economical cooking fuel at a cost of $0.006/kWh.

Extra: Stormwater management in Mpazi neighborhood

The Mpazi Rehousing Project has significantly improved residents living conditions, stronger resilience to heavy rainfall events being one (Uwaremwe 2024). In informal settlements, heavy rain often leads to flooding, mudslides, water pollution, damaged homes and displacement, making life more challenging for residents. Several measures have been taken to mitigate flooding in the area. Before, an uncontrolled river flowed through the neighborhood, serving as the primary drain of the area. This river has been upgraded to handle runoff from heavy rainfall and minimize soil erosion – the waterway has been widened and deepened, while also being reinforced with sturdy stone walls and bedrock construction (Figure 5). Furthermore, all the roads in the area have secondary drainage channels adjacent to the pathways, built in the same design as the main channel with a resilient stone structure. These channels are interconnected and direct stormwater down to the primary drain. Additionally, introducing green spaces enhances both the ground's infiltration gradient and the recreational value in the area (Uwaremwe 2024).

Figure 4. Removal of informal settlements and preparing the foundations of new blocks in Mpazi.

Discussion

In this discussion complexities of the SWM in Kigali are explored, examining achievements, challenges and the potential of biogas technology as a sustainable solution. By evaluating current practices and proposing innovative approaches, the aim is to offer insights and recommendations for enhancing SWM efficiency and fostering sustainable development in the city.

Figure 5. Upgraded main channel in Mpazi neighborhood.

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Evaluating Solid Waste Management in Kigali: Achievements and Challenges

The City of Kigali's efforts to improve waste collection coverage appear to have been successful. However, an upcoming challenge is separating biowaste from non-biowaste. Introducing initiatives such as public waste separation bins and activities like the community cleaning day Umuganda likely influence Rwandan citizens' attitudes toward waste management by promoting collective responsibility and environmental awareness. Other strategies to promote waste separation awareness could be media campaigns, community gatherings and posters. In Rwanda, radio is more commonly used than social media, making it a particularly effective medium. Furthermore, school programs are an effective way to educate children from a young age. With this in mind, one great advantage of operating a village-scale biogas system at the origin of waste generation is that the biowaste is less contaminated. Separating at source increases the value of the biowaste since it is not mixed with other types of waste.

The transition of Nduba Landfill from a semi-controlled open dumpsite to a sanitary landfill is crucial for improving SWM in Kigali. It is necessary for future endeavors towards a more circular and environmentally friendly landfill, incorporating on-site recycling and composting together with risk mitigation measures. Effective management and treatment of leachate water are crucial to prevent groundwater contamination and to minimize potential environmental and public health risks associated with landfill operations. However, multiple barriers have been identified in upgrading the SWM system. A significant one is the lack of financial support for implementing projects aimed at advancing the current systems. For instance, although substantial resources were invested in COWI's feasibility study for the development of SWM in Kigali including plans and design for a sanitary landfill, there is currently insufficient funding available to implement the suggested measures (Nyiraburanga 2024). Additionally, the upgrade to a sanitary landfill requires the involvement of numerous stakeholders with interconnected responsibilities, which further complicates and slows down the process.

Advancing Biogas Technology in Kigali: Key Findings

The evaluation of community-based biogas digesters reveals several key findings. Firstly, this low-tech solution creates a closed cycle of nutrients, leading to energy savings and a decrease in greenhouse gas emissions. The use of biogas digesters enhances water quality and contributes to the conservation of both imported and national resources, such as gas and wood. Secondly, waste can become an economic benefit for households by being utilized as cooking fuel, e.g. for heating water and powering gas lamps. Thirdly, adoption of initiatives like biogas programs improves livelihoods, empowers communities and fosters healthier and more sustainable environments. It benefits the role of women as they primarily oversee household waste management, cooking practices and are particularly susceptible to its health hazards. To summarize, it offers a decentralized and user-friendly method for converting waste into energy, which can reduce environmental degradation, generate economic gains and improve social conditions. The findings suggest that biogas digesters are not only suitable in rural areas of Rwanda, but in urban settings as well.

There was an attempt to visit a biogas digester during the field work in Rwanda. However, time constraints and difficulties accessing any of the prisons, which are the only places where digesters currently are utilized in urban areas in Kigali, prevented this. However, similar to the case of SWM upgrade, the main challenges for implementation of decentralized biogas digesters are funding, lack of knowledge for operation and maintenance, along with awareness of benefits.

Urban Upgrade in Mpazi Rehousing Project Through Biogas Investment

The extensive upgrade in Mpazi Rehousing Project goes beyond rehousing. Skat's aim of achieving sustainable urban development makes the project an ideal case study for investigating Waste-to-Energy solutions. Today, the SWM in Mpazi is ineffective. Although plans for separation-at-source exist, they are not implemented because residents typically transfer their garbage in large bags to the street on collection day. A suggestion to Skat is to create more accessible solid waste collection stations by relocating them close to the roads, replacing stationary waste containers with larger, movable dumpsters. Raising awareness about waste management practices and their importance among residents of Mpazi could help minimize littering, reduce pollutants in the neighborhood's main water stream and enhance the area's recreational value.

The potential for implementing a biogas digester has been evaluated in terms of biogas production and investment costs. According to the results, the biogas potential at Mpazi Rehousing Project appears to offer economic benefits. However, assumptions such as excluding costs of operation and maintenance and lack of up-to-date literature could negatively impact the results.

Conclusions

This master's thesis evaluated the potential of a Waste-to-Energy solution, focusing on transforming biowaste into biogas using a village-scale fixed dome digester. Waste collection coverage in Kigali reaches 88%, and the waste is transported to the semi-controlled Nduba Landfill. Currently, no waste reduction method is performed and no treatment method is applied to household waste. Suitable operational parameters for the urban biogas digester were evaluated and presented. For Mpazi Rehousing Project, a daily biogas production of 36–42 m^3 was estimated with an investment cost of $8,600–10,100, based on findings from Scenario I and II. The investigation revealed that Kigali, despite its clean reputation, faces significant SWM challenges such as inadequate infrastructure and informal waste disposal practices, highlighting the need for a sanitary landfill. Implementing small-scale investments like the community-based biogas digester presented could offer a more feasible and immediate solution while also paving the way for scaling up projects in Kigali. The potential integration of a biogas digester in Mpazi Rehousing Project not only aligns with sustainable urban development goals and already implemented national initiatives but also presents a cost-effective solution for Waste-to-Energy, thereby addressing both the waste management challenges and the energy needs of the urban residents.

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