"CLIENT II - International Partnerships for Sustainable Innovation"
LoSENS: LOCAL SUSTAINABLE ENERGY NETWORKS IN SENEGAL

WP4d:

Waste and Biogas Potential

WP4: Project Technicalities & Method

SPONSORED BY THE
Federal Ministry of Education and Research

Birkenfeld, March 28, 2024

SUBJECT:	***WP4d: Waste and Biogas Potential***
LOCATION:	City of Saint-Louis, Senegal
CATEGORY:	Knowledge Transfer and Feasibility Assessment
SYNOPSIS:	This report presents the findings of ***city Saint-Louis*** model region as part of ***"Local Sustainable Energy networks in Senegal"*** project with the objective of developing ***a biogas plant using the organic waste collected from the city***. This report provides an integrated and optimized waste management concept that is developed for the city of Saint-Louis. The main focus of the analysis is on the collection and processing of organic waste and its material and energy utilization. WP4d presents a feasibility study about installing a biogas plant that uses biowaste from different sources around the city.
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AD	Anaerobic Digestion
Bio-CNG	Combined Heat and Power
CET	Centre d'Enfouissement technique (CET) stands for technical landfill centre
CFA franc	Franc de la Communauté Financière d'Afrique. 1 EUR = 556 CFA-Franc[1]
CH_4	Methane
CHP	Combined heat and power
CO_2	Carbon Dioxide
DM	Dry Matter also knows as Total Solids (TS)
FM	Fresh Mass
GHG	Greenhouse Gas
H_2S	Hydrogen sulfide
HRT	Hydraulic retention time
Kg	kilogram
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) / German Association for Technology and Structures in Agriculture
kW_{el}	Electrical power capacity, electric output power
kWh_{el}	Unit of energy, Kilowatt hour electric energy
kWh_{th}	Unit of energy, Kilowatt hours of heat (thermal)
kW_{th}	Thermal power capacity, thermal output power
l	Liter
LNG	Liquefied Natural Gas (supersaturated; composition: Methane)
LoSENS	Local Sustainable Energy Networks in Senegal
LPG	Liquefied Petroleum Gas (Low Pressure Gas)
MSW	Municipal Solid Waste
Nl, Nm^3	Normal or cubic meter measured at standard temperature and pressure
Nm^3/FM	Normal cubic meter per unit of fresh matter
(n)	Normal cubic meter
oDM	Organic Dry Matter also known as Volatile Solids (VS)
OFMSW	Organic Fraction of Municipal Organic Waste
OLR	Organic Load Rate
PRN	Normalized Regrouping Points
SENELEC	Société nationale d'électricité du Sénégal
STEP	*Station d'Épuration des eaux usées* which means a (stabilization pond)
t	Metric tonne equivalent to 1,000 kg
UCG	Coordination and Management Unit

1 Executive Summary

A comprehensive feasibility study was carried out to assess the potential for organic waste valorization in Saint-Louis, Senegal. Drawing from a fact-finding mission in February 2022 and extensive literature research, a development of a technical design and economic feasibility analysis was conducted. The study was centered around Municipal Solid Waste (MSW), particularly the Organic Fraction of Municipal Solid Waste (OFMSW) for biogas production. Several waste streams were identified in the city such as cow and fish waste, slaughterhouse, and municipal solid waste. However, due to the insufficiency of the first three waste streams, this study focused on Municipal Solid Waste (MSW).

In this study, two scenarios with their potential locations were evaluated: the stabilization pond (STEP) using OFMSW with sludge, and the Gandon landfill using solely OFMSW. The Gandon Landfill was the preferred choice, and the chosen technology was dry anaerobic digestion using drive-in silo digester chambers.

The optimal use of the generated biogas is for electricity and heat generation. The Combined Heat and Power (CHP) unit has a potential electric output of approx. 300 kW_{el}, translating to 2.396.700 kWh_{el}/a, excluding the plant's own energy demand. A government partnership is desired for grid electricity injection, given the facility's location at a public landfill. The projected investment for the Gandon Landfill facility is approx. €2,58 million. Initial waste sorting, although conceptually proposed, is not part of this investment as it is anticipated to be covered in a different project scope, possibly involving other stakeholders.

The economic feasibility over a 20-year review period looks promising. Major income streams comprise electricity sales and organic fertilizer. The baseline scenario does not consider organic waste disposal revenues yet presents a 7.9-year payback period and an average annual profit of approx. €96,000 which are positive results. The preliminary analysis changing some sensitive parameters suggest better financial outcomes in modified scenarios, with the possibility of reducing the payback period to 5.6 years and even doubling the annual profit if the electricity tariff increases from 15 ct EUR/kWh to 20 ct EUR/kWh. Another scenario showed a shortened payback period of 6.5 years and an average annual profit of €180,000 by introducing a waste sorting and disposal fee of €10 per tonne.

The main partner of LoSENS that performed the feasibility study of a bigas plant in Saint-Louis, Senegal is *Greentec service the Biogas Expert*[1]. The company helped in data collection, the plant dimensioning and technical design, as well as the financial analysis related to the plant.

This project presents a promising avenue for the valorization of organic waste in Saint-Louis, Senegal, offering both environmental and economic benefits. The baseline scenario is financially viable, with additional potential for increased profitability in alternative scenarios.

[1] ÖKOBIT GmbH: https://www.oekobit-biogas.com/en/oekobit/

2 Status Quo of Waste in Senegal

Senegal, located in the western part of Africa, has a population of 16.7 million. Most of which are based in the capital city Dakar. In 2020 the country recorded a GDP of 24.9 billion dollars and a Gross National Income per capita of $1,430. This ranks the country in a low-middle-income position. Due to the corona pandemic, the GDP growth fell to 0.87% in 2020 from 4.4% in 2019 which impacted the country's economy (*Senegal Overview: Development News, Research, Data*, 2023).

Senegal, like most other countries in the Global South, is facing high population growth, accompanied by rapid urbanization. These trends go hand in hand with changing consumption patterns, which lead to an increase in levels and types of waste. In Senegal, the average daily volume of urban solid waste is around 8,664.4 tonnes, consisting mainly of fine materials (around 50%), particularly sand. Municipal solid waste per capita is around 0.5 kg a day. In the Dakar region, waste generation is estimated to be 2,684.5 tonnes a day, or 979,842 tonnes a year (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2021). Around 80% of the waste generated in Senegal is household waste, with more waste in the urban areas compared to rural areas due to the high consumption of packaged and wrapped goods (Yaah, 2018).

Just like some of the African developing countries, Senegal faces one of the biggest environmental problems besides global warming and erosion, which is plastic waste. In 2013, the Senegalese Government launched the National Waste Management Program (PNGD) as a mechanism to provide support and assistance at the municipal level. The objectives of the PNGD are to contribute to improving public health by ensuring more than 75% of the population have access to public sanitation services, generate wealth by reducing and recycling waste, aiming to increase the sector's annual turnover to more than €68.43 million, and create at least 15,000 jobs (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2021). In 2015, the Ministry of Environment and Sustainable Development declared that there is nearly 70,000 tons of plastic waste in nature, with Dakar being the major contributor of about 5 tons of plastic waste daily (*70 000 Tonnes de Déchets Plastiques Sont Dans La Nature (Experts)*, 2015).

In effort to solve this issue and reduce the plastic waste in Senegal, the Senegalese government established a new law N°2020-04 against plastic bags which will be implemented starting from 20 April 2020. This new law on the prevention and reduction of the impact of plastics on the environment repeals the law of May 2015. The latter prohibited the production, import, possession, distribution and use of "low micronnage" plastic bags. However, this law was not so effective as it did not reduce the pollution caused by plastic waste because it had a narrow scope, and it was difficult to distinguish between the plastic bags which are banned and those which are not with the naked eye. Therefore, the new law came to fill in these gaps and strengthen the old law by imposing taxes on non-recyclable plastics and banning the import of plastic waste to Senegal. It also prohibits the use of some single-use plastic and disposable plastic products (Fondation Heinrich Böll Sénégal, 2020).

In the capital, Dakar, the Coordination and Management Unit (UCG), an agency of the Ministry of Urban Planning, Housing and Public Hygiene, manages waste, in support of municipalities. As a result, the State pays directly for the collection service carried out by private concessionaires in the three departments of the agglomeration. Its desire to directly take charge of this sector, by the UCG, is underpinned by the lessons learned from the mixed results of the various previous experiences of direct management and delegated management.

In the regional capitals, the State intervenes in support of the municipalities through the UCG. Previously, its actions were more focused on one-off operations to clean up garbage dumps. However, over the past two years, they have become more structured and linked to door-to-door collection from households, the voluntary delivery of garbage to the Normalized Regrouping Points (PRN) set up in the districts, sweeping and the regular removal of street bins. In addition, it is important to note the development of three Integrated Waste Recovery Centers (CIVD), the purpose of which is to set up, in three large municipalities of the country (Touba, Tivaouane and Kaolack), a sustainable and rational integrating sorting, recovery and final disposal by landfill.

2.1 Waste Streams in Senegal

2.1.1 Domestic Solid Waste Streams

In general, the processing of solid waste generated by households is not regulated in Senegal. Primary waste collection is carried out using carts and tricycles. Throughout the country, primary collection is an informal activity and is not part of the official public service management system.

The different materials collected from households or recovered from dumps are sold to tradespeople who use them in their manufacturing processes (aluminum foundries, traditional blacksmiths, and garment makers), or to intermediaries who stock them for resale. Part of the waste is sold directly to merchants: items that, after a quick clean, go straight back onto the market (jars, bottles, etc.) and waste used as animal feed (food scraps, paper, cardboard, etc.).

Waste collection and transportation services are only available in the regional capitals and in some departmental capitals and are provided by struggling municipal utilities supported by the Solid Waste Management Coordinating Unit (UCG). All the solid waste collected or received is taken to uncontrolled dump sites located in old, abandoned quarries. The variety in types of solid waste means that each stream has significant potential. The potential rate for organic recovery from putrescible waste is 12%, for resource recovery (mainly iron and other metals, plastics, paper, and cardboard) it is 20%, and for energy recovery from textiles, wood and fuel it is 10%. However, 58% of solid waste is considered non-reusable, which means that sanitary landfill sites need to be constructed in compliance with applicable standards.

2.1.2 Industrial Solid Waste Streams

At the large scale in Senegal, manufacturers generate different types of waste. In each area of activity, they produce waste that is specific to their operations as well as ordinary industrial waste, mainly plastics, paper, and cardboard. These are either reused internally or transported to dedicated facilities or to a dump site. There is a separate stream that deals with special or hazardous industrial waste given its specific characteristics and the danger it presents to the people handling it. It is treated using a well-defined process agreed by the companies concerned, generally in a memorandum of understanding between the two parties.

