Food and Agriculture Organization of the United Nations

UNDP

SCALA Private Sector Engagement Facility Report

Feasibility Assessment for Biogas Potential Development in The Gambia

ABSTRACT

The Gambia faces critical challenges related to waste management and greenhouse gas emissions, which exacerbate climate change and hinder sustainable development. The country's rapid waste generation and inadequate management infrastructure result in significant emissions from landfills and open burning, while reliance on non-renewable energy sources further amplifies its carbon footprint. The Gambia has undertaken various climate adaptation and mitigation efforts to address these issues, including the National Adaptation Programme of Action (NAPA) initiated in 2007 and the National Adaptation Plan formulated in 2015. Following the ratification of the Paris Agreement, The Gambia submitted its first Nationally Determined Contribution (NDC) in 2021. It expanded its second NDC to target comprehensive greenhouse gas reductions, focusing on the forestry and waste sectors. The Government of The Gambia has formally requested support from the SCALA programme to enhance its biogas production.

This study evaluates the potential of biogas technology in The Gambia in response to energy shortages and waste management challenges. Biogas, produced from agricultural residues and waste, offers a promising solution for both renewable energy and improved waste management. The technology can mitigate greenhouse gas emissions, reduce environmental pollution, and generate sustainable energy while creating economic opportunities. The study assesses biogas production feasibility through resource potential and financial cost-benefit analyses, highlighting significant interest from the private sector and the potential for substantial emissions reductions.

The findings indicate that biogas technology can address critical energy and waste issues, providing environmental and economic benefits. However, successful implementation requires strategic investments, including financial support, technical expertise, and supportive policies. Recommendations include developing a feed-in tariff program, providing targeted financial mechanisms, and enhancing technical support for small-scale producers. Integrating biogas projects into existing markets and improving waste management regulations will be crucial for leveraging biogas technology to support The Gambia's climate goals and sustainable development. The study concludes with a call for further assessment and piloting of biogas systems, mainly through international collaboration and funding.

KEY MESSAGES

- ↗ Biogas technology offers a dual solution for The Gambia's waste management and energy needs, reducing greenhouse gas (GHG) emissions and generating sustainable energy
- ↗ The Gambia's government has sought SCALA programme support to enhance biogas potential production, aligning with its climate mitigation emission reduction goals
- ↗ Biogas can significantly cut GHG emissions by converting organic waste, biogas could reduce 7,900 tonnes of CO_2e annually and around 120,000 tonnes of CO_2e in 15-year technology lifespan from the studied case studies
- ↗ Private sector interest in biogas is strong due to energy shortages and high costs, presenting an opportunity for sustainable development and economic growth
- ↗ Successful biogas implementation requires strategic investments, including financial support, technical expertise, and supporting policies to maximize benefits and ensure sustainability
- ↗ Recommendations include developing a feed-in tariff, providing financial mechanism for small/medium-scale projects, and integrating biogas into existing markets and waste management systems.

ACKNOWLEDGEMENTS

This guide was produced by Lorenzo G. L. Traverso, Marco Colangeli and Lorenzo Testa from FAO, with the support of Aruna M. Jarju from NARI, and under the direction of the Scaling Up Climate Ambition on Land Use and Agriculture (SCALA) Private Sector Engagement Facility team.

The authors would like to acknowledge with great appreciation the valuable contributions, strategic guidance and comments received from Farrah Adam, Sambou Nget, Marie Chorr, Alhagie Abass Kinteh, and Zara Mustapha of UNDP, and Luis Rincon, Lapo Roffredi and Alessandro Spairani from FAO.

The authors would also like to thank Alpha Humma, Dodou Jallow and Jibril Jarju for their valuable contribution in supporting primary and secondary data collection, and Mr. Bafoday Sanyang (Focal Point Energy Officer Ministry of Petroleum and Energy), Mr. Momodou Jeng (Director of the West African Livestock Innovation Centre -WALIC), Mr. Joseph Axel Faye (Director of the Commercial Diary Farmers' Association), Mr. Baboucarr Jarju (CEO of M'bolo association), Dr. Dawda Badgie (Executive Director of the National Environment Agency (NEA), Mr. Maddy Kuyateh (Manager of the Abuko – Livestock Market and Slaughterhouse), Mr. Abubacarr B. Korta (Secretary of the Brikama Daral Livestock Association), Mohammed Sanwang (CEO of GFirm Poultry and Diary), Mr. Lalo Minteh (Owner of Alminteh Poultry farm), Ms. Sainabou Cons Fhall (Manager of the Bakoteh fish and vegetable market), Mr. Kan Mustapha Kanyi (Manager of the Bakoteh dumpsite), Mr. Bai Momar Taal (CEO of the ECOSOIL organic fertilizers and TROPINGO food industry), and Mr. Baba Saidykhan (Owner of Lamjaidy Dairy Farm), who have provided key data and insights for the analysis contained in this report. This report was edited by Melanie Pisano from UNDP.

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FOREWORD

The Gambia is confronted with major obstacles from climate change, such as higher temperatures, unpredictable rainfall, and elevated sea levels, resulting in crop failures, livestock deaths, and ongoing food insecurity. Acknowledging the pressing need to confront climate change, The Gambia's National Development Plan (NDP) for 2023-2027 emphasizes climate resilience as a core strategic action. The Ministry of Petroleum and Energy is collaborating with regional and international organizations to share information and develop climate projects, particularly on renewable energy sources like biogas.

In line with this dedication, we are excited to participate in the "Scaling up Climate Ambition on Land Use and Agriculture (SCALA)'s Private Sector Engagement (PSE) Facility." By engaging multiple stakeholders, this effort focuses on converting NDCs and/or NAPs into effective climate solutions in land use and agriculture. SCALA's dedication to promoting collaboration between the public and private sectors will speed up the execution of adaptation measures, enable the transfer of innovation, and mobilize crucial resources to guarantee the sustainability of these initiatives in The Gambia.

The private sector's strategic involvement in harnessing biogas potential in The Gambia is crucial to our climate adaptation strategy. Working with the SCALA PSE Facility will offer valuable perspectives on the private sector's climate change impacts and its important role in The Gambia's National Adaptation Plan process. This partnership will make it easier for the private sector to get involved, encourage funding in projects for adapting to and withstanding climate change effects, and highlight the value of securing investments against climate risks.

This report is a major result of the partnership between the Government of The Gambia and the SCALA program, backed by the UNDP and FAO offices in The Gambia. The country-wide assessment aims to evaluate the feasibility of biogas production, providing clear insights into greenhouse gas mitigation potential and associated costs and benefits while examining investment opportunities and encouraging private sector involvement in the strategic planning of biogas initiatives and public policy.

The results and suggestions of this research will be crucial for guiding climate policy, creating resilient interventions that address climate issues, effectively supporting long-term adaption and mitigation initiatives, and meeting NAP and NDC goals. Ultimately, this project will improve The Gambia's ability to endure sudden shocks and prolonged pressures from severe climate events, helping stabilize and strengthen our country.

Energy Officer
Ministry of Petroleum and Energy

EXECUTIVE SUMMARY

The Gambia faces significant challenges related to waste management and greenhouse gas emissions, which exacerbate climate change. The rapid increase in waste production and inadequate waste management infrastructure lead to substantial emissions from landfills and open burning, contributing to environmental degradation. Additionally, the country struggles with energy shortages and relies heavily on non-renewable sources like firewood and charcoal, further aggravating its carbon footprint.

To enhance its adaptive capacity to climate change, The Gambia developed the National Adaptation Programme of Action (NAPA) on Climate Change in 2007. It initiated the formulation of the National Adaptation Plan in 2015 with UNDP and UNEP support. These efforts identified entry points for mainstreaming adaptation across sectors like Agriculture and Natural Resources and developed a roadmap involving key stakeholders. In 2021, The Gambia submitted its first Nationally Determined Contribution (NDC) following the ratification of the Paris Agreement in 2016. With the ambition of achieving net-zero emissions by 2050, the country reviewed circular economy opportunities. It expanded its second NDC to include all greenhouse gas emissions, emphasizing forestry and waste sectors. The adaptation section was strengthened, including vulnerability analysis, adaptation actions, and financial needs. This led to the publication of "The Gambia 2050 Climate Vision", setting specific targets for becoming a climate-resilient, middle-income country through green economic growth and low emissions development. Key NDC priorities are agriculture, land use, energy, transport, waste management, and industrial processes.

To support these priorities and the National Development Plan (2023-2027), The Gambia seeks assistance for a biogas resource potential assessment and financial cost-benefit analyses of national biogas production potential. Indeed, biogas, derived from agricultural residues and waste, has significant potential to meet diverse energy needs in the country, including electricity generation, heating, and cooking. Implementing biogas production within waste management and segregating organic and non-organic waste can create optimal feedstock for biogas production, reducing environmental impact and generating sustainable energy.

Biogas aligns with global efforts towards waste reduction and cleaner energy. In The Gambia, embracing biogas and improved waste segregation can address waste challenges while contributing to energy needs. Additionally, digestate, a by-product of anaerobic digestion, can be used as a natural fertilizer, enhancing soil fertility and agricultural yields and reducing dependence on imported chemical fertilizers.

The development of the biogas system presents environmental and energy advantages and offers opportunities to mobilize the private sector, positively impacting the economy, employment, and local skills development. Strategic investments in biogas can address the country’s energy challenges, especially with the increasing electricity demand. This approach involves addressing transmission line gaps and investing in biogas, solar, and wind energy plants to meet energy demands and promote sustainable development. However, blind investments in biogas carry risks such as a lack of technical expertise, potential issues with technology providers, and financial uncertainties due to high initial costs and market fluctuations. Additionally, the viability of biogas projects can be affected by regulatory changes and the availability of consistent feedstock.

This study aims to evaluate the feasibility of biogas production in The Gambia, equipping the government and private sector with a comprehensive understanding of strategic planning of sustainable investments, detailing the biogas value chain from production to consumption. The assessment aims to provide clear insights into greenhouse gas mitigation potential and associated costs and benefits, demonstrating sustainable investment opportunities and involving private sector stakeholders. By focusing on engaging and supporting the private sector, this research seeks to explore sustainable solutions that can provide renewable energy, reduce environmental pollution, and stimulate economic growth. The outcomes are expected to highlight the viability of biogas technology to address critical energy and waste issues, thereby contributing to the overall well-being and development of Gambian communities.

The report is structured to provide a comprehensive overview and analysis of the biogas production potential in The Gambia.

Chapter 1 is an introduction that includes an overview of the country, detailing its climate, agro-ecological zones, national targets, and energy framework. This section also discusses policies and instruments supporting renewable energy development, outlines current challenges, and sets the study's objectives, including a technology overview. **Chapter 2** describes the approach and methodology, presenting the data collection strategy, the stakeholder mapping, the approach behind the country-wide biogas resource potential assessment, and the methodology to perform a financial and risk analysis. **Chapter 3** examines various studied sectors, including agriculture and livestock, the food industry, and waste management, providing a potential assessment of residues, particularly crop residues.

Subsequently, the report presents case studies and financial analysis to illustrate the feasibility and economic viability of biogas projects.

It also explores private sector opportunities for investment in biogas technology, highlighting the potential for sustainable development and economic benefits.

Finally, the report concludes with a summary of findings and recommendations for advancing biogas production in The Gambia.

1 INTRODUCTION

The energy demand is expected to rise significantly over the next few decades due to population growth, increased wealth, and dietary changes. This surge in demand will present substantial challenges and exert considerable pressure on resources in nearly all regions, especially in developing and emerging economies (Scarlat, 2018).

This is particularly true for the African continent, where securing access to dependable and sustainable energy continues to pose a significant challenge, bearing extensive consequences for economic advancement, healthcare, education, and overall quality of life. Although traditional energy sources such as fossil fuels and biomass have historically fulfilled energy needs, their detrimental environmental impacts, and restricted accessibility underscore the imperative for more eco-friendly alternatives.

In parallel with energy scarcity, another challenge is represented by the waste sector. The improper disposal of municipal solid waste and other forms of waste is a significant problem in Africa, particularly in West Africa. This lack of proper waste management across all sectors and levels of the value chains leads to environmental pollution and can have severe social and environmental consequences (Pekdogan *et al.*, 2024).

Waste and wastewater from various residential, agricultural, and food processing sites (e.g., livestock farms, slaughterhouses, or milk processing industries) are significant sources of water pollution and greenhouse gas (GHG) emissions in many African countries. Often, there are either no specific regulations for abattoirs or these regulations are poorly monitored and enforced. Consequently, wastewater frequently remains untreated and is discharged directly into local rivers and water sources, posing an immediate environmental threat and impeding the development of aquatic life. Furthermore, slaughterhouses and animal manure waste are vectors for zoonotic diseases — diseases that can be transmitted from animals to humans. The anaerobic degradation of this wastewater produces methane and carbon dioxide, which are potent contributors to climate change (Orisakwe, 2019).

A more serious threat is constituted by the open burning of municipal solid waste dumps, which has negative impacts on air quality and public health (Ferronato *et al.*, 2019). Similarly, the contamination of groundwater resources due to landfill leachate has created major problems in several African countries, affecting water and food security (UNEP, 2024). Addressing these waste management challenges requires comprehensive legislative and administrative measures to improve waste collection, treatment, and disposal services, as well as public awareness and participation. Sustainable solutions that minimize the environmental and health impacts of improper waste disposal are crucial for the well-being of communities in these regions.

One promising solution to the intertwined problems of energy scarcity and waste management is adopting biogas technology. Biogas, produced through the anaerobic digestion of organic waste, can provide a renewable source of energy while simultaneously addressing waste disposal issues. By converting agricultural residues, livestock manure, and food processing waste into biogas, communities can reduce their reliance on fossil fuels and mitigate the environmental pollution caused by waste.

Implementing biogas technology offers several social, environmental, and economic benefits. Environmentally, it reduces GHG emissions by capturing methane that would otherwise be released into the atmosphere from decomposing organic waste. Socially, biogas projects can improve public health by decreasing the pollution of water sources and reducing the incidence of zoonotic diseases. Additionally, biogas systems can provide a stable and clean source of energy for households, thereby improving the quality of life and contributing to energy security.

Economically, biogas production can create new opportunities for local businesses and generate employment in rural areas. Private sector investment in biogas infrastructure can stimulate economic growth by developing new markets for biogas and its by-products, such as bio-fertilizers. Furthermore, by reducing the costs associated with waste management and energy production, biogas can contribute to the economic resilience of communities.

The challenges associated with rising energy demand and inadequate waste management are particularly acute in The Gambia. The country's rapidly growing population and urbanization, coupled with limited energy infrastructure, have exacerbated the strain on existing resources. Moreover, traditional reliance on biomass and fossil fuels has led to significant environmental degradation and health issues. Waste management practices are often rudimentary, with improper disposal of municipal and industrial waste leading to severe pollution of water bodies and the atmosphere. This situation poses a formidable barrier to sustainable development and highlights the urgent need for innovative and sustainable solutions.

In order to enhance the country's adaptive capacity to climate change, the country prepared The Gambia National Adaptation Programme of Action (NAPA) on Climate Change in 2007 and initiated the formulation of the National Adaptation Plan in 2015 with support from UNDP and UNEP identifying entry points for mainstreaming adaptation across selected sectors including Agriculture and Natural Resources and developing a roadmap with key stakeholders. In 2021, the country submitted the first NDC as part of The Gambia's ratification of the Paris Agreement in July 2016. With its first NDC and guided by the aspiration to achieve net-zero emissions by 2050, the country conducted a review of circular economy opportunities and applied a more comprehensive approach to its second NDC. The Gambia extended the sectoral coverage to include all greenhouse gas emissions, including forestry and waste. The adaptation section was also strengthened, including vulnerability analysis, envisaged adaptation action, and financial needs (The Gambia Climate Promise NDC Update Report, 2021). In the same year, the country published The Gambia 2050 Climate Vision (LTV), setting specific targets to become a climate-resilient, middle-income country through green economic growth supporting sustainable, low-emissions development to reach net-zero carbon emissions by 2050. The recently validated 2050 Climate Vision of The Gambia establishes the political aspiration for The Gambia to achieve net zero emissions by 2050, guiding the NDC2.

Aligned with these priorities, in July 2022, the Government of The Gambia expressed its interest in receiving support from the Scaling up Climate Ambition on Land Use and Agriculture (SCALA) programme, which supports countries to build adaptive capacity and reduce greenhouse gas emissions in order to meet targets set out in their National Adaptation Plans (NAPs) and nationally determined contributions (NDCs). The Government of The Gambia has applied explicitly for support from the SCALA PSE Private Sector Engagement (PSE) Facility, which aims to strengthen private sector participation in adaptation initiatives across selected non-SCALA countries. The SCALA PSE Facility offers targeted support through three broad service lines, which include: i) outreach, opportunity mapping, and facilitating multi-stakeholder engagement; ii) assessing risks and business opportunities; and iii) de-risking and enabling private investment.

The following paragraphs provide an overview of the situation in The Gambia, highlighting critical issues related to energy and waste management.

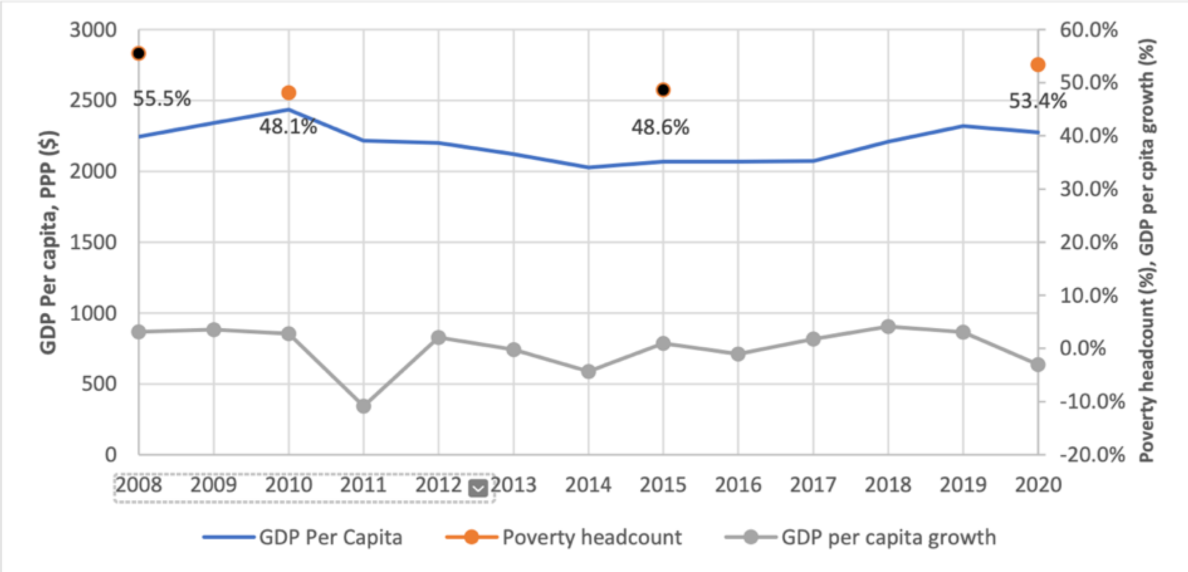
1.1 Country overview

The Gambia is the smallest country in mainland Africa, stretching 450 km along The Gambia River, and is one of the most densely populated countries on the Continent. The country's economy is undiversified, highly informal, and heavily dependent on imports, remittances, and tourism, with a small private sector. The main sectors driving economic growth are services, tourism, and agriculture, the latter accounting for close to 24 percent of GDP. Over two-thirds of Gambians reside in rural areas and derive their livelihoods mainly from agriculture and related activities. Agriculture is the primary source of income for over 70 percent of poor households and 90 percent of impoverished rural households. The agriculture sector, including forestry and fisheries, employs 9.2 percent of the working population and is mainly dependent on rainfall. This makes the economy vulnerable to the vagaries of the climate (MECCNAR, 2022; MECCNAR, 2021).

GDP growth is driven mainly by private consumption, whereas private or public sector investments contribute much less. Less than 5 percent of commercial banks' lending portfolio supports investments in the agriculture sector.

According to the World Bank (WB) (WB, 2014), Gambian households were hit hard by the COVID-19 crisis, leading to increased poverty.

Figure 1. Poverty and GDP growth trends- 2009-2020



Source: WB 2014

WB estimated that about 1.1 million Gambians were poor in 2020. In line with the increase in poverty, the average share of household expenditure on food increased slightly from 60 to 62 percent during this time. When measured against the international threshold for extreme poverty of US$2.15 per person per day, extreme poverty rose from 13.5 percent in 2015 to 21 percent in 2020 (**Figure 1**).

According to the Intergovernmental Panel on Climate Change, The Gambia is listed among the top 100 most vulnerable countries to climate change (IPCC). It is among the top 10 most vulnerable countries to coastal erosion, salinization and acidification of lowland soils, and sea-level rise worldwide. In recent years, the country has experienced increased frequency and intensity of drought, flooding, coastal erosion, windstorms, high temperatures, and intense and erratic rainfalls. These extreme weather events severely hinder the country's sustainable development and poverty eradication efforts. Droughts and floods are increasingly severe, resulting in reduced agricultural production and unsustainable extraction and exploitation of natural resources from forest ecosystems by rural households. In this sense, 85 percent of the domestic energy comes from fuel wood, which has destroyed forests and significantly contributes to adverse climate change effects. In addition, the rainy season and the erratic rainfall pattern impact farming systems, reducing the length of the growing period of rain-fed crops (MECCNAR, 2022).

1.1.1 Climate and agro-ecological zones

The influence of climate variability on traditional livestock production and agriculture in general might be obscure due to the small size of The Gambia. Nevertheless, the country can be divided into two distinct regional climate classifications:

- **Tropical Savannah:** This climate covers the western half of the country, encompassing coastal regions such as Banjul, the West Coast, the North Bank, and the Lower River Regions. The average annual temperature in this region is 25.6°C, and there is a single peak in average yearly rainfall ranging from 619 to 719 mm. The rainy season prevails from July to October. Humidity levels are generally low during the dry season (November–June) at around 47 to 56 percent, whereas they rise significantly during the rainy season, reaching 80 to 84 percent (Bahata, 2022).
- **Hot Semi-Arid (Sahelian Climate):** Encompassing the eastern half of the country, including Central River Region/North, Central River Region/South, and Upper River Region, this climate type has an average annual temperature of 28.9°C. The region experiences a single peak in average yearly rainfall, amounting to 675 mm. Throughout the year, humidity varies from 33 to 83 percent (Bahata, 2022).

The Gambia's climate is subtropical, with temperatures ranging from 29°C to 34°C. The country experiences a distinct rainy season from July to September, followed by a dry season from October to June. Notably, the country's eastern half tends to be slightly warmer and drier than the western part, resulting in varying climatic conditions.

Geographically, The Gambia is relatively flat, with about 75 percent of its landmass situated below an elevation of 20 meters above sea level (MASL). The highest elevations range from 53 to 60 MASL and can be found in regions such as the Lower River, Central River, and Upper River Regions.

1.1.2 National targets

The Gambia has set ambitious national targets to address climate change and transition to clean energy.

The Gambia has been developing a detailed transformational National Adaptation Plan (NAP) led by the Department of Water within the Ministry of Environment, Climate Change, and Natural Resources. In 2007, the country submitted its National Adaptation Programme of Action (NAPA), which addressed immediate to medium-term needs and highlighted existing gaps and vulnerabilities[1].

According to its national NDC, the country has committed to a conditional emissions reduction target of 49.7 percent by 2030 compared to a business-as-usual scenario. This target covers key sectors like agriculture, forestry, industry, energy, and waste. The country has developed a costed NDC implementation plan with 32 outcomes to achieve this.

[1] https://www.fao.org/in-action/naps/partner-countries/gambia/fr/

Looking further ahead, The Gambia has set a goal of reaching net-zero emissions by 2050 in its 2050 Climate Vision (MECCNAR, 2021). This vision outlines several key strategies, including:

- Progressively introducing clean and energy-efficient modes of transport, aiming for emissions reductions of 193.3 $GgCO_{2e}$ in 2030.
- Increasing the share of renewable energy to power the economy, targeting emissions reductions of 104 $GgCO_{2e}$ in 2030.
- Maintaining 30 percent of the country's land area under forest cover and implementing afforestation actions to achieve 330.5 $GgCO_{2e}$ in emissions reductions by 2030.

The Gambia's Long-Term Climate-Neutral Development Strategy 2050 further details the country's plans to transition the energy sector, including expanding solar, wind, hydropower, and biomass. This is crucial as The Gambia is highly dependent on imported fossil fuels, making it vulnerable to price volatility (MECCNAR, 2022).

1.2 Energy framework

In The Gambia, the achievement of green growth remains a challenge, as only 2.1 percent of the energy mix is from renewable energy (IRENA, 2023). Indeed, the energy landscape is characterized by significant reliance on fossil fuels, particularly oil, which accounts for 89 percent of primary energy sources. According to the World Bank, the country's annual energy demand is approximately 1,800 GWh, with an electrification rate of 51 percent (WB, 2023). Renewables constitute 11 percent of the primary energy sources for grid electricity. The grid extends over 1230 kilometers, covering 48 percent of the population. However, power outages are frequent, averaging 120 days per year, while maintenance is reported at a medium level. The grid's total capacity is 125 megawatts, as reported by NAWEC (NAWEC, 2022). Mini-grids are present at 30 sites across the country, providing localized energy solutions, while off-grid decentralized energy sources contribute 5 percent to the national energy supply, as indicated by NAWEC (NAWEC, 2022). This energy profile underscores The Gambia's ongoing challenges and opportunities in transitioning towards more sustainable and reliable energy systems to meet growing demand and enhance energy security.

According to the Country Strategy Paper 2021-2025 (ADB, 2021), the nation grapples with a pressing energy supply deficit, with electricity accessibility estimated at 56.2 percent for the general population and a mere 13 percent for rural areas.

At the national level, firewood is the primary and affordable household energy source, playing a central role in energy provision. While electricity generation and distribution are confined to coastal urban areas and select rural growth centers, natural gas adoption faces challenges due to its relatively high cost and limited popularity despite governmental efforts to enhance its viability and allure. In terms of individual household activities, an average of 0.17 cubic meters of wood consumption per capita annually has been estimated, underscoring the prevalence of firewood as a dominant energy source. Despite attempts to diversify energy options, firewood's importance remains unyielding in The Gambia's energy landscape (Jarju, *et al*. 2021).

The Renewable Energy Centre of The Gambia (GREC) operates under the auspices of the State Department for Trade, Industry, and the Environment (DOSTIE), tasked with spearheading renewable energy research, development, and promotion in conjunction with environmental initiatives. GREC is a pivotal technical support entity for the State Department of Forests, Natural Resources, and Environment. Despite the current lack of infrastructure to support advanced commercial endeavors, there are signs of improvement in the country. In particular, electricity accessibility in the Greater Banjul Area (GBA) has increased since the 2018 agreement between the Gambian government and Karpowership to deploy a 35-megawatts power ship until 2027 (ITA, 2022). Karpowership contributes to covering 60 percent of the country's total electricity demand. However, almost half of the population lacks access to electricity (ITA, 2022). Despite noteworthy operational and financial enhancements, the Electricity Company (NAWEC) has yet to achieve economic sustainability.

Within the energy sector, the potential for investment in electricity generation is considerable, given the projected demand surge. The country's national demand is anticipated to peak at 1.75 GWh by 2025, equivalent to an installed capacity of 200 megawatts. Limitations on the supply side have led to an increased demand for reliable generators and energy storage equipment, including inverters and renewable energy technologies. As the current transmission line deficiencies are addressed, investment prospects in electricity generation, particularly solar, wind, and bioenergy, are expected to play a key role in satisfying escalating energy requisites.

1.2.1 Policy and instruments supporting the development of renewable energy

National Energy Policy – Part II (Strategies and Action Plan) 2015-2020

The Renewable Energy sub-sector aims to promote and judiciously utilize renewable energy resources and technologies, thereby driving sustainable national development. This involves fostering the adoption of diverse sources like solar, wind, bioenergy (including biogas), and hydro. The goal includes increasing the share of renewable electricity generation as per the targets of the SE4ALL Initiative, facilitating renewable energy integration into the grid for cost savings and decentralized generation, and enhancing energy security through diversification and utility-scale projects. Furthermore, the sub-sector focuses on cultivating domestic production capacity for renewable technologies, conducting thorough environmental assessments, and ensuring that specific attention is given to developing biogas as a sustainable energy option. The Domestic Fuels/Household Energy aspect emphasizes sustainable fuelwood use, the devolution of forest management to communities, endorsing alternative fuels, advocating improved cooking stoves, heightening awareness about charcoal and firewood impact, developing information systems, and incentivizing private sector alternative fuel initiatives. Regarding

Environmental Sustainability, the emphasis is on comprehensive impact assessments for Energy Policy investments and building agency capacities for effective environmental management plan execution.

The Gambia's Electricity Sector Roadmap (2019-2025)

The ongoing Gambia River Basin Development Organization (OMVG) project will help bridge the country’s power supply gap by providing an additional 14 megawatts of hydroelectric power by end-2021. The Gambia's Electricity Sector Roadmap (2019-2025) aims to amplify electricity generation, targeting an available peak capacity of 200 megawatts by 2025. This ambitious vision encompasses 14 megawatts from the collaborative OMVG project involving Guinea and Senegal, along with an additional 50 megawatts from the Souapiti initiative, complemented by contributions from Independent Power Producers (IPPs) (ADB, 2021). Moreover, the roadmap prioritizes investments in transmission and distribution infrastructure, aiming to curtail power losses from 22 percent in 2020 to 17 percent by 2025. The strategy aspires to drive down electricity tariffs from US$/kWh 0.26 in 2020 to US$/kWh 0.18 by 2025. A pivotal goal of the plan is to attain 40 percent renewable energy integration by 2030. This objective hinges on a synergy of grid extension, mini-grids, and, notably, the inclusion of the OMVG hydropower project (ADB, 2021).

New Global Gateway grant

During the 5th Conference for Least Developed Countries at the United Nations (UN), an important partnership was unveiled. The Republic of The Gambia, in collaboration with the European Union (EU) and the European Investment Bank (EIB), proudly announced the formalization of a significant grant amounting to 24.08 million Euro from the EU Global Gateway initiative. This grant will work in tandem with an 8 million Euro EIB loan (EC, 2023). The primary objective of this financial support is to bolster the realization of a comprehensive renewable energy program encompassing both on-grid and off-grid generation and transmission and distribution networks throughout The Gambia. Anticipated to be transformative, this initiative holds the promise of revolutionizing electricity accessibility within rural communities across the nation. One of its key aims is to ensure that essential sectors such as education and healthcare can harness the benefits of dependable and environmentally friendly power sources. With a specific focus, the project is set to illuminate over 1,000 schools and 100 health centres located in remote areas of The Gambia. Presently constrained by limited access to electricity, these vital institutions are poised to thrive with the infusion of a steady energy supply. This will be achieved through the introduction of fresh connections to the national energy grid, as well as the provision of cutting-edge off-grid solar installations and battery systems (EC, 2023).

Vision 2050

In 2021 The Gambia published The Gambia's 2050 Climate Vision. In this comprehensive national document, The Gambia outlines its 2050 Climate Vision as a roadmap for guiding and stabilizing national efforts. This vision aims to inform short- and medium-term actions, such as policy initiatives and program interventions, that are in line with the Paris Agreement's call for long-term strategies for low greenhouse gas emissions and climate resilience. The primary goal is for The Gambia to become a climate-resilient, middle-income country by 2050, achieving sustainable, low-emission economic growth and contributing to global climate efforts.

The main objectives are:

- Achieving net-zero carbon emissions by 2050 with enhanced adaptive capacities and resilience, involving vigorous public efforts and citizen engagement.
- Acting urgently to address the significant challenges posed by climate change.
- Transforming The Gambia into an environmentally conscious nation, well-educated in sustainable development and natural resource management.

A key component of The Gambia's strategy for reducing emissions is adopting renewable energy technologies. The Gambian government outlined 28 specific renewable energy and energy efficiency targets for 2020 and 2030 in its Sustainable Energy Action Plan to achieve its conditional targets and attract international investors. Despite a slow start, progress is now evident. The existing policy framework, supported by the Renewable Energy Act, sets a 30 percent renewable energy goal in the national power mix by 2030. In March 2019, The Gambia launched its first large-scale photovoltaic project, delivering 20 megawatts of solar energy and 400 km of distribution. Remarkably, The Gambia has become the first country in Africa, and potentially the world, to provide renewable energy electrification to all 1,000 public schools and 100 health facilities, funded by the European Investment Bank[2].

National Feed-in tariff (2022)

In June 2022, The Gambia took a leading role in the regional energy transition by validating its feed-in tariff (FIT) and net metering scheme by the new Minister of Petroleum and Energy, H.E. Abdoulie Jobe. This scheme automatically qualifies any stakeholder with renewable energy generation capacity between 20 kW and 1.5 megawatts, paying them US$ 0.25 per kWh for surplus energy fed into the national grid every one to three months. Producers with a capacity exceeding 1.5 megawatts are encouraged to sign 15-year power purchase agreements with the national water and electricity company, NAWEC, allowing low-carbon power adopters of all sizes to contribute to the diversification and decentralization of the grid power supply. This significant step comes as The Gambia seeks to improve its 48 percent energy self-sufficiency and 60 percent electrification rate[3].

1.2.2 Examples of existing biogas facilities

The Gambia's first biogas plant is in Sukuta (**Figure 2**). This ground-breaking project, donated by Indian companies URJA Bio SYSTEMS from Pune and their West African partners TRISP Africa, was handed over to the Sukuta Health Centre and the local community. The primary objectives were to provide access to renewable energy and to establish a pioneering example that could inspire both the private sector and the government to embark on larger-scale renewable energy ventures. The plant is fed

[2] https://www.fao.org/faolex/results/details/fr/c/LEX-FAOC208266/
[3] https://energycapitalpower.com/the-gambia-net-metering-renewable-energy/?utm_content=216274832&utm_medium=social&utm_source=facebook&hss_channel=fbp-105729815176773

approximately 50 kg of cow dung/day and generates around two cubic meters of biogas daily, equivalent to about 1.2 kilograms of LPG daily. This energy resource is used to meet the cooking energy needs of the Sukuta Health Centre.

Figure 2. First-ever biogas plant in The Gambia (June 2024)

Another example is the artisanal biodigester operated by the M'bolo Association in The Gambia (**Figure 3**). M'bolo Association, a secular non-profit organization and delegation of Africa M'bolo for The Gambia and Senegal, embodies the Wolof concept of "Join" or "Come together," emphasizing collaborative efforts toward sustainable social and human development with cultural, social, and environmental respect.

Figure 3. Artisanal biodigester at M'bolo (June 2024)

Mbolo Association conducts training programs for women and youth in renewable energy, focusing on solar PV installation and system planning. Currently, Mbolo is engaged in a waste-to-compost project in collaboration with the EU delegation in The Gambia, assessing waste from 12 vegetable and fish markets nationwide.

1.3 Current challenges and study objectives

In The Gambia, the private sector faces significant challenges in waste management across various industries, including agriculture, food processing, livestock, and other manufacturing sectors. Two primary issues have been identified: (i) an ineffective waste disposal system and (ii) a lack of specific attention towards waste disposal issues. These problems stem from the absence of structured mechanisms to manage waste efficiently, such as segregated waste collection and proper disposal techniques. This inefficiency hampers environmental sustainability and poses health risks to the community.