As there are very few facilities authorized to treat ordinary industrial waste, health-care waste and hazardous industrial waste, this market offers attractive prospects for investors interested in setting up a sorting and treatment system for special waste.

There is a local industry for each kind of waste although the level of recycling or reuse varies according to the type of waste:

- Iron and other metals are processed by African Metallurgical Society (SOMETA), which uses the waste to make concrete reinforcing bars. The metal recycling market is well-established.
- Plastics stream is dominated by industrial plants that turn plastics into flakes and granules. Recycled plastic is used by a small core of plastics processors that are very dynamic and require significant investment.
- Organic waste is mainly retrieved during traditional collection operations for pig and cattle farmers and for vegetable growers who turn the waste into compost for their own use or for use on green spaces by private individuals or the hospitality industry. The organic waste reuse and recycling market is embryonic.
- Waste of electrical and electronic equipment (WEEE) is repaired or recovered for disassembly. The materials that are recovered are sold and recycled. Although WEEE treatment is still an informal activity it is a major concern for the Economic Community of West African States. Outside of recovery operations, the disposal of hazardous components that cannot be recycled or reused poses a real challenge.
- Paper and cardboard streams are operated by the only plant PRONAT. It consumes 2 tonnes of paper a day, which is less than 1% of national recyclable waste (less than the potential demand of 7%), to make egg trays from recycled paper. The rate of recovery of organic matter, paper and cardboard remains very low in Senegal.

For several years, the municipality of Saint-Louis has struggled to solve the problem of waste management. Therefore, a new program called the GIE[2] CETOM which stands for Collecte, Evacuation, et Traitement des Ordures Ménagères was initiated in 1994 to improve the management of solid waste in the city. In 1999, a "Global Cleanup Plan 1999-2003" was launched to plan cleanup actions by combining two measures (Les ateliers, 2010):

- Cleaning of urbanized areas and main streets done by the municipality. It consists of sweeping the island and the banks of Sor, the collection on the island and the center of

[2] GIE : is a French acronym for Le groupement d'intérêt économique, which means the economic interest grouping. It is an organisational form that seeks to align the economic orientation of a company with the community base of an association. The GIE is a socio-economic structure demonstrating a more assertive economic positioning of associations while integrating the possibility of sharing benefits between members.

Ndar-Toute (Langue Barbarie) and the removal of bins (4 m^3 containers) along the relay sites of the GIE.

- Cleaning in neighborhoods provided by organized community private operators who collect door to door using horse drawn carts. The waste is transported to relay sites from where it is evacuated by the municipal authority. The GIEs derive their resources from subsidies from the Commune and subscriptions from the populations (500 to 1000 FCA per month depending on the district).

The waste generated is collected in big bins and containers deposited at certain collection points "sites-relais" around the city. Then, big trucks (Figure 1) collect the waste from the different collection points and transport it to a landfill called "Centre d'Enfouissement technique (CET)" outside of the city of Saint-Louis. The Senegalese ministry in charge of environment started a program to construct engineered landfills or CETs in 11 cities in Senegal. One of them is the dumpsite of the municipality of Saint-Louis, located in the community of Gandon. This CET, which lies over an area of 2.5 ha with a burial capacity of 94,000 m^3 (GUENE, 2010). It was constructed so that the waste is disposed of without polluting the environment following the international standards. However, due to some logistic problems the CET lost its accreditation, and it now serves as a normal landfill.

Figure 1 | Big trucks for the collection waste from collection points, (© ÖKOBIT GmbH)

Once the waste is disposed of in the collection points (see Figure 2), small children and scavengers come and pick the biowaste such as fruit and vegetable waste and take it, whether to feed their domestic animals or sell it to other farmers. This leaves very small to non-existent amounts of biowaste that could reach the CET. On the site of the landfill, there are various children and women (see Figure 3) who, once the truck pours the waste, start manually sorting the waste to collect hard plastics or metals and sell it to people who are interested. For the LoSENS project the focus will be only on organic waste as it has a higher potential to be used for biogas production.

Figure 2 | A bin filled with mixed waste from Sor market, (© IfaS)

Figure 3 | Waste Dumping at the CET of Gandon, (© IfaS)

2.2 The Stakeholders

Le Partenariat, founded in 1981, is an international solidarity association that plays a crucial role as a facilitator and supporter of various technical and financial institutional partners to promote development in the Saint-Louis region. This organization is one of the key stakeholders in the project, having successfully implemented numerous initiatives in the region of Saint-Louis. They have provided valuable assistance in terms of conducting studies and establishing contacts with individuals in the city.

Another stakeholder that provided some contacts for agro-industrial companies is the GIZ Senegal and specifically in their office in Saint-Louis. The contact person there is the technical consultant of the Program “Réussir au Sénégal”; Mr. Cheikh Mbacké Niang. The GIZ aims to provide efficient and cost-effective services for the sustainable development of many countries worldwide. Similar to their vision, the project “Réussir au Sénégal” focuses on capacity building and offers training to the youth of Senegal in the region of Saint-Louis. Because over 80% of the population in Senegal is aged under 35 years. So, thanks to the training and academic courses the GIZ provides, many young people can obtain official certificates after completing the proper formal training to be technicians like electrical or mechanical technicians. The educational formation varies from 6 months to 3 years depending on the field studied. This project aims to reduce the unemployment rate in Saint-Louis and create well-educated and qualified technicians.

Among the contacts of the companies with biomass potential provided by GIZ are:

- CNT: Comba Nor Tiam is a big rice production company at 110 km from saint Louis.
- Massaér: is the person responsible for managing a fertilizer storage point in Savoigne.

The Waste Management Coordination Unit (UCG) plays a vital role as another stakeholder in this project because they bear the responsibility for waste collection and management. During the trip to Senegal, the responsible person arranged a city tour in Saint-Louis to provide insights into their waste collection and management system. The tour concluded with a visit to the Gandon landfill, where they showcased the disposal process. Additionally, they organized visits to various locations where biodigesters had already been constructed, such as the fish transformation cooperative.

In June 2022, the National Assembly unanimously passed a bill which establishes the National Integrated Waste Management Company (SONAGED). This new company will take over from the Waste Management Coordination Unit (UCG). One of the objectives of SONAGED is to establish a structure that promotes partnerships, including Public-Private Partnerships (PPPs), for the development and management of modern waste recovery infrastructure in line with the principles of a circular economy. Additionally, it aims to address youth unemployment by creating job opportunities. Moreover, SONAGED aims to enable local authorities to establish a more suitable form of public-private partnership for waste management and transformation within the framework of Decentralization Act 3 . They can be a potential stakeholder for future cooperation.

The involvement of merchants and vendors, particularly those engaged in selling fruits, vegetables, and fish, holds significant importance as key stakeholders in this project. As primary producers and suppliers of organic waste, their cooperation becomes essential for the successful implementation of the biogas plant in Saint-Louis. Establishing an agreement with them regarding waste collection from the markets will be a pivotal and indispensable step, ensuring a seamless biogas production process.

2.3 The Current Biogas Projects

In the effort of satisfying the energy demand of the growing population, Senegal has been implemented since 2009, the national domestic biogas programme (PNB- SN). This program aims at installing domestic biogas digesters more 52,000 digesters between 2021 and 2030 across the whole country .

Le Partenariat participates in the bioenergy production projects by working with agropastoral households under the scope of the PNB. Along with the commune of Saint- Louis and other local NGOs, Le Partenariat installed many biogas digesters in the region of Saint-Louis. So far, there are 73 biogas digesters projects in Saint-Louis installed within the framework of the PNB. 55 of these digesters are already installed and 18 are still under construction. Figure 4 shows the location of some of these biodigesters.

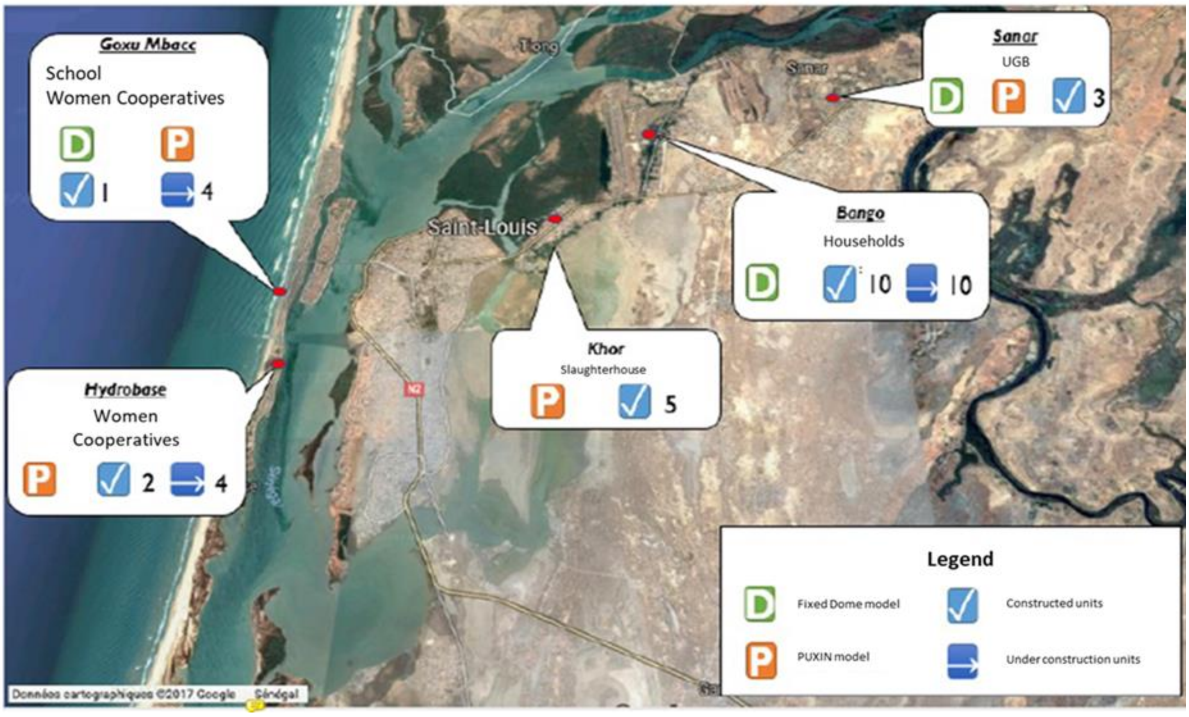


Figure 4 | Locations of Existing Biodigesters in Saint-Louis, (© IfaS)

Table 1 below summarizes all the details about the location, the model, and the type of feed of these digesters in the commune of Saint-Louis (Le Partenariat, 2017).

Table 1 | Summary of Different Biogas Digesters in Saint-Louis Municipality (Le Partenariat, 2017)

LOCATION	DIGESTERS	NEW DIGESTERS	PUXIN MODEL	FIXED DOME MODEL	TYPE OF FEED
Goxumbacc		4	4		Fish waste
Guet Ndar	2	4	6		Fish waste
UGB	3		1	2	Different
Khor Slaughterhouse	5		3		Cow dung, rumen
Podor Slaughterhouse	3		3		Cow dung, rumen
Goxumbacc school	1			1	Cow dung
Bango households	10	10		20	Cow dung
Guédé households	10			10	Cow dung
Rosso households	10			10	Cow dung
Gandiol households	10			10	Cow dung
CIH	1		1		Different

2.3.1 Technologies of the Biodigesters in Senegal

2.3.1.1 PUXIN Model

The PUXIN model is a family-sized digester used to produce and store biogas by converting organic waste, and human or animal manure into biogas and fertilizer. The biodigester, in the form of a big bottle, thanks to its cover in the shape of a bell, is built above the ground. The mechanization takes place inside the concrete body. It is connected to an input duct that feeds the system and an output duct which releases the residual water. The role of the bell on top of the tank is to capture the gas produced, the digester and the gasometer are submerged in water to put the gas under pressure and ensure good sealing. To avoid any risk of material breakage, a sulfur filter is installed to filter the biogas produced.

The process of biogas production inside the PUXIN model follows three steps as shown in Figure 5:

- **1st step**: In this step, both organic feed and water are introduced into the tank. The water level should be above the gasometer for a good seal.
- **2nd step**: The gas produced is then captured in the gasometer.
- **3rd step**: the gas pressure pushes the water out of the gasometer and the residual water which cleans the tank from the bio-digestate.

Sometimes overpressure can happen, which means that the gas escapes from the gasometer. This can be easily detected by the presence of bubbles.

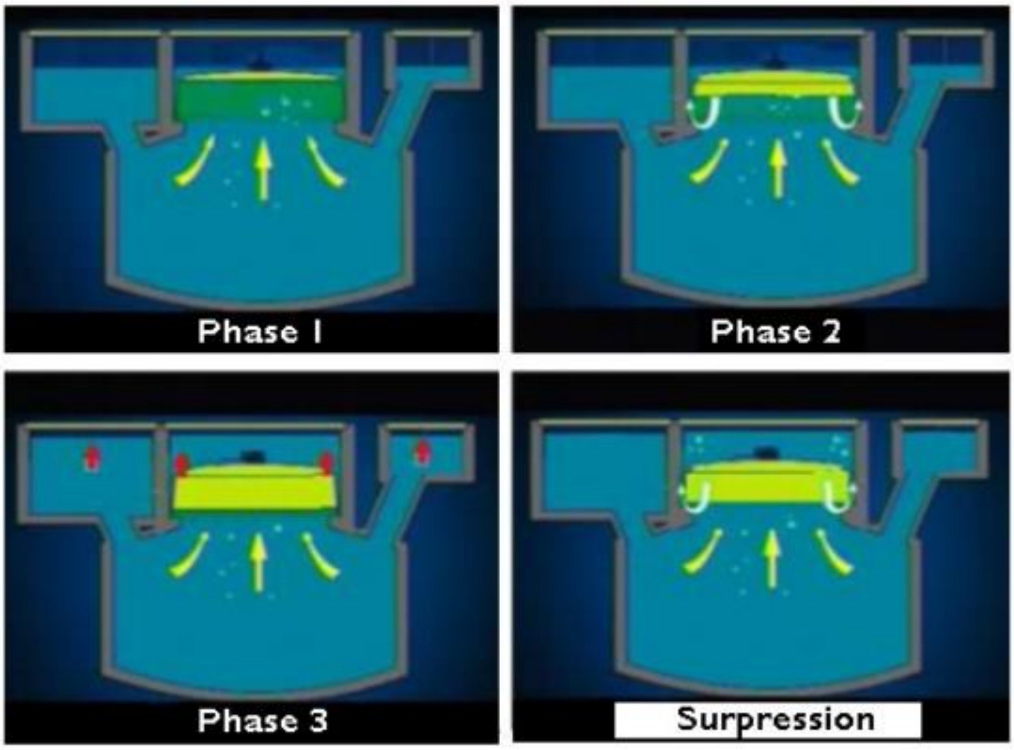


Figure 5 | PUXIN Model, (© IfaS)

2.3.1.2 Fixed Dome Model

Unlike the PUXIN model, the installation of the Chinese Fixed Dome Model (FDM) is almost buried underground with only a part of the concrete dome coming out above the ground. The biomass is fed into the system through an entrance, then passes through the dome. The latter is connected to the kitchen through pipes, so that the gas produced by the natural chemical process "Methanization" flows and be used for cooking or heating purposes. The inner side of the dome is covered with cement and paint to ensure good sealing. As for the digestate, it passes to the exit chamber. The overflow of the digestate feeds the compost pit (Le Partenariat, 2017). Figure 6 gives a sketch of the FDM installation.

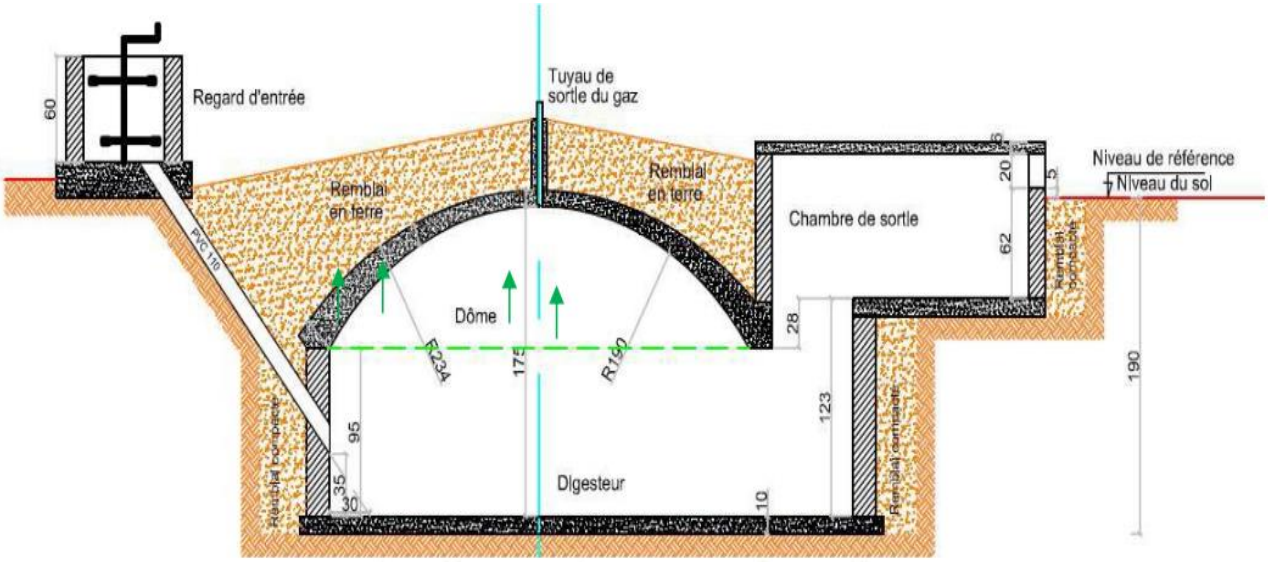


Figure 6 | A fixed Dome Model, (© IfaS)

Most of the fixed dome model designs in Senegal are built with a 10 m^3 digester. Which is equivalent to 60% of the domestic units. Such a digester in a fixed dome model can produce a daily gas volume of 3 to 4 m^3 which could be used for continuous cooking for 2 to 3h (Le Partenariat, 2017).

2.3.2 Waste Streams and Waste Producers in Saint-Louis

In the city of Saint-Louis, there is a potential of waste from livestock farming, but it is difficult to quantify and collect as most farmers are of small scale, and some are just nomads. Thus, no central collection of cow and goat dung is established. Within the system boundary (Commune Urbaine de Saint Louis – CUSL plus UGB), there are some goats in the city itself, that roam around in the markets or near residential areas without a central collection of manure. For example, the photo of the goat is taken from "Marché de Sor" which is located in the main Avenue Général de Gaulle as shown in the map. Therefore, it is hard to see the real potential from livestock farming in terms of organic waste. The Gaston-Berger University uses some of the livestock manure for their 3 small scale biogas plants already installed on campus. The biogas installations in households also use manure as feed for their plants.

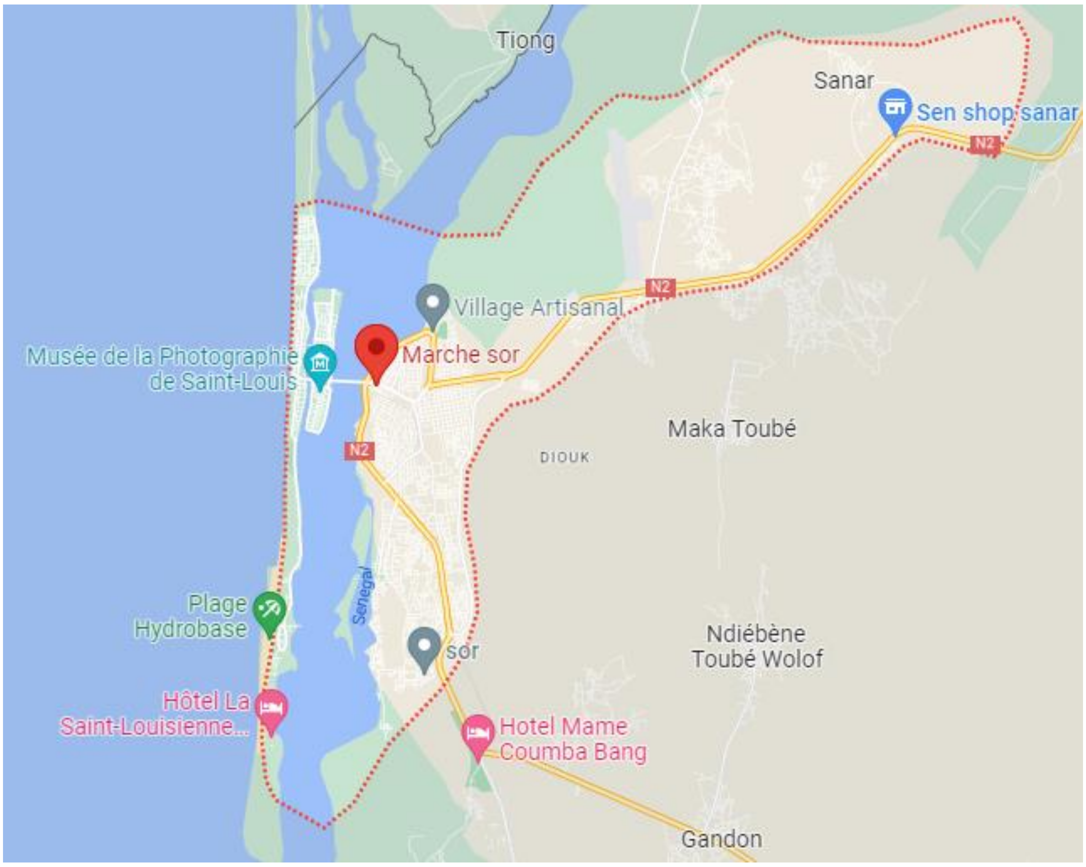


Figure 7 | Location of Sor Market

Figure 8 | Animals Roaming in Sor Market, (© IfaS)