One of the primary challenges is establishing systems that facilitate effective waste disposal, including:

- Implementing waste segregation processes.
- Setting up recycling and/or Waste-to-Energy (WtE) facilities.
- Developing waste management infrastructure.

Additionally, as previously discussed, the country grapples with challenges related to energy scarcity and unreliability. Many regions experience frequent power outages and depend heavily on unsustainable energy sources like firewood and charcoal. This exacerbates the environmental impact and underscores the need for alternative energy solutions.

Addressing these challenges requires concerted efforts and collaboration among various stakeholders. In July 2022, The Gambia requested support from the SCALA programme and its Private Sector Engagement Facility initiative to enhance their adaptive capacity and cut GHG emissions in line with their NAPs and NDCs.

To strategically contribute to the NDC, The Gambia 2050 Climate Vision (LTV) and the National Development Plan (2023-2027), including the substitution of firewood and charcoal from non-renewable sources for cooking, and the creation of biogas facilities by 2030, The Gambia requests assistance to conduct a country-wide biogas resource potential assessment, and three financial cost-benefit analyses, assessing the potential of a small, a medium and a large scale biogas productions in the country.

The biogas resource potential assessment provides clear backstopping on achievable GHG mitigation contributions from the sector and associated costs and benefits.

Consequently, the objective of this study was to evaluate the feasibility and impact of biogas as a solution to The Gambia's waste management and energy challenges. This included assessing biogas resource availability, analysing the economic viability of various scales of biogas projects, and fostering collaboration among stakeholders. It is also aimed to provide an indication of biogas's potential contribution to adaptation through increased livelihood opportunities and household resilience due to improved waste management and renewable energy generation.

Moreover, the project also aimed to bring together key players from the private sector, government, banks, and municipalities to create a dialogue on potential waste management alternatives. The main objective was to foster cooperation and explore sustainable and profitable solutions, such as biogas investments. By developing case studies (see **Chapter 4**), the project demonstrated that investing in biogas and other sustainable waste management practices can be both economically viable and environmentally beneficial.

1.4 Technology overview

Biogas technology is a process that converts organic waste into a renewable energy source called biogas (Kabevi, 2022). It involves anaerobic digestion, a natural process where microorganisms break down biodegradable materials such as agricultural residues, livestock manure, food industry by-products, and other organic wastes. This process occurs in a controlled environment without oxygen, facilitated by microorganisms called methanogens (Mengistu, 2015). The biogas produced is primarily composed of methane (CH_4) (50-70 percent) and carbon dioxide (CO_2), with small amounts of other gases like hydrogen sulfide. This biogas can be used for various purposes, including:

- Generating heat and electricity through combustion.
- Fuelling vehicles after compression and purification.
- Cooking and heating in households, especially in developing countries.

One of the significant advantages of biogas technology lies in its ability to efficiently manage organic waste streams. By converting these residues into biogas, the technology mitigates greenhouse gas emissions that would otherwise occur from the decomposition of organic matter in landfills or open environments. This not only reduces environmental pollution but also decreases the reliance on non-renewable fossil fuels, contributing to sustainable energy and waste management practices.

Moreover, biogas technology plays a crucial role in enhancing resource efficiency by producing a valuable by-product known as digestate. This nutrient-rich material can be used as organic fertilizer, thereby improving soil quality and agricultural productivity. In agricultural contexts, this dual benefit of energy generation and organic waste management is particularly significant, offering a sustainable solution that supports both environmental and economic goals. The biogas technology is scalable and can be applied to different sectors and sizes, from small-scale household digesters to large-scale farm and municipal waste treatment plants. In developing countries, domestic biogas plants are often suitable for smallholders with livestock, providing clean cooking energy and organic fertilizer (Abanades, 2022).

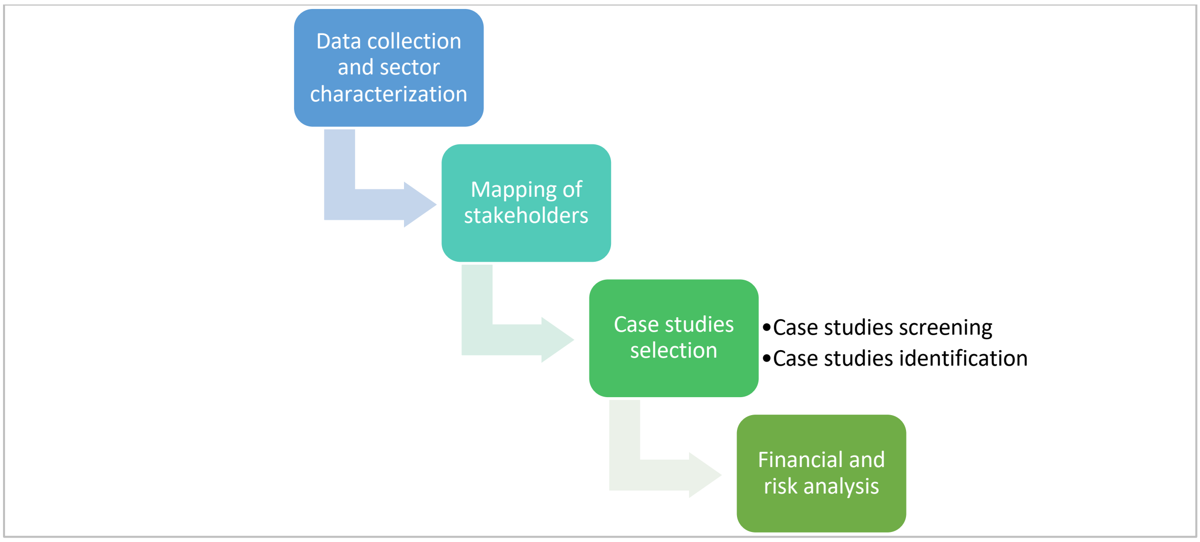
A wide array of biogas digester technologies exists on the market in various sizes, designs, and configurations (UNHCR, 2024). The most common types include continuous wet digestion systems, which operate by receiving daily inputs of fresh feedstock into an active bioreactor filled with high-water-content material. The waste material forms a slurry and flows like a fluid. The active bioreactor remains consistently full (steady-state system), with fresh material entering as digestate leaves.

1. **Fixed-dome plant**: This design features a rigid cylindrical bioreactor with a gas-holder dome. Gas produced is stored in the dome, increasing pressure when the outlet valve is closed, pushing digestate into an expansion chamber. Opening the valve for gas use decreases pressure, allowing slurry to return to the bioreactor. Typically built underground for temperature stability, it requires skilled construction due to gas tightness and is considered permanent infrastructure.
2. **Floating-drum biogas plant**: Consisting of a cylindrical bioreactor and a movable gas drum, gas produced lifts the drum, indicating gas production visually. The drum's weight creates gas pressure, which is adjustable by adding weights. It offers flexibility in gas storage capacity based on production and usage.
3. **Tubular polybag digester**: Utilizes a longitudinally shaped plastic or rubber bag as both bioreactor and gas holder. Slurry flows through in a plug-flow manner, avoiding short-circuiting. Gas pressure can be adjusted by adding weights, but the bag is fragile and needs protection from mechanical damage and sunlight. It's cost-effective but has a limited lifespan.
4. **Concrete digesters with balloon gas holders**: Primarily for large-scale systems, featuring aboveground concrete or steel bioreactors with flexible gas holders. Mixing pits for feedstock homogenization are common, often equipped with mixing tools and pumps. These digesters are robust but require substantial initial investment and maintenance.

2 APPROACH AND METHODOLOGY

The approach comprised four key steps. Initially, a thorough characterization of the sectors involved and the types of residues generated was conducted using primary data from field surveys and secondary data from existing reports. This step involved detailed data collection and analysis to understand the quantity, quality, and sources of the residues. The next step involved mapping the relevant stakeholders. Key stakeholders in The Gambia across various sectors, including government agencies, private companies, non-governmental organizations, and community groups, were identified and listed to understand their roles, interests, and influence. Among the selected stakeholders, potential case studies were identified. This selection was based on visits and assessments conducted during the mission. The goal was to find representative examples that could provide valuable insights and lessons for the study. Finally, environmental and financial analyses were performed. The environmental analysis used primary data from site assessments to evaluate biogas plant impacts, while the financial analysis, incorporating both primary and secondary data, assessed economic viability and investment needs.

Figure 4. Steps of the analysis



2.1 Data collection and sector characterization

The first step involved thoroughly characterizing the sectors involved and the types of residues generated. This process began with detailed data collection to understand the quantity, quality, and sources of organic residues that could be used for biogas production. The data collection focused on agricultural production, livestock farming, and agri-food industry outputs at both regional and country levels. Some of this information was gathered according to secondary literature, while other details were obtained through primary data collection according to data availability. Data collection considered data at both the national and regional levels, covering different areas of the countries. The origin of secondary data collected was mainly national statistics, FAOSTAT, sectoral reports, and national statistics from ministries and UN agencies, which are reported in the reference chapter of this report. An Excel data collection tool, followed by a database, was developed to capture comprehensive information from various business sectors.

2.2 Mapping of stakeholders

The next step involved mapping the relevant stakeholders across various sectors in The Gambia and understanding the biogas ecosystem. This included identifying and listing key stakeholders such as government agencies, private companies, civil society organizations and community groups, investors, and research institutions. Understanding the roles, interests, and influence of these stakeholders was crucial for developing effective engagement strategies.

Data collectors used a structured questionnaire to gather information on the stakeholders, including their contact details, roles, and perspectives on biogas production. The database gathered data on crop production volumes, livestock types and numbers, and the quantities and types of waste generated. It also inquired about current waste management practices, such as whether residues were composted, burnt, sold, or otherwise utilized. Data collectors were trained to administer the survey across different regions of The Gambia, ensuring broad coverage and the inclusion of diverse business types. The questionnaires were administered using *WhatsForm*, ensuring real-time data entry and submission via mobile. Collectors were located across different regions, including urban and rural areas, to capture a wide range of stakeholder views. The locations and names of the data collectors were documented, and their efforts were coordinated to ensure comprehensive coverage. To visually represent the scope of the data collection efforts, a GIS-based map was developed (**Annex 1**), highlighting the visited locations. This map provided a clear overview of the areas covered during the data collection process, illustrating the geographical distribution of stakeholders and the breadth of the study. **Annex 2** provides a graphic overview of the 72 identified stakeholders.

2.3 Case studies selection

2.3.1 Stakeholders screening

Among the 72 identified stakeholders, eight sites were selected for further assessments based on their relevance and potential for biogas production. Field visits were organized (during a scoping mission in the country) to conduct on-site assessments. The identified sites are listed below:

1. Abuko – Livestock Market and Slaughterhouse.
2. Brikama – Livestock Market and Slaughterhouse.
3. GFirm Poultry and Diary.
4. Alminteh Poultry farm.
5. Bakoteh fish and vegetable market.
6. Bakoteh dumpsite.
7. ECOSOIL organic fertilizers and TROPINGO food industry.
8. Lamjaidy Dairy Farm.

2.3.2 Identification of case studies

The final step of the selection, based on the detailed information collected during the field visits, was to select 4 case studies, ultimately chosen for a detailed feasibility assessment.

The selected case studies considered private and public businesses of different sizes, covering small-scale, medium-scale, and large-scale operations. This allowed the study to cover a broad spectrum of biogas production scenarios.

The analysis did not include small-scale production at the household or small farm level. During the multistakeholder consultations, it was repeatedly reported that in past experiences, this technology has yet to find continuity of use in small-scale businesses. This was due to two primary reasons: firstly, small private entities generally lack the financial capacity to cover the initial investment, with a basic small biogas system costing approximately starting from US$5,000. Secondly, past experiences indicate that when these entities acquire such technology through grants or without personal financial investment – equity or loans - they often struggle to maintain these systems. Likely, this is, in turn, also due to the lack of training on anaerobic digestion management. Such insights have been reinforced during discussions with government officials and research centres.

The cases chosen included:

1. *Small-scale:* ***GFirm Farm***
   Poultry and dairy livestock farm
   Biogas to replace electricity and diesel expenses + surplus to national grid

2. *Medium-scale:* ***Abuko Market***
   Livestock Market and Slaughterhouse
   Biogas to replace firewood, electricity and diesel expenses

3. *Medium-scale:* ***Bakoteh Market***
   Fish and vegetable market
   Biogas to replace firewood, electricity + surplus to national grid

4. *Large-scale:* ***Bakoteh dumpsite***
   National dumpsite
   Biogas to produce electricity for the national grid

These case studies were selected for their relevance to the biogas sector, based on factors such as the type and volume of residues generated, existing waste management practices, and the readiness of stakeholders to engage in biogas projects.

A full assessment of these case studies, including detailed findings and analyses, is provided in **Chapter 4** of this report. The case studies that were not selected for the analysis are briefly described in the same chapter as well.

2.4 Financial and risk analysis

This assessment employs a standard Cost-Benefit Analysis (CBA) approach to unveil potential net profits, with the aim to:

- Evaluate the consolidated investment's profitability, comparing scenarios with the project (WP) against those without (WoP).
- Gauge the profitability for investors.
- Outline cash flows that form the foundation for calculating socio-economic costs and benefits.

Aligned with the CBA framework outlined by the European Commission, impact categories were identified and associated with the alternative scenario involving biofuel production within the respective countries. However, impacts beyond the countries' borders, such as global market distortions, were not taken into consideration. Reference values, conversion factors, prices, and other pertinent information vital for the analysis are presented in **Table 1**, details of which can be found in the respective sections.

The annual net benefits of producing biogas can be expressed as follows:

$$\pi b(Q) = Pb(Qb) - (wLb + fFb + nNb + eUb - mMb)$$

Table 1. Considered variables for the annual net benefits of producing biogas

Symbol	Description
b	Biogas
πb(Q)	Annual net benefits.
Pb	Price of biogas as the final product in the market
w	Unit wages
Lb	Quantity of labour force (salary)
f	Unit price of feedstock (if feedstock is purchased)
Fb	Quantity of feedstock required per unit of biogas production
n	Per unit cost of inputs
Nb	Related inputs
e	Price of utilities, including electricity, biogas, and coal
Ub	Miscellaneous
m	Market price of by-products
Mb	Number of by-products generated during the digestion process

Cost figures have been collected through surveys from the National Consultants to the case study farm based on a set of data collection sheets provided by the team of FAO International Consultants. Following up on this first round of data collection, the review of the data and their interpretation of the preliminary understanding of cost conditions needed to be researched further. Figures were reported originally in local currency, these have then been converted to USD using the average exchange rate of June 2024 (UN conversion Dallasis/Dollars).

The methodology employed capital costs in biogas-to-electricity conversion systems to calculate the capital expenses (CAPEX), encompassing several (critical) stages and ensuring a comprehensive assessment of expenses (**Annex 3**).

5. **Pretreatment**: This phase addresses the initial processing requirements dictated by the diverse properties of the feedstock used in biogas systems. Variations in total solids necessitate specific dilution rates and pretreatment techniques, such as hygenization, crushing, and homogenization, to optimize the substrate for subsequent digestion.
6. **Equipment**: The analysis includes a detailed inventory of all necessary units for converting feedstock into biogas, its purification, and generating electricity. The considered equipment includes:
    - Continuous Stirred Tank Reactor (CSTR) digester
    - Effluent storage pool
    - Buffer tank
    - Odor control system
    - Metering pumps
    - Additional pumps
    - Trommel screen
    - Mixers
    - Post-digestion tank (for gravity separation)
    - Gas collection equipment
    - Desulfurizing tower
    - Reciprocating engine
3. **Building and installation costs**: This component accounts for the expenses associated with expanding existing facilities to house the biogas and electricity generation systems, reflecting the infrastructural investments required for such enhancements.
4. **Electricity distribution system**: When electricity surplus is sent to national grids, the costs for this equipment were derived from the FAO BEFS RA Tools[4], specifically from the biogas industrial module. To ensure the data's relevance, these costs were updated using the Intratec cost index for 2023, which adjusts for inflation and market changes by comparing the index values of the target year with those from the original data collection year. The feedstock composition profoundly influences the pretreatment requirements and associated costs. Manure-based systems demand dilution and mixing, along with other pretreatment steps, whereas wastewater-derived substrates are typically pre-diluted, reducing pretreatment needs. Additionally, the methane content in the biogas varies, with small and medium systems yielding

[4]https://openknowledge.fao.org/server/api/core/bitstreams/872b9901-a271-406a-b1b9-d96fb81efb02/content

around 60 percent methane, compared to 73 percent in large systems. This higher purity in large systems reduces purification requirements and thus lowers costs.

Following the methodology elucidated in the Guide to Cost-Benefit Analysis of Investment Projects by the European Commission (EC, 2014), the determination of investment revenues and expenditures facilitated the assessment of project profitability. This measurement is characterized by the financial net present value (NPV) and financial internal rate of return (IRR) on investment. Financial discount rates were identified as advised by discussions with local commercial banks. Notably, salvage values attributed to key investments contribute to the calculation of NPV and are integrated into the final year's cash flow (Sn) (**Table 2** and **Table 3**).

The formula for calculating NPV is as follows:

$$NPV = \sum_{t=0}^{n} a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_n}{(1+i)^n}$$

Table 2. Variables of the financial Net Present Value NPV

Symbol	Description
s	Annual financial net benefit
t	Time
at	Financial discount factor
i	Financial discount rate

While the IRR is given by the following equation:

$$\mathbf{0} = \sum \frac{\boldsymbol{S_t}}{(\mathbf{1} + \boldsymbol{FRR})^{\boldsymbol{t}}}$$

Table 3. Variables of the financial Internal Rate of Return IRR

Symbol	Description
S	Balance of cash flow
t	Time
at	Financial discount factor
i	Financial discount rate

The sensitivity analysis allows for the identification of the critical variables with the largest impact (positive, negative) on the project (risk analysis). A variable is defined as critical when a variation of ±1 percent in its initial value gives rise to a variation of more than ±1 percent in the value of the NPV (EC, 2014). Switching values were calculated and a scenario analysis was completed combining the critical values.

3 ASSESSMENTS OF THE STUDIED SECTORS

3.1 Agriculture and livestock

This section provides an overview of the agriculture sector in The Gambia, considering both crops and livestock. The intention is to create a comprehensive understanding, covering various aspects of agricultural activities in the region.

Figure 5. Livestock market in Serekunda area (June 2024)

3.1.1 Overview

Agriculture: According to the International Institute for Applied Systems Analysis (IIASA) (IIASA, 2023), The Gambia relies strongly on agriculture, but the sector is plagued by significant environmental and socio-economic challenges that threaten the livelihoods of local people, leading to poverty, malnutrition, and related health issues. Crop production, mainly subsistence and rain-fed, is marked by persistent declines in productivity for key staples like rice, maize, groundnut, and millet. Recent decades have seen a rise in adverse climatic events, further impeding agricultural output in The Gambia and widening yield gaps compared to neighbouring West African countries. Additionally, the country's heavy reliance on food imports, including over 80 percent of its rice consumption, leaves its food system vulnerable to external shocks. Any climatic or socioeconomic disruptions in rice-exporting countries can severely impact The Gambia's food supply and nutritional security.

In 2021, The Gambia's agricultural landscape, as outlined by FAOSTAT figures (**Table 4**), revealed a variety of crops cultivated within the nation. These crops provide insights into the agricultural dynamics of the country, showcasing both its potential and challenges. Among the crops, rice stood out with a production of 41,900 tonnes annually from an area of 65,000 hectares, underscoring its role as a staple food source. Millet, cultivated across 100,000 hectares, yielded 36,000 tonnes, reflecting its enduring presence in The Gambia's agricultural activities. Oil palm fruit, covering 3,511 hectares, exhibited a yield of 9,989.7 kilograms per hectare. Groundnuts, with an output of 35,000 tonnes from 40,000 hectares, played a significant role in The Gambia's agricultural output. In parallel, maize reported a production of 20,000 tonnes from 35,000 hectares, emphasizing its importance as a pivotal crop. The agricultural panorama extended further, encompassing crops like cassava, diverse vegetables, fruits, and more, each with distinct production figures that collectively contribute to The Gambia's food security.

Table 4. Crops production (tonnes/year), cultivated surface (ha) and related yields (Kg/ha) in The Gambia in 2021

AGRICULTURE			
CROP	**Production [tonnes/year]**	**Area harvested [ha]**	**Yield [Kg/ha]**
Rice	41,900	65,000	644.6
Millet	36,000	100,000	360.0
Oil palm fruit	35,071	3,511	9,989.7
Groundnuts, excluding shelled	35,000	40,000	875.0
Maize (corn)	20,000	35,000	571.4
Other vegetables, fresh n.e.c.	12,991	2,072	6,269.7
Cassava, fresh	11,827	2,948	4,012.0
Other fruits, n.e.c.	8,220	1,628	5,050.6
Sorghum	6,000	10,000	600.0
Cashew nuts, in shell	2,741	1,647	1,664.0
Sesame seed	2,713	7,000	387.5
Other pulses n.e.c.	2,402	11,867	202.4
Mangoes, guavas and mangosteens	1,421	268	5,311.0
Cereals n.e.c.	787	3,363	234.0
Seed cotton, unginned	543	1,561	348.0
TOTAL	**217,616**	**285,865**	

Source: FAOSTAT 2024

While these figures shed light on The Gambia's agricultural output, it is evident that challenges, such as enhancing yields and addressing climate-related risks, persist. These statistics offer valuable insights into the diverse agricultural landscape of The Gambia, emphasizing the critical need for sustainable practices to safeguard food security and its population's livelihoods.

Livestock: production is primarily traditional and small-scale, lacking a strong commercial focus. This sector is marked by inadequate management practices, low productivity, limited off-take rates, and a high prevalence of diseases, which collectively contribute to elevated mortality rates across all livestock species (Bahta, 2022).

Figure 6. Milking cows in Serekunda areas (June 2024)

According to FAOSTAT, in the year 2021, The Gambia's livestock production presented a diverse range of primary and processed products. The production of raw cattle milk reached 75,379 tonnes, underscoring its significance as a primary dairy product. Additionally, 4,321 tonnes of fresh or chilled cattle meat were processed, alongside 1,630 tonnes of fresh or chilled chicken meat, contributing to the meat industry. Hen eggs in shell added another dimension with 1,007 tonnes, emphasizing the importance of poultry. Fresh or chilled goat meat accounted for 892 tonnes, while 830 tonnes of edible cattle offal were processed, further diversifying the meat products. Pig meat, amounting to 505 tonnes, contributed to the pork industry (**Table 5**).

Table 5. Primary and processed livestock production (tonnes/year) in The Gambia in 2021

AGRICULTURE	
CATEGORY	**Production [tonnes/year]**
Raw milk of cattle	75,379
Meat of cattle with the bone, fresh or chilled	4,321
Meat of chickens, fresh or chilled	1,630
Hen eggs in shell, fresh	1,007
Meat of goat, fresh or chilled	892
Edible offal of cattle, fresh, chilled or frozen	830
Meat of pig with the bone, fresh or chilled	505
Raw hides and skins of cattle	501
Meat of sheep, fresh or chilled	311
Edible offal of goat, fresh, chilled or frozen	214
Cattle fat, unrendered	130
Raw hides and skins of goats or kids	114
TOTAL	**87,396**

Source: FAOSTAT 2024

Raw hides and skins of cattle and goats were processed, yielding 501 tonnes and 114 tonnes respectively, highlighting the utilization of these byproducts. Similarly, 311 tonnes of sheep meat and 214 tonnes of edible goat offal demonstrated the comprehensive nature of livestock processing. Cattle fat, unrendered, added 130 tonnes to the production mix, showcasing the utilization of various parts of the animals. Overall, The Gambia's livestock production in 2021 displayed a multifaceted industry catering to both meat and non-meat products (**Table 5**).

According to The Gambia Livestock Analysis published by the International Livestock Research Institute (ILRI) (Bahta *et al*, 2022), the bulk of livestock production occurs in predominantly traditional and small-scale settings, often lacking a commercial orientation. This scenario is marked by suboptimal management, low productivity, low off-take rates, and a high incidence of diseases, leading to elevated mortality rates across all livestock species. Cattle production plays a crucial role in the agropastoral/mixed farming system, contributing essential resources such as manure, milk, meat, and serving as a reserve income source for fulfilling sociocultural and other obligations. The following production systems are practiced:

- **Extensive system**: This prevalent system integrates livestock and crop production (mixed farming). It relies on indigenous breeds with limited productivity (N'Dama and Gobra/zebu), often lacking improvement programs. Transhumance and internal migration are common practices during the dry season to locate suitable pastures and water sources.
- **Semi-intensive system**: Selected animals, including draught animals, receive supplementary feeding through agro-industrial by-products and crop residues to enhance meat, milk, manure, and draught power.
- **Intensive system**: Mainly implemented in urban and peri-urban areas, this system employs pure breeds (primarily European breeds) and crosses of N'Dama and European breeds to boost overall productivity in terms of both milk and meat. The utilization of artificial insemination (AI) is a common practice for performance improvement.

3.1.2 Residues and waste potential

Agriculture: According to FAOSTAT data, the country cultivates and processes a great variety of agricultural crops, leading to the production of both agricultural residues and processing by-products. Agricultural residues and by-products have gained significant attention as valuable resources in sustainable energy production. When combined with animal manure, they offer a promising basis for producing biogas. Besides, by combining animal manure with agricultural residues and by-products, a synergistic effect may be achieved. The mixture balances the nutrient composition and improves the digestion process, leading to more efficient biogas production while reducing methane emissions. Specifically, the Carbon-to-Nitrogen ratio (C/N ratio) is a key factor in biogas production through AD. It represents the balance between carbon and nitrogen in organic material. The microorganisms breaking down the material need both elements, but in specific proportions. An optimal C/N ratio (around 20:1 to

30:1) supports efficient digestion (Khanal, 2019). Too much carbon with respect to nitrogen slows down the process, while excess nitrogen can be toxic. Agricultural residues, with high carbon content, are often added to manure to balance this ratio. This boosts biogas production by providing the needed carbon and optimizing microbial activity.

At the national level, large amounts of rice straw and husk per year are produced, with 40 percent used for animal feed and compost, leaving 60 percent unused, indicating significant potential for bioenergy (primary data from field collection). Similarly, for millet leaves and stems, 40 percent used for animal feed and compost, leaving 60 percent unused, indicating significant potential for bioenergy (primary data from field collection). Oil palm fruit, with an annual quantity of around 35,000 tonnes (FAOSTAT, 2024), sees only 30 percent used for animal feed, leaving 70 percent available for alternative uses(primary data from field collection). Groundnuts and maize residues, both critical in the agricultural sector, are utilized for animal feed and sale with 60 percent usage and 40 percent remaining available, highlighting moderate opportunities for bioenergy (primary data from field collection).

According to the primary data collected from field, vegetable leaves are largely collected by municipalities, with 52 percent used and 48 percent remaining. Cassava leaves and stems, amounting to 60,000 tonnes annually, are primarily thrown away or used for cooking, with an even split between usage and waste. Sorghum straw, with a quantity of 40,000 tonnes per year, is used for fencing and animal feed at a rate of 50 percent, indicating a balanced usage and potential for bioenergy exploitation. Cashew nut shells and sesame cake, at 10,000 and 15,000 tonnes per year respectively, have higher rates of disposal (80 and 70 percent unused), suggesting significant untapped potential for bioenergy. Cereals straw, with 70,000 tonnes per year, is mostly unused (80 percent), offering substantial opportunities for alternative uses. Cotton stalks, at 20,000 tonnes per year, are used for animal feed at a rate of 30 percent, with the remaining 70 percent unused.

Regionally, Banjul, with no significant farming areas, shows limited availability for bioenergy. In contrast, the Central River, Lower River, North Bank, Upper River, and West Coast regions demonstrate more significant potential. For instance, in the Central River region, rice straw and husk, millet leaves and stems, and groundnuts are predominantly used for animal feed and compost, with 70 percent available for bioenergy. Similarly, in the Lower River and North Bank regions, significant portions of rice straw, millet, oil palm fruit, and groundnut residues are used for animal feed and sale, but with consistent 70 percent availability for bioenergy. The Upper River and West Coast regions follow similar patterns, with notable quantities of agricultural residues available for bioenergy.

Overall, the data highlights a considerable potential for bioenergy across various regions, with significant portions of agricultural and livestock residues currently unused or underutilized. This presents opportunities for enhancing bioenergy production, thereby contributing to sustainable energy solutions and waste management.

Livestock:_Livestock residues, including cattle and sheep manure and waste generated from slaughterhouses, represent a significant yet underutilized resource in composting and bioenergy production. Though produced in smaller quantities than agricultural residues like crop stubble or forestry by-products, these organic materials have substantial potential. According to information collected from the primary data collection, markets, slaughterhouses, and livestock farms in The Gambia sell their manure only partially and exclusively during the dry season. This seasonal limitation indicates that a considerable amount of manure remains underutilized for the rest of the year, representing a missed opportunity for consistent composting and bioenergy production. This practice limits the potential benefits of manure as a resource and highlights the need for better management and utilization strategies to harness this valuable organic material year-round. The study considered livestock residues in two of its case study sites.

3.1.3 Energy demand and barriers

Agriculture: Energy demand in the agricultural sector is driven by various activities, incorporating irrigation, mechanized farming, processing of agricultural products, and storage. In The Gambia, the sector is strongly dependent on traditional energy sources. Indeed, firewood is widely used in the country for cooking, crop drying, and other agricultural processes, contributing to deforestation and environmental degradation. According to FAO, 84 percent of domestic energy in The Gambia comes from firewood[5]. Moreover, in the country, diesel generators are commonly employed for irrigation and powering machinery, with high associated operational costs and GHG emissions.

The limited access to reliable electricity further worsens the energy challenges in the agricultural sector in The Gambia. In fact, many rural areas lack connection to the national grid, and those connected often experience frequent power outages, averaging 120 days per year. This irregularity in power supply interrupts agricultural operations, affecting productivity and crop yields. The high cost of renewable energy technologies is another substantial barrier for the country. Despite the potential of solar and biogas technologies to provide sustainable energy solutions, the initial capital investment required for their installation is often too expensive for smallholder farmers. For instance, constructing a small-scale biogas plant in The Gambia may require an investment of up to US$10,000, which is beyond the financial capacity of many local small-scale farmers. Access to finance and subsidies is essential to promote the adoption of these technologies.

Furthermore, farmers in the country lack technical knowledge and capability regarding the utilization of renewable energy solutions. Many farmers need to become more familiar with the benefits and operation of technologies like solar-powered irrigation systems and biogas digesters. To address this, targeted training and capacity-building programs are essential.

[5] https://www.fao.org/4/X6790E/X6790E05.htm#:~:text=Based percent20on percent20household percent20activities percent20alone,meters percent20of percent20wood percent20per percent20annum.

Livestock: As known, energy is essential also in the livestock sector, primarily for water pumping, cooling for dairy products, feed processing, and waste management. Also in this case, in The Gambia, the sector relies heavily on diesel generators, while renewable energy solutions remain prohibitively expensive and technically challenging for many local farmers.

3.2 Food industry

3.2.1 Overview

Food processing involves transforming raw agricultural commodities into processed foods. This includes activities such as grinding grains, preserving fruits and vegetables in cans, and processing meat and dairy products. In The Gambia, the food processing industry encompasses several key sectors crucial to the economy. Millet processing involves aggregators collecting from farmers, with processors de-husking and milling grains using traditional and motorized methods. Industrial processors like GHE and Jal Healthy Foods are emerging players, focusing on both domestic and export markets, though their European market presence remains limited (MoA, 2019). Maize processing is predominantly decentralized, with over 80 percent handled by small, informal mills. Industrial-scale processing opportunities exist but have not been fully realized (MECNAR, 2019).

The groundnut industry features The Gambia Groundnut Corporation leading in shelling and crushing operations, although challenges persist in achieving optimal yields.

Figure 7. Women selecting groundnuts after toasting (June 2024)

Vegetable processing is nascent, highlighted by a recently established tomato processing plant capable of significant daily production but currently reliant on imported paste. With potential investment, the plant could catalyse local tomato production and create substantial employment.

Within the project, slaughterhouses are analysed as one of the food industries. The Gambia has several slaughterhouses operating nationwide, playing a crucial role in the local economy and food industry. Slaughterhouses in The Gambia face significant challenges, including inadequate infrastructure, poor hygiene standards, and limited regulatory oversight. The information gathered indicates that these slaughterhouses are unsustainable, with practices that pose serious environmental, health, and ethical concerns.

In fruit processing, private investors like Tropingo and GHE are prominent, focusing on mangoes. Tropingo exports dried mangoes to Europe and explores markets in Saudi Arabia, Dubai, and Nigeria, while GHE processes mangoes into juice, contributing significantly to local fruit processing. Artisanal processors complement these efforts by producing diverse mango products. These food processing industries in The Gambia offer opportunities for growth and investment yet face challenges such as infrastructure limitations and market access barriers that require strategic solutions for sustainable development.

Figure 8. Slaughterhouse in Serekunda area (June 2024)

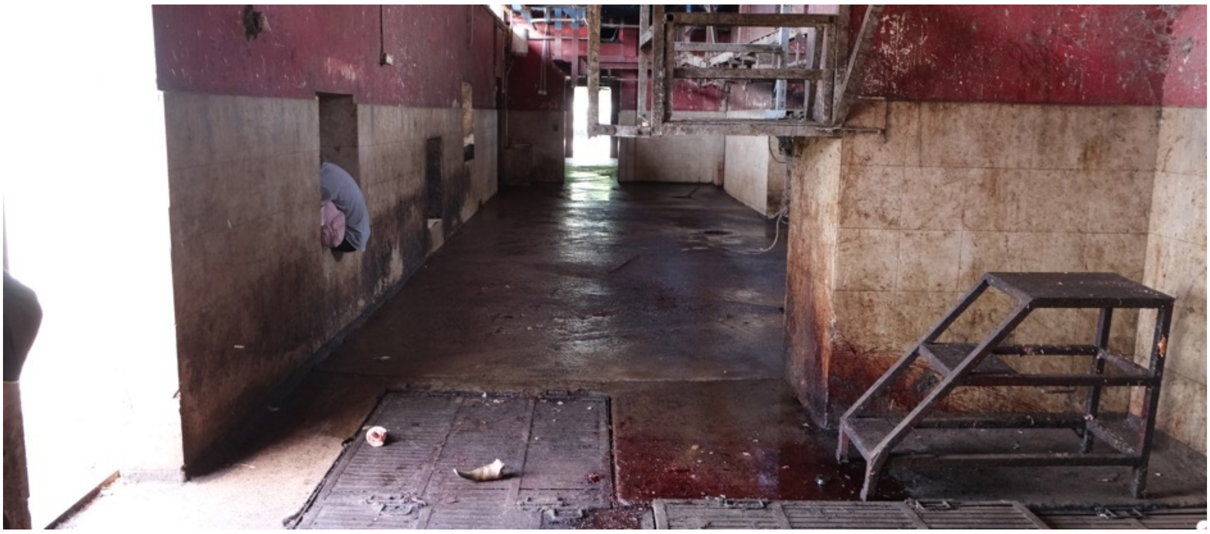


Table 6 presents selected 2020 data from FAOSTAT detailing the food processing landscape in The Gambia. Particularly, the production of palm oil amounted to 4,200 tonnes/year, reflecting a significant contribution to the local edible oil industry. Additionally, 3,000 tonnes/year of malted barley were processed, likely intended for beer production. Another substantial output was 3,000 tonnes/year of groundnut oil, underscoring the importance of this crop in the region. Palm kernels, amounting to 2,499 tonnes/year, were also processed, likely for multiple purposes including oil extraction. Moreover, 290 tonnes/year of cotton seed were processed, highlighting a lesser but notable aspect of the agricultural activities. The Gambia's processing of cotton lint, specifically ginned cotton, resulted in a production of 180 tonnes/year. This denotes a contribution to the textile sector, albeit on a comparatively smaller scale. These production figures showcase the significant role of palm oil, groundnut oil, and malted barley in the country's processing industries, along with contributions from palm kernels, cotton seed, and cotton lint.

Table 6. Crop products processed (tonnes/year) in The Gambia in 2020

AGRICULTURE	
CROP product	**Production [tonnes/year]**
Palm oil	4,200
Beer of barley, malted	3,000
Groundnut oil	3,000
Palm kernels	2,499
Cotton seed	290
Cotton lint, ginned	180
TOTAL	**13,169**

Source: FAOSTAT 2024

3.2.2 Residues and waste potential

The food processing industry in The Gambia produces a substantial number of organic residues and waste that represent a significant potential for biogas production. The primary sources of these residues include processing activities in the groundnut, vegetable, fruit, and palm oil sectors. Groundnut shells, vegetable peels, fruit pulp, and palm kernel shells are abundant by-products that can be effectively utilized as feedstock for biogas production.

In the groundnut industry, large quantities of shells and processing waste are produced annually. For example, The Gambia Groundnut Corporation (GGCC) processes about 35,000 tonnes of groundnuts annually, resulting in a significant number of shells and processing residues (FAOSTAT, 2024). These residues are often underutilized. Similarly (own interviews), vegetable processing units generate large amounts of organic waste, including peels and trimmings, which can be converted into biogas.

Palm oil production generates a variety of residues, including empty fruit bunches (EFB), palm press fiber, and palm kernel shells. In The Gambia, these by-products are typically disposed of through open burning or dumping, leading to environmental pollution (own interviews). Utilizing these residues for biogas production can mitigate their negative environmental impact while generating renewable energy. The data estimates that 35,071 tonnes of oil palm fruit are produced annually, producing a large number of residues, of which only 30 percent is currently utilized (own interviews).

Additionally, in The Gambia, slaughterhouses also represent an important element in the food industry, while producing large quantities of animal waste, including blood, fat, and offal. The data collected in place indicates that the Abuko slaughterhouse alone produces 830 tonnes of cattle offal and other residues annually.

3.2.3 Energy demand and barriers

One of the primary barriers within The Gambia's food processing is the reliance on non-renewable energy sources, such as diesel and firewood. This reliance not only contributes to greenhouse gas emissions but also experiences high operational costs due to the instability of fuel prices and the ineffectiveness associated with traditional energy sources. Another significant barrier is the frequent and prolonged power outages experienced in many parts of the country. The lack of a reliable energy supply hinders the growth and productivity of the food processing sector, limiting its ability to scale operations and meet market demands. In The Gambia, power outages contribute to an estimated 15 percent loss in processed goods annually[6].

3.3 Markets (livestock, fish, and vegetables)

3.3.1 Overview

The Gambian government has supported the creation of several markets over the years, with the main objectives of enhancing food security and reducing poverty in the country. These markets offer cold chain equipment such as ice makers, meat cutters, and cold storage to keep food fresh for farmers and private vendors. Additionally, vendors have access to lighting via the national grid and sometimes through solar energy systems, as well as improved water quality and sanitation systems. Waste management systems are also often present, though they typically lack separation and proper disposal methods.

Figure 9. View of the Bakoteh market (June 2024)

A prime example of these initiatives is the markets unit of Kanifing Municipal Council (KMC). Over the years, the Council has promoted local economic development by constructing markets with affordable

[6] https://www.gtai.de/resource/blob/37530/d7c2040f3fd3d3c58a7cbe62c8d3384e/pro201805185005-data.pdf

canteen fees for start-up businesses. Currently, the Council manages nine standard markets, and ten satellite markets strategically located within the municipality.

Notable markets include the Abuko Market and the Bakoteh Fish Market and Ice Plant, which are assessed in the following chapters. Private market users pay three types of revenue fees to the Council: daily fees, canteen rental, and monthly kiosk fees. The daily fee is ten Dalasis across the board. Canteen rental and monthly kiosk fees vary by market, ranging from Dalasis 500 per month for a temporary kiosk to Dalasis 3,000 per month for a well-built canteen, or some US$7.5 and US$44.3, respectively. The Markets Manager coordinates and supervises the staff daily, addresses vendors' complaints, and provides relevant information regarding market operations. The Manager also collaborates with the Environment and Sanitation Department to maintain market cleanliness and with the Municipal Police Commissioner to ensure market security (KMC, 2024). These markets play a crucial role in engaging the private sector and improving the quality of food available. By potentially providing essential infrastructure such as cold storage and ice makers, the markets can help vendors maintain the freshness and safety of perishable goods. This is particularly important in a country like The Gambia, where high temperatures quickly spoil food. Enhanced food quality leads to increased consumer confidence and demand, which, in turn, supports local producers and vendors. The availability of affordable canteen fees for start-ups encourages entrepreneurship and economic diversification. Small businesses can thrive in these markets, contributing to the region's economic growth. Moreover, the structured fee system, with varying charges depending on the facility type, ensures that new and established vendors can find suitable and affordable spaces to operate.

3.3.2 Residues and waste potential

Every year, Gambian markets generate tonnes of trash; much of its organic waste, which, along with plastic, cardboard, and other rubbish, ends up in landfills at the city's infamous Bakoteh dumpsite or other dumpsites around the Serekunda area (EC, 2024). In an effort to tackle the organic waste problem, WasteAid, a UK-based NGO, in partnership with the Kanifing Municipal Council (KMC) and Women's Initiative. The Gambia has been awarded €100,000 by the EU Global Climate Change Alliance (GCCA+) to pilot an innovative approach to divert organic waste into productive materials (EC, 2024). Some of the markets interviewed (primary data collection) generate significant amounts of organic waste, primarily from vegetables, fruits, and manure from cattle markets. Despite the large quantities produced—ranging, in some cases, from 146 to 1,000 tonnes of vegetable waste annually—the organic waste from these markets is primarily discarded at dumpsites rather than being composted or repurposed. Additionally, there is currently no waste separation at the markets. However, during discussions with the market managers, they expressed willingness to invest in separation units (bins) to segregate organic waste, which could then be used to produce energy needed by the private vendors at the markets. The willingness of market managers to invest in waste separation units offers a potential avenue for improving this situation. For a deeper understanding and to explore the high potential of this waste, two markets were selected as case study sites and are further assessed in **Chapter 4**.

3.3.3 Energy demand and barriers

Energy is a critical need for vendors in these markets. Reliable electricity is essential for operating cold chain equipment, lighting, and other essential tools that ensure the quality and safety of food products. Access to the national grid and the integration of solar energy systems help mitigate the challenges posed by power outages and high electricity costs. Solar energy provides a sustainable and cost-effective solution for meeting the energy needs of vendors, especially in remote or underserved areas.

The markets themselves also have substantial energy requirements to support overall operations. Ensuring a stable and efficient energy supply is vital for the continuous functioning of refrigeration units, lighting, and other infrastructure. Addressing these energy needs is crucial for maintaining the quality and availability of fresh food, supporting vendor activities, and ensuring the overall success and sustainability of the markets.

3.4 Waste sector

Up-to-date statistics regarding food waste in the country are unavailable. Nevertheless, it is acknowledged that the insufficient storage infrastructure exacerbates waste generation, causing highly perishable and often nutritious products like vegetables, fruits, milk, and fish to have short durations (FAO, 2022). In certain markets, there are community waste management initiatives that incorporate composting processes (Wasteaid, 2021)[7].

Figure 10. Dumpsite in Serekunda area (June 2024)

According to the GAMWORKS Report on Bakoteh Dumpsite (GAMWORKS, 2003), at national level, the amount of municipal solid waste (MSW) produced annually in the country is 433,620,000 tonnes. Out of this total, 303,534,000 tonnes are collected annually. At the source, 40 percent of the waste is separated into categories such as plastic, metal, and organic, while at the landfill, 20 percent of the waste undergoes further separation. 40 percent of the organic waste is subjected to further transformation (e.g., compost, biogas, or fuel). The three principal urban areas in The Gambia are Banjul City, Kanifing Municipality and Brikama. Presently the solid waste from these areas is disposed

[7] https://unfccc.int/sites/default/files/resource/crfs_gambia_casestudy.pdf

of in Mile 2, Bakoteh and Tambana Dump Sites respectively. The local councils in each of these municipalities is responsible for solid waste management in their jurisdiction (GAMWORKS, 2003).

3.4.1 Manjai-Kotu landfill

According to Jarju, A.M., Solly, B., & Jarju, O.M. (Jarju, *et al.,* 2021), in The Gambia, effective management of solid and liquid waste is a pressing concern, both for the government and the population. The Serekunda area and its surroundings rely solely on the Manjai-Kotu landfill site for solid waste disposal, which operates as an open dump. This waste originates from households and the bustling Serekunda market, a key vegetable and condiment hub. The waste often starts by being openly discarded in streets before ending up in landfills. The discarded materials include plastics, rubber, wood, metals, paper, residual condiments, and vegetables. This prevailing waste management practice involves open dumping and burning, a trend frequently observed in resource-limited economies.

Yet, the challenges are poised to intensify. Predictions point to a substantial increase in urban solid waste in The Gambia, surging from 211,000 tonnes in 2012 (with 84,000 tonnes collected) to a projected 471,000 tonnes in 2025 (with an expected collection of 282,000 tonnes) (Jarju, *et al*., 2021). Simultaneously, liquid waste, predominantly generated by households and industries, forms a significant issue. It encompasses wastewater, domestic waste, and various forms of agricultural and agri-food waste. This liquid waste finds its way into open sites and rivers due to the absence of proper treatment facilities, resulting in untreated waste with no avenue for reuse.

3.4.2 Bakoteh Dumpsite

The Bakoteh Dumpsite, situated in Manjaikunda, was established in 1983. It spans over 18 hectares and has a total capacity of 1,200,000 cubic meters. The site's expected operational lifespan is 10-15 years until it reaches full capacity. Each year, the Bakoteh Dumpsite receives 255,000 tonnes of municipal solid waste (MSW), with 50 percent of this being organic material, e.g., food scraps. The site does not accept separated organic waste, so it does not handle purely organic material without metal, plastic, or other contaminants. Regarding on-site separation, the Bakoteh Dumpsite does not conduct organic waste separation from mixed MSW. Furthermore, the facility lacks a mechanical separation unit, a lagoon for wastewater (WW) from MSW, and a system for WW treatment.

3.4.3 Mile 2 Dumpsite

The Mile 2 Dumpsite, located in Banjul, was established in 1985. It covers a surface area of 5 hectares and has a total capacity of 350,000 tonnes, with an expected lifetime of 10 years to reach maximum capacity. The site receives 60,000 tonnes of municipal solid waste (MSW) per year, of which 50 percent is organic material, e.g. from food scraps. No separated organic waste is delivered to the landfill, only mixed waste including organic and other materials. In terms of on-site separation, the Mile 2 Dumpsite does not perform organic waste separation from mixed MSW. Additionally, the site lacks a mechanical separation unit. It also does not have a lagoon for wastewater (WW) from MSW, nor does it have a system for WW treatment.

3.4.4 Tambana Dumpsite

The Tambana Dumpsite, situated in Brikama Jamisa, was established in 1990. It covers an area of 10 hectares and has a total capacity of 700,000 tonnes, with an expected operational lifespan of 10-15 years until it reaches maximum capacity. Annually, the site receives 100,000 tonnes of municipal solid waste (MSW), 60 percent of which consists of organic material like food scraps. No separated organic waste is delivered to the landfill since waste separation is not enforced in The Gambia, meaning it does not handle purely organic material that is free from metal, plastic, and other contaminants.

Regarding on-site separation, the Tambana Dumpsite does not perform organic waste separation from mixed MSW. Additionally, the facility does not have a mechanical separation unit. It also lacks a lagoon for wastewater (WW) derived from MSW, and there is no system in place for WW treatment.

4 CASE STUDIES ASSESSMENT

This chapter presents and discusses the results of four case studies, representing a range of scales and sectors. The first case study is GFirm Poultry and Dairy, a small-scale poultry and dairy farm with moderate residue outputs. The second case study is Abuko Livestock Market and Slaughterhouse, a medium-sized operation focusing on livestock and generating significant residues. The third case study is Bakoteh Fish and Vegetable Market, also medium-sized, handling fish and vegetables and producing substantial organic waste. The fourth case study is Bakoteh Dumpsite, a large-scale operation with extensive waste management needs. The case studies were selected from a list of identified stakeholders and visited during a scoping mission. Key considerations for selecting these case studies included feedstock availability, energy consumption, the size of the operations, and the stakeholders' willingness to invest in biogas if demonstrated viable. This ensured the selection of stakeholders with a strong interest in and potential to benefit from biogas technology. For each case study, a general description of the farm's operations is provided, along with an analysis of the baseline GHG emissions and the potential for mitigation through the introduction of biogas technology. Additionally, the chapter includes a financial and risk analysis for each case, assessing the viability and potential challenges associated with biogas implementation. The findings are concluded with a synthesis of the overall impacts and recommendations for future practice.

Table 7 present the baseline energy use at the 4 case studies. It details the annual energy usage from electricity, diesel, and firewood. At Gfirm, a poultry and dairy farm, the consumption includes 244,966 kWh/year from the electricity grid and 27,375 litres/year of diesel, with no data on firewood use. Abuko Livestock market and Slaughterhouse uses 42,019 kWh/year of electricity, 865 litres/year of diesel, and 920 tonnes/year of firewood. Bakoteh vegetable and fish market consumes 9,181 kWh/year of electricity and 9 tonnes/year of firewood, with no diesel usage reported. The Bakoteh dumpsite has no recorded energy consumption for the sources listed. **Table 8** outlines the types and quantities of feedstock potentially used for biogas production and the corresponding biogas output for various case studies. In the Gfirm case, 5,667 tonnes of manure per year yield 178,649 m³ of biogas annually. At Abuko Market, 196 tonnes of manure and 70,889 kgCOD/year of solid wastewater (SWW) produce 376,320 m³/year of biogas. The Bakoteh Market utilizes 4,294 tonnes per year of OMSW to generate 290,993 m³ of biogas. Finally, the Bakoteh Dumpsite, using 10,950 tonnes per year of OMSW, results in the highest biogas production at 1,314,000 m³/year. Each case study demonstrates the varying biogas production potential based on different types and amounts of feedstock. **Table 9** summarizes the biogas production, financial revenues, and GHG mitigation potential for different sites. Gfirm produces 178,649 m³ of biogas per year, generating revenues of US$99,131 and mitigating 526 tonnes of CO_{2e} annually. Abuko Market yields 376,320 m³ of biogas annually, with revenues of US$61,215 and a mitigation potential of 332 tonnes of CO_{2e} per year. Bakoteh Market produces 290,993 m³ of biogas, earning US$134,681 and mitigating 1,888 tonnes CO_{2e} annually. The Bakoteh Dumpsite has the highest output, with 1,314,000 m³ of biogas per year, resulting in revenues of US$618,152 and a GHG mitigation potential of 5,164 tonnes CO_{2e} annually. **Table 10** outlines the annual and cumulative GHG emissions reductions for four sites: Gfirm, Abuko Market, Bakoteh Market, and Bakoteh Dumpsite. Gfirm consistently reduces 527 tonnes CO_{2e} annually, resulting in a cumulative reduction of 7,901 tonnes over 15 years. Abuko Market achieves an annual reduction of 332 tonnes CO_{2e}, accumulating to 4,984 tonnes. Bakoteh Market contributes 1,888 tonnes CO_{2e} per year, with a total reduction of 28,327 tonnes. Bakoteh Dumpsite shows the highest annual reduction at 5,164 tonnes CO_{2e}, leading to a cumulative mitigation of 77,463 tonnes.

Table 7. Baseline energy use by source of the studied case studies

Case study	Typology	Scale	Electr. Grid [kWh/year]	Diesel [L/year]	Firewood [t/year]
Gfirm	Poultry and dairy farm	Small	244,966	27,375	-
Abuko Market	Livestock market and Slaughterhouse	Medium	42,019	865	920
Bakoteh Market	Vegetable and fish market	Medium	9,181	-	9
Bakoteh Dumpsite	Dumpsite	Large	-	-	-

Source: Primary data collection

Table 8. Available feedstock and potential biogas production at the studied case studies

Case study	Manure [t/year]	SWW (TOWi) [KgCOD/year]	OMSW [t/year]	Biogas [m^3/year]
Gfirm	5,667	-	-	178,649
Abuko Market	196	70,889	-	376,320
Bakoteh Market	-	-	4,294	290,993
Bakoteh Dumpsite	-	-	10,950	1,314,000

Source: Primary data collection

Table 9. Annual biogas yield, annual revenues and GHG mitigation potential of the studied case study sites

Case study	Biogas [m3/year]	Revenues [USD/year]	Mitigation [tCO_{2e}/year]
Gfirm	178,649	99,131	526
Abuko Market	376,320	61,215	332
Bakoteh Market	290,993	134,681	1,888
Bakoteh Dumpsite	1,314,000	618,152	5,164

Source: Own calculations

Table 10. Mitigation of GHG emissions CO_{2eq} [Tonnes/year] over 15 years project lifespan

Year	1	2	3	4	5	6 to 14	15
Gfirm	527	527	527	527	527	[…]	527
Cumulated	527	1,053	1,580	2,107	2,634	[…]	7,901
Abuko Market	332	332	332	332	332	[…]	332
Cumulated	332	664	997	1,329	1,661	[…]	4,984
Bakoteh Market	1,888	1,888	1,888	1,888	1,888	[…]	1,888
Cumulated	1,888	3,777	5,665	7,554	9,442	[…]	28,327
Bakoteh Dumpsite	5,164	5,164	5,164	5,164	5,164	[…]	5,164
Cumulated	5,164	10,328	15,493	20,657	25,821	[…]	77,463
Total mitigation	**7,912**	**7,912**	**7,912**	**7,912**	**7,912**	[…]	**7,912**
Cumulated mitigation	**7,912**	**15,823**	**23,735**	**31,646**	**39,558**	**[…]**	**118,674**

Source: Own calculations

4.1 Gfirm poultry and dairy farm (small size)

4.1.1 Case study description

GFirm Farm, managed by Mr. Mohammed Sanwang, the CEO, consists of five distinct units designed to maintain biological safety. These include four poultry units and one dairy unit. The poultry units house approximately 130,000 birds for egg and hatchery production, while the dairy unit has around 75 productive animals and 20 young animals.

Figure 11. Intensive poultry production unit at GFirm farm (June 2024)

GFirm Farm's operations involve significant energy consumption, including electricity from the national grid (NAWEC) and diesel fuel. The electricity, costing around 10,000 Dalasi per day (approximately US$143.83 per day[8]), is used for pumping water, operating fans and cooling systems, and milk pasteurization. Diesel consumption averages 75 litres per day, primarily for generators used during power outages.

There is potential for biogas production at the farm, which could reduce the reliance on diesel and electricity while addressing the environmental risks of improper manure disposal. The Farm owners interested in exploring biogas solutions and has indicated that the farm could invest in such initiatives.

4.1.2 Baseline GHG emissions and mitigation potential

The paragraph discusses the baseline GHG emissions generated yearly at the case study by different sources. It also explores the potential for biogas production from manure produced by poultry (100,000 heads) and dairy cows (75 heads) on farms. The paragraph also highlights the significant potential for environmental and energy-related mitigation through the introduction of biogas production and consumption. For reference, an average 15-year technology lifetime was considered for the biogas systems. By substituting conventional energy sources with biogas and managing waste more

[8] 1 Gambian Dalasi (GMD) corresponds to about US$0.01438 (2024), https://www.gbosdata.org

effectively, the facility can achieve substantial reductions in greenhouse gas emissions and other pollutants.

Table 11 summarizes and lists the baseline emissions produced by the Gfirm farm highlighting significant sources of environmental impact. The most substantial contributor is manure (both from poultry and cattle), underscoring the need for improved management practices. Diesel also represents a considerable impact, followed by electricity from the grid. By using the available manure, in total, the case study has a biogas potential production of around 178,649 m^3/year, or 107,191 m^3/CH_4 per year. Considering the availability of feedstock, the calculated installed capacity of a biogas plant would be 50 kW (**Table 12**).

Table 13 presents the energy consumption of various sources at the case study site and the biogas needed to replace these energy sources. The annual electricity consumption from the grid is 881,879.1 MJ, which requires 114,530 m³ of biogas to replace. The potentially available biogas (178,649 m^3/year) meets this need completely. Diesel consumption stands at 303,417.4 MJ per year, requiring 39,405 m³ of biogas for replacement, with the residual potentially available biogas (64,119 m^3/year) also covering 100 percent of this need. Overall, the total energy consumption from these sources is 1,185,297 MJ per year, necessitating 153,934 m³ of biogas to replace both. The total potentially available biogas production can fulfil the energy needs of the farm for electricity and diesel replacement.

Table 11. GFirm's GHG Emissions by source per year and considering 15 years of biogas technology lifespan

Source	tCO_{2eq}/year	tCO_{2eq}/15yrs project lifespan
Manure (poultry + cattle)	912.1	13,681.5
Diesel	78.8	1,182
Electricity GRID	68.3	1,024.5
Total	1,059.2	15,800

Source: Own calculations using IPCC methodologies

Table 12. GFirm's potential annual biogas and CH4 production, installed capacity and annual electricity production

Item	Value	Unit
Annual biogas potential production	178,649	m^3/year
Annual CH_4 potential production	107,191	m^3/year
Plant installed capacity	50	kW
Annual potential electricity production	382,141	MWh/year

Source: Own calculations

Table 13. GFirm's energy consumption and biogas requirement

Source	Consumption [MJ/year]	Biogas needed to replace baseline [m^3/yr]	Biogas Availability to replace energy needs [m^3];[percent]
Electricity GRID	881,879,1	114,530	100 %
Diesel	303,417.4	39,405	100 %
Total	1,185,297	153,934	100 %

Source: Own calculations

More detailed information on GHG emissions and biogas potential production are provided from the list (A-E) below.

Animal manure: Manure production was calculated considering 100,000 poultry heads and 75 dairy cows. As suggested by literature (Tancsuk, 2019), an average manure production of 150 g/head/day was considered to calculate the amount of manure from poultry. Along the same lines, an average manure production of 7 Kg/animal was considered for dairy cows.

Figure 12. GFirm's automatic manure collector technology (June 2024)

Animal manure sold uncomposted to farmers or discharged in the near fields, when applied to the soil produces both direct and indirect GHG emissions, including methane (CH_4) and nitrous oxide (N_2O), according to IPCC 2006 methodology for direct and indirect emissions – livestock and manure management[9]. In total, approximately 912.1 tonnes of CO_2 equivalents (CO_{2eq}) are emitted annually (baseline) from the manure produced at Gfirm. This includes direct emissions from uncomposted manure amount to 640,088 tonnes CO_{2eq} per year, and indirect emissions, including N_2O from atmospheric deposition and leaching/runoff, amount to 272,037 tonnes CO_{2eq} per year.

The potential biogas production is calculated by utilizing a biogas yield of 0.08 m^3/kg and 0.045 m^3/kg as suggested by Langeveld (2016) for poultry manure and dairy cattle manure, respectively. The total annual biogas production from the manure at the farm is around 178,649 m^3/year. The potential mitigation from the collection of the manure used to produce biogas would therefore be around 912.1 tCO_{2e}/year, or some 13,681.5 tCO_{2e}/15 year of technology life span.

Biogas surplus: The total amount of biogas produced will be sufficient to meet the annual energy needs of the farm, with an additional biogas surplus of approximately 24,715 m^3 per year. According to IRENA (2023), the emission factor for electricity produced in The Gambia in 2023 was 279 tCO_{2e}/GWh. With an expected electricity production from the biogas surplus of around 0.0529 GWh per year, the project may result in an additional 14.75 tonnes of CO_2 equivalents per year, or approximately 221.25 tCO_{2e} over a 15-year lifespan. By also considering the mitigation potential of the electricity produced for NAWEC, the overall investment's mitigation potential would be approximately 526.7 tCO_{2e}.However,

[9] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

grid connection challenges and opportunities have not been investigated in this assessment, therefore the displacement of electricity from the grid cannot be considered in this inventory for emission reductions as in the most likely scenario the surplus biogas would be flared.

Diesel: The farm has three diesel generators used to cover the energy gaps from the grid for a total consumption of around 75 liters per day. In total, approximately 78.7 tonnes of CO_2 equivalents are emitted annually by these generators. This has been assessed using the IPCC 2006 methodology – for stationary combustion[3] sources. The electricity supply of 84,282.6 kWh/year (equivalent to 303,417.4 MJ/year) from diesel generators can be replaced by biogas. The biogas required to replace diesel-generated electricity is around 39,404.8 m³/year. The potential mitigation from the collection of the manure used to produce biogas would therefore be around 78.7 tCO_{2e}/year, or some 1,180.5 tCO_{2e}/15 year (biogas technology life span).

Electricity (Grid): According to IRENA (IRENA, 2023), the emission factor for electricity produced in The Gambia in 2023 was 279 tCO_{2e}/GWh. With a final consumption of around 0.245 GWh per year, the farm's GHG emissions from electricity consumption amount to approximately 68.35 tonnes of CO_2 equivalents per year. This annual electricity demand (equivalent to 881,879.19 MJ/year) can be met by substituting grid electricity with locally produced electricity from biogas. Considering a lower heating value (LHV) of 22.00 MJ/m³ for biogas and a conversion efficiency of 0.35, the biogas required to replace grid electricity used on farm is 147,529.77 m³/year. Such substitution would reduce reliance on fossil fuel-based power generation, leading to a decrease in associated GHG emissions. By replacing this electricity with biogas, the facility can eliminate these emissions entirely, achieving an annual reduction of some 1,025.25 tCO_{2e} over the technology lifespan (15 years).

4.1.3 Financial analysis

A comprehensive financial cost-benefit analysis (CBA) was conducted to evaluate the feasibility of implementing a biogas biodigester at the GFirm case study. The primary objective of the study was to assess the economic viability of substituting conventional energy sources, namely electricity from the grid and diesel for electricity generation, with biogas. Additionally, the study aimed to evaluate the profitability of using the surplus biogas to generate electricity for sale to the national grid. In general, the farm's energy-related expenses are significant. Annual electricity expenses amount to approximately US$54,432 for a total consumption of around 245,000 kWh/year. In addition, diesel expenses amount to approximately US$34,000/year for the consumption of 27,375 liters/year, primarily used for providing electricity during outages from the national grid. By producing biogas at the facility, significant savings can be achieved for a total amount of around US$88,432 per year. This will ensure reliable and clean energy provision for the farm without increasing cost (**Table 14**).

Table 14. GFirm's potential annual savings by producing biogas

Savings	Amount [USD/year]	Unit cost [USD/unit]
Electricity bill	54,432	0.235 [USD/kWh]
Diesel for electricity	34,008	1.23 [USD/litre][10]
Total	**88,440**	**-**

Source: Own calculations

In addition to the potential annual energy savings achieved by the farm, there would be enough surplus biogas generated to supply the national grid with approximately 52,866 kWh/year of electricity. This could potentially generate a total revenue of around US$11,747 per year. As mentioned in the introduction, NAWEC and the Minister of Petroleum and Energy have established a feed-in tariff for renewable energy producers selling to the grid, set at US$0.25/kWh. However, to adopt a conservative approach, this study considered a lower tariff equal to the rate paid for purchasing energy from the grid, which is US$0.235/kWh. The US$0.235 tariff was used to allow for a conservative estimate, as the project team was not able to confirm whether the US$0.25 tariff is currently in place; this matter will be further discussed with the government and NAWEC. The assumed 0.235 feed-in tariff (FiT) for electricity produced from biogas is designed to cover the comprehensive costs of production and ensure economic viability. This rate is intended to account for operational expenses such as feedstock, maintenance, and labour, as well as the substantial initial capital investment required for biogas infrastructure. Analysis indicates that the US$0.235 tariff allows producers to achieve profitability and a reasonable return on investment. Additionally, sensitivity analysis shows that this assumed tariff remains resilient to variations in production costs, inflation, and economic conditions, thereby supporting long-term financial stability and encouraging sustained investment in biogas-generated electricity. Aggregated CAPEX for the biogas biodigester project is detailed in **Table 15**.

Table 15. GFirm's Capital expenditures

Item	Unit	Value
Digester size		
Capacities	(kWe)	49.16
Capacities	m^3 Biogas/year	196,820
Operating period	h/year	7,200
Heat Production	GJ/year	-
Volume Reactor	m^3	131
Subtotals		
Pretreatment	USD	7,865.51
Equipment	USD	101,296.44
Building	USD	35,691.23
Installation	USD	26,987.33
Electricity Distribution network	USD	37,647.29
Grand total	**USD**	**209,487.81**

Source: Own calculations using FAO BEFS RA Tools (Intratec cost index for 2023)

[10] https://www.globalpetrolprices.com/Gambia/diesel_prices/

The biogas plant would have a power capacity of 49.16 kWe, and the reactor volume would be 131 cubic meters, enough to generate 196,820 cubic meters of biogas annually, with an operational period of 7,200 hours each year. The financial breakdown of the project totals US$209,487.81, including pretreatment costs at US$7,865.51, equipment costs at US$101,296.44, building costs at US$35,691.23, installation costs at US$26,987.33, and electricity distribution network costs at US$37,647.29. Disaggregated capital costs are provided in **Annex 3**. Operating costs (OPEX) do not include feedstock and transportation since waste and residues are collected for free and always available on-site. OPEX, mainly maintenance and materials, are calculated at 10 percent of the total investment, which amounts to approximately US$21,000 per year. Fixed costs include labour for two skilled and two unskilled workers, totalling around US$20,000 per year, and capital depreciation over a 15-year lifespan, which is approximately US$14,000 per year. This brings the total annual operating and fixed costs to around US$55,000 per year. Financial analysis indicated substantial potential savings from transitioning away from grid electricity (80 percent fossil generated), diesel and firewood. However, the initial investment required a CAPEX of around approximately US$210,000, 60 percent of which was financed through a loan at a fixed interest rate of 6 percent over a 10-year term, allowing the investor to reduce the capital expenditures to around US$83,800 - US$125,700 (**Figure 13**).

Figure 13. Cost Benefit Analysis (CBA) of biogas investment at the GFirm farm

Year	0	1	2	3	4	5	6	7	8	9	10 to 15
Energy consumption											
Electricity consumption [kWh/year]	244,966	244,966	244,966	244,966	244,966	244,966	244,966	244,966	244,966	244,966	244,966
Diesel consumption [L/year]	27,375	27,375	27,375	27,375	27,375	27,375	27,375	27,375	27,375	27,375	27,375
Electricity from biogas surplus [kWh/year]	52,866	52,866	52,866	52,866	52,866	52,866	52,866	52,866	52,866	52,866	52,866
Diesel market price [USD/L]	1.23	1.24	1.25	1.27	1.28	1.29	1.31	1.32	1.33	1.35	1.43
Electricity tarif [USD/kWh]	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.26
Electricity feed-in tarif [USD/kWh]	0.235	0.24	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.26	0.27
Revenues											
Savings from replaced electricity expenses		54,432	54,976	55,526	56,081	56,642	57,208	57,780	58,358	58,942	62,568
Savings from replaced diesel expenses		34,008	34,348	34,692	35,038	35,389	35,743	36,100	36,461	36,826	39,091
Revenues from electricity sales		12,548	12,673	12,800	12,928	13,057	13,188	13,320	13,453	13,587	14,423
Operating costs											
Operating costs (10% CAPEX) [USD/year]		*(20,948.78)*	*(21,158.27)*	*(21,369.85)*	*(21,583.55)*	*(21,799.39)*	*(22,017.38)*	*(22,237.55)*	*(22,459.93)*	*(22,684.53)*	*(24,080.08)*
Labour		*(20,000.00)*	*(20,200.00)*	*(20,402.00)*	*(20,606.02)*	*(20,812.08)*	*(21,020.20)*	*(21,230.40)*	*(21,442.71)*	*(21,657.13)*	*(22,989.48)*
Capital depreciation		*(13,965.85)*	*(13,965.85)*	*(13,965.85)*	*(13,965.85)*	*(13,965.85)*	*(13,965.85)*	*(13,965.85)*	*(13,965.85)*	*(13,965.85)*	*(13,965.85)*
Cash Flow											
+ Avoided expenses and Revenues		100,987.26	101,997.13	103,017.11	104,047.28	105,087.75	106,138.63	107,200.01	108,272.01	109,354.73	116,082.25
- *'Operating costs [USD/year]*		*(20,948.78)*	*(21,158.27)*	*(21,369.85)*	*(21,583.55)*	*(21,799.39)*	*(22,017.38)*	*(22,237.55)*	*(22,459.93)*	*(22,684.53)*	*(24,080.08)*
Operating Cash Flow	-	**80,038**	**80,839**	**81,647**	**82,464**	**83,288**	**84,121**	**84,962**	**85,812**	**86,670**	**92,002**
- Investments [USD]	- 209,488										
- Fixed costs [USD/year]		*(33,965.85)*	*(34,165.85)*	*(34,367.85)*	*(34,571.87)*	*(34,777.93)*	*(34,986.05)*	*(35,196.26)*	*(35,408.56)*	*(35,622.99)*	*(36,955.34)*
- Loan annuity		*(17,077.61)*	*(17,077.61)*	*(17,077.61)*	*(17,077.61)*	*(17,077.61)*	*(17,077.61)*	*(17,077.61)*	*(17,077.61)*	*(17,077.61)*	-
Total Cash Flow	**- 209,488**	**28,995**	**29,595**	**30,202**	**30,814**	**31,433**	**32,058**	**32,689**	**33,326**	**33,970**	**55,047**
Cumulative Cash Flow	*- 209,488*	*- 180,493*	*- 150,897*	*- 120,696*	*- 89,881*	*- 58,449*	*- 26,391*	*6,298*	*39,624*	*73,593*	*376,681*
Payback Year	-	-	-	-	-	-	-	*Payback*	-	-	-
CF shareholders	- 83,795	28,995	29,595	30,202	30,814	31,433	32,058	32,689	33,326	33,970	55,047
Cumulative Cash Flow	*- 83,795*	*- 54,800*	*- 25,205*	*4,997*	*35,811*	*67,244*	*99,302*	*131,990*	*165,316*	*199,286*	*502,374*
Payback Year	-	-	-	*Payback*	-	-	-	-	-	-	-
Loan and Capital structure											
Equity private financing	**- 83,795**										
Loan	**- 125,693**	**60%**	of initial investment								
Constant interest rate	**6%**										
Duration of loan (years)	10										
Grace period (year)	-										
Loan repayment plan	Constant installments										
Loan outstanding (BoP)	**125,693**	**125,693**	**116,157**	**106,048**	**95,334**	**83,976**	**71,937**	**59,176**	**45,649**	**31,310**	**- 0**
- Interests		7,542	6,969	6,363	5,720	5,039	4,316	3,551	2,739	1,879	-
- Capital repaid		9,536	10,108	10,715	11,358	12,039	12,761	13,527	14,339	15,199	-
Loan outstanding (EoP)	**125,693**	**116,157**	**106,048**	**95,334**	**83,976**	**71,937**	**59,176**	**45,649**	**31,310**	**16,111**	**- 0**
Project profitability											
NPV	92,748.97 USD										
NPV to shareholders	209,131.08 USD										
Project IRR	**14.2%**										
IRR to shareholders	36.9%										
payback (years)	**7**										
Shareholders payback (years)	3										

Despite these challenges, and considering a discount rate of 8 percent, the project demonstrated promising financial prospects, boasting a positive Net Present Value (NPV) of US$92,749, an Internal Rate of Return (IRR) of 14.2 percent, and a payback period of 7 years. These metrics indicate favourable project economics and suggest that the project is financially attractive and capable of recouping initial investments within a reasonable timeframe.