There is also a market in the city where they sell and buy cows every day. This was considered as a potential source for cow dung. However, according to a study carried out by Le Partenariat to assess the possibility of installing a biogas plant in that market, the waste quantity is very low, so they dropped this project. Another potential place for animal waste is the Bangho Ranch which is a cow farm owned by the daughter of the mayor of Saint-Louis.

- **Bangho ranch (Diaary)**: it is a farm that houses around 40 cows and raise them for the purpose of producing milk. They have different cow species mainly for milk production such as Holstein and Montbéliarde which can produce between 50 to 100 liters of milk per day. The average daily cow dung produced amounts to around 2 tonne.

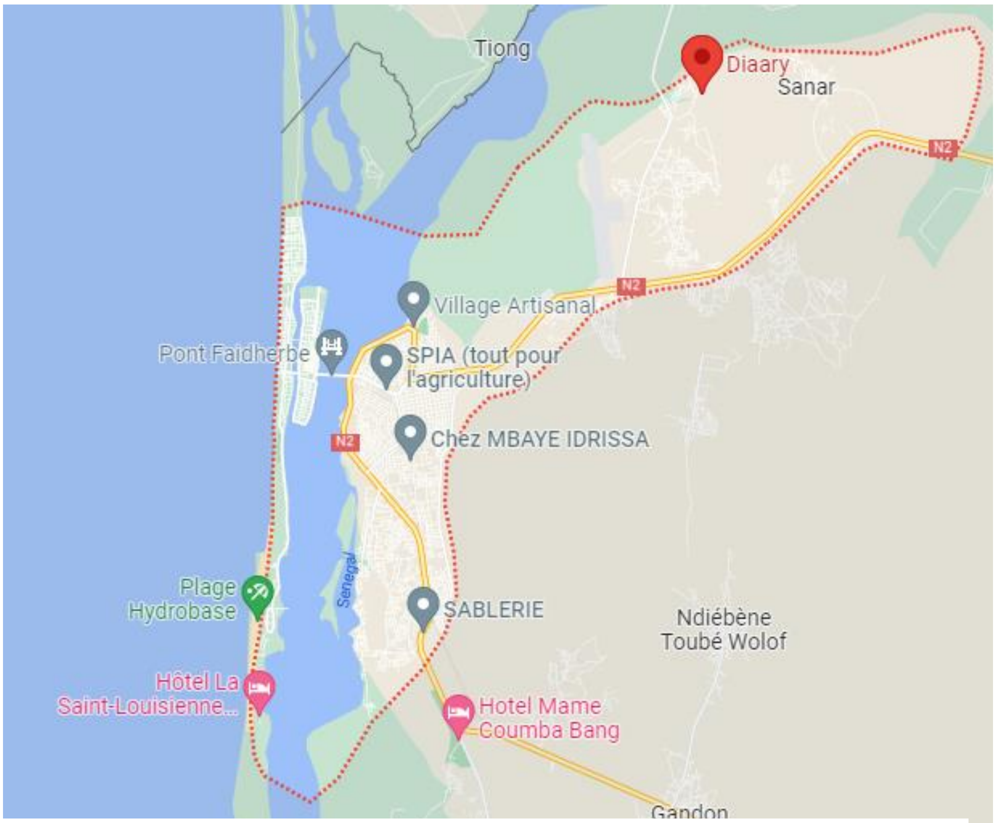


Figure 9 | Location of Dairy Products and Cow Farm "Diaary"

Figure 10 | Left: Cows in Farm "Diaary", (© IfaS) Right: Manure at Bangho Farm, (© ÖKOBIT GmbH)

Within the scope of the project (CUSL+UGB), there is an interesting potential, though in small quantities, from the agricultural waste. In the farm at UGB, there is waste from tomato and peanuts farming. After the harvest, the agricultural waste is left on the fields for it to be collected later by nearby farmers to give to their animals and a portion of it is used as fertilizer for the fields on the farm. As for the city of Saint-Louis, because it is a small city, it does not have many agricultural activities except for urban agriculture.

However, in the nearby regions outside of Saint-Louis, there are many big companies in the agro-industry such as cultivating fruits, vegetables, and rice. Some of these big companies are Les Grands Domaines de Sénégal (GDS), Compagnie Agricole de Saint-Louis (CASL), and SOCAS.

- **Les Grands Domaines de Sénégal (GDS)[3] :** is a branch of the French company la Compagnie Fruitière in Marseilles in France. It is located 11 km far from the Gaston-Berger University. They cultivate mainly tomatoes, bananas, mangoes, and corn. And then, ship it to Europe. They use cow dung as fertilizer which they buy from a nearby cow farm called Bango farm. They are currently thinking of building their own biogas plant and using their waste as feed to save on the costs of buying fertilizer from outside.
- **Compagnie Agricole de Saint-Louis du Sénégal (CASL)[4]:** is a company that produces rice for the local market, situated at 50 km from the UGB. Their aim is to reduce food insecurity in Senegal by producing quality rice. They also develop cultivation contracts with small local producers to help in the development of rice cultivation in their region. The agricultural waste of this company is the rice hull and rice straw. This company has some potential, but it is far from the geographical boundaries of the project.

Figure 11 | Location of the Rice Company "CASL"

[3] GDS, Compagnie Fruitière, www.compagniefruitiere.fr
[4] Compagnie Agricole de Saint-Louis du Sénégal, www.casl-senegal.com

- **SOCAS**[5]: is an agro-industrial company located in 20.5 km from UGB. They specialize in producing tomatoes and transformed tomato products such as ketchup and tomato sauce cans. They have a capacity of 150 000 tons of fresh tomatoes.

Figure 12 | Location of Agro-Industrial Company "SOCAS"

Poultry excrement (see Figure 14) was also considered as a potential source of biomass. As there are many chicken farms at the city of Sain-Louis. One of the farms that was visited during the trip was the Chechek farm at the University of Gaston Berger (UGB). The farm has around 5,000 chickens, raised to be sold for meat as shown in Figure 13. The chickens are raised for 41 days before they are slaughtered and sold to restaurants on campus or to outside clients.

Figure 14 | Chicken Manure, (© IfaS)

Figure 13 | Chicken Raised in Chechek Farm at UGB, (© IfaS)

For this project, it was decided that the focus will be on only three waste streams (households, markets, and restaurants) because they showed good potential, and their waste is not used

[5] SOCAS : www.socas-senegal.com

yet in any biogas plants. Unlike the other locations which all have biogas plants that can be used after fixing.

2.4 Summary of the Trip Outcome

2.4.1 Household and Restaurant Waste

Based on observations during the trip, the household waste is deposited in the different collection points around the city. These points are defined by the UCG to make the solid waste collection process easier and faster. There seems to be enough potential of organic material in the household waste from observing the different collection points around the city. For the restaurant waste, it is mostly cooking oils and fats which are not reused in feeding pigs like in other countries. Organizing a collection campaign for this type of waste seems to be an interesting future step which could be incorporated in the city's waste management program. This will also create more job opportunities for the young individuals of Saint-Louis.

2.4.2 Vegetable Market Waste

During the visit of the three markets (Sor, Pikine, and Ndar), it was observed that there is a good potential of biowaste from the collection bins near each market. However, there were some children pickers who often came to check these bins looking for any organic food they could collect for either feeding their personal animals or selling to other people. The rest of the waste is then collected by the UCG trucks and taken to the landfill in Gandon.

2.4.3 Agricultural Waste

For the agricultural waste, there were not many agricultural companies within the scope of the project as most of the agro-industrial companies that were visited during this trip were located outside of the city of Saint-Louis. They showed they have good biomass potential from agricultural activities. However, their waste was not included in the analysis as they are outside of the scope of the project area.

2.4.4 Fisheries

Saint-Louis stands as the fishing capital, boasting a unique abundance of boats and diverse fishing techniques that are unparalleled elsewhere. Therefore, there exists a potential for biowaste generated by the fish transformation sector. However, there are already six digesters with a volume of $10m^3$ which use the fish waste. In addition to the digesters, a $30m^3$ gas storage is utilized to produce energy for various fish processing purposes instead of using firewood. Unfortunately, an accurate estimation of the quantity of fish waste could be obtained as the responsible person was absent, and the accompanying person did not possess the necessary information.

2.4.5 Slaughterhouse

Saint-Louis has a new abattoir called Abattoir de Fass, managed by the private company SOGAS. Although there has been a biogas plant installed at the abattoir since 2004, it is currently non-functional with the reason unknown due to the absence of the abattoir manager during the meeting. Butchers and private clients bring animals to the abattoir, pay a service fee, and receive prepared meat. Leftover animal manure is collected near the abattoir and freely accessible to farmers for use as fertilizer. Animal horns are collected and sold for making buttons, while cow skins are dried and later sold to individuals shipping them to Nigeria and Ghana for accessory production. The blood mixed with cow dung is collected and pumped 300 meters away into the forest using an underground pump.

2.4.6 Animal Waste

In Saint-Louis, it was observed that there are many goats and sheep roaming around freely in the markets. So, considering the manure potential from these animals will be challenging, as there is no way of collecting it. As for cows, the farm visited during the trip showed willingness to give part of their collected waste for the biogas plant under the frame of a collaboration. Where they can get energy in return.