The sensitivity analysis, conducted with a 5 percent variation of key variables, highlighted the significant impact of the electricity tariff (market price) and the diesel market price on the Net Present Value (NPV) of the project. When the electricity tariff (market price) varied by 5 percent, NPV fluctuated by -25 percent and +25 percent respectively. Similarly, a 5 percent variation in diesel market price resulted in a NPV change of -15 percent and +15 percent (**Table 16**).

Table 16. GFirm's sensitivity analysis results: impact of variable variation on Net Present Value

SENSITIVITY ANALYSIS (5 percent)									
Variables	Variation of variables			Variation of NPV					
	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent
Diesel market price [USD]	1.169	1.23	1.292	78,489	92,749	107,009	-15 %	0 %	15 %
Electricity tariff [USD/kWh]	0.209	0.22	0.231	69,925	92,749	115,573	-25 %	0 %	25 %
E. Feed-in tariff [USD/kWh]	0.223	0.235	0.247	87,487	92,749	98,011	-6 %	0 %	6 %
Operating costs [USD/yr]	19,901	20,949	21,996	101,533	92,749	83,965	9 %	0 %	-9 %
Labour [USD/yr]	19,000	20,000	21,000	101,135	92,749	84,363	9 %	0 %	-9 %
Capital depreciation [USD/yr]	13,268	13,966	14,664	98,283	92,749	87,215	6 %	0 %	-6 %
Loan interest rate [percent]	5.7	6.00	6.3	94,252	92,749	91,236	2 %	0 %	-2 %

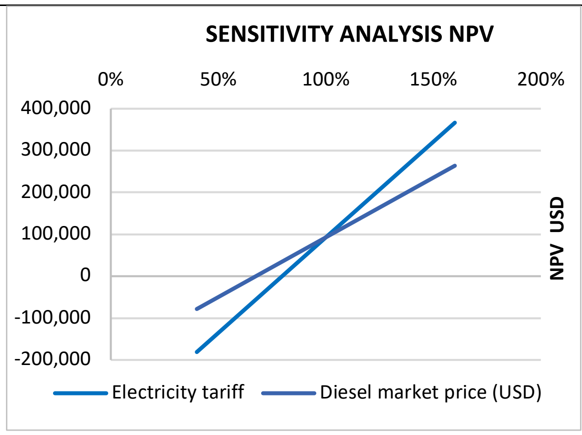
Source: Own calculations

This underscores the importance of meticulous consideration and potential mitigation strategies for these variables in project planning and decision-making.

A further step considers only the selected variable that exceeded 15 percent of NPV fluctuation. **Table 17** illustrates the impact of varying Electricity tariff (market price) (USD) and diesel market price (USD) on the Net Present Value (NPV) of the investment. The NPV ranges from US$-181,143 to US$366,641 as the electricity tariff increases from 40 percent to 160 percent of its original value. Similarly, changes in diesel market price from 40 percent to 160 percent of its original value resulted in NPV variations from US$-78,374 to US$263,872. The sensitivity analysis further demonstrated the robustness of the investment by revealing that both variables require a variation exceeding 20 percent to render the Net Present Value (NPV) negative. This resilience underscores the project's ability to withstand significant fluctuations in these key variables without adversely affecting its overall profitability (**Table 17**).

Table 17. GFirm's impact of variable variation on Net Present Value for electricity tariff and diesel market price

	Electricity tariff (USD)		Diesel market price (USD)	
	NPV	Variable	NPV	Variable
160 %	366,641	0.35	263,872	1.97
140 %	275,344	0.31	206,831	1.72
120 %	184,046	0.26	149,790	1.48
100 %	92,749	0.22	92,749	1.23
80 %	1,452	0.18	35,708	0.98
60 %	-89,846	0.13	-21,333	0.74
40%	-181,143	0.09	-78,374	0.49



Source: Own calculations

4.1.4 Conclusions

Based on the detailed case study of Gfirm poultry and dairy farm, the implementation of biogas technology presents a promising solution to address the environmental and energy-related challenges faced by the farm. Currently, improper disposal of manure and reliance on diesel and grid electricity result in significant greenhouse gas emissions and financial costs. By adopting biogas systems, the farm could utilize the abundant manure from poultry and dairy units to produce biogas, thereby reducing dependency on conventional fuels.

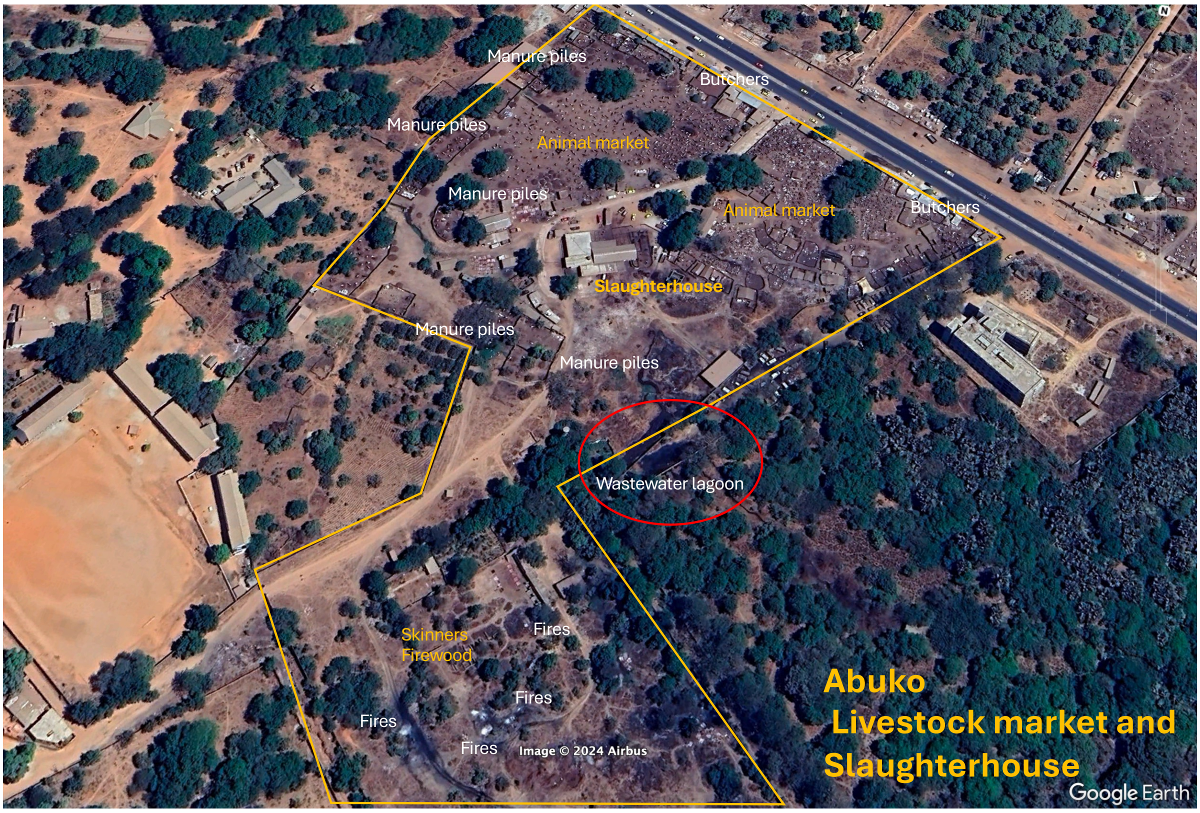
The transition to biogas not only offers environmental benefits through substantial reductions in greenhouse gas emissions but also economic advantages. The farm stands to achieve significant savings on energy expenses and can potentially generate additional revenue from the sale of surplus biogas and bio digestate. The financial analysis supports the viability of the biogas project, demonstrating a positive Net Present Value (NPV) and an Internal Rate of Return (IRR) of 14.2 percent, with an anticipated payback period of seven years. Sensitivity analysis further confirms the robustness of the project, indicating profitability even under variable conditions. Aligning the selling price of biogas with market rates could enhance the project's financial returns. This initiative aligns with broader sustainable development goals, promoting environmentally friendly practices and enhancing resilience in the community. The biogas project at GFirm thus offers a comprehensive approach to mitigating environmental impacts, reducing operational costs, and contributing to sustainable agricultural practices. It exemplifies how integrating renewable energy solutions in agricultural operations can lead to significant environmental and economic gains.

4.2 Abuko – Livestock market and slaughterhouse (medium size)

4.2.1 Case study description

Abuko town is in the West Coast Division, in the western part of the country, 10 kilometres southwest of the capital city Banjul. The 259-acre (105 ha) Abuko Nature Reserve, created in 1968, lies to the south of the town. It is the most visited tourist attraction in The Gambia, with over 30,000 visitors annually. The reserve contains tropical canopy forests near the Lamin Stream, giving way to the Guinean savanna further from the water. It is home to many species of birds, four primates, and a variety of reptiles.

Figure 14. Aerial view of the Abuko market and slaughterhouse



At the northern border of the Abuko Reserve, there is the Abuko cattle market (**Figure 14**).

The Abuko market hosts a livestock market, a government-owned slaughterhouse, and approximately 63 private skinner activities. The market is part of the KMC market units developed by the Government to increase food security and income generation. The site was visited, and data was collected from Mr. Maddy Kuyateh, the manager of the market.

Livestock market: The market surrounds the slaughterhouse and accommodates an average of 40-50 animals daily (**Figure 14**). During religious festivals like Eid al-Adha, the market hosts hundreds of live animals, mainly cows and goats.

Manure management varies with the season. In the dry season, some manure from the market is collected, piled, and sold in 30 kg bags to farmers at less than 100 Dalasi per bag (about US$1.438), while the rest is wasted. In the rainy season, rainwater significantly reduces the collection rate, resulting in nearly all manure being wasted. The primary energy source at the market is electricity from the national grid, used to pump water for washing and drinking water for animals.

Figure 15. Live animals at the Abuko market (June 2024)

Slaughterhouse: The slaughterhouse, previously a private company, is now owned by the Ministry of Agriculture. It slaughters around 40-50 animals daily, primarily cows. Manure produced here is piled outside, with some sold to farmers during the dry season and the rest left on the ground. A sewage system collects the Slaughterhouse wastewater (SWW) from cleaning activities, which produces sludge discharged into a lagoon about 400 meters away, eventually reaching a river near the Abuko Nature Reserve. This direct discharge, along with the improper disposal of solid waste near the lagoon, poses severe environmental risks.

Figure 16. The Abuko slaughterhouse (June 2024)

The waste management practices contribute to greenhouse gas emissions from decomposing manure and organic waste, exacerbating climate change. Improper disposal also presents infection and health hazards to the local community. During the rainy season, manure runoff contaminates water bodies, affecting water quality and aquatic ecosystems. The lagoon discharge near Abuko Nature Reserve threatens its biodiversity and natural resources.

Electricity from the national grid is the main energy source at the slaughterhouse, used for machinery and heat production. Monthly electricity expenses (market + slaughterhouse) are around 60,000 Dalasi (US$863) for 52,174 kWh, with additional costs for a diesel generator and fuel for a diesel tractor used in the market. The slaughterhouse is equipped with a solar PV system and a cooling system, though both are currently non-functional.

Skinners: Near the slaughterhouse (**Figure 14**), 63 skinners use firewood as their sole energy source for processing animal skins, consuming around 40 kg of firewood daily each. This totals 75.6 tonnes of firewood monthly, costing 567,000 Dalasi (approximately US$8,167), contributing to deforestation. Skinners are independent, private-sector actors. They process animal skins from the slaughterhouse into various products, including belts, bags, and other apparel. This role involves the meticulous removal of skins from carcasses, followed by a series of preparation processes, including boiling. The skinner ensures that the skins are adequately treated and prepared, making them suitable for further use in various industries, such as leather production. The boiling process requires significant energy input to sterilize and soften the skins, making them suitable for further uses.

Figure 17. Skinner boiling a cow skin (June 2024)

In conclusion, given the significant waste generation, unsustainable management practices, urgent need for alternative energy solutions, and relevance of private sector interests and investment opportunities, the Abuko market is an ideal case study for the SCALA project. The area produces considerable manure and organic waste, most of which is improperly disposed of, posing environmental and health risks. The direct discharge of wastewater into a lagoon near the Abuko Nature Reserve further threatens the local ecosystem. Moreover, the need for energy might justify biogas investments, offering a sustainable and renewable energy source that can reduce reliance on conventional fuels such as firewood, electricity, and diesel.

The cooperative management is open to collaboration if biogas technology proves feasible. This technology could reduce greenhouse gas emissions, improve waste management, and provide renewable energy for the facility and community. Butchers and skinners, who currently rely on firewood, would benefit from a sustainable energy supply, reducing deforestation and environmental impact. As an additional benefit of the biogas project, biodigestate will be produced at the Market. This nutrient-rich byproduct will be available for farmers to purchase. Utilizing biodigestate can significantly enhance soil health and improve crop yields (Garcìa-Lopez, 2023). This integration aligns with the SCALA project's goals of promoting sustainable business practices and enhancing climate resilience.

4.2.2 Baseline GHG emissions and mitigation potential

The paragraph discusses the baseline GHG emissions generated yearly in the case study by different sources. It also explores the potential for biogas production from manure produced by animals both inside and outside the slaughterhouse, as well as from SWW generated during the animal slaughtering process and currently discharged into the lagoon. The paragraph also highlights the significant potential for environmental and energy-related mitigation through the introduction of biogas production and consumption considering a 15-year technology lifespan for the biogas systems.

By substituting conventional energy sources with biogas and managing waste more effectively, the facility can substantially reduce greenhouse gas emissions and other pollutants.

Table 18 summarizes and lists the baseline emissions produced by the Abuko market, highlighting significant sources of environmental impact. The most substantial contributor is SWW, underscoring the need for improved management practices. Firewood burning also represents a considerable impact, followed by manure, the electricity from the grid and a small amount of diesel consumption.

Table 18. Abuko's GHG Emissions by source per year and considering 15 years of biogas technology lifespan

Source	tCO_{2eq}/year	tCO_{2eq}/15yrs project lifespan
Manure	32.3	484.5
Wastewater	141.0	2,115.0
Electricity GRID	11.7	175.5
Diesel	2.5	37.5
Firewood	144.6	2,169.0
Total	332.1	4,981.5

Source: Own calculations using IPCC methodologies

By using the available manure and SWW, in total, the case study has a biogas potential production of around 376,320 m^3/year, or 225,792 m^3/CH4 per year. The calculated installed capacity and size a of biogas plant would therefore be around 100 kW (**Table 19**).

Table 19. Abuko's potential annual biogas and CH4 production, installed capacity and annual electricity production

Item	Value	Unit
Annual biogas potential production	376,320	M3/year
Annual CH4 potential production	225,792	M3/year
Plant installed capacity	103	kW
Annual potential electricity production	776.7	MWh/year

Source: Own calculations

Table 20 presents the energy consumption of various sources at the case study site and the biogas needed to replace these energy sources. The annual electricity consumption from the grid is 151,269.12 MJ. Such an energy need would require about 19,645.34 m^3 of biogas in a generator. Considering the biogas potential, this electricity demand could be fully covered.

On the other hand, the annual diesel consumption amounts to 4,794.12 MJ per year. Meeting this energy requirement would require approximately 1,622.61 m^3 of biogas in a generator. Given the biogas potential, this demand could be fully met.

Instead, the annual firewood consumption is considerably higher at 15,636,600 MJ, which would require 710,754.55 m^3 of biogas to completely replace it. However, after addressing other energy needs, only 356,052.32 m^3 of biogas would be available, covering just 50 percent of the total requirement.

Overall, the total energy consumption from all sources is 15,792,663 MJ per year, requiring 731,022.50 m³ of biogas to fully replace it. However, with only 376,320.27 m³ of biogas available, this can cover just 51 percent of the total energy needs.

Table 20. Abuko's energy consumption and biogas requirement

Source	Consumption [MJ/year]	Biogas needed to replace baseline [m3/yr]	Biogas Availability to replace energy needs [m3];[percent]
Electricity GRID	151,269.12	19,645.34	19,645.34 (100 %)
Diesel	4,794.12	622.61	622.61 (100%)
Firewood	15,636,600	710,754,55	356,052.32 (50%)
Total	15,792,663	731,022.50	376,320.27 (51%)

Source: Own calculations

More detailed information on GHG emissions and biogas potential production are provided from the list below.

Animal manure: Considering the number of animals inside and outside the slaughterhouse (40 + 40 animals/day) and using the average manure production per animal of around 7 kg/day (provided by the market manager during the field visit), around 560 kg of manure are either abandoned in nearby fields or sold for use as uncomposted fertilizer every day. When applied to the soil, manure produces both direct and indirect GHG emissions, including CH_4 and N_2O, according to IPCC 2006 methodology for direct and indirect emissions – livestock and manure management[11].

Figure 18. Manure pile at the Abuko market (June 2024)

In total, approximately 32 tonnes of CO_2 equivalents are emitted annually (baseline) from the manure. This includes direct emissions from uncomposted manure (22,7 tonnes CO_{2eq} per year) and indirect emissions, including N_2O from atmospheric deposition and leaching/runoff (9,6 tonnes CO_{2eq} per year). The potential biogas production is calculated using a biogas yield of 0.045 m³/kg as suggested by Langeveld (2016). The total annual biogas potentially produced from the manure at the market and slaughterhouse would be around 8,820 m³/year. The potential mitigation from the collection of the

[11] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

manure used to produce biogas would therefore be around 32 tCO_{2eq}/year, or some 485 tCO_{2eq}/15 years (technology life span).

Slaughterhouse wastewater (SWW): The untreated slaughterhouse wastewater (SWW) produces high GHG emissions due to CH_4 and N_2O. About 40 animals, with an average wight of 250 Kg per animal, are slaughtered daily at the Abuko slaughterhouse. According to literature (Limeneh, 2022), the average proportions of solid waste are as follows: 38 percent is classified as final edible and commercially viable product, while 15 percent consists of liquid waste and solid waste combined. GHG emissions (CH_4+N_2O) have been calculated by applying the IPCC 2006 methodology for waste waters from slaughterhouses[12].

Anaerobic digestion is a promising technology for the efficient treatment of high strength wastewater while producing biogas as a valuable by-product. SWW presents higher proportions of organic substrate molecules for the methanogenesis than sanitary sewage sludge thus facilitating the production of the highest biogas (Ng, 2022). This SWW is laden with protein, fats, high organic content, microbes, and various emerging pollutants, including pharmaceutical and veterinary residues. Proper characterization of this wastewater is essential to apply effective treatment methods, ensuring that its discharge does not harm the environment (Ng, 2022). As effective means of proper SWW disposal, anaerobic digestion can be an optimal solution to eliminate environmental and human risks while also producing green energy.

Figure 19. Slaughterhouse wastewater SWW system (June 2024)

According to IPCC methodologies, the Abuko Market has a GHG emission intensity from wastewater discharge into a lagoon of approximately 141 tonnes of CO_2 equivalents per year, or some cumulated 2,115 tCO_{2e} over 15 year of technology life span. Considering the total WW produced and discharged, the total annual biogas production from SWW is calculated to be approximately 367,500 m^3/year.

[12] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Electricity (Grid): According to IRENA (IRENA, 2023), the emission factor for electricity produced in The Gambia in 2023 was 279 tCO_{2e}/GWh. With a final consumption of around 0.042 GWh per year, the farm's GHG emissions from electricity consumption amount to approximately 11.7 tonnes of CO2 equivalents per year. This annual electricity demand (equivalent to 151,269.12 MJ/year) can be met by substituting it with the newly produced biogas. Considering an LHV for biogas of 22.00 MJ/m³ and a conversion efficiency of 0.35, the biogas required to replace grid electricity used on the farm would be approximately 19,645.34 m³/year. Such substitution would reduce reliance on fossil fuel-based power generation, leading to a decrease in associated GHG emissions. By replacing this electricity with biogas, the facility can eliminate these emissions entirely, achieving an annual reduction of about 11.72 tCO_{2e}/year or some 175.8 tCO_{2e} over the technology lifespan (15 years).

Diesel: In total, approximately 2.5 tonnes of CO_2 equivalents are produced annually from the use of a diesel generator to cover energy gaps and from a tractor used to transport and discharge manure in the fields. This has been assessed using the IPCC 2006 methodology – stationary combustion[3]. The electricity supply of 1,331.70 kWh/year (equivalent to 4,794.12 MJ/year) from diesel generators can be replaced by biogas. The biogas required to replace diesel-generated electricity is around 622.61 m³/year. The diesel used by the tractor will be eliminated since the manure will be used on site for energy purposes. By replacing this diesel with biogas, the facility can eliminate these emissions entirely, achieving a 100 percent reduction of 2.5 tonnes CO_{2e}/year or some 37.5 tonnes CO_{2e} over 15 years technology lifespan.

Figure 20. Diesel generator at the Abuko market and slaughterhouse (June 2024)

Firewood: According to IPCC 2006 methodology – stationary combustion[13], the total GHG emissions generated by the burning of firewood by the skinners amount to around 144.5 tonnes of CO_2 equivalents per year. This figure excludes CO_2 emissions during the burning process, which are considered biogenic. The total does not include CH_4 and N_2O emissions.

[13] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

Figure 21. Truck transporting firewood at the Abuko market (June 2024)

The total energy consumption from firewood is 15,636,600 MJ/year. Approximately 710,754 m^3/year of biogas would be required to replace this with biogas. The amount of biogas potentially obtained by digesting the manure and the SWW would not be sufficient to cover the full energy need of all 63 skinners. In fact, after using the produced biogas to replace 100 percent of the electricity and diesel consumption, only 50 percent (7,818,300 MJ/year) of the amount of firewood used by the skinners can be effectively displaced by biogas. This transition will alleviate deforestation pressures and improve indoor air quality by reducing smoke from firewood burning. The facility could eliminate these emissions by replacing firewood with biogas, achieving a 50 percent reduction of 144.5 tCO_{2e}/year or some 1,083.5 tCO_{2e} over 15 years of technology lifespan (50 percent of baseline emissions).

4.2.3 Financial analysis

A comprehensive financial cost-benefit analysis (CBA) was conducted to evaluate the feasibility of implementing a biogas biodigester in the Abuko case study. The study's primary objective was to assess the economic viability of substituting conventional energy sources, namely electricity from the grid, diesel for electricity generation, and firewood for thermal energy in skin processing, with biogas.

The market's energy-related expenses are significant. Monthly electricity expenses amount to approximately 60,000 Dalasi, or some US$885, for the consumption of 52,174 kWh, primarily used for pumping water and providing drinking water for animals. In addition to this, there are extra costs incurred for operating a diesel generator and fuelling an old diesel tractor.

The slaughterhouse faces additional challenges with its non-functional cooling and solar systems, which may increase operational costs and inefficiencies. Adjacent to the facility, 63 skinners utilize firewood exclusively for processing animal skins, with each skinner consuming about 40 kg of firewood daily. This results in a total monthly consumption of 75.6 tonnes of firewood, costing around 567,000 Dalasi (approximately US$8,166.60). This practice not only incurs a high financial cost but also exacerbates deforestation issues. Significant savings can be achieved by producing biogas at the facility. The potential annual savings include US$9,241 from the electricity bill, US$531 as diesel for electricity, US$531 as diesel for manure transport, and US$101,823 for firewood. Regarding firewood, only 50 percent of its consumption would be covered by biogas production. Considering the baseline unit cost of firewood of US$0.0065/MJ and applying the same cost for the newly produced biogas sold by the market to the skinners, the final revenues from the replaced firewood would be around US$50,346/year. This will ensure reliable and clean energy provision for the skinner without increasing costs. The total potential annual savings by transitioning to biogas production would be US$61,215/year (**Table 21**).

Table 21. Abuko's potential Annual Savings by Producing Biogas at the Facility

Savings	Amount [USD/year]	Unit cost [USD/unit]
Electricity bill	9,241	0.22 [USD/kWh]
Diesel for electricity	531	1.23 [USD/litre][14]
Diesel (manure transport)	531	
Firewood (50 % covered)	50,346	0.11 [USD/Kg] or 0.0065 [USD/MJ]
Total	**60,649**	**-**

Source: Own calculations

Aggregated capital expenditures (CAPEX) are reported in **Table 22**. The biogas plant would have a power capacity of 104 kWe and generate 400,935 cubic meters of biogas annually, operating for 7,200 hours each year. The reactor volume would be 45 cubic meters, and there would not be heat production (0 GJ/year). The financial breakdown of the project would total US$111,170, including pretreatment at US$2,887, equipment at US$82,286, building at US$13,402, and installation at US$12,595. No costs are associated with the electricity distribution network because all biogas produced are intended for use within the Abuko market, with no surplus available for sale. Disaggregated capital costs are provided in **Annex 3**.

Table 22. Capital expenditures of the Abuko case study investment

Item	Unit	Value
Electrical Installed Capacity	(kWe)	104
Biogas volume	m3 Biogas/year	400,935
Operating period	h/year	7,200
Heat Production	GJ/year	0.0
Reactor Volume	m3	45
Subtotals		
Pretreatment	USD	2,887
Equipment	USD	82,286
Building	USD	13,402
Installation	USD	12,595
Electricity Distribution network	USD	0
Grand total	**USD**	**111,170**

Source: Own calculations using FAO BEFS RA Tools (Intratec cost index for 2023)

[14] https://www.globalpetrolprices.com/Gambia/diesel_prices/

Operating costs (OPEX) are do not include feedstock and transportation, since waste and residues are collected for free and always available in place. OPEX, mainly maintenance and materials, are calculated as 10 percent of the total investment, which amounts to approximately US$11,000 per year. Fixed costs include labour for two skilled and two unskilled workers, totalling around US$20,000 per year, and capital depreciation over a 15-year lifespan, which is approximately US$7,500 per year. This brings the total annual operating and fixed costs to around US$30,000 per year.

Financial analysis indicated substantial potential savings from transitioning away from grid electricity (80 percent fossil-generated), diesel, and firewood. However, the initial investment required a CAPEX of around US$112,000, 60 percent of which was financed through a loan at a fixed interest rate of 6 percent over a 10-year term, allowing the investor to reduce the capital expenditures to around US$44,500. The amount covered by the loan would be around US$66,700 (**Figure 22**).

Despite these challenges, and considering a discount rate of 8 percent, the project demonstrated promising financial prospects, boasting a positive Net Present Value (NPV) of US$30,585, an Internal Rate of Return (IRR) of 11.9 percent, and a payback period of 8 years. These metrics indicate favourable project economics and suggest that the project is financially attractive and capable of recouping initial investments within a reasonable timeframe.

Figure 22. Cost Benefit Analysis (CBA) of biogas investment at the Abuko Market

Year	0	1	2	3	4	5	6	7	8	9	10 to 15
Energy consumption											
Electricity consumption [kWh/year]	42,019	42,019	42,019	42,019	42,019	42,019	42,019	42,019	42,019	42,019	42,019
Diesel consumption [L/year]	864	864	864	864	864	864	864	864	864	864	864
Biogas to replace firewood 50% [m3/year]	356,052	356,052	356,052	356,052	356,052	356,052	356,052	356,052	356,052	356,052	356,052
Diesel market price [USD/L]	1.2300	1.242	1.255	1.267	1.280	1.293	1.306	1.319	1.332	1.345	1.428
Electricity tarif [USD/kWh]	0.2200	0.222	0.224	0.227	0.229	0.231	0.234	0.236	0.238	0.241	0.255
Biogas price [USD/m3]	0.1400	0.141	0.143	0.144	0.146	0.147	0.149	0.150	0.152	0.153	0.163
Revenues											
Replaced electricity expenses [USD/year]		9,337	9,430	9,524	9,620	9,716	9,813	9,911	10,010	10,110	10,732
Replaced diesel expenses [USD/year]		1,073	1,084	1,095	1,106	1,117	1,128	1,139	1,151	1,162	1,234
Revenues from biogas to skinner [USD/year]		50,346	50,849	51,358	51,871	52,390	52,914	53,443	53,977	54,517	57,871
Operating and fixed costs											
Operating costs (10% CAPEX) [USD/year]		*(11,116.95)*	*(11,228.12)*	*(11,340.40)*	*(11,453.81)*	*(11,568.35)*	*(11,684.03)*	*(11,800.87)*	*(11,918.88)*	*(12,038.07)*	*(12,778.65)*
Labour		-20,000.00	-20,200.00	-20,402.00	-20,606.02	-20,812.08	-21,020.20	-21,230.40	-21,442.71	-21,657.13	-22,989.48
Capital depreciation		- 7,411	- 7,411	- 7,411	- 7,411	- 7,411	- 7,411	- 7,411	- 7,411	- 7,411	- 7,411
Cash Flow											
+ Avoided expenses and Revenues		60,755.77	61,363.33	61,976.96	62,596.73	63,222.70	63,854.93	64,493.48	65,138.41	65,789.80	69,837.19
- 'Operating costs [USD/year]		*(11,116.95)*	*(11,228.12)*	*(11,340.40)*	*(11,453.81)*	*(11,568.35)*	*(11,684.03)*	*(11,800.87)*	*(11,918.88)*	*(12,038.07)*	*(12,778.65)*
Operating Cash Flow	**-**	**49,639**	**50,135**	**50,637**	**51,143**	**51,654**	**52,171**	**52,693**	**53,220**	**53,752**	**57,059**
- Investments [USD]	- 111,170										
- Fixed costs [USD/year]		*(27,411.30)*	*(27,611.30)*	*(27,813.30)*	*(28,017.32)*	*(28,223.38)*	*(28,431.50)*	*(28,641.70)*	*(28,854.01)*	*(29,068.44)*	*(30,400.79)*
- Loan annuity		*(9,062.63)*	*(9,062.63)*	*(9,062.63)*	*(9,062.63)*	*(9,062.63)*	*(9,062.63)*	*(9,062.63)*	*(9,062.63)*	*(9,062.63)*	-
Total Cash Flow	**- 111,170**	**13,165**	**13,461**	**13,761**	**14,063**	**14,368**	**14,677**	**14,988**	**15,303**	**15,621**	**26,658**
Cumulative Cash Flow	*- 111,170*	*- 98,005*	*- 84,543*	*- 70,783*	*- 56,720*	*- 42,351*	*- 27,675*	*- 12,686*	*2,617*	*18,237*	*164,128*
Payback Year	-	-	-	-	-	-	-	-	*Payback*	-	-
CF shareholders	- 44,468	13,165	13,461	13,761	14,063	14,368	14,677	14,988	15,303	15,621	26,658
Cumulative Cash Flow	*- 44,468*	*- 31,303*	*- 17,842*	*- 4,081*	*9,982*	*24,350*	*39,027*	*54,015*	*69,318*	*84,939*	*230,829*
Payback Year	-	-	-	-	*Payback*	-	-	-	-	-	-
Loan and Capital structure											
Equity private financing	**- 44,468**										
Loan	**- 66,702**	**60%** of initial investment									
Constant interest rate	**6%**										
Duration of loan (years)	10										
Grace period (year)	-										
Loan repayment plan	Constant installments										
Loan outstanding (BoP)	**66,702**	**66,702**	**61,641**	**56,277**	**50,591**	**44,564**	**38,175**	**31,403**	**24,225**	**16,615**	**-**
- Interests		4,002	3,698	3,377	3,035	2,674	2,291	1,884	1,453	997	-
- Capital repaid		5,061	5,364	5,686	6,027	6,389	6,772	7,178	7,609	8,066	-
Loan outstanding (EoP)	**66,702**	**61,641**	**56,277**	**50,591**	**44,564**	**38,175**	**31,403**	**24,225**	**16,615**	**8,550**	**-**
Project profitability											
NPV	30,584.87 USD										
NPV to shareholders	92,345.72 USD										
Project IRR	**11.9%**										
IRR to shareholders	32.0%										
payback (years)	**8**										
Shareholders payback (years)	4										

Source: Own calculations

The sensitivity analysis, conducted with a 5 percent variation in key variables, highlighted the significant impact of the biogas selling price and the Labour expenditure (fixed cost) on the Net Present Value (NPV) of the project.

Table 23. Sensitivity analysis results: impact of variable variation on Net Present Value of Abuko Market

SENSITIVITY ANALYSIS (5%)									
Variables	Variation of variables			Variation of NPV					
	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent
Diesel market price [USD]	1.1685	1.23	1.2915	30,135	30,585	31,035	-1 %	0 %	1 %
Electricity tariff [USD/kWh]	0.209	0.22	0.231	26,670	30,585	34,500	-13 %	0 %	13 %
Biogas selling price [USD/m3]	0.133	0.14	0.147	9,474	30,585	51,696	-69 %	0 %	69 %
Operating costs [USD/yr]	10,561	11,117	11,673	35,246	30,585	25,923	15 %	0 %	-15 %
Labour [USD/year]	19,000	20,000	21,000	38,971	30,585	22,198	27 %	0 %	-27 %
Capital depreciation [USD/yr]	7,040	7,411	7,782	33,522	30,585	27,648	10 %	0 %	-10 %
Loan interest rate [%]	5.7	6.00	6.3	31,382	30,585	29,782	3 %	0 %	-3 %

Source: Own calculations

When biogas selling prices varied by 5 percent, NPV fluctuated by -69 percent and +69 percent respectively. Similarly, a 5 percent variation in labour expenses resulted in an NPV change of +27 percent and -27 percent (**Table 23**). This underscores the importance of meticulous consideration and potential mitigation strategies for these variables in project planning and decision-making.

A further step considers only the selected variable that exceeded 15 percent of NPV fluctuation. **Table 24** illustrates the impact of the varying biogas selling prices (USD) and labour expenses on the Net NPV of the investment. As the biogas selling price increases from 40 percent to 160 percent of its original value, the NPV ranges from US$-222,748 to 283,918. Similarly, changes in labour expenses from 40 percent to 160 percent of its original value, lead to corresponding NPV fluctuations of US$131,222 to -70,052. The sensitivity analysis demonstrated a variation of less than 20 percent on both the selling price of biogas and the labour expenses would generate a negative NPV. It is important to remember that this study considered a selling price for biogas (USD/MJ) equal to the current price (USD/MJ) of the firewood paid by the skinners at the market. This price (US$0.14/$m^3$) is extremely low compared to the average EU price, US$0.35[15]/$m^3$ of April 2024.

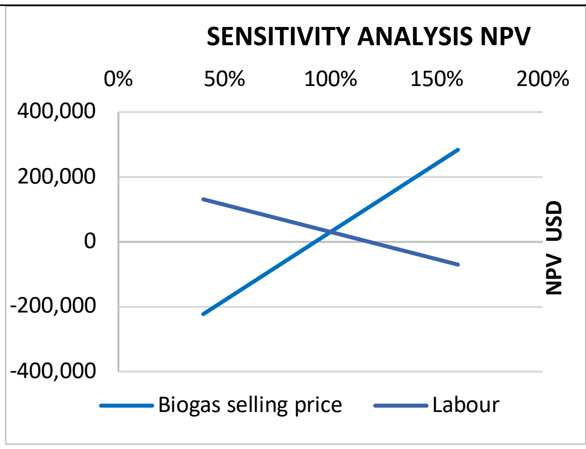
For skinners, who currently pay a low price for firewood, the project offers a significant advantage by providing a potentially cheaper or stable-priced alternative energy source, based on a low assumed price of US$0.14 per cubic meter.

15 https://thedocs.worldbank.org/en/doc/5d903e848db1d1b83e0ec8f744e55570-0350012021/related/CMO-Pink-Sheet-April-2024.pdf

For private investors, while there is a noted sensitivity to price variations, the situation might be more favourable than initially perceived.

Table 24. Impact of variable variation on Net Present Value (NPV) for biogas selling price and labour expenses

	Biogas selling price (USD)		Labour expenses (USD)	
	NPV	Variable	NPV	Variable
160 %	283,918	0.22	-70,052	32,000
140 %	199,473	0.20	-36,507	28,000
120 %	115,029	0.17	-2,961	24,000
100 %	30,585	0.14	30,585	20,000
80 %	-53,859	0.11	64,131	16,000
60 %	-138,304	0.08	97,676	12,000
40 %	-222,748	0.06	131,222	8,000



Source: Own calculations

4.2.4 Conclusions

In conclusion, the Abuko livestock market and slaughterhouse case study highlighted significant challenges in waste management and energy consumption that pose environmental and health risks. The current practices, including improper disposal of manure and wastewater, result in substantial greenhouse gas emissions, water contamination, and deforestation. Implementing biogas technology in the Abuko market offers a comprehensive solution to these issues.

The production of biogas from manure and slaughterhouse wastewater can reduce reliance on conventional fuels such as firewood, electricity, and diesel, leading to a significant decrease in greenhouse gas emissions and other pollutants. The biogas project could also provide economic benefits, including considerable savings on electricity and diesel costs and the potential for generating revenue from biogas and biodigestate sales. With a positive Net Present Value (NPV) of around US$30,584 and an Internal Rate of Return (IRR) of 12 percent, the project is financially viable. It can recoup the initial investment within eight years.

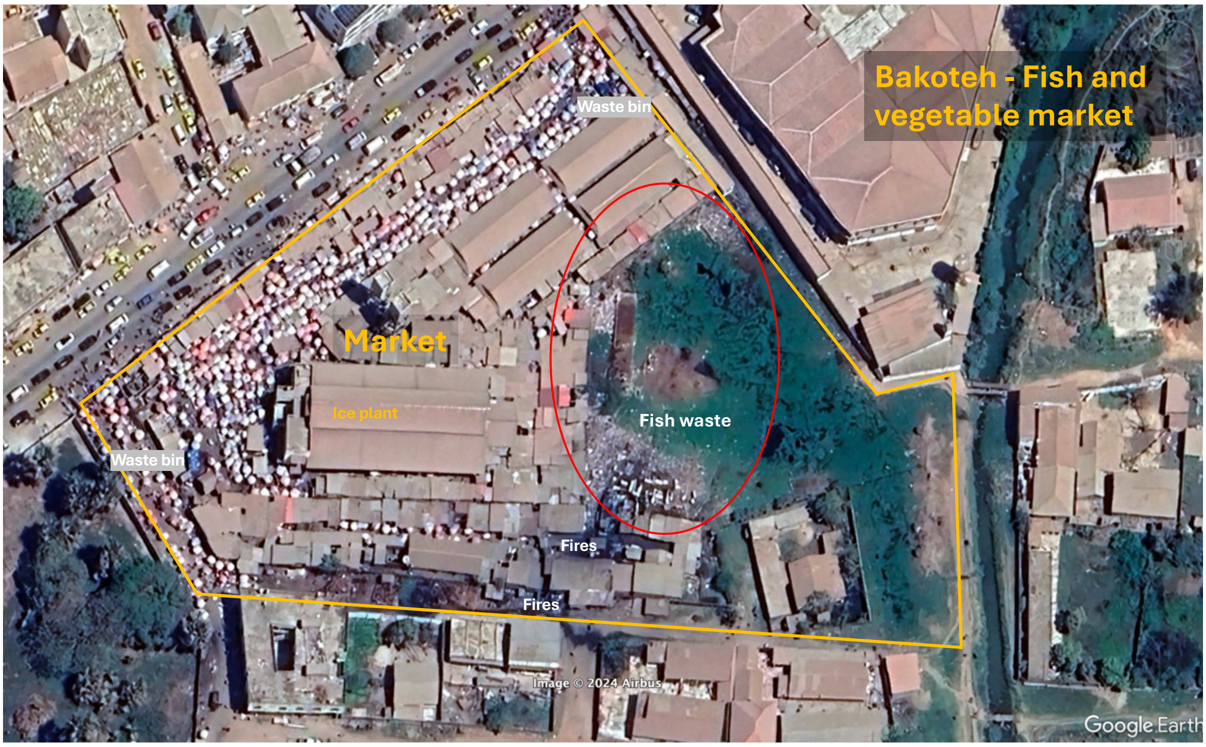
The sensitivity analysis indicates that the biogas investment project is already profitable, even with the current low selling price assumed in the analysis. This profitability provides a solid foundation for the project's financial viability. However, aligning the selling price of biogas more closely with the higher average prices observed in the EU could further enhance the project's revenue potential. In addition, the analysis revealed that labour expenses should be carefully considered, as they are a sensitive variable. Additionally, the use of bio digestate as fertilizer can enhance soil health and improve crop yields for local farmers. This initiative aligns with the SCALA project's goals of promoting sustainable business practices and enhancing climate resilience. By addressing the environmental and economic challenges at the Abuko market, the biogas project can contribute to a more sustainable and resilient community, benefiting both the facility and the broader region.

4.3 Bakoteh fish and vegetable market (medium size)

4.3.1 Case study description

The market is a large vegetable and fish market in Bakoteh. During the scoping mission, FAO's and UNDP's team had a meeting with the manager, Ms. Sainabou Cons Fhall. The market also has an ice production plant composed of two units. The units are outdated, almost 11 years, and only one is currently working. They used to produce 10 + 10 tonnes of ice per day; today, only one unit is producing 3 tonnes/day. In the past years, the previous manager has reported that inconsistent electricity and water supply from the National Water and Electricity Company (NAWEC) has severely disrupted market operations. In an interview[16], the manager explained that the market's reliance on NAWEC for power has affected their ability to produce ice, crucial for preserving fish, leading to reduced sales. The market continues to struggle with inadequate water and electricity supplies, essential for its functioning.

Figure 23. Aerial view of the Bakoteh fish and vegetable market



The main waste produced at the market includes mixed solid waste (60 percent organic) and fish waste. The organic waste is collected and piled in a field and sold as fertilizer after drying. The mixed waste is collected in large bins (10 tonnes each). Two bins per day are collected and transported to the Bakoteh dumpsite. This means that around 12 tonnes of organic waste are available at the market every day

[16] https://foroyaa.net/nawec-disrupts-bakoteh-fish-market-business-manager/

and are not currently used for other purposes. The fish waste per day amounts to approximately 260 kg. The dried fish waste is sold as fertilizer at 100 Dalasi per bag, so approximately US$1.44, (30 kg bag). There is a significant amount of groundnut processing through roasting. To do this, the market consumes around 25 kg of firewood per day, costing approximately 500 Dalasi per day. Electricity is the main cost for the market, with a daily bill from NAWEC of around 3,800 Dalasi (US$54.68), or 11,400 Dalasi (US$164.71) per month. Considering a market tariff of 14.9 Dalasi (US$0.21) per kWh, this results in approximately 765 kWh per month.

This case study is particularly compelling. The market generates a substantial amount of vegetable waste daily, which is currently sent to the nearby dumpsite. Additionally, fish waste accumulates and is underutilized. The manager highlighted the potential for separating the waste to recover the organic fraction. Furthermore, there is a need to find alternative energy sources to reduce the high costs associated with electricity and firewood, and to enhance ice production capacity.

4.3.2 Baseline GHG emissions and mitigation potential

The paragraph discusses the baseline GHG emissions generated yearly in the case study by different sources. It also explores the potential for biogas production from vegetable and fish waste produced by vendors at the market. The paragraph also highlights the significant potential for environmental and energy-related mitigation through the introduction of biogas production and consumption, considering a technology lifetime of 15 years for the biogas system. By substituting conventional energy sources with biogas and managing waste more effectively, the market can achieve substantial reductions in greenhouse gas emissions and other pollutants.

Table 25 summarizes and lists the baseline emissions produced by the Bakoteh market highlighting significant sources of environmental impact. The most substantial contributor is organic waste, underscoring the need for improved management practices. Electricity from the grid and firewood burning are also considered in the analysis.

Table 25. Bakoteh Market's GHG emissions by source per year and considering 15-year of biogas technology lifespan

Source	tCO_{2eq}/year	tCO_{2eq}/15yrs project lifespan
Organic Solid Waste OSW	1,717.00	25,755.0
Electricity GRID	2.56	38.4
Firewood	1.38	20.7
Total	1.721.00	25,815.0

Source: Own calculations using IPCC methodologies

By using the available organic solid waste (OSW), in total, the case study has a biogas potential production of around 376,320 m^3/year, or 225,792 m^3/CH_4 per year. The calculated installed capacity and size a of biogas plant would therefore be around 80 kW (**Table 26**).

Table 26. Bakoteh market's potential annual biogas and CH_4 production, installed capacity and annual electricity production

Item	Value	Unit
Annual biogas potential production	290,993	m^3/year
Annual CH_4 potential production	181,150	m^3/year
Plant installed capacity	83	kW
Annual potential electricity production	622,452	MWh/year

Source: Own calculations

Table 27 presents the energy consumption of various sources at the case study site and the biogas needed to replace these energy sources. Firewood consumption is significantly high, at 148,750 MJ annually. Meeting this energy requirement would need approximately 6,761.3 m³ of biogas for in a generator. Considering the biogas potential, this demand could be fully covered.

Table 27. Bakoteh market's energy consumption and biogas requirement

Source	Consumption [MJ/year]	Biogas needed to replace baseline [m^3/yr]	Biogas Availability to replace energy needs [%]
Firewood	148,750	6,761.3	100 %
Electricity GRID	33,052.3	4,292.5	100 %
Total	181,802.3	11,053.8	100 %

Source: Own calculations

The annual electricity consumption from the grid is 33,052.3 MJ. Such energy need would require about 4,292.5 m³ of biogas in a generator. Given the biogas potential, this demand could be fully met. Overall, the total energy consumption from all sources is some 11,053.8 MJ per year, requiring 11,053.8 m³ of biogas to cover it fully. The total available biogas is 290,993 m³. Therefore, the total energy need would be fully covered, ensuring a large surplus of 279,936 m³/year.

More detailed information on GHG emissions and biogas potential production are provided from the list below.

Organic Solid Waste (OSW): The assessment considered both vegetable and fish waste.

Vegetables: Vegetables are collected in bins managed by the Kanifing Municipal Council (KMC) and transported to the Bakoteh dumpsite. Approximately 12 tonnes of organic waste, primarily vegetables and fruits, are transported and disposed of at the dumpsite daily, amounting to about 4,200 tonnes annually.

Figure 24. Waste collection at the Bakoteh market (June 2024)

Fish waste: Fish waste is also produced in large quantities at the market. A total of 94 tonnes of fish waste are collected and disposed of in a field near the market. Like the vegetables in the dumpsite, this waste is left abandoned on the ground, generating greenhouse gas emissions and posing a threat to environmental and human health.

Figure 25. Fish waste in a field near the Bakoteh market

When applied to the soil, vegetable, fruit, and fish wastes produce both direct and indirect greenhouse gas emissions, including CH_4 and N_2O. In total, approximately 32 tonnes of CO2 equivalents are emitted annually (baseline) from the manure. This includes direct emissions from uncomposted manure, amounting to 22,7 tonnes CO_{2e} annually. Indirect emissions, including N_2O from atmospheric deposition and leaching/runoff, amount to 9,6 tonnes CO_{2e} per year. The calculation used emission factors for vegetables and fish waste from Nordahl, 2020.

The potential biogas production is calculated by utilizing a biogas yield of 300 l/KgVS-1 of biogas for vegetable and fruit wastes, as suggested by Esperanza, 2020, and 792 CH_4Nm^3/t VS for fish waste, as suggested by Nges, 2012. The total annual biogas production from both the vegetable and fish wastes at the market is around 290,993 m^3/year. The potential mitigation from the collection of the waste used to produce biogas would therefore be around 1,717 tCO_{2e}/year, or some 25,755 tCO_{2e}/15 year of technology life span.

Electricity (Grid): According to IRENA (IRENA, 2023), the emission factor for electricity produced in The Gambia in 2023 was 279 tCO_{2e}/GWh. With a final consumption of around 0.0092 GWh per year, the market's GHG emissions from electricity consumption amount to approximately 2.56 tonnes of CO2 equivalents per year. This annual electricity demand (equivalent to 33,052.3 MJ/year) can be met through the substitution of biogas. Considering a LHV for biogas of 22.00 MJ/m³ and a conversion efficiency of 0.35, the biogas required to replace grid electricity used on farm is 147,529.77 m³/year. Such substitution would reduce reliance on fossil fuel-based power generation, leading to a decrease in associated GHG emissions. By replacing this electricity with biogas, the facility can eliminate these emissions entirely, achieving an annual reduction of some 38.4 tCO_{2e} over the technology lifespan (15 years).

Firewood: According to IPCC 2006 methodology – stationary combustion[17], the total GHG emissions generated by burning firewood by private vendors toasting peanuts amount to around 1.38 tonnes of CO_2 equivalents per year. This figure excludes CO_2 emissions during the burning process, which are considered biogenic, while CH_4 and N_2O emissions are included. The total energy consumption from firewood is 148,750 MJ/year. To replace this with biogas, approximately 6,761.36 m³/year of biogas are required. By replacing this electricity with biogas, the facility could eliminate these emissions, achieving a 100 percent reduction or some 20.7 tCO_{2e} over 15 years technology lifespan.

Figure 26. Firewood consumption at the Bakoteh market (June 2024)

This transition will alleviate deforestation pressures and improve indoor air quality by reducing smoke from firewood burning.

Biogas surplus: The total amount of biogas produced will be sufficient to cover the annual energy needs of the market and an additional biogas surplus of around 279,939 m^3/year. According to IRENA

[17] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

(2023), the emission factor for electricity produced in The Gambia in 2023 was 279 tCO_{2e}/GWh. With an expected electricity production from the biogas surplus of around 0.6 GWh per year, the project may result in an additional 167.07 tonnes of CO_2 equivalents per year, or approximately 2,506 tCO_{2e} over a 15-year lifespan.

By considering the mitigation potential of the electricity produced for NAWEC, the overall investment's mitigation potential would be approximately 1,888 tCO_{2e}.

4.3.3 Financial analysis

Also, in the case of the Bakoteh market, a comprehensive CBA was conducted to evaluate the feasibility of implementing a biogas biodigester. The study's primary objective was to assess the economic viability of substituting conventional energy sources, namely electricity from the grid and firewood for thermal energy in skin processing, with biogas and to evaluate the viability of producing electricity to be sold to the national grid.

The market's annual electricity expenses amount to approximately 2,019 Dalasi for the consumption of 9,181 kWh/year, primarily used for ice production, fans, and lighting (**Table 28**). In the market, several private processors (mainly women) toast groundnuts consuming about 8,750 kg of firewood per year, costing around 65,625 Dalasi or US$969 per year. This practice not only incurs a high financial cost, but also exacerbates deforestation issues (**Table 22**). As the introduction mentions, NAWEC and the Minister of Petroleum and Energy have established a feed-in tariff for renewable energy producers selling to the grid, set at US$0.25 /kWh. However, to adopt a conservative approach, this study considered a lower tariff equal to US$0.235 /kWh. The main output the market can generate are revenues obtained by selling electricity to the grid, with annual revenues amounting to US$142,127. The unit cost for electricity sold to the grid is US$0.235/kWh (**Table 28**). By producing biogas at the facility, savings can be achieved. The potential annual savings include US$2,019 on the electricity bill, US$969 on firewood, and US$142,127 in revenues from the electricity sold to the national grid (**Table 28**).

Table 28. Potential annual savings by producing biogas at the Bakoteh market

Savings and revenues	Amount [USD/year]	Unit cost [USD/unit]
Electricity bill	2,019	0.22 [USD/kWh]
Firewood	969	0.11 [USD/Kg]
Electricity to the grid	142,127	0.235 [USD/kWh]
Total	**145,155**	**-**

Source: Own calculations

Aggregated CAPEX is detailed in **Table 29** for the Bakoteh case study. The biogas plant in this case study would have a power output of 83 kWe and produce 332,400 cubic meters of biogas annually, operating for 7,200 hours each year. The reactor volume would be 162 cubic meters, with no heat production (0 GJ/year). Due to the typology of the feedstock, which would require a significantly large digester to accommodate the volume, the CAPEX would be notably higher.

Table 29. Capital expenditures of the Bakoteh case study investment

Item	Unit	Value
Digester size		
Capacities	(kWe)	83
Capacities	m^3 Biogas/year	332,400
Operating period	h/year	7,200
Heat Production	GJ/year	0.0
Volume Reactor	m3	162
Subtotals		
Pretreatment	USD	8,218.06
Equipment	USD	120,892.45
Building	USD	37,290.97
Installation	USD	29,035.98
Electricity Distribution network	USD	94,572.39
Grand total	**USD**	**290,009.85**

Source: Own calculations using FAO BEFS RA Tools (Intratec cost index for 2023)

The total financial investment for the project amounts to US$290,009.85, broken down into specific categories: pretreatment costs are US$8,218.06, equipment costs are US$120,892.45, building costs are US$37,290.97, installation costs are US$29,035.98, and costs associated with the connection to the electricity distribution network are US$94,572.39. Disaggregated capital costs are provided in **Annex 3**.

Operating costs (OPEX) do not include feedstock and transportation, since waste and residues are collected for free and always available in place. OPEX, are mainly maintenance and materials, are calculated as 10 percent of the total investment, which amounts to approximately US$29,000 per year. Fixed costs include labour for two skilled and two unskilled workers, totalling around US$20,000 per year, and capital depreciation over a 15-year lifespan, which is approximately US$19,300 per year. This brings the total annual operating and fixed costs to around US$73,300 per year.

Financial analysis indicated potential savings from transitioning away from grid electricity, diesel, and firewood, as well as high revenues from selling the electricity to the national company NAWEC. However, the initial investment required a CAPEX of approximately US$290,010, 60 percent of which was financed through a loan at a fixed interest rate of 6 percent over a 10-year term, allowing the investor to reduce the capital expenditures to around US$116,000. The amount covered by the loan would be around US$174,000 (**Figure 27**). Despite these challenges, and considering a discount rate of 8 percent, the project demonstrated promising financial prospects, boasting a positive Net Present Value (NPV) of US$195,678, an Internal Rate of Return (IRR) of 17.3 percent, and a payback period of 6 years. These metrics indicate favourable project economics and suggest that the project is financially attractive and capable of recouping initial investments within a reasonable timeframe (**Figure 27**).

Figure 27. Cost Benefit Analysis (CBA) of biogas investment at the Bakoteh market

Year	0	1	2	3	4	5	6	7	8	9	10 to 15
Energy consumption											
Electricity consumption [kWh/year]	9,181	9,181	9,181	9,181	9,181	9,181	9,181	9,181	9,181	9,181	9,181
Firewood consumption [Kg/year]	8,750	8,750	8,750	8,750	8,750	8,750	8,750	8,750	8,750	8,750	8,750
Electricity from biogas surplus [kWh/year]	598,808	598,808	598,808	598,808	598,808	598,808	598,808	598,808	598,808	598,808	598,808
Firewood market price [USD/Kg]	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.13
Electricity tarif [USD/kWh]	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.26
Electricity feed-in tarif [USD/kWh]	0.235	0.24	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.26	0.27
Revenues											
Savings from replaced electricity expenses		2,040	2,060	2,081	2,102	2,123	2,144	2,166	2,187	2,209	2,345
Savings from replaced diesel expenses		972	982	992	1,002	1,012	1,022	1,032	1,042	1,053	1,117
Revenues from electricity sales		142,127	143,548	144,984	146,434	147,898	149,377	150,871	152,379	153,903	163,371
Operating costs											
Operating costs (10% CAPEX) [USD/year]		*(29,000.98)*	*(29,290.99)*	*(29,583.90)*	*(29,879.74)*	*(30,178.54)*	*(30,480.33)*	*(30,785.13)*	*(31,092.98)*	*(31,403.91)*	*(33,335.88)*
Labour		*(25,000.00)*	*(25,250.00)*	*(25,502.50)*	*(25,757.53)*	*(26,015.10)*	*(26,275.25)*	*(26,538.00)*	*(26,803.38)*	*(27,071.42)*	*(28,736.86)*
Capital depreciation		*(19,333.99)*	*(19,333.99)*	*(19,333.99)*	*(19,333.99)*	*(19,333.99)*	*(19,333.99)*	*(19,333.99)*	*(19,333.99)*	*(19,333.99)*	*(19,333.99)*
Cash Flow											
+ Avoided expenses and Revenues		145,139.17	146,590.56	148,056.47	149,537.03	151,032.40	152,542.73	154,068.15	155,608.84	157,164.92	166,833.73
- *'Operating costs [USD/year]*		*(29,000.98)*	*(29,290.99)*	*(29,583.90)*	*(29,879.74)*	*(30,178.54)*	*(30,480.33)*	*(30,785.13)*	*(31,092.98)*	*(31,403.91)*	*(33,335.88)*
Operating Cash Flow	-	**116,138**	**117,300**	**118,473**	**119,657**	**120,854**	**122,062**	**123,283**	**124,516**	**125,761**	**133,498**
- Investments [USD]	- 290,010										
- Fixed costs [USD/year]		*(44,333.99)*	*(44,583.99)*	*(44,836.49)*	*(45,091.51)*	*(45,349.09)*	*(45,609.24)*	*(45,871.99)*	*(46,137.37)*	*(46,405.41)*	*(48,070.85)*
- Loan annuity		*(23,641.83)*	*(23,641.83)*	*(23,641.83)*	*(23,641.83)*	*(23,641.83)*	*(23,641.83)*	*(23,641.83)*	*(23,641.83)*	*(23,641.83)*	-
Total Cash Flow	**- 290,010**	**48,162**	**49,074**	**49,994**	**50,924**	**51,863**	**52,811**	**53,769**	**54,737**	**55,714**	**85,427**
Cumulative Cash Flow	*- 290,010*	*- 241,847*	*- 192,774*	*- 142,779*	*- 91,856*	*- 39,993*	*12,819*	*66,588*	*121,325*	*177,038*	*650,604*
Payback Year	-	-	-	-	-	-	*Payback*	-	-	-	-
CF shareholders	- 116,004	48,162	49,074	49,994	50,924	51,863	52,811	53,769	54,737	55,714	85,427
Cumulative Cash Flow	*- 116,004*	*- 67,842*	*- 18,768*	*31,226*	*82,150*	*134,013*	*186,825*	*240,594*	*295,331*	*351,044*	*824,610*
Payback Year	-	-	-	*Payback*	-	-	-	-	-	-	-
Loan and Capital structure											
Equity private financing	**- 116,004**										
Loan	**- 174,006**	**60%**	of initial investment								
Constant interest rate	**6%**										
Duration of loan (years)	10										
Grace period (year)	-										
Loan repayment plan	Constant installments										
Loan outstanding (BoP)	**174,006**	**174,006**	**160,804**	**146,811**	**131,978**	**116,255**	**99,588**	**81,921**	**63,195**	**43,345**	**- 0**
- Interests		10,440	9,648	8,809	7,919	6,975	5,975	4,915	3,792	2,601	-
- Capital repaid		13,201	13,994	14,833	15,723	16,667	17,667	18,727	19,850	21,041	-
Loan outstanding (EoP)	**174,006**	**160,804**	**146,811**	**131,978**	**116,255**	**99,588**	**81,921**	**63,195**	**43,345**	**22,304**	**- 0**
Project profitability											
NPV	195,678.44 USD										
NPV to shareholders	356,795.02 USD										
Project IRR	**17.3%**										
IRR to shareholders	43.6%										
payback (years)	**6**										
Shareholders payback (years)	3										

The sensitivity analysis, which included a 5 percent variation in key variables, revealed the critical influence of the electricity feed-in tariff and operating costs on the Net Present Value (NPV) of the project. When the electricity feed-in tariff varied by 5 percent, the NPV changed significantly, decreasing by 30 percent when the tariff dropped to 95 percent of its base value and increasing by 32 percent when it rose to 105 percent (**Table 30**).

Table 30. Sensitivity analysis results: impact of variable variation on Net Present Value for the Bakoteh market case study

SENSITIVITY ANALYSIS (5%)									
Variables	Variation of variables			Variation of NPV					
	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent
Firewood market price [USD/Kg]	0.10	0.110	0.1155	195,271	195,678	196,086	-0.2 %	0 %	0.2 %
Electricity tariff [USD/kWh]	0.21	0.220	0.231	194,823	195,678	196,534	-0.4 %	0 %	0.4 %
Electricity feed-in tariff [USD/kWh]	0.22	0.235	0.24675	136,082	195,678	255,275	-30 %	0 %	30 %
Operating costs	27,551	29,001	30,451	207,839	195,678	183,518	6 %	0 %	-6 %
Labour [USD/year]	23,750	25,000	26,250	206,161	195,678	185,195	5 %	0 %	-5 %
Capital depreciation [USD/year]	18,367	19,334	20,301	203,340	195,678	188,017	4 %	0 %	-4 %
Loan interest rate [%]	5.7	6.0	6.3	197,759	195,678	193,584	1 %	0 %	-1 %

Source: Own calculations

In contrast, operating costs had a smaller, yet notable, impact, with a 5 percent increase leading to a 6 percent decrease in NPV and a 5 percent decrease resulting in a 6 percent increase in NPV. Additionally, changes in labour costs showed a similar pattern, where a 5 percent increase in labour costs resulted in a 5 percent decrease in NPV, and a 5 percent decrease in labour costs led to a 5 percent increase in NPV.

A further step in the sensitivity analysis considered only the variable that exceeded a 15 percent fluctuation in Net Present Value (NPV). As only the electricity feed-in tariff surpassed this threshold, the analysis focused exclusively on this variable.

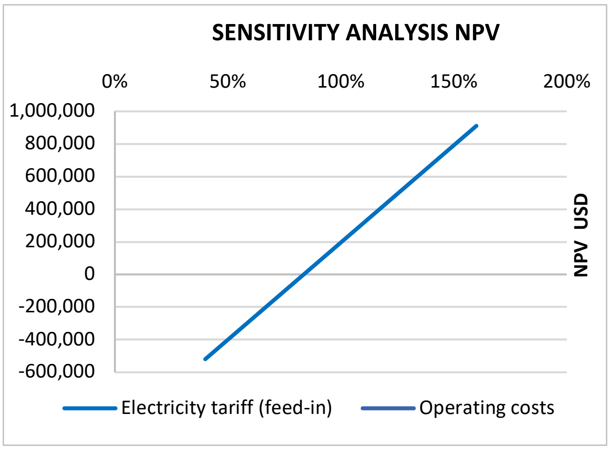
Table 31 illustrates the impact of varying the electricity feed-in tariff on the NPV. The NPV ranged from US$-519,484 to US$910,841 as the tariff increased from 40 percent to 160 percent of its original value. The analysis showed that a decrease in the feed-in tariff to 20 percent or below resulted in a negative NPV, indicating that the project becomes unprofitable if the tariff drops by 20 percent or more from its base value. This highlights the project's sensitivity to changes in the feed-in tariff, underscoring the importance of this factor in maintaining financial viability.

In June 2022, The Gambia took a significant step forward in the energy transition under the leadership of its new Minister of Petroleum and Energy, by implementing a feed-in tariff (FIT) and net metering scheme[18]. This initiative supports renewable energy producers, offering a tariff of US$0.25 per kWh for surplus energy fed into the national grid, applicable to stakeholders with generation capacities between 20 kW and 1.5 megawatts. This rate is significantly higher than the US$0.235 tariff used in the Cost-Benefit Analysis, suggesting that the financial outlook for bioenergy projects could be more favourable under the new scheme. The US$0.235 tariff was used to allow for a conservative estimate, as the project team was not able to confirm whether the US$0.25 tariff is currently in place; this matter will be further discussed with the government and NAWEC. For producers with capacities exceeding 1.5 megawatts, the government encourages the signing of 15-year power purchase agreements with the national water and electricity company, NAWEC. This policy aims to enhance the country's energy self-sufficiency—currently at 48 percent—and to increase the electrification rate, which stands at 60 percent, by promoting the diversification and decentralization of the grid power supply.

[18]https://energycapitalpower.com/the-gambia-net-metering-renewable-energy/?utm_content=216274832&utm_medium=social&utm_source=facebook&hss_channel=fbp-105729815176773

Table 31. Impact of variable variation on Net Present Value for feed in electricity tariff for the Bakoteh market case study

	Feed in Electricity tariff (USD)	
	NPV	Variable
160 %	910,841	0.376
140 %	672,454	0.329
120 %	434,066	0.282
100 %	195,678	0.235
80 %	-42,709	0.188
60 %	-281,097	0.141
40 %	-519,484	0.094



Source: Own calculations

4.3.4 Conclusions

In conclusion, the Bakoteh fish and vegetable market case study revealed critical challenges in waste management and energy consumption that have notable environmental and operational impacts. A key issue is the substantial quantity of organic and fish waste currently abandoned at the dumpsite. This large volume of waste is highly GHG-intensive, contributing significantly to greenhouse gas emissions and environmental degradation. Implementing biogas technology presents a powerful solution to these issues. By converting the high-volume organic waste and fish waste into biogas, the market can achieve substantial reductions in greenhouse gas emissions. The potential annual reduction of 1,717 tCO2e from biogas production underscores the significant emission mitigation potential of this project. Addressing the current practice of leaving waste at the dumpsite, which is a major source of GHG emissions, can greatly enhance the environmental benefits of the biogas initiative. Moreover, the project’s surplus biogas can be utilized to generate additional revenue by supplying electricity to the national grid, enhancing the overall financial performance. By transforming waste into energy and addressing the high GHG emissions from current waste disposal practices, the biogas project not only improves operational efficiency but also contributes significantly to environmental sustainability.

The financial analysis further supports the feasibility of the project. With an initial capital expenditure of US$290,009.85, the biogas project offers robust financial benefits, including a positive Net Present Value (NPV) of US$195,678 and an Internal Rate of Return (IRR) of 17.3 percent. The 6-year payback period indicates a reasonable timeframe for recouping the investment. However, the sensitivity analysis highlights the project's vulnerability to changes in key variables, particularly the electricity feed-in tariff. The analysis revealed that a 20 percent reduction in the tariff could lead to a negative NPV, jeopardizing the project's profitability. This sensitivity underscores the importance of stable and supportive policy frameworks to ensure the financial success of such renewable energy initiatives. The Gambia's introduction of a higher feed-in tariff of US$0.25 per kWh for renewable energy, as part of its energy transition strategy, further enhances the financial attractiveness of biogas projects. This tariff is notably higher than the US$0.235 per kWh rate used in the project's CBA, suggesting that the financial benefits could be even greater under the new scheme. This initiative aligns with broader sustainability goals, offering a solution that addresses both the market's operational challenges and its substantial environmental impact. By effectively managing the large amounts of organic waste and reducing GHG emissions, the biogas project provides a significant opportunity for enhancing the market's sustainability and resilience, benefiting both the facility and the surrounding community.

4.4 Bakoteh Dumpsite (large size)

4.4.1 Case study description

Bakoteh dumpsite is situated in the West Coast Region (WCR) of The Gambia, with geographical coordinates at approximately Latitude 13° 27' 57" N and Longitude 16° 42' 1" W. Covering an area of 17.5 hectares, it is the largest solid waste site in the country. It is located near the country's largest orphanage, several schools, and is surrounded by residential communities to the west and south. The area is plagued by a persistent odour from decaying waste, frequent fire outbreaks and smoke, making it a challenging environment for residents. Additionally, the water table in the vicinity is polluted with high lead concentration reported, complicating efforts toward sustainable development. The dumpsite, established approximately 40 years ago, has undergone recent improvements highlighted during our meeting with the manager. Historically plagued by issues such as lack of fencing and open burning by unauthorized individuals, significant progress was made in 2021 with the installation of a 17-kilometer fence funded by the Kanifing Municipal Council (KMC). This measure has effectively reduced fire incidents and regulated access to the site. However, challenges persist due to the absence of a waterproof liner able to prevent leaching. During the rainy season, the site experiences leaching of pollutants into the ground, leading to contaminated water streams flowing onto adjacent streets.

Figure 28. Aerial view of the Bakoteh Dumpsite in Serrekunda

The dumpsite receives approximately 60 tonnes of mixed waste daily, with an organic waste fraction ranging between 40 percent to 60 percent. Currently, the site operates without consuming electricity but relies solely on diesel for mechanized operations.

Given its size and operational challenges, the dumpsite presents a potential opportunity as large-scale site for study under the SCALA PSE project. There is potential to explore biogas production from the organic waste fraction through investments in mechanical and biological separation units and biodigesters. Additionally, assessing optimal tariff structures from NAWEC, the electricity provider, could enhance the feasibility and sustainability of such initiatives.

Figure 29. The Bakoteh Dumpsite (June 2024)

4.4.2 Baseline GHG emissions and mitigation potential

The average amount of organic municipal solid waste (OMSW) annually delivered at the dumpsite is around 10,950 tonnes. Considering a biogas yield from OMSW of around 120 m^3/ton of waste, as suggested by Rolewicz-Kalińska (Rolewicz-Kalińska, 2020), and a CH_4 content of 73 percent as suggested by Mavridis (Mavridis 2021), the dumpsite has a total biogas production potential of around 1,314,000 m^3 per year for a total potential electricity production of 2,810,725 kWh per year. The estimated installed capacity for the plant would be 375 kWe (**Table 32**).

Table 32. Potential annual biogas and CH4 production, installed capacity, and annual electricity production at the Bakoteh Dumpsite case study site

Item	Value	Unit
Annual biogas potential production	1,314,000	m^3/year
Annual CH4 potential production	964,476	m^3/year
Plant installed capacity	375	kW
Annual potential electricity production	2,810,725	MWh/year

Source: Own calculations

More detailed information on GHG emissions and biogas potential production are provided from the list below.

OMSW: The total organic waste delivered at the dumpsite is 10,950 tonnes per year. With an average emission intensity of 400 kg CO_{2eq} per tonne of organic waste (Nordahl, 2020), the total GHG emissions from this waste amount to 4,380 tonnes CO_{2e} per year. Over of the technology lifespan (15 years), the total GHG emissions mitigation from the organic waste management through biogas production would be some 65,700 tonnes CO_{2e}.

Electricity (Grid): According to IRENA (2023), the emission factor for electricity produced in The Gambia in 2023 was 279 tonnes CO_{2e} per GWh. Bakoteh Dumpsite could produce 1,314,000 m^3 of biogas annually. Given a LHV of 22.00 MJ/m^3 and a conversion efficiency of 0.35, the biogas required to replace grid electricity used would be 4,292.51 m^3/year. By substituting grid electricity with renewable energy generated by the biogas plant, the Bakoteh Dumpsite could offset the equivalent of 784.19 tonnes CO_{2e} annually or 11,763 tonnes CO_{2e} over the lifespan of the biogas plant.

In total, the GHG potential reduction of the investment (avoided emission of OMSW and electricity substitution) would amount to an estimated **5,164 19 tonnes CO_{2e} annually, or some 77,463.19** tonnes CO_{2e} over 15 years.