3 Project Outline and Planning

The LoSENS project strives to create an efficient waste management approach for Saint-Louis's community, emphasizing the collection of organic waste, converting waste into energy, and material recovery. All the scientific and technical aspects, such as the necessary technical groundwork, biomass availability, economic feasibility, optimal sites, potential product applications, and the subsequent impacts, will be tackled in this sub-project and incorporated into the broader project blueprint. The main aim is to boost renewable energy output by efficiently processing biological waste.

The main partner of this project, to help realize the feasibility study of a biogas plant, is a German company called Greentec[6]. They are considered biogas experts as a leading figure in the biogas industry, with a legacy of over 250 projects both domestically and internationally. Renowned for constructing technically advanced and substrate-flexible biogas and biomethane plants, the company tailors its solutions to match the unique conditions of each client's site. With a dedicated team of engineers, economists, and environmental technicians, ÖKOBIT emphasizes both environmental sustainability and economic efficiency. Their comprehensive approach spans from consultation and profitability analyses to full turnkey plant construction, ensuring optimal quality and safety standards, all while fostering close partnerships with clients and staying actively involved in industry research and standards development.

The results presented in this report are derived from a business trip to Saint-Louis that took place in February 2022, combined with local studies and the formulation of a technical design specifically customized for Saint-Louis. An economic feasibility assessment has been built on this basis. Before embarking on the ground research, a specialized survey and a methodological approach suited for the local scenario were crafted, which set the direction for the research. The exploration in Saint-Louis and its neighbouring regions highlighted potential organic waste sources suitable for biogas production, such as waste from cattle and fish sold in markets, byproducts from slaughterhouses, and typical municipal waste, especially vegetable residues from marketplaces. Due to certain limitations in quantity or specific intended applications, the primary emphasis has transitioned towards municipal waste. The analysis delves into two Anaerobic Digestion (AD) techniques tailored for the Organic Fraction of Municipal Waste (OFMSW): a Wet AD method partnering with a stabilization pond for co-digestion with sludge and a Dry AD approach at Gandon's Landfill exclusively utilizing OFMSW. The research also investigates several business models suitable for the Saint-Louis context.

[6]ÖKOBIT GmbH: https://www.greentec-service.com/

4 ÖKOBIT GmbH Analysis Results

4.1 Development of Methodology

The feasibility study delivered by ÖKOBIT GmbH, proposed an assessment about installing a centralized biogas plant to treat the organic waste and generate biogas. Biogas plants offer several benefits, transforming organic waste into biogas, which grants environmental pollution and reduces reliance on fossil fuels. This sustainable approach ensures local energy security and offers economic gains through the sale of energy and organic byproducts like fertilizers. Moreover, by addressing greenhouse gas emissions and landfill waste, these plants enhance environmental health. Furthermore, they contribute to job creation and skill development across various levels, as seen in regions like Saint-Louis, demonstrating their adaptability and potential for local economic enhancement.

To comprehensively assess the biomass potential in the city of Saint-Louis, data was sourced from online literature and additional documents were procured from project partners in Senegal, notably Le Partenariat. A team, led by a representative from ÖKOBIT Mrs. Montserrat Lluch Cuevas, visited Senegal to validate this literature-derived data and to fill any informational gaps crucial for the analysis. During the visit, a series of interviews with local residents and officials were conducted, facilitated through both Le Partenariat and the GIZ in Saint-Louis. A structured questionnaire was developed to estimate the available biomass and the potential for biogas production. While many respondents were cooperative and answered the questions, their lack of specific quantitative data concerning waste quantities was challenging. To conduct the feasibility study, gaps were supplemented with estimates from academic literature and grounded assumptions based on the experience of ÖKOBIT.

In the feasibility study, two scenarios were proposed for the biogas production based on anaerobic digestion (AD) of the organic fraction of municipal solid waste. AD is a method to produce biogas and organic fertiliser through a biochemical degradation of organic material in the presence of bacteria and absence of oxygen. The first scenario (A) is biogas production with wet AD and the second scenario (B) is about producing biogas using dry AD. The two methods are explained in the following paragraphs.

Scenario (A) with Wet Anaerobic Digestion (AD): it is a biological process to break down organic matter by microorganisms in the absence of oxygen and in a wet environment. The main benefit of this technology is the ability to optimally mix the materials which enhances the digestion process and the biogas production. In this study, single phase-mesophilic wet fermentation in a continuous flow was suggested. Table 2 outlines the advantages and disadvantages of wet AD.

Table 2 | List of Advantages and Disadvantages of Wet AD

ADVANTAGES	DISADVANTAGES
Greater flexibility in the materials to be treated	▪ Need to add liquid to reduce the dry matter of the mixture if it is higher than 20% (in general terms) ▪ Lower dry matter content for the digestate ▪ Production of wet digestate that can modify practices for land application and lead to additional investments (slurry tankers)
Optimal substrate mixing	▪ Requires robust and costly mixing equipment ▪ Significant energy requirements of the facility to run pumps and agitators
Integrated biological desulphurisation	▪ Separation is required if solid digestate is needed. Digestate has a liquid pumpable consistency which needs to be separated into a liquid and solid fraction (if necessary).

Scenario (B) with Dry Anaerobic Digestion (AD): in this study, a discontinuous or batch dry AD was used, where the biogas production is carried with loading and unloading stages. This will allow continuous biogas production as multiple digesters will run simultaneously. However, the conventional batch dry AD was not used in this case, instead an innovative drive-in silo chamber technology was proposed. Table 3 summarises the advantages and disadvantages of dry AD.

Table 3 | List of Advantages and Disadvantages of Dry AD

ADVANTAGES	DISADVANTAGES
Dry matter / total solids 20-40% compared to 20% maximum for wet digestion No water requirement High loading rates Suitable for feedstocks with high fibre contents	Not totally mixed In discontinuous systems, the microbial process has to start for each batch (inoculum material but it is always available) Depending on the nature of the feedstock, large quantities of structure material is required
Low power and heat needs	Well management of the variation of biogas and heat production necessary
Less complex system compared to wet AD systems Less critical equipment (pumps, agitation systems, feeding equipment) and less maintenance required	Space requirements are higher More local civil works
Management ofseveral digesters simultaneously Easily handling and use of various substrates per unit of digesters Modular process: process failure affects only one module	Need of a wheel loader for loading and also for unloading of the digestate is necessary, instead of automatic dosing units and/or pumps. Dosing units (the hopper) need also to be loaded, but the feeding inside the digester is done automatically.
Very tolerant system for contaminants (sand, fibres, large particles, etc.)	
Production of land-applied solid digestate similar to manure	The conventional technology is more expensive than wet AD. It is not commonly used in agriculture but employed for managing organic solid waste
System can be designed as mobile container systems or stationary concrete box systems	Regular emissions during batch change

The proposed technology differs from conventional garage fermenters. The novel technology uses a gas-tight membrane as a cover that also serves as a gas holder as shown in Figure 15. In contrast, traditional garage fermenters have concrete roofs and external gas storage. These classic fermenters are commonly used in waste management due to cost considerations. The drive-in silo technology is innovative as it can be standardized, easily constructed, and is cost-efficient. The design resembles agricultural drive-in silos. This technology is designed to prevent biogas from escaping during substrate changes, optimizing greenhouse gas balance and biogas production. It is expected to be cost-effective and simplify operations.

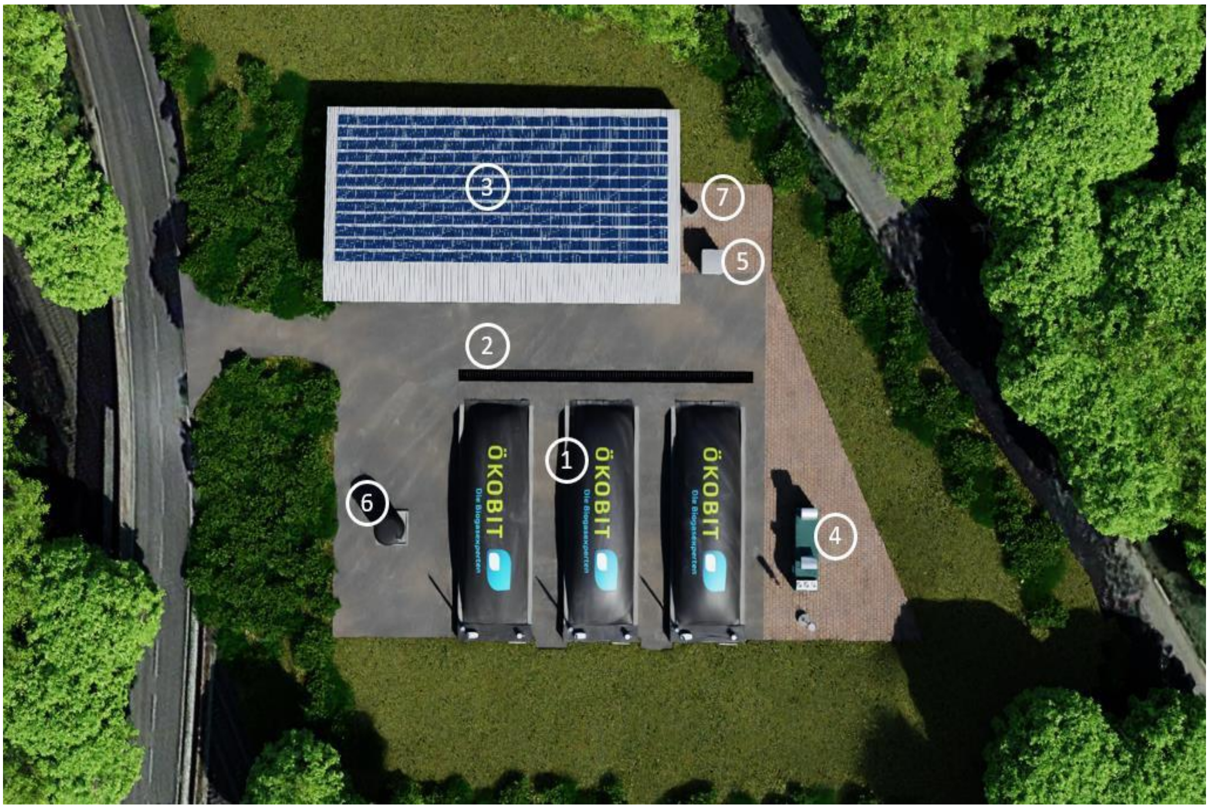


Figure 15 | Drive-in Silo Biogas Plant with Three Chambers. 1) Drive-in Silo Chamber, 2) Work Area, 3) Post-Rotting, 4) CHP, 5) Transformer, 6) Dirty Water Tank, (© ÖKOBIT GmbH)

The process follows the steps below:

- **Construction:** Reduced costs due to the removable foil cover, no need for high walls, concrete ceilings, or complex loading doors.
- **Ventilation:** Reduced needs because of the design that eliminates explosive atmospheres without purging.
- **Gas Storage:** The fermenter's foil cover acts as a gas storage, eliminating the need for external systems.
- **Air Ingress:** Reduced air presence minimizes energy loss from aerobic substrate degradation.
- **Operation:** Outdoor operation reduces health hazards.
- **Post-Operational Use:** The fermenter can be reused as an agricultural silo.