4.4.3 Financial analysis

As per the previous case studies, for the case of the Bakoteh dumpsite, a comprehensive CBA was conducted to evaluate the feasibility of implementing a biogas biodigester. The study's primary objective was to assess the viability of investing in biogas technology. To adopt a conservative approach, this study considered a low feed-in tariff equal to US$0.20 USD/kWh, much lower than the other small and medium-scale investments (US$0.235/kWh) or the one set by NAWEC and the Minister of Petroleum and Energy for renewable energy producers selling to the grid (US$0.25/kWh[19]). Moreover, the US$0.235 tariff was used to allow for a conservative estimate, as the project team was not able to confirm whether the US$0.25 tariff is currently in place; this matter will be further discussed with the government and NAWEC. The main output the market can generate are revenues obtained by selling electricity to the grid, with annual revenues amounting to US$567,766 (**Table 33**).

Table 33. Potential annual savings by producing biogas at the Bakoteh Dumpsite

Savings and revenues	Amount [USD/year]	Unit cost [USD/unit]
Electricity on grid	142,127	0.19 [USD/kWh]
Total	**145,155**	**-**

Source: Own calculations

Aggregated capital expenditures (CAPEX) for the Bakoteh case study are detailed in **Table 34**. The biogas digester in this project has a power capacity of 375 kWe and produces 1,232,877 cubic meters of biogas annually, operating for 7,200 hours each year. The digestor volume would be 584 cubic meters. Due to the typology of the feedstock, which necessitates a larger digester to accommodate the volume of feedstock, the CAPEX is notably higher than other case studies where more digestable feedstock allowed for smaller volume digestors.

The total financial investment for the project amounts to US$1,250,575. This investment is broken down into specific categories: separation costs are US$300,000, pretreatment costs are US$25,650.24, equipment costs are US$409,117.12, building costs are US$116,392.74, installation costs are US$92,394.83, and costs associated with the electricity distribution network are US$307,020.08. Disaggregated capital costs are provided in **Annex 3**.

Table 34. Capital expenditures of the Bakoteh Dumpsite case study investment

Item	Unit	Value
Digester size		
Capacities	(kWe)	375
Capacities	m3 Biogas/year	1,232,877
Operating period	h/year	7,200
Heat Production	GJ/year	0.0
Volume Reactor	m^3	584
Subtotals		
Separation unit for FOMSW	USD	300,000
Pretreatment	USD	25,650.24
Equipment	USD	409,117.12
Building	USD	116,392.74
Installation	USD	92,394.83
Electricity Distribution network	USD	307,020.08
Grand total	**USD**	**1,250,575**

Source: Own calculations using FAO BEFS RA Tools (Intratec cost index for 2023)

[19] https://energycapitalpower.com/the-gambia-net-metering-renewable-energy/?utm_content=216274832&utm_medium=social&utm_source=facebook&hss_channel=fbp-105729815176773

Operating costs (OPEX) do not include feedstock and transportation since waste is collected for free and always available in place. OPEX, which mainly consists of maintenance and materials, is calculated as 10 percent of the total investment, which amounts to approximately US$125,000 per year. Fixed costs include labour, totalling around US$100,000 per year, and capital depreciation over a 15-year lifespan, which is approximately US$63,300 per year. This brings the total annual operating and fixed costs to around US$73,300 per year.

Financial analysis indicated potential savings from transitioning away from grid electricity, diesel and firewood and high revenues from the selling of the electricity to the national company NAWEC. However, the initial investment required a CAPEX of approximately US$1,250,575, 60 percent of which was financed through a loan at a fixed interest rate of 4 percent over a 10-year term, allowing the investor to reduce the capital expenditures to around US$500,230. The amount covered by the loan would be around US$750,000 (**Figure 30**). Despite the high CAPEX and OPEX, and considering a discount rate of 8 percent, the project demonstrated promising financial prospects, boasting a positive Net Present Value (NPV) of US$270,491, an Internal Rate of Return (IRR) of 11.1 percent, and a payback period of 9 years. These metrics indicate favourable project economics and suggest that the project is financially attractive and capable of recouping initial investments within a reasonable timeframe (**Figure 30**).

Figure 30. Cost Benefit Analysis (CBA) of biogas investment at the Bakoteh Dumpsite

Year	0	1	2	3	4	5	6	7	8	9	10 to 15
Energy consumption											
Electricity consumption [kWh/year]	-	-	-	-	-	-	-	-	-	-	-
Electricity production [kWh/year]	2,810,725	2,810,725	2,810,725	2,810,725	2,810,725	2,810,725	2,810,725	2,810,725	2,810,725	2,810,725	2,810,725
Electricity tarif [USD/kWh]	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.26
Electricity feed-in tarif [USD/kWh]	0.20	0.20	0.20	0.21	0.21	0.21	0.21	0.21	0.22	0.22	0.23
Revenues											
Savings from replaced electricity expenses		-	-	-	-	-	-	-	-	-	-
Revenues from electricity sales		567,766	573,444	579,179	584,970	590,820	596,728	602,695	608,722	614,810	652,633
Operating costs											
Operating costs (10% CAPEX) [USD/year]		(125,057.50)	(126,308.08)	(127,571.16)	(128,846.87)	(130,135.34)	(131,436.69)	(132,751.06)	(134,078.57)	(135,419.35)	(143,750.37)
Labour		(125,057.50)	(126,308.08)	(127,571.16)	(128,846.87)	(130,135.34)	(131,436.69)	(132,751.06)	(134,078.57)	(135,419.35)	(143,750.37)
Capital depreciation		(83,371.67)	(83,371.67)	(83,371.67)	(83,371.67)	(83,371.67)	(83,371.67)	(83,371.67)	(83,371.67)	(83,371.67)	(83,371.67)
Cash Flow											
+ Avoided expenses and Revenues		567,766.42	573,444.08	579,178.52	584,970.31	590,820.01	596,728.21	602,695.49	608,722.45	614,809.67	652,632.86
- 'Operating costs [USD/year]		(125,057.50)	(126,308.08)	(127,571.16)	(128,846.87)	(130,135.34)	(131,436.69)	(132,751.06)	(134,078.57)	(135,419.35)	(143,750.37)
Operating Cash Flow	-	**442,709**	**447,136**	**451,607**	**456,123**	**460,685**	**465,292**	**469,944**	**474,644**	**479,390**	**508,882**
- Investments [USD]	- 1,250,575										
- Fixed costs [USD/year]		(208,429.17)	(209,679.74)	(210,942.82)	(212,218.54)	(213,507.00)	(214,808.36)	(216,122.72)	(217,450.23)	(218,791.02)	(227,122.04)
- Loan annuity		(92,510.74)	(92,510.74)	(92,510.74)	(92,510.74)	(92,510.74)	(92,510.74)	(92,510.74)	(92,510.74)	(92,510.74)	-
Total Cash Flow	**- 1,250,575**	**141,769**	**144,946**	**148,154**	**151,394**	**154,667**	**157,972**	**161,311**	**164,683**	**168,089**	**281,760**
Cumulative Cash Flow	- 1,250,575	- 1,108,806	- 963,860	- 815,707	- 664,313	- 509,646	- 351,673	- 190,362	- 25,679	142,409	1,686,944
Payback Year	-	-	-	-	-	-	-	-	-	Payback	-
CF shareholders	- 500,230	141,769	144,946	148,154	151,394	154,667	157,972	161,311	164,683	168,089	281,760
Cumulative Cash Flow	- 500,230	- 358,461	- 213,515	- 65,362	86,032	240,699	398,672	559,983	724,666	892,754	2,437,289
Payback Year	-	-	-	-	Payback	-	-	-	-	-	-
Loan and Capital structure											
Equity private financing	**- 500,230**										
Loan	**- 750,345**	**60%**	of initial investment								
Constant interest rate	**4%**										
Duration of loan (years)	10										
Grace period (year)	-										
Loan repayment plan	Constant installments										
Loan outstanding (BoP)	**750,345**	**750,345**	**687,848**	**622,851**	**555,255**	**484,954**	**411,841**	**335,804**	**256,726**	**174,484**	**-**
- Interests		30,014	27,514	24,914	22,210	19,398	16,474	13,432	10,269	6,979	-
- Capital repaid		62,497	64,997	67,597	70,301	73,113	76,037	79,079	82,242	85,531	-
Loan outstanding (EoP)	**750,345**	**687,848**	**622,851**	**555,255**	**484,954**	**411,841**	**335,804**	**256,726**	**174,484**	**88,953**	**-**
Project profitability											
NPV	270,491.58 USD										
NPV to shareholders	611,131.66 USD										
Project IRR	**11.1%**										
IRR to shareholders	30.7%										
payback (years)	**9**										
Shareholders payback (years)	4										

The sensitivity analysis, incorporating a 5 percent variation in key variables, highlights the significant influence of the electricity feed-in tariff, operating costs, labour costs, capital depreciation, and loan interest rates on the Net Present Value (NPV) of the project. The analysis reveals that changes in the electricity feed-in tariff have the most substantial impact on NPV. Specifically, a 5 percent decrease in the tariff (from US$0.20/kWh to US$0.19/kWh) results in an 88 percent decrease in NPV, dropping to US$32,415. Conversely, a 5 percent increase in the tariff (to US$0.21/kWh) leads to an 88 percent increase in NPV, rising to US$508,568 (**Table 35**).

Operating costs also significantly affect the NPV. A 5 percent increase in operating expenses decreases the NPV by 19 percent, from US$270,492 to US$218,052. On the other hand, a 5 percent decrease in operating costs increases the NPV by 19 percent, up to US$322,931. The same percentage variation in labour costs yields a similar NPV response, with a 19 percent decrease or increase in NPV corresponding to changes in these costs. Capital depreciation impacts the NPV to a lesser extent, with a 12 percent change in NPV observed when the annual depreciation varies by 5 percent. Specifically, a decrease in depreciation to US$79,202/year results in an NPV of US$303,529, while an increase to US$87,540/year lowers the NPV to US$237,454 (**Table 35**).

Finally, the loan interest rate has the smallest impact on NPV among the variables analysed. A 5 percent change in the interest rate, from 4.00 percent to either 3.80 percent or 4.20 percent, results in a 2 percent variation in NPV, reflecting its relatively stable effect compared to other factors (**Table 35**).

Table 35. Sensitivity analysis results: impact of variable variation on Net Present Value for the Bakoteh Dumpsite

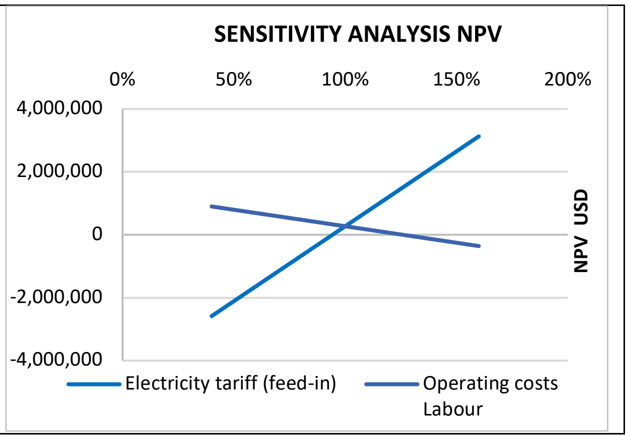
SENSITIVITY ANALYSIS (5%)									
Variables	Variation of variables			Variation of NPV					
	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent	95 percent	100 percent	105 percent
Electricity feed-in tariff [USD/kWh]	0.19	0.20	0.21	32,415	270,492	508,568	-88 %	0 %	88 %
Operating costs	118,804	125,057	131,310	322,931	270,492	218,052	19 %	0 %	-19 %
Labour [USD/year]	118,804	125,057	131,310	322,931	270,492	218,052	19 %	0 %	-19 %
Capital depreciation [USD/year]	79,202	83,371	87,540	303,529	270,492	237,454	12 %	0 %	-12 %
Loan interest rate [%]	3.80	4.00	4.2	276,200	270,492	264,755	2 %	0 %	-2 %

Source: Own calculations

A further step in the sensitivity analysis considered only the variable that exceeded a 15 percent fluctuation in Net Present Value (NPV). Among the variables analysed, only the electricity feed-in tariff surpassed this threshold, prompting a focused examination of its impact. **Table 36** illustrates how varying the electricity feed-in tariff influences the NPV.

Table 36. Impact of variable variation on Net Present Value for electricity feed-in tariff and labour, operating expenses of Bakoteh Dumpsite

	Electricity feed-in tariff [USD/kWh]		Operating costs; Labour expenses [USD/year]	
	NPV	Variable	NPV	Variable
160 %	3,127,412	0.32	-358,780	200,091
140 %	2,175,105	0.28	-149,023	175,080
120 %	1,222,798	0.24	60,734	150,068
100 %	270,492	0.20	270,492	125,057
80 %	-681,815	0.16	480,249	100,046
60 %	-1,634,122	0.12	690,006	75,034
40 %	-2,586,429	0.08	899,763	50,023



Source: Own calculations

The analysis showed a substantial range in NPV from -US$617,708 to US$1,060,892, as the tariff changed from 40 percent to 160 percent of its original value. Notably, the project becomes unprofitable with a negative NPV if the tariff drops to 80 percent or below of its base value, highlighting a critical threshold for financial viability. This analysis underscores the project's sensitivity to fluctuations in the electricity feed-in tariff, emphasizing the importance of this factor in maintaining the project's financial health. The significant impact of the feed-in tariff on NPV indicates that any reductions could seriously compromise the project's profitability, while increases could significantly enhance its economic viability. This focused sensitivity analysis underscores the critical role of the electricity feed-in tariff in ensuring the project's financial sustainability. The significant impact of the tariff on the Net Present Value (NPV) illustrates that maintaining or improving the rate is crucial for the project's viability. A decrease below 20 percent of the base tariff value renders the project unprofitable, while increases significantly enhance its economic prospects.

Also, in this case, it is important to mention how, in June 2022, The Gambia took a significant step forward in the energy transition under the leadership of its new Minister of Petroleum and Energy by implementing a feed-in tariff (FIT) and net metering scheme[20]. This initiative supports renewable energy producers, offering a tariff of US$0.25 per kWh for surplus energy fed into the national grid, applicable to stakeholders with generation capacities between 20 kW and 1.5 megawatts. This rate is significantly higher than the US$0.20 tariff used in the CBA, suggesting that the financial outlook for bioenergy projects could be more favourable under the new scheme. For producers with capacities exceeding 1.5 megawatts, the government encourages signing 15-year power purchase agreements with the national water and electricity company, NAWEC. This policy aims to enhance the country's energy self-

[20] https://energycapitalpower.com/the-gambia-net-metering-renewable-energy/?utm_content=216274832&utm_medium=social&utm_source=facebook&hss_channel=fbp-105729815176773

sufficiency—currently at 48 percent—and to increase the electrification rate, which stands at 60 percent, by promoting the diversification and decentralization of the grid power supply.

4.4.4 Conclusions

The Bakoteh dumpsite case study highlights the significant potential for biogas production from organic municipal solid waste (OMSW) to mitigate greenhouse gas emissions and generate renewable energy. However, the financial viability of such projects is heavily influenced by the electricity feed-in tariff, which emerged as the most critical variable in our sensitivity analysis. A five percent variation in the feed-in tariff resulted in significant fluctuations in the project's Net Present Value (NPV), demonstrating that the financial success of the project hinges on a favourable and stable tariff rate. The introduction of a feed-in tariff (FIT) and net metering scheme in The Gambia, offering US$0.25 per kWh for surplus energy fed into the national grid, is a step in the right direction. However, for sustained success, it is crucial that these tariffs are maintained at a level that covers the costs of production and provides a reasonable return on investment. Furthermore, the duration of such incentives must be sufficient to encourage long-term investments, typically spanning 15 years or more, aligning with the lifespan of the technologies involved.

In conclusion, while the technical potential and environmental benefits of biogas production at Bakoteh dumpsite are clear, the project's financial viability is sensitive to changes in policy and economic conditions. To unlock the full potential of bioenergy projects in The Gambia and similar contexts, it is imperative to establish a comprehensive policy framework that includes appropriate tariffs, incentives, and supportive measures to ensure the sustainability and attractiveness of investments in renewable energy. This approach will not only enhance energy self-sufficiency but also contribute to broader environmental and developmental goals.

4.5 Other relevant cases with potential

4.5.1 Brikama – livestock market and slaughterhouse

The Brikama livestock market and slaughterhouse, located about a 10-minute drive apart, present significant waste management challenges. The market hosts around 500 animals weekly, producing approximately 6.3 tonnes of manure, with some given to the government and sold to farmers. However, unsold manure, especially during the rainy season, leads to greenhouse gas emissions and water contamination. Energy expenses are primarily for electricity, costing around 2,250 Dalasi per day. The slaughterhouse, operating only half a day, has a capacity for 20 animals and produces 5,000 kg of manure monthly. The improper storage of liquid waste led to an underground tank explosion last year. The facility's electricity costs are 800 Dalasi per month. Despite low energy consumption, the significant post-production risks from unmanaged waste at these sites highlight the need for improved waste handling and biogas technology. The explosion incident at the slaughterhouse underscores the dangers of improper waste management. With local managers' willingness to collaborate, these sites offer an opportunity for smaller-scale interventions focused on enhancing waste management practices rather than large-scale energy production.

The Brikama site was not selected as one of the SCALA project case study sites.

Figure 31. Pictures of the Brikama cattle market and slaughterhouse

Livestock market

Manure piles near the slaughterhouse

Slaughterhouse's undisposed wastewater

Slaughterhouse's exploded wastewater system

4.5.2 Alminteh Poultry Farm

Alminteh Poultry Farm, owned by Mr. Lalo Minteh, houses around 50,000 animals for eggs and hatchery. The farm produces three types of manure: pure, mixed with groundnut shells and wood chips, and processed. Manure production averages 60 bags per day, with prices ranging from 150 to 250 Dalasi per bag, or some US$2.2 and US$3.7, respectively. Manure is collected using a traction automatic technology, processed, and sold, while liquid waste is disposed into a lagoon, posing environmental risks. The farm's energy needs are met through two solar systems, diesel generators costing 350 Dalasi per day, and a small, unreliable grid supply. Additionally, the farm produces 5 tonnes of cashews annually, wasting around 15 tonnes of cashew fruit.

Given the significant organic waste and unreliable electricity, Alminteh Poultry Farm has potential for biogas production to reduce diesel and electricity consumption. The current disposal of wastewater not only contributes to greenhouse gas emissions but also highlights the need for improved waste management. Mr. Minteh is interested in exploring biogas solutions, which could enhance the farm's sustainability by addressing both energy and waste management challenges.

Alminteh farm site was not selected as one of the SCALA project case study sites.

Poultry farm

Manure collector

Bags of pure manure

Liquid manure pond

Manure processor

Wastewater lagune

4.5.3 ECOSOIL organic fertilizers and TROPINGO food industry

Mr. Bai Momar Taal owns Ecosoil and Tropingo, two companies with distinct focuses. Ecosoil produces organic fertilizers from the sludge of a residential wastewater treatment plant, mixed with milled groundnut shells. Last year, Ecosoil produced around 6,000 tonnes of fertilizer, meeting EU standards for water treatment and ensuring low levels of heavy metals and organic pollutants. Tropingo, a food processing company specializing in dehydrated mangoes, has been out of operation for the past two years due to a scarcity of fresh mangoes caused by urbanization and climate change. The plant needs 8 tonnes of mangoes daily to function and generates 3 tonnes of organic waste and 0.5-1 ton of groundnut shells daily, which are disposed of at a nearby dumpsite.

Mr. Taal plans to revive Tropingo by importing mangoes from neighbouring countries and experimenting with climate-resilient mango plantations. He is interested in biogas technology and has the financial capacity to invest in such initiatives. Tropingo's potential for investment and Mr. Taal's proactive approach to overcoming operational challenges make it a promising candidate for inclusion in our study, contingent on resolving the mango supply issues.

Tropingo/Ecosoil company was not selected as one of the SCALA project case study sites.

Sewage plant near ECOSOIL

Groundnut mill at ECOSOIL

TROPINGO food industry

Mango fruits before processing

4.5.4 Lamjaidy dairy farm

The focus is on three dairy farms, with two located near Serrekunda. Farm 1 and Farm 2 each have 20 milking animals, producing 30 liters of milk daily, sold at 60 Dalasi per litre. Both farms generate daily revenues of 1800 Dalasi and incur diesel costs of 150 Dalasi per day. These farms operate with low energy consumption, focusing primarily on milk production. Despite their efficiency, the owner lacks the resources to invest in biogas technology, making it difficult to consider these farms for inclusion in the SCALA PSE project, even on a small scale. The financial constraints and low energy usage limit their potential for significant biogas interventions.

Lamjaidy farm site was not selected as one of the SCALA project case study sites.

A dairy farm

Milking of dairy cow

5 PRIVATE SECTOR OPPORTUNITIES FOR INVESTMENT IN BIOGAS TECHNOLOGY

5.1 Stakeholders and private sector mapping

The mapping exercise of stakeholders (**Annex 2, Annex 4**) reveals a diverse range of business typologies, regional distributions, and national institutions, totalling 72. The primary business types identified include agricultural farms (both crops and mixed crops with livestock), food industries, livestock farms, livestock markets, slaughterhouses, landfills, and vegetable markets. Each typology plays a distinct role in the local economy, reflecting the agricultural and livestock-based nature of the region's economy.

As explained in the methodology, the stakeholders were identified for their potential interest in biogas production based on feedstock (residues/waste) availability and energy consumption. Agricultural and livestock operations generate significant amounts of organic waste. Food industries and markets also produce substantial organic residues that can be harnessed for energy. Landfills and slaughterhouses provide additional sources of feedstock, enhancing the feasibility and sustainability of biogas initiatives and making them prime candidates for biogas projects. The research team better understood the regional capacities and opportunities for biogas production by mapping these stakeholders. Notably, results from the questionnaires used in the primary data collection during stakeholder mapping provided a comprehensive overview of several stakeholders across different regions. Each stakeholder's profile includes general operational information, waste-residues management practices, and energy usage. The profiles cover the name and contact details of the business and respondent, the region and specific address, and the establishment date. Information on the total capacity and expected operational lifetime of each business was also included, highlighting the scale and longevity of these sites.

5.1.1 Agricultural farms

Most stakeholders are engaged in agricultural farming, primarily focusing on crops. These farms are dispersed across various regions, with significant concentrations in the West Coast Region, Central River Region (CRR), and Lower River Region (LRR). These farms are often community-driven, involving associations and groups, highlighting a collaborative approach to agriculture. The primary data collected provides insights into crop production activities, residue management practices, and energy use across various agricultural farms. This overview covers the types and quantities of crops produced, the management and utilization of agricultural residues, and the associated energy consumption.

Specifics by the agricultural farm are reported in **Table 37** below:

Table 37. List of agricultural farms identified during primary data collection

Bakau Women Agric. Garden **Location:** Bakau, KMC, **Total Capacity:** 20,000 tonnes/year, **Crops Produced:** Vegetables (12,000 tonnes/year on 0.7 ha), Cassava (10,000 tonnes/year on 0.5 ha), **Residue Management:** Leaves (3 tonnes/year, 85 percent used as animal feed, burnt), Leaves and stems (3 tonnes/year, sold), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
Gambia Songhai **Location:** Charmen, North Bank Region, **Total Capacity:** 40,000 tonnes/year, **Crops Produced:** Vegetables (17,000 tonnes/year on 1.5 ha), Maize (15,000 tonnes/year on 30.5 ha), Millet (14,000 tonnes/year on 7 ha), Beans (14,000 tonnes/year on 10 ha), **Residue Management:** Leaves (5 tonnes/year, 85 percent used as animal feed, burnt), Leaves/stalks (7 tonnes/year, sold), Leaves/stem (1,000 tonnes/year, burnt), Straw (1,000 tonnes/year, sold), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
LUMO SAREH BOJO **Location:** Sareh Bojo Village, URR, **Total Capacity:** 30,000 tonnes/year, Crops **Produced:** Information not provided, **Residue Management:** Leaves (3 tonnes/year, 85 percent used as animal feed, burnt), Leaves and stems (3 tonnes/year, composted and sold, 40 percent), **Energy Use:** Information not specified, **Annual Expenditure:** US$2,000/year
Mal Rah Ngeh **Location:** Kerr Ngor Nyan, North Bank Region, **Total Capacity:** 1,000 tonnes/year, **Crops Produced:** Vegetables and legumes (3,000 tonnes/year on 0.5 ha), Millet (5,000 tonnes/year on 0.5 ha), **Residue Management:** Leaves (4 tonnes/year, 85 percent used as animal feed, burnt), Leaves and stems (1 tonne/year, composted and sold, 40 percent), **Energy Use:** Information not specified, **Annual Expenditure:** US$1,500/year
Banjulding Women Garden **Location:** Banjulding, West Coast Region, **Total Capacity:** 1,000 tonnes/year, **Crops Produced:** Vegetables (7,000 tonnes/year on 0.6 ha), Rice (9,000 tonnes/year on 0.6 ha), **Residue Management:** Leaves (4 tonnes/year, 100 percent used as animal feed, burnt), Straw and husk (3 tonnes/year, composted, animal feed), **Energy Use:** Information not specified, **Annual Expenditure:** US$1,800/year
Bangura's Banana Farm **Location:** Kerr Sanyang, Lower Niumi, **Total Capacity:** 8,000 tonnes/year, **Crops Produced:** Banana (15,000 tonnes/year on 4.5 ha), **Residue Management:** Leaves (4 tonnes/year, 100 percent composted), **Energy Use:** Information not specified, **Annual Expenditure:** US$1,500/year
NYODEMAA AGRO-BUSINESS **Location:** Bansang, CRR – South, **Total Capacity:** 5,000 tonnes/year, **Crops Produced:** Plantation (18,000 tonnes/year on 3.4 ha), Banana (12,000 tonnes/year on 1.5 ha), Millet (10,000 tonnes/year on 1.5 ha), **Residue Management:** Leaves (3 tonnes/year, 100 percent used as animal feed, burnt), Leaves/stem (2 tonnes/year, burnt), Leaves and stem (300 tonnes/year, burnt), **Energy Use:** Information not specified, **Annual Expenditure:** US$1,200/year
ALLAH TENTU FARM **Location:** Tubanding / Bansang, CRR – South, **Total Capacity:** 5,000 tonnes/year, **Crops Produced:** Vegetable (18,000 tonnes/year on 3.2 ha), Groundnut (30,000 tonnes/year on 2.5 ha), Beans (8,000 tonnes/year on 1.5 ha), **Residue, Management:** Leaves (5 tonnes/year, 98 percent used as animal feed, burnt), Leaves/stem (4 tonnes/year, animal feed/sold, 90 percent), Leaves and stem (700 tonnes/year, animal feed), **Energy Use:** Information not specified, **Annual Expenditure:** US$1,000/year
MAURO FARM **Location:** Sapu, CRR – South, **Total Capacity:** 12,000 tonnes/year, **Crops Produced:** Information not provided, **Residue Management:** Leaves (3 tonnes/year, usage details not specified), **Energy Use:** Information not specified, **Annual Expenditure:** US$1,200/year
KINTEH KUNDA KEMBENG KAFO **Location:** Sifoe, Kombo South, West Coast Region, **Total Capacity:** 2,000 tonnes/year, **Crops Produced:** Vegetable (4,000 tonnes/year on 0.5 ha), **Residue Management:** Leaves (3 tonnes/year, animal feed, burnt), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
BULOCK KAPONGNA JAMARI'S ASSOCIATION **Location:** Bulock Village - Fogni Berefet, West Coast Region, **Total Capacity:** 1,000 tonnes/year, **Crops Produced:** Vegetable (4,000 tonnes/year on 0.5 ha), Cassava (6,000 tonnes/year on 1.5 ha), **Residue**

Management: Leaves (3 tonnes/year, animal feed, burnt), Leaves and stems (8 tonnes/year, sold), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
NYOFELLEH KAMBENG KAFOO **Location:** Nyofelleh Village - Kombo South, West Coast Region, **Total Capacity:** 1,000 tonnes/year, **Crops, Produced:** Vegetable (3,000 tonnes/year on 0.4 ha), **Residue Management:** Leaves (3 tonnes/year, animal feed, burnt), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
SWEARASEH KAFOO **Location:** Berefet - Fogni Berefet, West Coast Region, **Total Capacity:** 2,000 tonnes/year, **Crops Produced:** Vegetable (5,000 tonnes/year on 1.5 ha), **Residue Management:** Leaves (2 tonnes/year, animal feed, burnt), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
KAMBENG KAFOO **Location:** Bintang - Fogni Bintang Karanai, West Coast Region, **Total Capacity:** 2,000 tonnes/year, **Crops Produced:** Vegetable (4,000 tonnes/year on 0.5 ha), Groundnut (10,000 tonnes/year on 1 ha), **Residue, Management:** Leaves (3 tonnes/year, animal feed, burnt), Leaves and stems (8 tonnes/year, sold), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
FASS JOM GROUP **Location:** Brikama South, West Coast Region, **Total Capacity:** 20,000 tonnes/year, **Crops Produced:** Vegetable (5,000 tonnes/year on 1 ha), **Residue Management:** Leaves (2 tonnes/year, animal feed, burnt), **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
KANTONG KUNDA SANUYORO KAFOO **Location:** Kantong Kunda-Kiang West, Lower River Region, **Total Capacity:** 5,000 tonnes/year, **Crops Produced:** Vegetable (5,000 tonnes/year on 0.5 ha), **Residue Management:** Information not provided, **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
DUMBUNTO WOMEN GARDEN ASSOCIATION **Location:** Dumbunto - Kiang West, Lower River Region, **Total Capacity:** 5,000 tonnes/year, **Crops Produced:** Vegetable (5,000 tonnes/year on 0.5 ha), **Residue Management:** Information not provided, **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
MANDUAR VEGETABLE GARDEN **Location:** Manduar - Kiang West, Lower River Region, **Total Capacity:** 5,000 tonnes/year, **Crops Produced:** Vegetable (5,000 tonnes/year on 0.5 ha), **Residue Management:** Information not provided, **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
BAMAKO VEGETABLE GARDEN **Location:** Bamako - Kiang Central, Lower River Region, **Total Capacity:** 5,000 tonnes/year, **Crops Produced:** Vegetable (5,000 tonnes/year on 0.5 ha), **Residue Management:** Information not provided, **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified
NEMA VEGETABLE GARDEN **Location:** Kiang, Lower River Region, **Total Capacity:** 5,000 tonnes/year, **Crops Produced:** Vegetable (5,000 tonnes/year on 0.5 ha), **Residue Management:** Information not provided, **Energy Use:** Information not specified, **Annual Expenditure:** Information not specified

Source: Data from primary data collection

5.1.2 Livestock farms

Livestock farming is another critical sector, with farms spread across the North Bank Region, CRR, and Niamina East. Additionally, livestock markets are present, primarily in the West Coast Region, serving as vital nodes for the distribution and sale of livestock.

The data provides a comprehensive view of various livestock farms, detailing their capacity, livestock types, grazing practices, residue management, and energy use. This summary highlights each farm's operational specifics and residue handling, including energy consumption for electricity and heat.

Specifics by livestock farms farm are reported in **Table 38** below:

Table 38. List of livestock farms identified during primary data collection

The Italian Family Poultry Farm **Location:** Bansang, CRR South, **Total Capacity:** 1,500 birds, **Livestock Production:** Poultry: 800 birds (year-round grazing), **Residue Management:** Poultry Manure 446 tonnes/year, Use: Composted and sold (27 percent composted, 63 percent sold) **Energy Use:** Electricity: 15,000 kWh/year (Grid) Heat: 20,114 gallons/year (LPG / Propane), **Annual Expenditure:** US$30,171 (electricity and heat)
Adam's Poultry **Location:** Mamutfana, Niamina East, **Total Capacity:** 2,000 birds, **Livestock Production:** Poultry 1,000 birds (year-round grazing), **Residue Management:** poultry Manure 565 tonnes/year, Use: Composted and sold (94 percent), **Energy Use:** Electricity: 20,000 kWh/year (Grid), Heat: 25,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$37,500 (electricity and heat)
Saffiatou Ceesay's Poultry Farm **Location:** Mamutfana, Niamina East, **Total Capacity:** 3,000 birds, **Livestock Production:** Poultry: 1,500 birds (year-round grazing), **Residue Management:** Poultry Manure: 700 tonnes/year, Use: Composted and sold (100 percent), **Energy Use:** Electricity: 30,000 kWh/year (Grid), Heat: 30,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$45,000 (electricity and heat)
Jamagen Adult Literacy Livestock Coop. Society **Location:** Jamagen, North Bank Region, **Total Capacity:** 1,000 livestock heads, **Livestock Production:** Cattle: 47 heads (Seasonal grazing), Poultry: 900 birds (year-round grazing), Sheep: 53 heads (Seasonal grazing), Goats: Not specified, **Residue Management:** Cattle Manure: 741 tonnes/year, Poultry Manure: 607 tonnes/year Use: Composted and sold (98 percent), Sheep Manure: 271 tonnes/year, Goat Manure: Not specified, **Energy Use:** Electricity: 18,000 kWh/year (Grid), Heat: 15,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$22,500 (electricity and heat)
Mal Rah Ngeh **Location:** Kerr Ngor Nyan, North Bank Region, **Total Capacity:** 1,000 livestock heads, **Livestock Production:** Not specified, **Residue Management:** Cattle Manure: 0.1 tonnes/year Use: Composted (80 percent), Poultry Manure: 1 ton/year Use: Composted and sold (40 percent), **Energy Use:** Electricity: 25,000 kWh/year (Grid), Heat: 10,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$15,000 (electricity and heat), **Notes:** Challenges in poultry production, including local housing, feed, marketing, and sourcing of birds.
Abuko Daral Association **Location:** Abuko, KMC, **Total Capacity:** Not specified, **Livestock Production:** Cattle: 15,657 heads (Seasonal grazing), Poultry: 1,000 birds (Seasonal grazing), Sheep: 8,114 heads (Seasonal grazing), Goats: 10,123 heads (Seasonal grazing), **Residue Management:** Cattle Manure: 2,818.26 metric tonnes/year Use: Composted (30 percent), Poultry Manure: 2.5 metric tonnes/year Use: Compost, manure (0.2 percent), Sheep Manure: 1,459.52 metric tonnes/year Use: Manure and compost (50 percent), Goat Manure: 1,822.14 metric tonnes/year Use: Manure and compost (45 percent), **Energy Use:** Electricity: 40,000 kWh/year (Grid), Heat: 35,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$52,500 (electricity and heat)
Sare Bojo Lumo **Location:** Sare Bojo Village, Upper River Region, **Total Capacity:** Not specified, **Livestock Production:** Cattle: 3,968 heads (Seasonal grazing), Poultry: 300 birds (Seasonal grazing), Sheep: 5,462 heads (Seasonal grazing), Goats: 6,497 heads (Seasonal grazing), **Residue Management:** Cattle Manure: 2,380.8 metric tonnes/year Use: Composted (5 percent), Poultry Manure: 1.2 metric tonnes/year Use: Compost, manure (0.5 percent), Sheep Manure: 3,277.2 metric tonnes/year Use: Manure and compost (50 percent), Goat Manure: 3,898.2 metric tonnes/year Use: Manure and compost (45 percent), **Energy Use:** Electricity: 35,000 kWh/year (Grid), Heat: 40,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$60,000 (electricity and heat)
Brikama Daral Association **Location:** Brikama College, West Coast Region, **Total Capacity:** Not specified, **Livestock Production:** Cattle: 2,585 heads (Seasonal grazing), Poultry: 500 birds (Seasonal grazing), Sheep: 9,250 heads (Seasonal grazing), Goats: 3,343 heads (Seasonal grazing), **Residue Management:** Cattle Manure: 1.551 tonnes/year Use: Composted (0.5 percent), Poultry Manure: 1.2 metric tonnes/year Use: Composted (0.2 percent), Sheep Manure: 483.6 metric tonnes/year Use: Composted (1.5 percent), Goat Manure: 42.7 metric tonnes/year Use: Composted (45 percent), **Energy Use:** Electricity: 28,000 kWh/year (Grid), Heat: 28,000 gallons/year (LPG / Propane) **Annual Expenditure:** US$42,000 (electricity and heat)
Gfirm **Location:** Sambuya, West Coast Region, **Total Capacity:** 700,000 litres, **Livestock Production:** Cattle: 75 heads (year-round grazing), Poultry: 500,000 birds (year-round grazing), **Residue Management:** Cattle

Manure: 837.55 tonnes/year Use: Composted (97 percent), Poultry Manure: 26,040 tonnes/year Use: Composted and sold (89 percent), **Energy Use:** Electricity: 50,000 kWh/year (Grid), Heat: 50,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$75,000 (electricity and heat)
Alminteh **Location:** Tanjai, West Coast Region, **Total Capacity:** 300,000 liters, **Livestock Production:** Poultry: 350,000 birds (year-round grazing), **Residue Management:** Poultry Manure: 1,488 tonnes/year Use: Composted and sold (97 percent), **Energy Use:** Electricity: 45,000 kWh/year (Grid), Heat: 45,000 gallons/year (LPG / Propane), **Annual Expenditure:** US$67,500 (electricity and heat)

Source: Data from primary data collection

5.1.3 Slaughterhouses

Slaughterhouses are strategically placed in key regions like the West Coast Region, Farafenni, Soma, Basse, and Brikama-Ba. These facilities are essential for meat processing and distribution, supporting both local consumption and broader market needs. Table 39 provides detailed information about various slaughterhouses, focusing on their capacity, waste management practices, and energy consumption. The data includes the total capacity, the quantity of solid waste and blood/wastewater produced, how these wastes are utilized, and the details of electricity and heat usage.

Table 39. List of slaughterhouses identified during primary data collection

Brikama Slaughterhouse **Location:** Brikama, West Coast Region, **Date of Establishment:** 1999, **Total Capacity:** 7,440 heads, **Waste Management:** Solid Waste: 357.05 tonnes/year, composted (100 percent), Blood and Wastewater: 21.6 tonnes/year, composted (100 percent), **Energy Use:** Electricity**:** 50,000 kWh/year (Grid), US$8,500/year, Heat**:** 300 gallons/year (LPG), US$7,200/year (for heating water)
Abakou Slaughterhouse **Location:** Abakou, KMC/Banjul, **Date of Establishment:** 1978, **Total Capacity:** 21,204 heads, **Waste Management:** Solid Waste: 4,093.86 tonnes/year, composted (100 percent), Blood and Wastewater: 28.8 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 200,000 kWh/year (Grid), US$34,000/year, Heat: 1,000 gallons/year (LPG), US$24,000/year (high heating requirement)
Farafenni Slaughterhouse **Location:** Farafenni, NBR, **Date of Establishment:** 2000, **Total Capacity:** 5,580 heads, **Waste Management:** Solid Waste: 13.52 tonnes/year, composted (100 percent), Blood and Wastewater: 0.5 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 15,000 kWh/year (Grid), US$2,400/year (lower heating needs)
Soma Slaughterhouse **Location:** Soma, LRR, **Date of Establishment:** 2013, **Total Capacity:** 6,324 heads, **Waste Management:** Solid Waste: 15.45 tonnes/year, composted (100 percent), Blood and Wastewater: 1.5 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 20,000 kWh/year (Grid), US$3,400/year, Heat: 200 gallons/year (LPG), US$4,800/year (moderate heating needs)
Basse Slaughterhouse **Location:** Basse, URR, **Date of Establishment:** 1990, **Total Capacity:** 7,068 heads **Waste Management:** Solid Waste: 3,028.80 tonnes/year, composted (100 percent), Blood and Wastewater: 14.4 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 150,000 kWh/year (Grid), US$25,500/year, Heat: 800 gallons/year (LPG), US$19,200/year (significant heating requirement)
Brikama-Ba Slaughterhouse **Location:** Brikama-Ba, CRR, **Date of Establishment:** 2011, **Total Capacity:** 4,464 heads, **Waste Management:** Solid Waste: 72.7 tonnes/year, composted (100 percent), Blood and Wastewater: 0.1 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 10,000 kWh/year (Grid), US$1,700/year, Heat: 50 gallons/year (LPG), US$1,200/year (minimal heating needs)

Source: Data from primary data collection

5.1.4 Food industry

A smaller segment of stakeholders operates within the food industry, processing and marketing food products. These businesses are strategically located in regions with higher population densities, such as the West Coast Region and Kanifing Municipal Council (KMC), indicating a focus on serving larger markets.

Table 40 provides detailed information about various food industry enterprises, focusing on their capacity, production outputs, waste management practices, and energy consumption. The data includes the total capacity, the quantity of different products produced annually, types of waste/residues, how these wastes are utilized, and the details of electricity and heat usage.

Table 40. List of food industries identified during primary data collection

Kharafi Kafuta **Location:** Kafuta, West Coast Region, **Date of Establishment:** 2010, **Total Capacity:** 500 tonnes, 25 years, **Production:** Vegetables: 100t Fruits: 200t, **Waste Management:** 1 ton/day, 365 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 100,000 kWh/year (Grid), US$17,000/year, Heat: 150 gallons/year, US$3,600/year
Fruit, Banana Farming **Location:** Latrikunda, KMC, **Date of Establishment:** 2015, **Total Capacity:** 300 tonnes, 20 years, **Production:** Bananas: 150t Mangoes: 50t, **Waste Management:** 0.5 tonnes/day, 182.5 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 50,000 kWh/year (Grid), US$8,500/year, Heat: 100 gallons/year, US$2,400/year
Bakau Women's Garden **Location:** Bakau, KMC, **Date of Establishment:** 2000, **Total Capacity:** 200 tonnes, 15 years, **Production:** Vegetables: 200t, **Waste Management:** 0.3 tonnes/day, 109.5 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 30,000 kWh/year (Grid), US$5,100/year, Heat: 60 gallons/year, US$1,400/year
Sukuta Women's Garden **Location:** Sukuta, West Coast Region, **Date of Establishment:** 2005, **Total Capacity:** 250 tonnes, 20 years, **Production:** Vegetables: 250t, **Waste Management:** 0.4 tonnes/day, 146 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 35,000 kWh/year (Grid), US$5,950/year, Heat: 70 gallons/year, US$1,680/year
Sinchu Alagie Poultry Farm **Location:** Sinchu Alagie, CRR South, **Date of Establishment:** 2012, **Total Capacity:** 400 tonnes, 25 years, **Production:** Broilers: 400t, **Waste Management:**1 ton/day, 365 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 80,000 kWh/year (Grid), US$13,600/year, Heat: 120 gallons/year, US$2,880/year
Gui Jahanka Community Garden **Location:** Gui Jahanka, Upper River Region, **Date of Establishment:** 2008, **Total Capacity:** 150 tonnes, 20 years, **Production:** Pepper: 50t, Salad: 50t Onions, Tomatoes: 50 tonnes/year, **Waste Management:** 0.2 tonnes/day, 73 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 20,000 kWh/year (Grid), US$3,400/year, Heat: 50 gallons/year, US$1,200/year
Gunjur Fish Smoking Facility **Location:** Gunjur, Southern Gambia, **Date of Establishment:** 2016, **Total Capacity:** 100 tonnes, 15 years, **Production:** Smoked Fish: 100t, **Waste Management:** Fish Waste: 0.3 tonnes/day, 109.5 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 25,000 kWh/year (Grid), US$4,250/year, Heat: 55 gallons/year, US$1,320/year
Brufut Fish Landing Site **Location:** Brufut, West Coast Region, **Date of Establishment:** 2017, **Total Capacity:** 120 tonnes, 20 years, **Production: Smoked Fish:** 120t, **Waste Management:** Fish Waste: 0.4 tonnes/day, 146 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 28,000 kWh/year (Grid), US$4,760/year, Heat: 60 gallons/year, US$1,440/year
Tanji Fish Landing Site **Location:** Tanji, West Coast Region, **Date of Establishment:** 2018, **Total Capacity:** 130 tonnes, 20 years, **Production: Smoked Fish:** 130t, **Waste Management:** Fish Waste: 0.4 tonnes/day, 146 tonnes/year,

composted (100 percent), **Energy Use:** Electricity: 32,000 kWh/year (Grid), US$5,440/year, Heat: 65 gallons/year, US$1,560/year

Source: Data from primary data collection

5.1.5 Vegetable and livestock Markets

Markets for agricultural and vegetable products are prevalent, particularly in the West Coast Region, KMC, and Lower River Region. These markets facilitate the sale of fresh produce, supporting local farmers and providing essential food supplies to urban populations.

The stakeholder mapping underscores a well-distributed network of agricultural and livestock activities across multiple regions, with each business type playing a specific role in the local economy. The West Coast Region emerges as a hub for diverse activities, including agriculture, food processing, and livestock trade, while other regions like CRR and LRR show strong agricultural and livestock farming activities. This diverse typology and regional distribution highlight the multifaceted nature of the local economy, deeply rooted in agricultural and livestock sectors.

This summary provides detailed information about various markets, focusing on their capacity, waste management practices, and energy consumption. The data includes the total capacity, types and quantities of waste generated, how these wastes are utilized, and the details of electricity and heat usage. Specifics by markets are reported in the Table 41 below:

Table 41. List of vegetable and livestock markets identified during primary data collection

Daral Abuko **Type of Market:** Livestock Market, **Location:** Abuko, West Coast Region, **Date of Establishment:** 1995, **Total Capacity:** 1000 tonnes, **Expected lifetime:** 30 years, **Waste Management:** Manure: 1 ton/day, 365 tonnes/year, composted (100 percent), **Energy Use:** Electricity: 50,000 kWh/year (Grid), US$8,500/year, Heat: 200 units/year, US$4,800/year
Pasteff **Type of Market:** Agricultural/vegetable Market, **Location:** Njawara Village, NBR, **Date of Establishment:** 2000, **Total Capacity:** 500 tonnes, **Expected lifetime:** 25 years, **Waste Management:** Chicken manure: 0.001 tonnes/day, 3.65 tonnes/year, composted (100 percent), Vegetable Waste: 0 percent daily, 37 percent annually, composted (100 percent), **Energy Use:** Electricity: 20,000 kWh/year (Grid), US$3,400/year, Heat: 50 units/year, US$1,200/year
Bakoteh Market **Type of Market:** Agricultural/vegetable Market, **Location:** Bakoteh, KMC, **Date of Establishment:** 1980, **Total Capacity:** 700 tonnes, **Expected lifetime:** 35 years, **Waste Management:** Vegetable Waste: 0.5 tonnes/day, 182.5 tonnes/year, Fruit Waste: 0 percent daily, 73 percent annually, **Energy Use:** Electricity: 35,000 kWh/year (Grid), US$5,950/year, Heat: 100 units/year, US$2,400/year
Brikama Market **Type of Market:** Agricultural/vegetable Market, **Location:** Brikama, West Coast Region, **Date of Establishment:** 1990, **Total Capacity:** 1200 tonnes, **Expected lifetime:** 30 years, **Waste Management:** Vegetable Waste: 1 ton/day, 365 tonnes/year, **Fruit Waste:** 110t annually, **Energy Use:** Electricity: 50,000 kWh/year (Grid), US$8,500/year, Heat: 200 units/year, US$4,800/year
Basse Market **Type of Market:** Agricultural/vegetable Market, **Location:** Basse, Upper River Region **Date of Establishment:** 1985, **Total Capacity:** 800 tonnes, **Expected lifetime:** 30 years, **Waste Management:** Vegetable Waste: 0.8 tonnes/day, 292 tonnes/year, Fruit Waste: 73t/year composted (100 percent), Manure: 37t/year, **Energy Use:** Electricity: 40,000 kWh/year (Grid), US$6,800/year, Heat: 150 units/year, US$3,600/year
Janjangbureh Market **Type of Market:** Agricultural/vegetable Market, **Location:** Janjangbureh, Central River Region **Date of Establishment:** 2005, **Total Capacity:** 600 tonnes, **Expected lifetime:** 25 years

Waste Management: Vegetable Waste: 0.5 tonnes/day, 182.5 tonnes/year, Fruit Waste: 37t annually, **Energy Use:** Electricity: 30,000 kWh/year (Grid), US$5,100/year, Heat: 80 units/year, US$1,920/year
Kerewan Market **Type of Market:** Agricultural/vegetable Market, **Location:** Kerewan, North Bank Region, **Date of Establishment:** 1998, **Total Capacity:** 900 tonnes, **Expected lifetime:** 28 years, **Waste Management:** Vegetable Waste: 0.9 tonnes/day, 328.5 tonnes/year, Fruit Waste: 1t daily, 73t annually, Manure: 37t annually, composted (100 percent), **Energy Use:** Electricity: 45,000 kWh/year (Grid), US$7,650/year, Heat: 180 units/year, US$4,320/year
Mansakonko Market **Type of Market:** Agricultural/vegetable Market, **Location:** Mansanko, Lower River Region, **Date of Establishment:** 2010, **Total Capacity:** 400 tonnes, **Expected lifetime:** 20 years, **Waste Management:** Vegetable Waste: 0.4 tonnes/day, 146 tonnes/year, Fruit Waste: 37t annually, Manure: 18t annually, **Energy Use:** Electricity: 25,000 kWh/year (Grid), US$2,400/year

Source: Data from primary data collection

5.1.6 Dumpsites

For MSW management, the data reveals the annual quantity of waste processed, the share of different waste types, and their specific uses, such as composting. Additionally, it addresses the handling of the organic fraction of MSW, indicating whether organic waste is pre-separated at the source and the percentage of organic waste utilized. Energy usage details encompass the source of energy, predominantly from the grid, and provide annual consumption and expenditure figures for both electricity and heat. Any additional relevant information about energy use is also noted. The data also highlights whether each site receives pre-separated organic waste and if they have mechanical-biological separation units, offering insights into the waste management processes and operational practices of each stakeholder involved in the landfill/dumpsite operations. Several stakeholders are involved in managing landfills or dumpsites, primarily linked with area councils. These sites are crucial for waste management and are in regions like KMC, CRR, and URR, ensuring waste disposal services are available across significant urban and semi-urban areas. Specifics by Dumpsite are reported in Table 42 below:

Table 42. List of dumpsites identified during primary data collection

KUNTAUR AREA COUNCIL **Total capacity**: 61,200 m³, **Expected lifetime**: 15 years, **MSW Quantity**: 5 tonnes/year, **Organic Waste**: 100 tonnes/year, **Energy Usage**: 15,000 kWh electricity, 10,000 kWh heat, **Annual Expenditure**: US$1,500 for electricity, US$1,000 for heat
BRIKAMA AREA COUNCIL **Total capacity**: 384,000 m³, **Expected lifetime**: 20 years, **MSW Quantity**: 358 tonnes/year, **Organic Waste**: 43,800 tonnes/year, **Energy Usage**: 50,000 kWh electricity, 25,000 kWh heat, **Annual Expenditure**: US$5,000 for electricity, US$2,500 for heat
BASSE AREA COUNCIL **Total capacity**: 300,000 m³, **Expected lifetime**: 15 years, **MSW Quantity**: 13,140 tonnes/year, **Organic Waste**: 13,140 tonnes/year, **Energy Usage**: 40,000 kWh electricity, 15,000 kWh heat, **Annual Expenditure**: US$4,000 for electricity, US$1,500 for heat
JAJANGBUREH AREA COUNCIL **Total capacity**: 72 m³, **Expected lifetime**: 15 years, **MSW Quantity**: 9,125 tonnes/year, **Organic Waste**: 9,125 tonnes/year, **Energy Usage**: 20,000 kWh electricity, 10,000 kWh heat, **Annual Expenditure**: US$2,000 for electricity, US$1,000 for heat
KANIFING MUNICIPAL COUNCIL **Total capacity**: 17 m³, **Expected lifetime**: 15 years, **MSW Quantity**: 255,500 tonnes/year, **Organic Waste**: 255,500 tonnes/year, **Energy Usage**: 60,000 kWh electricity, 30,000 kWh heat, **Annual Expenditure**: US$6,000 for electricity, US$3,000 for heat

KEREWAN AREA COUNCIL **Total capacity**: 2,016 m³, **Expected lifetime**: 15 years, **MSW Quantity**: 120 tonnes/year, **Organic Waste**: 2,016 tonnes/year, **Energy Usage**: 30,000 kWh electricity, **Heat**: Not specified, **Annual Expenditure**: US$3,000 for electricity
MANSAKONKO AREA COUNCIL **Total capacity**: 6,048 m³, **Expected lifetime**: 20 years, **MSW Quantity**: 180 tonnes/year, **Organic Waste**: 6,048 tonnes/year, **Energy Usage**: 25,000 kWh electricity, **Heat**: Not specified, **Annual Expenditure**: US$2,500 for electricity
BANJUL CITY COUNCIL **Total capacity**: 200 m³, **Expected lifetime**: 20 years, **MSW Quantity**: 23,520 tonnes/year, **Organic Waste**: 23,520 tonnes/year, **Energy Usage**: 35,000 kWh electricity, **Heat**: Not specified, **Annual Expenditure**: US$3,500 for electricity

Source: Data from primary data collection

5.2 SWOT analysis

Table 43 summarizes the SWOT analysis for investments in biogas technology in The Gambia, focusing on the biogas potential and implications for private sector engagement. It provides a comprehensive view of the factors influencing biogas investment, addressing both the advantages and challenges associated with this renewable energy technology.

Table 43. SWOT analysis of biogas investments

Aspect	Strengths:	Weaknesses	Opportunities	Threats
Economic	Significant cost savings on diesel and grid electricity; positive NPV and IRR in studied cases, energy dependence of businesses.	High initial capital investment; financial sensitivity to market conditions.	Potential revenue from biogas and bio digestate; supportive renewable energy policies; potential to integrate with other technologies for hybrid solutions.	Fluctuations in energy prices and feed-in tariffs; competition from other renewable energy technologies.
Environmental	Reduces greenhouse gas emissions; improves waste management; aligns with sustainable practices.	Requires ongoing technical maintenance; variability in feedstock quality.	Growing interest in environmental sustainability drives demand for biogas.	Regulatory changes affecting environmental policies; inconsistent feedstock supply.
Social	Enhances local soil health; contributes to community sustainability; reduces reliance on external energy.	Technical expertise required can limit local engagement; high labour costs.	Opportunities for community education on renewable energy benefits; potential local job creation.	Community opposition or misunderstanding of biogas benefits; feedstock competition from other industries.
Operational	Scalability potential for larger operations; established technology with proven benefits.	Consistency of feedstock supply can be unpredictable; operational complexities.	Advances in biogas technology can improve efficiency; potential for regional integration and partnerships.	Technical failures or inefficiencies; dependency on stable feedstock supply; competition for feedstock.

Strengths: Biogas investments offer substantial economic benefits by significantly reducing reliance on diesel and grid electricity (dependence on energy), leading to cost savings. Financially, the assessed biogas projects show positive Net Present Value (NPV) and Internal Rate of Return (IRR), making them economically viable. Environmentally, biogas technology plays a crucial role in reducing greenhouse gas emissions and improving waste management, aligning with sustainable practices. Socially, biogas systems enhance soil health and reduce dependence on external energy sources, supporting community sustainability.

Weaknesses: Despite these advantages, biogas projects face several challenges. The high initial capital investment required for setting up biogas systems can be a barrier for potential investors. Additionally, the financial success of biogas projects is sensitive to market conditions and fluctuations in energy prices. The technology demands specialized technical expertise and ongoing maintenance, which can limit local engagement. Consistency and reliability of feedstock supply can be problematic, impacting the stability of the biogas system.

Opportunities: There are significant opportunities for biogas investment. The growing focus on environmental sustainability and renewable energy can drive demand for biogas. Supportive policies and incentives from governments can enhance the financial attractiveness of biogas projects. Advances in biogas technology can improve system efficiency and reduce costs. Regional integration and partnerships can further support biogas development. Additionally, biogas projects offer potential for community education and job creation, fostering local support and involvement.

Threats: Several threats could impact biogas investments. Changes in regulatory policies and feed-in tariffs can affect financial projections and project viability (this is the case of the studied case study investments). Market competition from other renewable energy technologies (or feedstock uses) might influence the profitability of biogas projects. Variability in energy prices and feedstock availability poses financial risks. Additionally, community opposition or lack of understanding about biogas benefits can hinder project acceptance and success. Competition for feedstock from other industries might also affect project sustainability.

Table 44 summarizes the SWOT analysis for each case study, focusing on the biogas potential and implications for private sector engagement.

Table 44. SWOT analysis of the 4 case study sites

Aspect	GFirm Poultry and Dairy Farm	Abuko Livestock Market and Slaughterhouse	Bakoteh Fish and Vegetable Market	Bakoteh Dumpsite
Strengths:	- Strong energy dependence - Significant reduction in greenhouse gas emissions by utilizing manure. - Reduces dependency on diesel and grid electricity, leading to cost savings.	- Strong energy dependence - Reduces greenhouse gas emissions and pollution - Savings on diesel and electricity - Positive NPV (US$ 30,584) and IRR (12 percent)	- Strong energy dependence - Significant reduction in greenhouse gas emissions - Revenue potential from biogas to national grid - Positive NPV (US$ 195,678) and IRR (17.3 percent)	- Mitigates greenhouse gas emissions from municipal solid waste - Potential revenue from biogas - Positive NPV and long-term financial benefits - Contributes to sustainable waste management

	- Positive Net Present Value (NPV) and Internal Rate of Return (IRR) of 14.2 percent. - Aligns with sustainable agricultural practices.	- Enhances soil health	- Addresses waste management sustainably	
Weaknesses	- Requires significant capital investment - Financial sensitivity to market rates and conditions - Technical maintenance required	- High initial costs - Labour expenses impact profitability	- High initial capital requirement - Sensitivity to feed-in tariff fluctuations	- High initial investment - Financial success depends on stable feed-in tariffs and policies
Opportunities	- Potential revenue from surplus biogas and bio digestate - Leveraging supportive renewable energy policies - Potential to integrate with other technologies for hybrid solutions	- Potential to benefit from higher feed-in tariffs - Revenue from biogas and bio digestate sales - Potential to integrate with other technologies for hybrid solutions	- Enhanced profitability with higher feed-in tariffs - Opportunity to leverage supportive policy frameworks - Potential to integrate with other technologies for hybrid solutions	- Potential benefits from new feed-in tariff policies - Opportunity to influence policy for long-term sustainability - Job creation - Potential to integrate with other technologies for hybrid solutions
Threats	- Fluctuations in energy prices impact profitability - Policy changes could affect financial outcomes	- Financial viability dependent on stable tariffs and policies - Market competition from other renewable energy sources	- Sensitivity to energy tariff variations - Project viability dependent on favourable policies	- Variations in tariffs and policy conditions could impact financial outcomes - Risk of competition from other technologies

At GFirm Poultry and Dairy Farm, private sector involvement is crucial for securing the initial investment needed for biogas technology. Success depends on leveraging financial incentives and ensuring market conditions are favourable for biogas and bio digestate sales. For the Abuko Livestock Market and Slaughterhouse, the private sector must manage labour costs and engage with policymakers to secure stable feed-in tariffs. This engagement helps optimize financial returns from energy savings and sales of biogas and bio digestate. The Bakoteh Fish and Vegetable Market project shows that private sector players need to focus on stable feed-in tariffs to ensure financial viability. Active involvement in policy advocacy is essential to maintain favourable tariff conditions. In the Bakoteh Dumpsite case, the private sector's role includes navigating feed-in tariff policies and ensuring project sustainability. Engaging with policymakers to secure favourable conditions is critical for the project's financial success.

5.3 Risks and barriers analysis

5.3.1 Financial risks and barriers

- Initial Capital Investment: The high upfront costs associated with biogas technology can be a significant barrier. Securing financing is often challenging, particularly for small and medium-sized enterprises (SMEs) in the private sector. The need for substantial investment in infrastructure and technology might deter potential investors.
- Variable Feed-in Tariffs: The financial viability of biogas projects is highly sensitive to feed-in tariffs or energy pricing policies. Fluctuations or reductions in these tariffs can adversely affect project profitability. A stable and supportive tariff regime is crucial for ensuring financial returns.
- Operational Costs: Ongoing operational and maintenance costs can strain financial resources. For example, labour costs and the cost of maintaining biogas systems need careful management to avoid unforeseen financial burdens.
- Market Prices for By-products: Revenue from biogas and bio digestate sales is dependent on market prices. Low or fluctuating prices for these by-products can affect the overall profitability of the projects. Establishing stable market conditions and long-term contracts can mitigate this risk.

5.3.2 Technical risks and barriers

- Technology Reliability: The success of biogas projects hinges on the reliability and efficiency of the technology used. Technical failures or inefficiencies can increase maintenance costs and reduce energy production. Ensuring the quality of technology and regular maintenance is critical.
- Feedstock Variability: The quality and quantity of feedstock (manure, organic waste, etc.) can vary, affecting biogas production rates. Consistent feedstock supply and quality are necessary for stable biogas output.
- Infrastructure Challenges: Adequate infrastructure for biogas production, storage, and distribution must be in place. Inadequate infrastructure can lead to inefficiencies and increased operational challenges.

5.3.3 Policy and regulatory barriers

- Policy Uncertainty: Changes in government policies or regulations related to renewable energy can create uncertainty. This can impact investment decisions and project stability. Engaging with policymakers to ensure supportive and consistent regulations is important.
- Regulatory Compliance: Navigating the regulatory landscape can be complex. Compliance with environmental and safety regulations is necessary but can be burdensome and costly. Clear and streamlined regulatory processes can ease this burden.

- Incentives and Support Programs: The availability and effectiveness of government incentives or support programs for biogas projects can vary. Insufficient incentives may reduce project attractiveness to private investors.

5.3.4 Social and community barriers

- Community Acceptance: Local communities' perceptions and acceptance of biogas projects can influence their success. Addressing concerns about potential odors, safety, and other impacts through community engagement and communication is essential.
- Skill and Knowledge Gaps: There may be a lack of technical expertise and knowledge about biogas technology among local operators. Training and capacity-building initiatives are necessary to ensure effective project management and operation.
- Land Use and Environmental Concerns: Projects must address any concerns related to land use and environmental impacts. Ensuring that biogas projects are environmentally sustainable and aligned with local land use plans is crucial.

The successful implementation of biogas projects across the case studies in The Gambia depends on addressing financial, technical, policy, and social barriers. Key strategies include securing reliable financing, managing operational costs, stabilizing feed-in tariffs, ensuring technology reliability, and engaging with communities and policymakers. By proactively addressing these risks and barriers, biogas projects can achieve greater sustainability and contribute to environmental and economic benefits.

5.4 Potential sources of funding and investment opportunities

To advance biogas projects in The Gambia, a range of funding sources and financial mechanisms can be utilized. Each source offers different types of financial support and mechanisms, making it crucial to match project needs with the appropriate funding options.

It is important to note that no specific information has been collected regarding grants and loans available from government agencies, local banks, or international financial institutions. As such, this analysis does not include details on government-backed funding programs or financial products offered by local and international banks that could also support the implementation and scaling of these biogas initiatives. Further investigation into these potential funding avenues would be beneficial to provide a complete picture of available financial resources and mechanisms.

To address this lack of information a workshop will be organized in The Gambia. This workshop aims to bring together representatives from these potential funding bodies to discuss and explore available financial resources and mechanisms for supporting the biogas projects. By facilitating direct engagement with these institutions, the workshop will provide a platform to identify and secure funding opportunities, enhancing the feasibility and implementation of biogas initiatives in the country.

Green Climate Fund (GCF): The GCF provides grants and concessional loans for projects that aim to combat climate change and promote low-emission technologies. For biogas projects, GCF support could cover capital expenditures, operational costs, and technical assistance. The GCF's investment criteria align well with renewable energy and waste management projects, making it a strong candidate for funding. For instance, GCF has funded similar waste-to-energy projects in other developing countries, demonstrating its capacity to support biogas initiatives.

Examples:

- PROREFISH (2022-2028), Climate Resilient Fishery Initiative for Livelihood Improvement in The Gambia, US$25 million
- GCF (2016-2025) Large-scale Ecosystem-based Adaptation in The Gambia: developing a climate-resilient, natural resource-based economy

Global Environment Facility (GEF): GEF offers grants and blended finance (a mix of grants and concessional loans) to projects that address environmental and climate challenges. Biogas projects in The Gambia could benefit from GEF funding to support technology deployment, capacity building, and monitoring. GEF's track record includes funding waste management and renewable energy projects globally, providing a precedent for supporting biogas technologies.

Examples:

- GEF, FAO, Adapting Agriculture to Climate Change in The Gambia 2016. US$6.2 million grant
- GEF, IFAD, Integrated Landscape Management Gambia, 2022, US$4.7 million grant
- GEF, Conservation International, strengthening capacity of institutions in The Gambia to meet transparency requirements of the Paris Agreement, US$1.1 million grant, 2021

European Union (EU): The EU provides funding through programs like Horizon Europe, which supports innovative research and technology development, and the EU External Action funding, which targets sustainable development projects in partner countries. Biogas projects can access EU grants for research and development, pilot projects, and implementation. The EU has previously financed renewable energy projects in Africa, including biogas, showcasing its commitment to supporting clean energy solutions.

- EU, EU Global Climate Change Alliance (GCCA+), Women tackling The Gambia's waste problem. 100k EUR
- Multiannual Indicative Programme (MIP) for The Gambia for 2021-2027 amounts to €119 million

European Investment Bank (EIB): The EIB offers loans and grants for projects that advance environmental sustainability and energy efficiency. EIB financing could be used for infrastructure development, technology acquisition, and capacity building for biogas projects. The EIB has supported numerous renewable energy projects worldwide, including waste-to-energy initiatives, making it a suitable source of financial support.

- EIB (2017), Gambia Renewable Energy, 141 million Euro

Islamic Development Bank (IsDB): The IsDB provides project financing through loans, grants, and equity investments, focusing on sustainable development and economic growth. Biogas projects can apply for IsDB funding to support large-scale implementations and technological advancements. The IsDB has financed renewable energy projects in various countries, demonstrating its interest in sustainable energy solutions.

- IsDB (2023) to Strengthen Collaboration in Education, Energy and Transportation

International Finance Corporation (IFC): As part of the World Bank Group, the IFC offers investment and advisory services to support private sector projects. Biogas projects can benefit from IFC's equity and debt financing and technical assistance for project development and implementation. The IFC has a history of investing in renewable energy projects, including biogas, thus aligning well with the needs of such initiatives.

- IFC, Fish and livestock project

World Bank (WB): The WB provides loans, grants, and technical assistance for projects that address climate change and promote sustainable development. Biogas projects could leverage WB support for infrastructure development, policy reforms, and capacity building. The World Bank's previous investments in renewable energy projects, including waste-to-energy, underline its potential support for biogas initiatives. The combined national and regional energy projects under supervision are over US$200 million.

- The Gambia Electricity Restoration and Modernization Project (GERMP, P163568) was approved for US$43 million in May 2018 with additional financing of US$41 million approved in 2020.
- Complementary regional projects include the OMVG Regional Interconnection Project (with US$47 million World Bank financing out of a US$86 million allocation).
- The ECOWAS Regional Access Project (US$66 million allocation for The Gambia).

International Fund for Agricultural Development (IFAD): IFAD offers grants and loans to enhance agricultural productivity and sustainability. Given the link between agricultural waste and biogas production, IFAD funding could support projects integrating biogas systems with agricultural operations. IFAD has previously funded agricultural and waste management projects that align with biogas project objectives.

- (2019) Resilience of Organizations for Transformative Smallholder Agriculture Project, US$60.7 million
- (2012) National Agricultural Land and Water Management Development Project, US$76.6 million

UN Capital Development Fund (UNCDF): UNCDF provides financial support and investment for projects to reduce poverty and support local development. Their focus on innovative financial solutions and community-driven approaches aligns with the goals of biogas projects in The Gambia. UNCDF could offer grants or blended finance solutions that combine grants with loans to enhance the financial viability of biogas initiatives, especially in rural and underserved areas.

- US$15 million from the EU to finance the Jobs, Skills, and Finance (JSF) Programme, tackling job creation, skills development, and improved access to finance while building community-level adaptation to climate change with a focus on women and youth. One of the financed projects aims to produce organic fertilizer from groundnut shells, building and benefitting from the previous success of financing TROPINGO to become a leading producer and exporter of organic and ethically sourced mango products in the region.
- LoCAL's performance-based climate resilience grant (PBCRG) approach, aim at creating jobs, particularly in the green economy.

Each of these funding sources provides distinct financial mechanisms that can be tailored to meet the specific needs of biogas projects in The Gambia. By strategically engaging with these institutions and aligning project proposals with their funding criteria, biogas initiatives can secure the necessary resources to achieve successful implementation and sustainability.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions and Recommendations

Climate change mitigation potential

- Across the sectors examined, significant energy consumption and poor waste management practices were consistently identified. This was particularly evident in private agricultural and livestock operations, including entities like the poultry and dairy producer Gfirm and other studied farms. These facilities invest considerable financial resources annually to meet their energy demands. At the same time, inadequate waste disposal practices pose severe environmental risks, such as soil and water contamination, and contribute to increased greenhouse gas emissions.
- The fish, animal, and vegetable markets also present substantial opportunities for improvement. These markets generate large volumes of organic waste, including animal droppings, which are often left unutilized and improperly disposed of, missing out on potential waste-to-energy conversion opportunities. Additionally, urban dumpsites, particularly the main one in Serrekunda, where organic material comprises about 60 percent of the urban solid waste stream, represent a significant yet untapped potential for energy production. This potential could be realized by applying technologies designed to separate and process organic matter effectively.
- The adoption of biogas technology has the potential to reduce greenhouse gas emissions across all sites significantly. By diverting organic waste from traditional disposal methods—such as dumping and open burning—into biogas production, these projects can mitigate substantial amounts of CO2 equivalent emissions. For instance, the Bakoteh Fish and Vegetable Market alone could reduce emissions by 1,717 tCO2e annually. This environmental benefit addresses local pollution issues and broader climate change challenges. Across all sites, the total annual GHG reduction is 7,912 tonnes CO_{2e}, accumulating to 118,674 tonnes over the 15-year period, indicating substantial environmental benefits from the project.

Social and economic impact

- Biogas projects have the potential to create significant job opportunities in both rural and urban areas. Employing waste management, biogas production, and system maintenance could particularly benefit youth and women.
- Implementing biogas projects could positively impact local economies by reducing energy costs and generating additional income from organic waste management. This would contribute to greater financial resilience within communities.

- By improving waste management practices, biogas projects could reduce health risks associated with improper waste disposal, leading to better living conditions and public health outcomes.

Environmental sustainability

- Using bio-slurry from biogas production as a fertilizer can enhance soil health, offering a sustainable alternative to chemical fertilizers. This could lead to improved agricultural productivity and sustainability.
- Integrating biogas projects with organic farming practices could promote sustainable agriculture by reducing the need for synthetic inputs, thereby enhancing environmental sustainability.
- Biogas projects could contribute to biodiversity conservation by reducing deforestation and land degradation, mainly through decreased reliance on fuelwood. This would help preserve natural habitats and ecosystems.