The operation involves a batch process, with the substrate periodically sprinkled with percolate. Solid input materials are introduced in batches, and approximately every three to four days, one fermenter is opened for batch changeover, a process that lasts about 8 hours. The operation involves steps like substrate removal, fermenter refilling, cleaning the work area, and an optional post-rotting or post-fermentation for digestate conditioning.

A comparative analysis between the dry and wet anaerobic digestion showed that in the case of Saint-Louis, it is optimal to do dry anaerobic digestion. The decision was made based on the different criteria presented in Table 4 which showed that dry AD has more advantages and is more suitable to the city than wet AD.

Table 4 | A Comparative Table for Selecting the Most Suitable AD Technology According to Local Conditions in Saint-Louis

CRITERIA	*WET ANAEROBIC DIGESTION*	***Dry digestion***
Input and digestate characteristic	• Input mix with up to 20% dry matter content • Lower dry matter content of digestate • Digestate is pumpable -> separation of digestate would be necessary to obtain a solid fraction (if desired) • Need of water can be critical in case of water scarcity unless there are waste liquid substrates available (e.g. wastewater or sludge). • Due to high storage and transportation costs (if relevant), it's advisable to minimize the quantity of liquid digestate or process water. Dilution with other on-site water sources dilutes the NPK content.	• Both inputs and digestate are in solid form and stackable • Low amount of water • Dry matter content ranges 20-40%
Impacts of dry matter content / water consumption	• Adding liquid inputs to dilute the DM-content leads to a higher input volume, resulting in larger tanks (more investment) and also more energy consumption. • The need for digestate storage for a given time frame increases approximately in proportion to the additional liquid added. • Cost of new input materials should be considered, if applicable	• High organic loading rate
Resistance to sand	• Vulnerable to sand, frequent removal of sand sediment at tank bottom required. This is a challenge for small plants with only one digester tank since the process needs to be stopped for maintenance works. In addition, it can result in pipe blockages and equipment/pump wear, ultimately leading to increased.	• Very tolerant system for contaminants like sand. This is a significant consideration in the context of Saint-Louis.

	• maintenance expenses and component replacements.	
Process stability	• Vulnerable to contaminants or pollutants that OFMSW may contain (inhibitory potential)	• Tolerant system against contaminants (even larger stones, pieces of wood or iron). • In addition, due to the parallel configuration of modules, each one operates independently. In the event of a failure, only the individual chamber module is affected.
Type of process	• Continuous fermentation	• Batch discontinuous fermentation proposed -> microbial process has to start over for each batch with inoculum which is however always available in the percolate tanks
Feeding and workload	• Every day the dosing unit needs to get fed. • Feeding and supervision is just a few hours per day. • High degree of automation is possible, but costly	• The batch changeover is done once per month per digester chamber. For the proposed plant, the time between changeovers is 3,38 days for each nine chambers. • Per batch, loading/unloading works require a full-day work with a loader
Energy needs	• Significant energy requirements (electricity and heat) for the facility to run pumps and agitators, as well as for the digestate separator if required. • Additional liquid inputs or process water also demand heating, pumping and mixing)	• Low power and heat needs -> lower operating costs (there are no agitators and pumping are only required for percolate). • Fuel is more necessary since the wheel loader is used also to unload digestate (could be substituted by bio-methane, but costly)
Complexity/ equipment	• Agitators, pumping station, dosing unit, gas tight fermentation product storage, separator, more sensors and more complex control system and monitoring. • Most of the key equipment might need to be imported as it is not available in the local market.	• Less components and therefore less maintenance • Opportunity for local companies since a major part of the investment refer to civil infrastructure. • Unskilled staff with loader driver's license • One skilled technical supervisor

	• This leads to a potential dependence not only on the initial investment but also on potential future maintenance and spare parts. • More skilled staff required	• Affordable technology with most of the components available locally
Flexibility in design / expansion potential	• Digester tanks can be designed to allow a certain reserve capacity. • Expansion of the biogas plant is more complex	• Scalable technology. Easily expansion by adding further chambers modules. As per the proposed plant, each chamber has a capacity to treat about 1.230 t/a. • If future expansion is anticipated, it's important to consider this from the outset to ensure that all integrated systems have a certain buffer or reserve capacity
Replication potential	• Initial successful pilot or demonstration plants serve as the most effective approach for achieving replication.	• Thanks to its simple construction design that involves a significant portion of local civil works, it enables local construction, low dependency in both oversees equipment and specific skilled staff to operate complex equipment. • The waste management infrastructure in Saint-Louis already includes similar infrastructures, indicating that the technology in question aligns well with the existing local context and local companies can readily undertake the construction of this technology. This familiarity can lead to a positive reception within the local community. • Other cities in Senegal may likely share a similar infrastructure and context, which could lead to a positive reception of the technology there as well
Additional benefits		• Possibility to test easily other local feedstock that potentially suitable for dry AD nine fermenter chambers working in parallel
Limitations	• Water availability to dilute OFMSW. • The necessity for precise sorting methods depends on whether there is a separate collection of organic waste at household level or at recycling	• Only suitable for certain solid/stackable materials • The storability of biomass should be assessed for each project.

	facility. This requires separate projects and educational programs to promote waste separation.	• A minimum of three chambers is recommended to ensure constant gas utilization • In the context of Saint-Louis, a smaller plant consisting of only 3 chambers means changeovers every 10 days. Storing OFMSW for 10 days is not advisable, as OFMSW should ideally be fed fresh unless proper storage conditions are ensured. • Storing properties of feedstock material should be considered during dimensioning and limits the minimum plant size

4.2 Identification of Potential for Energy Savings

4.2.1 Quantification of Organic Fraction of Municipal Solid Waste

The organic Fraction of Municipal Solid Waste (OFMSW) refers to the amount of waste that is contaminated but includes organic materials. This waste has more value once it is separated from the inorganic components. It is generally difficult to get data for the African continent due to data scarcity. However, in this study, numbers from trustworthy databases were used and compared with the data found during the business trip.

In the city of Saint-Louis, the organic waste is generated from markets, food processing, households, and agricultural activities. This waste, however, does not end up entirely in the landfill. Instead, it is used as animal feed or to make compost. Therefore, the actual amount of organic waste is much smaller than the theoretical or potential estimates. As for old cooking oil and fats, they are not reused to feed pigs like in other countries. The animal manure is widely used as an organic fertilizer in the agricultural farms. These characteristics showcase the dynamics of organic waste in the city.

Based on the assumption that "*the current production of waste in Saint-Louis is estimated at nearly 80 tonnes per day. The collection rate is less than 30%*" (Greentec service GmbH, 2023), this means that the waste collected will be around 24 t/day in the city of Saint-Louis, leaving 56 t/day uncollected. However, in this study, a baseline of 80 t/day is used considering that in the future the waste collection management in the city will be improved and this amount will be reached. This amount will generate approximately 29,200 t per annum. This amount falls in the range between the minimum and maximum number of inhabitants as shown in Table 5.

Table 5 | MSW quantity range based on population of Saint-Louis

DATA	MIN VALUE	MAX VALUE	SOURCE
Population (inhabitants)	176,000	237,500	176,000 habitants by 2022 (*World Cities Database*, 2022) 201,300 habitants by 2014 (Commune de Saint-Louis, 2014) 237,500 habitants by 2015 ((*Saint-Louis (Sénégal)*, 2015)
Specific MSW generation (kg/capita/d) in Saint-Louis	0.40*	0.44**	* Self-calculation assuming 80 t/d as waste generation; **(Kaza et al., 2018)
MSW potential (t/a)	25,500	38,000	

The MSW is composed of 47% sand, fine elements, stones and clay, 42% organic waste, 3% plastic, 2% scrap, and 6% others as summarized in the graph of Figure 16.

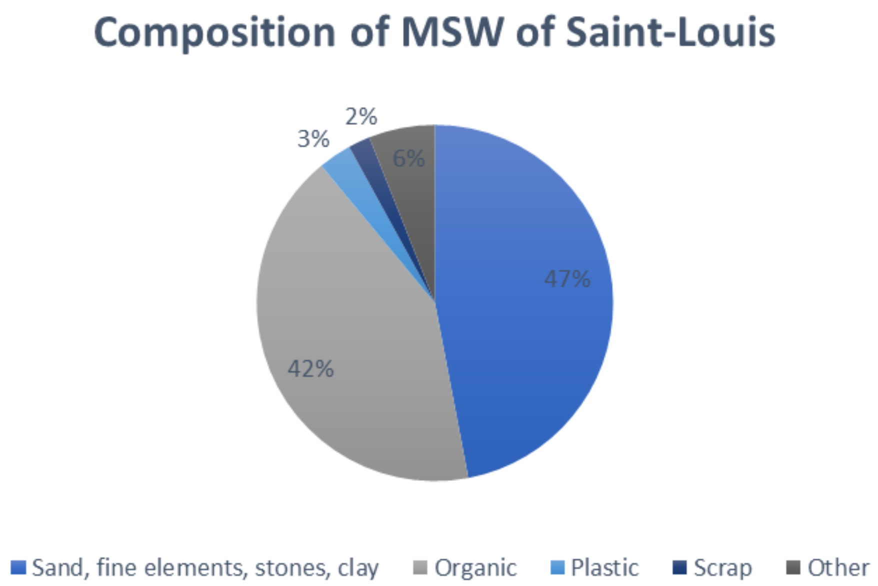
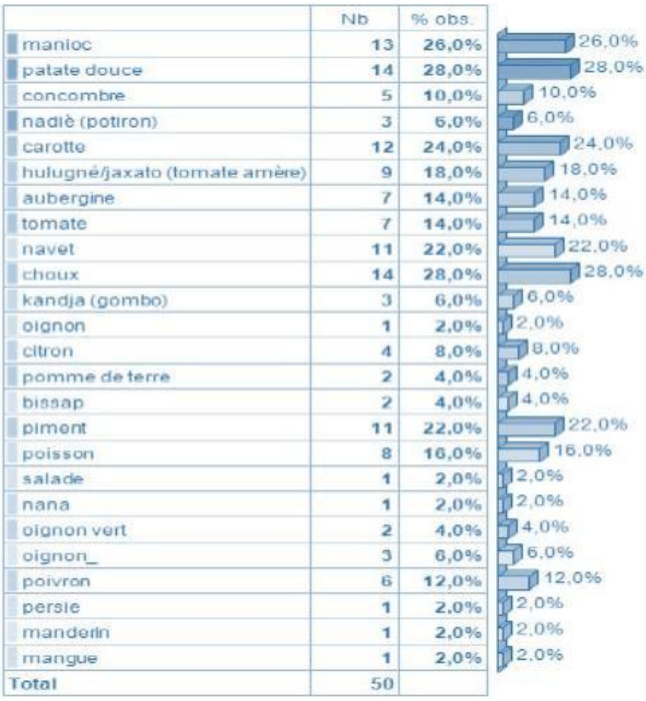