Financing

- Across all four case studies, the financial analyses consistently indicate the economic benefits of biogas projects. Each project demonstrated a positive Net Present Value (NPV) and a reasonable Internal Rate of Return (IRR), with payback periods ranging from six to eight years. These findings highlight the financial feasibility of biogas systems, especially when integrated into existing agricultural and market operations. However, sensitivity analyses revealed that financial returns highly depend on energy prices, feed-in tariffs, and labor costs. To maximize financial gains, aligning biogas selling prices with market rates and ensuring supportive economic policies are in place is crucial.
- Given the identified potential for biogas production and waste-to-energy projects, it is recommended that the Gambian government, potentially supported by recognized international organizations, support a feed-in tariff (FiT) program specifically tailored to incentivize renewable energy initiatives. Such a program could encourage investment in biogas projects across various scales—medium to large-scale operations—and improve waste management practices in sectors with high organic waste output, such as agriculture, livestock, and urban markets. One such initiative is a feed-in tariff proposed by the Minister of Petroleum and Energy and the national electricity company, NAWEC, designed explicitly for energy produced from renewable sources (e.g., solar) and fed into the national grid.
- It is crucial to develop targeted support mechanisms to address the challenges faced by small private entities (below 50kWe) in adopting biogas technology. Initiatives should focus on providing accessible and flexible financing options for small-scale producers. These could include low-interest loans or subsidies that reduce the financial burden of initial investments.
- To improve system maintenance and sustainability, it is recommended that training programs and technical support be implemented tailored to the needs of small-scale operators. Such

programs should emphasize practical maintenance skills and offer ongoing assistance to ensure the long-term success of biogas systems. Engaging with local financial institutions and technical experts to create a supportive ecosystem will help enhance biogas technology's adoption and effective utilization at the household and small farm levels.

Governance, regulation, and enabling environment

- Several categories of organizations, formal and informal, can be used as entry points to enhance knowledge and better understand the benefits of biogas and the need for its adoption. These include farmer associations, governmental markets and NGOs (such as M'bolo NGO), research centres (such as WALIC and the Commercial Dairy Association), the National Energy Agency (NEA), etc. These organizations are important platforms for localizing and scaling up emerging private-sector partnerships to promote the use of biogas.
- Efforts should be made to integrate biogas projects into existing energy markets, through partnerships with local utilities or community energy schemes. Aligning biogas selling prices with market rates can enhance revenue streams and improve project viability.
- There is a need to develop waste management policies and regulations, particularly for sectors that produce significant amounts of organic waste. This waste has the potential to be transformed into energy or compost, which can enhance sustainability and resource efficiency.
- Raising awareness among stakeholders, including local communities and businesses, about biogas technology's environmental and economic benefits can drive broader adoption and support for these initiatives.
- Foster public-private partnerships to build a robust supply chain infrastructure, ensuring the availability of biogas technology and materials.
- Strengthen policy frameworks to support adopting and scaling biogas projects, including incentives for private sector investment.
- Develop institutional mechanisms to coordinate biogas initiatives across different sectors, such as agriculture, energy, and waste management.
- Advocate for integrating biogas into national energy and environmental policies, aligning with international climate commitments.
- Finally, the recommendation is to seek additional resources to pilot a biogas system in the country, covering one of the studied sectors.

Training and capacity building

- Develop specialized training programs for local communities, farmers, and small businesses on biogas technology installation and maintenance.
- Promote knowledge exchange programs between The Gambia and other West African countries with successful biogas projects.

- Establish certification programs for technicians and engineers in biogas technology to ensure a skilled workforce. This could also be done through NGOs (e.g., M'bolo) and national research centres (e.g., NARI or WALIC).

Innovation and technology

- Encourage research and development (R&D) in biogas technologies suited to The Gambia's specific organic waste streams.
- Explore innovative waste-to-energy technologies beyond biogas, such as pyrolysis and gasification, to diversify energy sources.
- Promote digital tools and platforms for monitoring and managing biogas systems, improving efficiency and reducing operational costs.

Market development and supply chain

- Map out the biogas supply chain to identify key actors and potential production, distribution, and sales bottlenecks.
- Develop strategies to create and expand markets for biogas products, including electricity, cooking gas, and organic fertilizers.

Infrastructure

- Through improved access to energy, The Gambia could increase the share of renewables in its energy mix and enhance local production. However, despite its successful adoption in other West African countries, biogas technology has yet to be implemented in The Gambia, highlighting a missed opportunity for sustainable development.
- The study revealed a significant number of private sector actors across various levels of the supply chain who show a strong interest in biogas production. This interest stems from the unreliable electricity supply, high electricity and diesel costs, and abundant organic residues and waste suitable for biogas conversion.

6.2 Stakeholder Validation Workshop for the Biogas Resource Potential Assessment (conducted hybrid)

The Stakeholder Validation Workshop for the Biogas Resource Potential Assessment Draft Report was held at the National Agricultural Research Institute (NARI) in Brikama, The Gambia, and online. The hybrid workshop included 23 online participants and 16 in-person attendees who represented various sectors, including government bodies, private enterprises, agriculture, energy, and waste management. The event was part of the ongoing efforts by the SCALA UNDP Programme to assess the potential of biogas resources in The Gambia and explore the feasibility of biogas as an alternative energy solution for multiple sectors.

The workshop provided a platform for stakeholders to review and validate the draft findings, raise concerns, and suggest potential improvements. Several key points were discussed:

- **NAWEC Feed-in Tariff (FIT) Proposal**: NAWEC submitted a feed-in tariff proposal to the Gambia Public Utilities Regulatory Authority (PURA) for approval. If approved, this proposal would allow energy generated from biogas plants to be fed into the national grid, supporting renewable energy integration.
- **Bio-Waste and Compost Plan**: Plans to manage bio-waste, including a composting initiative at the Bakoteh dumpsite, are progressing. The objective is to convert the dumpsite into a modern landfill capable of generating organic fertilizers to boost agricultural productivity. Supported by the European Union (EU), the project is currently in the feasibility study phase. This study examines the technical, environmental, and financial feasibility of transforming the Bakoteh site and expanding to two additional locations: Mile2 - Banjul and Tambana - Brikama. These sites will serve as key hubs in the bio-waste management and composting network, aiming to reduce waste, promote recycling, and produce organic fertilizers for local farming. This plan has the potential to significantly reduce waste management challenges while contributing to sustainable agricultural practices through organic fertilizer production.
- **Bakoteh Fish Market Waste Management**: A stakeholder highlighted the potential for developing a management plan for the Bakoteh Fish Market, where fish waste is currently being underutilized. Fish residuals are used as manure, but a significant portion is discarded. There is potential for converting this waste into biogas or other valuable products.
- **Energy Challenges at Kharafi Farms**: A representative from Kharafi Farms in Kafuta, Kombo East, shared that their farm spends millions of Gambian Dalasis on electricity generated from diesel engines. The farm expressed interest in exploring biogas as an alternative energy source to reduce reliance on the grid and diesel-powered engines.
- **Space and Technology for Biogas Plants**: Concerns were raised regarding whether The Gambia has the necessary space and technology to build and operate large-scale biogas plants if funding becomes available. Participants discussed the need for capacity building and technology transfer to implement biogas projects successfully.
- **Blood Slurry Management in Livestock Markets**: The Department of Livestock's representative highlighted the growing issue of blood slurry from over 70 animal markets nationwide. The stakeholders emphasized the importance of addressing this environmental hazard, suggesting that biogas could offer a solution for managing waste.

The workshop concluded with a commitment from all stakeholders to collaborate in addressing the challenges of waste management and energy production through biogas technology. The biogas lead expert will incorporate the feedback from the workshop into the final report.

The success of this workshop marked a significant step towards sustainable energy solutions, and the proposed biogas projects have the potential to provide cleaner energy alternatives while addressing critical environmental issues such as waste management and soil degradation.

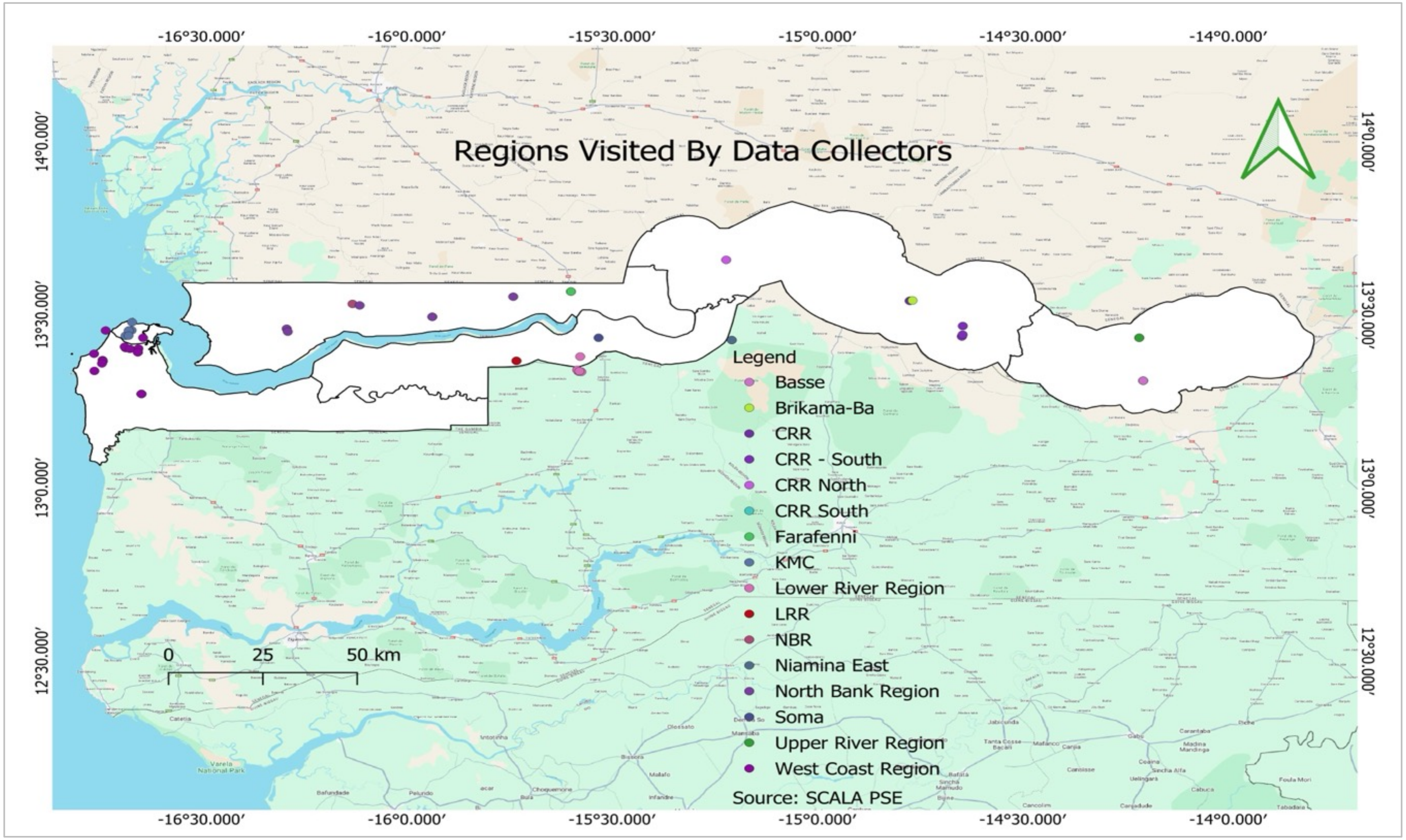
Key Follow-Up Actions:

- **EU Focal Point Engagement**: The EU representative promised to share the contact information of the biogas assessment expert. This expert will guide the next phase of the feasibility study and provide technical insights on biogas production and processing.
- **Funding Availability:** The EU representative confirmed that funding is available for parties interested in pursuing biogas projects. This funding will support both the feasibility studies and the implementation phase. Interested stakeholders are encouraged to engage with the EU directly for further collaboration. The representative has also shared her contact details for follow-up discussions.
- **Commitments from Stakeholders:** Stakeholders collectively agreed to continue supporting the development of biogas plants. NAWEC and agricultural bodies have pledged to provide additional resources, including technical expertise and potential locations for biogas installations, to ensure the project's success.

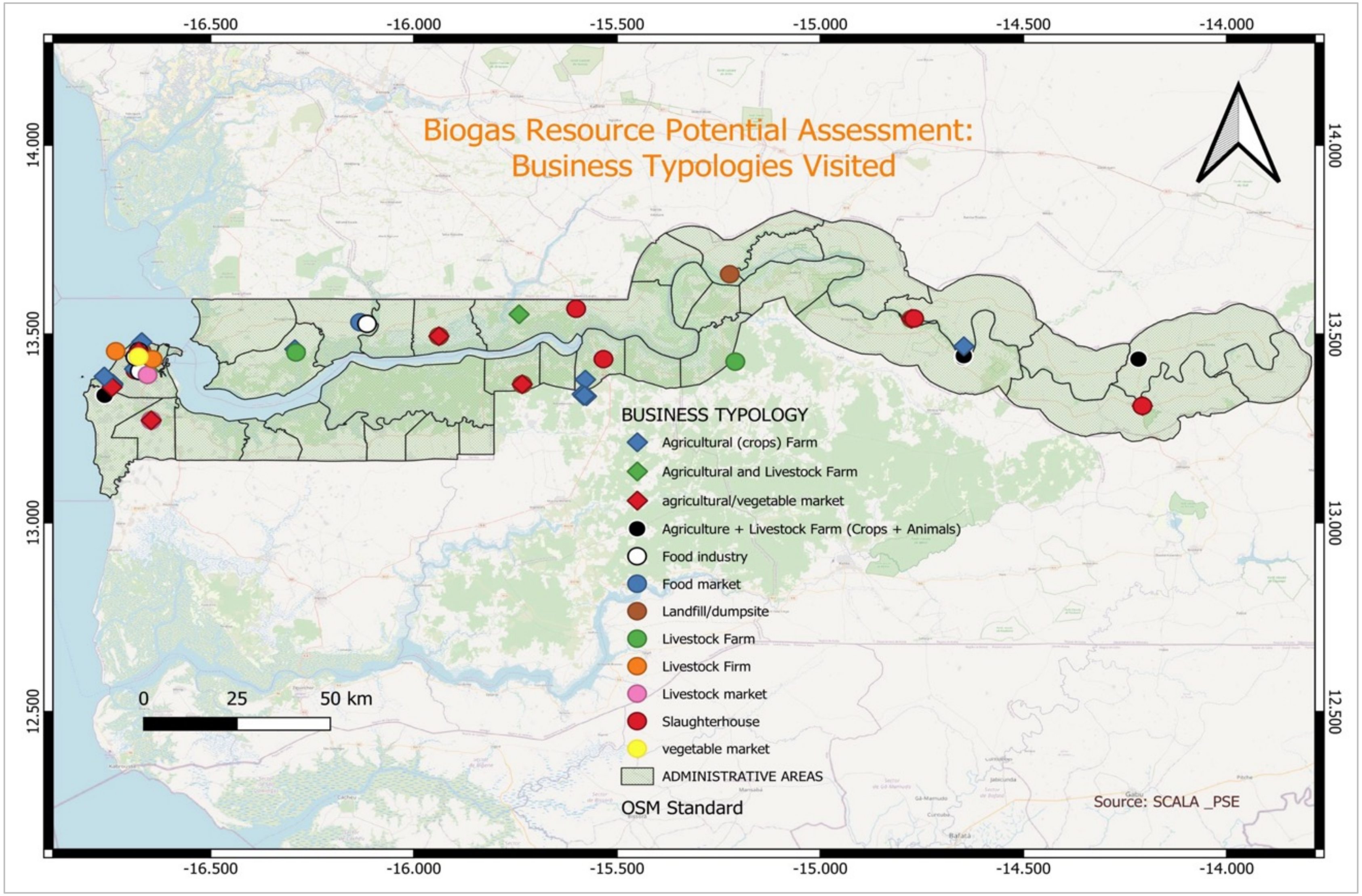
Leveraging these engagements and with available resources, the following steps will involve detailed planning, collaboration with local and international experts, and securing the necessary infrastructure for the successful rollout of biogas initiatives in The Gambia.

ANNEXES

Annex 1. Map of primary data collection locations (May-July 2024)



Annex 2. Map of stakeholders identified during field visits



Annex 3. Capital costs of suggested investments

	Bakoteh (LS)	Bakoteh (MS)	Abuko (MS)	Gfirm (SS)
Pretreatment	USD	USD	USD	USD
Other (Hygenization, crushing, homogenization)	$ 4,791.31	$ 1,535.08	$ 485.28	$ 1,469.23
Pre-processing equipment	$ 20,858.93	$ 6,682.97	$ 2,401.75	$ 6,396.28
Subtotal	**$ 25,650.24**	**$ 8,218.06**	**$ 2,887.03**	**$ 7,865.51**
Equipments				
Digester CSTR	$ 77,442	$ 24,812	$ 8,917	$ 23,747
Effluence storage pool	$ 35,695	$ 11,436	$ 4,110	$ 10,946
Buffer tank	$ 6,516	$ 2,088	$ 750	$ 1,998
Odor Control System	$ 18,206	$ 5,833	$ 2,096	$ 5,583
Metering Pumps	$ 8,568	$ 2,745	$ 987	$ 2,627
Pumps	$ 19,277	$ 6,176	$ 2,220	$ 5,911
Trommel screen	$ 23,561	$ 7,549	$ 2,713	$ 7,225
Mixers	$ 8,568	$ 2,745	$ 987	$ 2,627
Post digestion tank (for gravity separation)	$ 6,516	$ 2,088	$ 750	$ 1,998
Gas collection equipment	$ 32,129	$ 10,294	$ 3,699	$ 9,852
Desulfurizing tower	$ 369	$ 118	$ 42	$ 113
Reciprocating Engine (5 kW - 7 MW)	$ 172,270	$ 45,009	$ 55,015	$ 28,669
Subtotal	**$ 409,117.12**	**$ 120,892.45**	**$ 82,286.24**	**$ 101,296.44**
Building				
Building w/slab	$ 27,417	$ 8,784	$ 3,157	$ 8,407
50' Truck weighing scales	$ 14,008	$ 4,488	$ 1,613	$ 4,296
Foundation for scales inclu. Const.	$ 8,568	$ 2,745	$ 987	$ 2,627
Front-End Loader	$ 25,275	$ 8,098	$ 2,910	$ 7,750
Solids drying area concrete slab	$ 41,125	$ 13,176	$ 4,735	$ 12,611
Subtotal	**$ 116,392.74**	**$ 37,290.97**	**$ 13,401.76**	**$ 35,691.23**

Installation	USD	USD	USD	USD
Connection and earthing	$ 7,506	$ 1,961	$ 2,397	$ 1,249
Land Preparation	$ 37,321	$ 11,957	$ 4,297	$ 11,444
Installation CSTR	$ 2,086	$ 546	$ 663	$ 347
Infrastructure (fencing)	$ 19,779	$ 6,337	$ 2,277	$ 6,065
Infrastructure (roads)	$ 25,703	$ 8,235	$ 2,960	$ 7,882
Subtotal	**$ 92,394.83**	**$ 29,035.98**	**$ 12,594.50**	**$ 26,987.33**

Electricity Distribution network				
Primary electricity cable	$ 232,785	$ 74,582	$ -	$ 11,764
Secondary cable, installation and meter	$ 74,235	$ 19,990	$ -	$ 25,883
Subtotal	**$ 307,020.08**	**$ 94,572.39**	**$ -**	**$ 37,647.29**

Totals	**Bakoteh (LS)**	**Bakoteh (MS)**	**Abuko (MS)**	**Gfirm (SS)**
Capacities (kWe)	375	83	104	49.16
Pretreatment	$ 25,650.24	$ 8,218.06	$ 2,887.03	$ 7,865.51
Equipments	$ 409,117.12	$ 120,892.45	$ 82,286.24	$ 101,296.44
Building	$ 116,392.74	$ 37,290.97	$ 13,401.76	$ 35,691.23
Installation	$ 92,394.83	$ 29,035.98	$ 12,594.50	$ 26,987.33
Electricity Distribution network	$ 307,020.08	$ 94,572.39	$ -	$ 37,647.29
Totals	**$ 950,575.01**	**$ 290,009.85**	**$ 111,169.53**	**$ 209,487.81**

Annex 4. List of stakeholders mapped

S/N	Organization	Type of stakeholder	Description	Sectors	Position in the sector	Location
1	WEST AFRICAN LIVESTOCK INNOVATION CENTRE (WALIC)	Public	A key public entity focused on research and innovation in livestock management. WALIC plays an essential role in improving livestock productivity and sustainability in The Gambia.	Livestock, livestock markets	Government entity or regulator	Banjul
2	COMMERCIAL DIARY FARMERS' ASSOCIATION	Public	A collective of dairy farmers committed to improving milk production and processing in The Gambia.	Livestock, livestock markets	Government entity or regulator	Banjul
3	M'BOLO ASSOCIATION	Private	An NGO focused on training women and youth in sustainable practices including renewable energy and organic farming	Livestock, livestock markets, vegetable and fish markets	Civil society organization	Banjul
4	NATIONAL ENVIRONMENT AGENCY (NEA)	Public	A government agency responsible for coordinating environmental protection and management activities in The Gambia.	Environment	Government entity or regulator	Banjul
5	GERMAN EMBASSY	Public	The German Embassy in The Gambia supports various development projects, including those related to environmental sustainability and renewable energy.	Environment and Energy	Intl development/multilateral/UN	Banjul
6	MINISTRY OF AGRICULTURE	Public	The primary government body overseeing agriculture and livestock activities in The Gambia	Agriculture and livestock	Government entity or regulator	Banjul
7	MINISTRY OF PETROLEUM AND MINES	Public	Responsible for managing The Gambia's energy resources, including oil and gas.	Energy	Government entity or regulator	Banjul
8	MINISTRY OF ENVIRONMENT, CLIMATE CHANGE AND NATURAL RESOURCES	Public	The primary government body overseeing Environment, Climate Change and Natural Resources in The Gambia	Environment and Natural Resources	Government entity or regulator	Banjul
9	MINISTRY OF GENDER CHILDREN AND SOCIAL WELFARE	Public	A government body that integrates gender and social welfare issues into national development plans.	Social Welfare	Government entity or regulator	Banjul
10	NATIONAL WATER AND ELECTRICITY	Public	The main provider of water and electricity in The Gambia.	Energy and water	Government entity or regulator	Banjul

	COMPANY (NAWEC)					
11	DELEGATION OF THE EUROPEAN UNION TO THE GAMBIA	Public	Represents EU interests in The Gambia, supporting initiatives in agriculture, environment, and energy through policy advocacy, funding, and technical assistance.	Agriculture, Environment, and Energy	Intl development/multilateral/UN	Banjul
12	EUROPEAN INVESTMENT BANK (EIB)	Public	Provides long-term investment and financial services for projects in agriculture and energy, supporting sustainable economic development and renewable energy initiatives.	Agriculture and Energy	Intl development/multilateral/UN	Banjul
13	WORLD BANK	Public	An international development bank that provides financial services and support for projects in agriculture and energy, aimed at fostering sustainable development in The Gambia.	Agriculture and Energy	Intl development/multilateral/UN	Banjul
14	AFRICAN DEVELOPMENT BANK	Public	A regional development bank that funds projects and provides financial support to promote sustainable economic growth and development in The Gambia.	Agriculture and Energy	Intl development/multilateral/UN	Banjul
15	GAMBIA SONGHAI INITIATIVE	Public	An initiative focused on animal production and agroforestry, aimed at enhancing agricultural practices and promoting sustainable development in The Gambia.	Animal production & Agroforestry	Production	North Bank Region
16	ISLAMIC DEVELOPMENT BANK	Public	A regional development bank that provides financial and technical assistance to member countries. The Senegal Hub supports projects in The Gambia focused on sustainable development, including renewable energy initiatives like biogas production, to enhance energy security and reduce environmental impact.	Agriculture and Energy	Intl development/multilateral/UN	Banjul
17	UN CAPITAL DEVELOPMENT FUND (UNCDF)	Public	The UNCDF provides investment capital and technical support to the least developed countries, including The Gambia. UNCDF is involved in funding and promoting renewable energy projects, such as biogas, to improve energy access and economic resilience in vulnerable communities.	Agriculture and Energy	Intl development/multilateral/UN	Banjul
18	INTERNATIONAL FINANCE CORPORATION (IFC)	Public	A member of the World Bank Group, IFC works to encourage private sector investment in developing countries.	Agriculture and Energy	Support services/Intl development/multilateral/UN	Banjul
19	IFAD	Public	The International Fund for Agricultural Development (IFAD) supports rural development projects aimed at reducing poverty and hunger. IFAD is involved in promoting sustainable agricultural practices in The Gambia.	Agriculture	Support services/Intl development/multilateral/UN	Banjul

20	GAMBIA RENEWABLE ENERGY CENTER (GREC)	Public	A key institution under the State Department for Trade, Industry, and the Environment, GREC is responsible for advancing research and development in renewable energy. GREC plays a central role in promoting biogas technology and other renewable energy solutions in The Gambia.	Energy	Research and Development	Banjul
21	SWAMI GAMBIA LIMITED	Private	An agricultural farm focused on crop production, contributing to the agricultural sector in the West Coast Region.	Agriculture	Production	West Coast Region
22	BAKAU WOMEN AGRIC. GARDEN	Private	A women-led agricultural garden focused on crop production, playing a significant role in food security and income generation in KMC.	Agriculture	Production	KMC
24	MAURO FARM	Private	An agricultural farm specializing in crop production, supporting local agriculture in CRR-South.	Agriculture	Production	CRR-South
25	BULOCK KAPONGNA JAMARI'S ASSOCIATION	Private	An agricultural association engaged in crop production, enhancing food security and supporting the local economy in the West Coast Region.	Agriculture	Production	West Coast Region
26	NYOFELLEH KAMBENG KAFOO	Private	An agricultural association focused on crop production, playing a crucial role in agricultural development in the West Coast Region.	Agriculture	Production	West Coast Region
27	KAMBENG KAFOO	Private	An agricultural association focused on crop production, playing a vital role in local food security and agricultural development in the West Coast Region.	Agriculture	Production	West Coast Region
28	FASS JOM GROUP	Private	An agricultural group engaged in crop production, contributing to the agricultural output and community development in the West Coast Region.	Agriculture	Production	West Coast Region
29	KANTONG KUNDA SANUYORO KAFOO	Private	An agricultural association dedicated to crop production, supporting local food security and economic activities in the Lower River Region.	Agriculture	Production	Lower River Region
30	DUMBUNTO WOMEN GARDEN ASSOCIATION	Private	A women-led agricultural garden focused on crop production, enhancing food security and providing income for women in the Lower River Region.	Agriculture	Production	Lower River Region
31	MANDUAR VEGITABLE GARDEN	Private	A community vegetable garden focused on crop production, contributing to local food security and providing a source of income in the Lower River Region.	Agriculture	Production	Lower River Region
32	BAMAKO VEGITABLE GARDEN	Private	A vegetable garden that focuses on crop production, playing a key role in local agriculture and food security in the Lower River Region.	Agriculture	Production	Lower River Region

33	NEMA VEGITABLE GARDEN	Private	A community vegetable garden engaged in crop production, supporting food security and local agriculture in the Lower River Region.	Agriculture	Production	Lower River Region
34	SWEARASEH KAFOO	Private	An agricultural market association focused on providing a platform for the sale and distribution of crops, supporting local agriculture in the West Coast Region.	Agriculture	Wholesaler/Food Market	West Coast Region
35	SEREKUNDA MARKET	Public	A major agricultural market that serves as a central hub for the sale and distribution of vegetables and other crops in KMC.	Agriculture	Wholesaler/Food Market	KMC
36	BRIKAMA MARKET	Public	An agricultural market serving as a key location for the distribution and sale of crops and vegetables in the West Coast Region.	Agriculture	Wholesaler/Food Market	West Coast Region
37	BASSE MARKET	Public	A regional agricultural market that plays a critical role in the sale and distribution of vegetables and other crops in URR.	Agriculture	Wholesaler/Food Market	URR
38	JANJANGBUREH MARKET	Public	An agricultural market that supports the sale and distribution of crops, contributing to local food security in CRR.	Agriculture	Wholesaler/Food Market	CRR
39	KEREWAN MARKET	Public	An agricultural market that facilitates the sale and distribution of crops, playing a vital role in supporting local agriculture in NBR.	Agriculture	Wholesaler/Food Market	NBR
40	MANSAKONKO MARKET	Public	A local agricultural market that supports the sale and distribution of crops, contributing to food security in the Lower River Region.	Agriculture	Wholesaler/Food Market	LRR
41	LUMO SAREH BOJO	Private	A mixed agriculture and livestock farm focused on crop and animal production, playing a significant role in agricultural development in URR.	Agriculture and Livestock	Production	URR
42	FARAFENI LUMO ASSOCIATION	Private	A mixed agriculture and livestock association engaged in crop and animal production, supporting local agriculture and livestock in the North Bank Region.	Agriculture and Livestock	Production	North Bank Region
43	NYODEMAA AGRO-BUSINESS	Private	A mixed agriculture and livestock business focused on crop and animal production, contributing to the agricultural economy in CRR-South.	Agriculture and Livestock	Production	CRR-South

44	ALLAH TENTU FARM	Private	A mixed agriculture and livestock farm dedicated to crop and animal production, enhancing local agriculture in CRR-South.	Agriculture and Livestock	Production	CRR-South
45	KINTEH KUNDA KEMBENG KAFO	Private	An agricultural and livestock farm focused on crop and animal production, supporting food security and local agriculture in the West Coast Region.	Agriculture and Livestock	Production	West Coast Region
46	KHARAFI KAFUTA	Private	A food industry player focused on agricultural production, contributing to the food supply chain in the West Coast Region.	Agriculture	Production	West Coast Region
47	FRUIT, BANANA FARMING	Private	An agricultural farm specializing in fruit and banana production, playing a vital role in the local food industry in KMC.	Agriculture	Production	KMC
48	PASTIVE PAULTRY FARMING	Private	A poultry farm focused on livestock production, contributing to food security and the poultry industry in the North Bank Region.	Agriculture	Production	North Bank Region
49	TROPINGO FOODS	Private	A food industry company engaged in agricultural production, supporting the food supply chain and agricultural development in KMC.	Agriculture	Production	KMC
50	KUNTAUR AREA COUNCIL	Public	A public council managing landfill/dumpsite operations, playing a role in environmental services in CRR North.	Environment	Government entity or regulator	CRR North
51	BRIKAMA AREA COUNCIL	Public	A public council responsible for managing landfill/dumpsite services, contributing to environmental management in the West Coast Region.	Environment	Government entity or regulator	West Coast Region
52	BASSE AREA COUNCIL	Public	A public council overseeing landfill/dumpsite management, providing essential environmental services in URR.	Environment	Government entity or regulator	URR
53	JAJANGBUREH AREA COUNCIL	Public	A public council managing landfill/dumpsite operations, supporting environmental services in CRR.	Environment	Government entity or regulator	CRR
54	KANIFING MUNICIPAL COUNCIL	Public	A public council responsible for managing landfill/dumpsite services, contributing to environmental management in KMC.	Environment	Government entity or regulator	KMC
55	KEREWAN AREA COUNCIL	Public	A public council overseeing landfill/dumpsite management, providing environmental services in LRR.	Environment	Government entity or regulator	LRR
56	MANSAKONKO AREA COUNCIL	Public	A public council responsible for landfill/dumpsite management, contributing to environmental services in NBR.	Environment	Government entity or regulator	NBR

57	JAMAGEN ADULT LITERACY LIVESTICK COOP. SOCIETY	Private	A livestock farm cooperative focused on livestock production, enhancing the local livestock sector in the North Bank Region.	Livestock	Production	North Bank Region
58	MAL RAH NGEN	Private	A livestock farm engaged in livestock production, supporting the local livestock industry in the North Bank Region.	Livestock	Production	North Bank Region
59	THE ITALIAN FAMILY PAULTRY FARM	Private	A poultry farm specializing in livestock production, contributing to the poultry industry in CRR South.	Livestock	Production	CRR South
60	ADAM'S POULTRY	Private	A poultry farm focused on livestock production, supporting food security and the poultry sector in Niamina East.	Livestock	Production	Niamina East
61	SAFFIATOU CEESAY'S POULTRY FARM	Private	A poultry farm dedicated to livestock production, playing a role in the poultry industry in Niamina East.	Livestock	Production	Niamina East
62	GFIRM	Private	A livestock firm engaged in livestock production, contributing to the local livestock sector in the West Coast Region.	Livestock	Production	West Coast Region
63	ALMINTEH	Private	A livestock firm focused on livestock production, supporting the livestock industry in the West Coast Region.	Livestock	Production	West Coast Region
64	DARAL ABUKO	Private	A livestock market providing a platform for the sale and trade of livestock, supporting the livestock industry in the West Coast Region.	Livestock	Market	West Coast Region
65	BRIKAMA DARAL ASSOCIATION	Private	A livestock market association focused on the sale and trade of livestock, contributing to the local livestock market in the West Coast Region.	Livestock	Market	West Coast Region
66	BRIKAMA	Private	A slaughterhouse engaged in livestock processing, playing a key role in the meat production industry in the West Coast Region.	Livestock	Processing	West Coast Region
67	ABAKOU - ABATOIR	Private	A slaughterhouse dedicated to livestock processing, supporting the meat production industry in the West Coast Region.	Livestock	Processing	West Coast Region
68	FARAFENNI	Private	A slaughterhouse focused on livestock processing, contributing to the meat production industry in Farafenni.	Livestock	Processing	Farafenni
69	SOMA	Private	A slaughterhouse engaged in livestock processing, playing a key role in the meat production industry in Soma.	Livestock	Processing	Soma
70	BASSE	Private	A slaughterhouse dedicated to livestock processing, supporting the meat production industry in Basse.	Livestock	Processing	Basse

71	BEIKAMA-BA	Private	A slaughterhouse focused on livestock processing, contributing to the meat production industry in Brikama-Ba.	Livestock	Processing	Brikama-Ba
72	BAKOTEH MARKET	Public	A public vegetable market that serves as a central hub for the sale and distribution of crops and vegetables in KMC.	Agriculture	Wholesaler/Food Market	KMC

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Scaling up Climate Ambition on Land Use and Agriculture through Nationally Determined Contributions and National Adaptation Plans (SCALA), funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) through the International Climate Initiative (IKI).

SCALA responds to the urgent need for increased action to cope with climate change impacts in the agriculture and land use sectors. The twenty million Euro programme will support at least twelve countries in Africa, Asia and Latin America to build adaptive capacity and to implement low emission priorities.

Country support includes strengthening policies, adopting innovative approaches to climate change adaptation and removing barriers related to information gaps, governance, finance, gender mainstreaming and integrated monitoring and reporting. To achieve this shift, the programme will engage the private sector and key national institutions.

SCALA supports countries to develop the capacity to own and lead the process to meet targets set out in their National Adaptation Plans and Nationally Determined Contributions under the Paris Agreement, and to achieve the Sustainable Development Goals. The SCALA initiative builds on another FAO-UNDP led programme, Integrating Agriculture in National Adaptation Plans (2015-2020) which is currently phasing out.

Food and Agriculture Organization of the United Nations
www.fao.org/in-action/scala/en

United Nations Development Programme
www.adaptation-undp.org/scala

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