Figure 16 | Composition of MSW

Market waste is also part of the municipal solid waste. An overview of its composition and quantity was done in the study as well. Based on a comprehensive study done on the three markets of Saint-Louis, 28% of the waste is reusable whereas the rest is not. The daily estimated organic waste amount is between 937 and 3,247 kg. animal farm owners and breeders come at the end of every day to collect the waste either for free or for in return of a small charge (50 fcfa/kg). To quantify this waste, it is important to take a look at its origin and destination at the end of the day. Figure 17 shows the different types of products sold in the markets, whereas the graph in Figure 18 shows the destination of the market waste.



	Nb	% obs.
manioc	13	26,0%
patate douce	14	28,0%
concombre	5	10,0%
nadiè (potiron)	3	6,0%
carotte	12	24,0%
hulugné/jaxato (tomate amère)	9	18,0%
aubergine	7	14,0%
tomate	7	14,0%
navet	11	22,0%
choux	14	28,0%
kandja (gombo)	3	6,0%
oignon	1	2,0%
citron	4	8,0%
pomme de terre	2	4,0%
bissap	2	4,0%
piment	11	22,0%
poisson	8	16,0%
salade	1	2,0%
nana	1	2,0%
oignon vert	2	4,0%
oignon_	3	6,0%
poivron	6	12,0%
persie	1	2,0%
manderin	1	2,0%
mangue	1	2,0%
Total	50	

Figure 17 | Percentage of the Different Products in Ndar-Toute Market, (© ÖKOBIT GmbH)

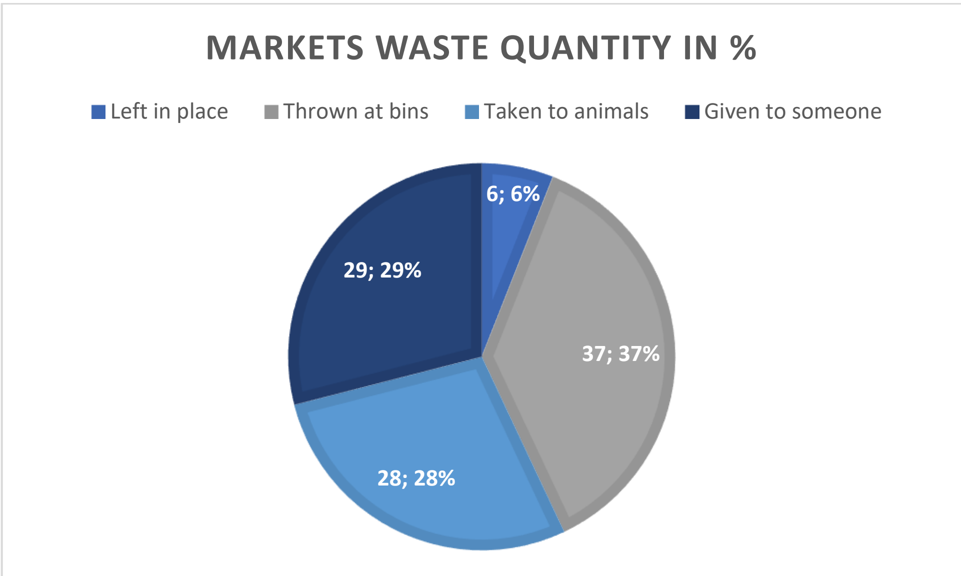


Figure 18 | Destination and Quantity of the Three Markets Waste

After analysing the existing potential of the municipal solid waste, the final design results were obtained and displayed in Table 6. In conclusion, a total of 11,100 t/a of OFMSW will be digested to produce an annual CH_4 yield of 593,906 Nm^3. This is equivalent to 989,843 Nm^3/a of biogas (Table 6).

Table 6 | Final Design Data and Biogas Potential of MSW

FINAL DESIGN DATA	*VALUE*	*UNIT*
Raw or fresh MSW, quantity	80	t/d
Raw or fresh MSW, quantity	29,200	t/a
% Organic in MSW	42	%
Recovery rate (losses due to logistic, processing, separation, picking)	90	%
OFMSW	30.4	t/d
Annual OFMSW	11,100	t/a
CHARACTERISTICS AND BIOGAS YIELD OF OFMSW	***VALUE***	***UNIT***
Total Solids	29	% in FM
Volatile Solids	50	% in DM
CH_4 content	60	%
Methane yield	369	Nl/kg oDM
Specific biogas yield	89.2	Nm^3/t FM
Annual CH_4 yield	593,906	Nm^3 CH_4/a
Annual Biogas yield	989,843	Nm^3/a
Biogas yield per hour	113	Nm^3/h

4.2.2 Technical Designs

The technical designs for both technologies were done by ÖKOBIT, with simulations and calculations of the mass, energy and CO_2 emission savings of each scenario. The wet AD process is demonstrated in the diagram flow of Figure 19.

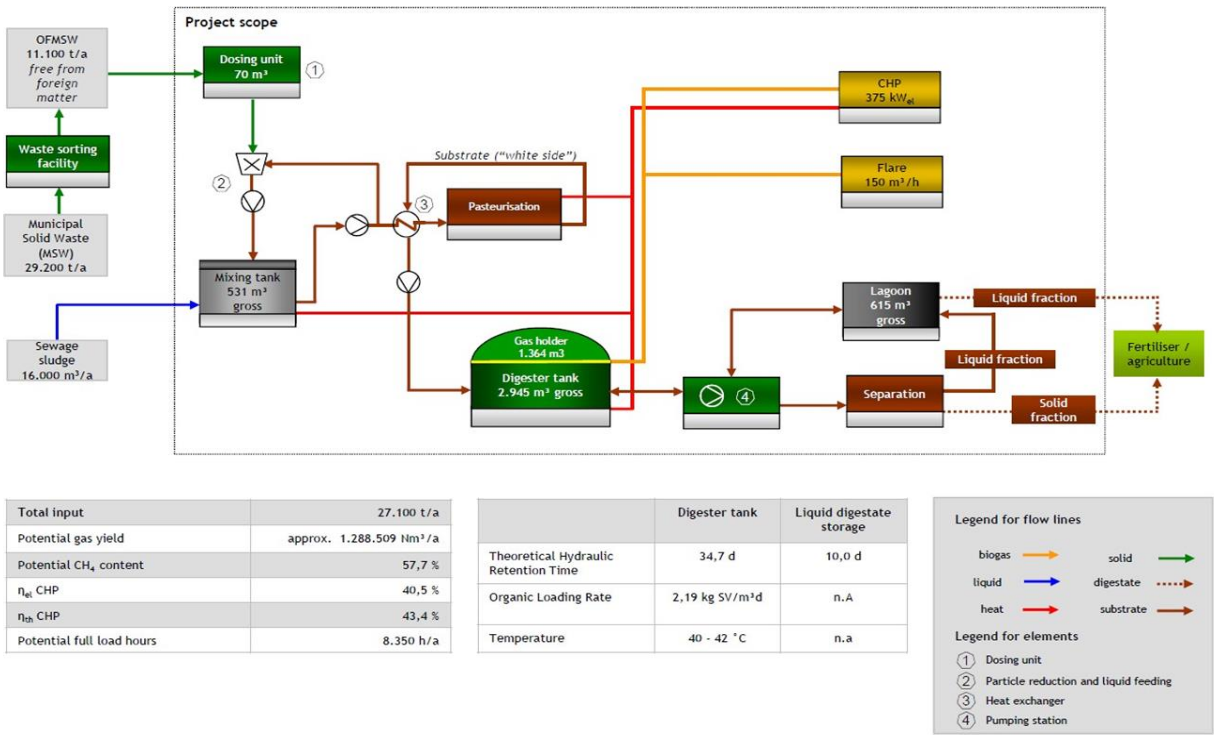


Figure 19 | Diagram Flow of Wet AD, (© ÖKOBIT GmbH)

In this scenario, 11,100 t/a of OFMSW and 16,000 m³/a of sewage sludge are processed to generate biogas. This biogas fuels a CHP unit, generating sustainable electricity and heat. The wet AD process utilizes a CHP with an 84% efficiency and an annual operational rate of 95.3%. The cumulative energy yield amounts to approximately 7,731,055 kWh/a, divided into 3,131,100 kWh/a of electricity and 3,355,000 kWh/a of heat. The remaining balance accounts for energy losses, as depicted in Figure 20. By substituting traditionally produced electricity with 100% of the electricity produced with the CHP unit, CO_2 emissions can be reduced by 1,946 t/a.

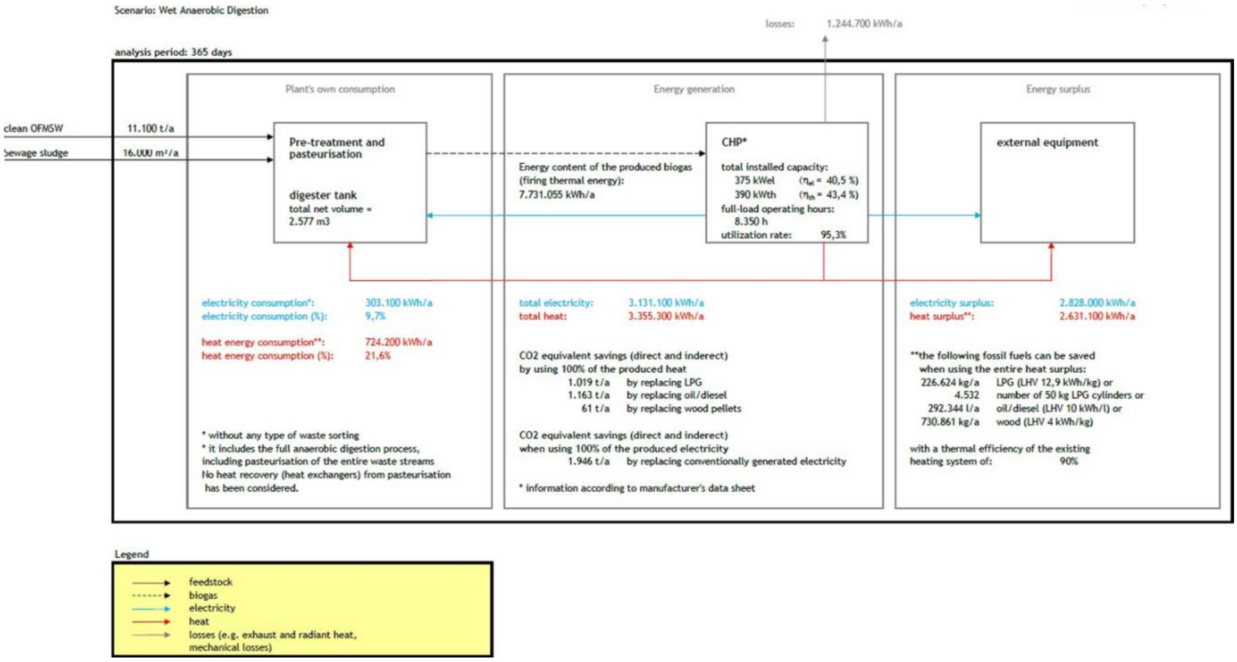
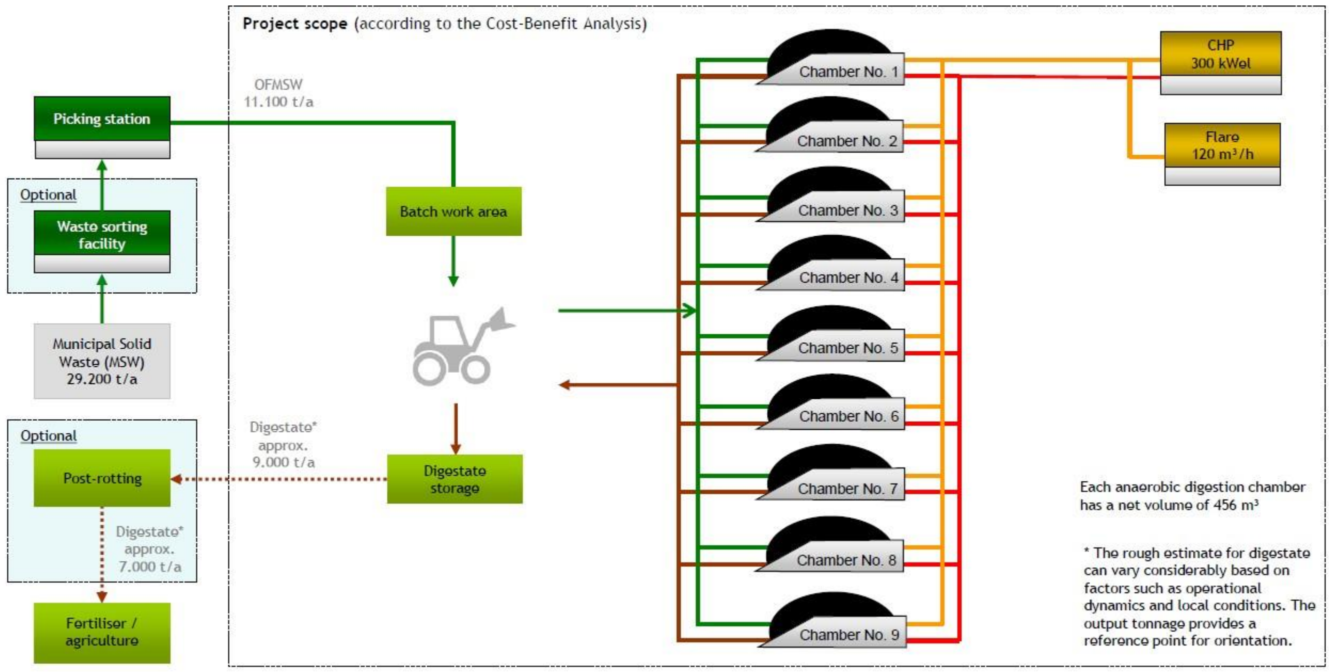


Figure 20 | Energy and CO_2 Balance of Wet AD, (© ÖKOBIT GmbH)

In the other scenario (dry AD), 11,000 t/a of OFMSW is input in 9 separate chambers to produce biogas as demonstrated in Figure 21.



Total sorted OFMSW	11.100 t/a
Potential gas yield	approx. 989.843 m³/a
Potential CH_4 content	60,0 %
η_{el} CHP	41,6 %
η_{th} CHP	42,7 %
Potential full load hours	8.235 h/a

Batch AD parameter	
Theoretical Retention Time (per chamber)	91,25 d
Time between changeover (per chamber)	30,42 d
Time between changeovers (entire plant)	3,38 d
Tonnage per batch changeover	102,78 t
Temperature	40 - 42 °C

Legend
Biogas → Solid →
Liquid → Digestate ····→
Heat → Substrate →

Figure 21 | Diagram Flow of Dry AD, (© ÖKOBIT GmbH)

The biogas obtained from the dry anaerobic digestion will be used to run a CHP unit with an efficiency of 84.3% and an annual operation rate of 44.3%. This CHP will convert biogas to a total of 5,939,055 kWh/a of energy. This is divided into 2,470,700 kWh/a of electricity and 2,536,000 kWh/a of heat. The rest is considered as energy losses. Using 100% of the electricity produced by the CHP will save around 1,536 t/a of CO_2 emissions as depicted in Figure 22.

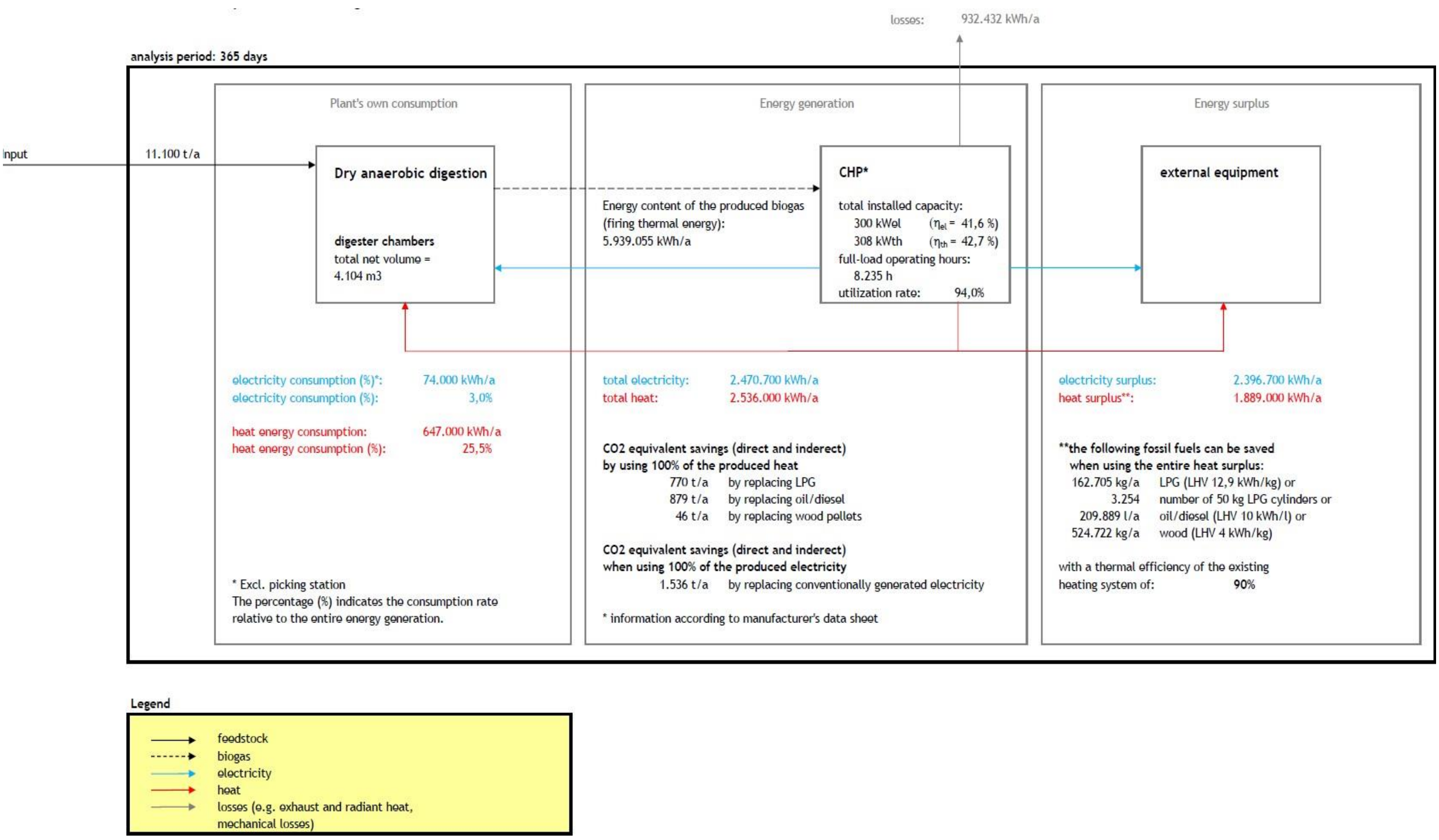


Figure 22 | Energy and CO_2 Balance of Dry AD, (© ÖKOBIT GmbH)

4.2.3 Site Location

There are two different sites for the biogas plants as presented in Figure 23 depending on the two scenarios:

- Scenario (A) of wet AD: the proposed location is *the station de lagunage* (stabilization pond). It is currently used as a wastewater discharge point and referred to as STEP which stands for (Station d'épuration des eaux usées).
- Scenario (B) of dry AD: the proposed location for this is Landfill of Gandon (CET), which is a bit outside Saint-Louis.

Figure 23 | Locations of CET and STEP, (© ÖKOBIT GmbH)

Figure 24 and Figure 25 show the aerial views of Gandon landfill and the STEP with the layout plans of the biogas plants in each location respectively.

Figure 24 | Aerial View of Gandon Landfill Location and Layout Design of Dry AD Biogas Plant, (© ÖKOBIT GmbH)

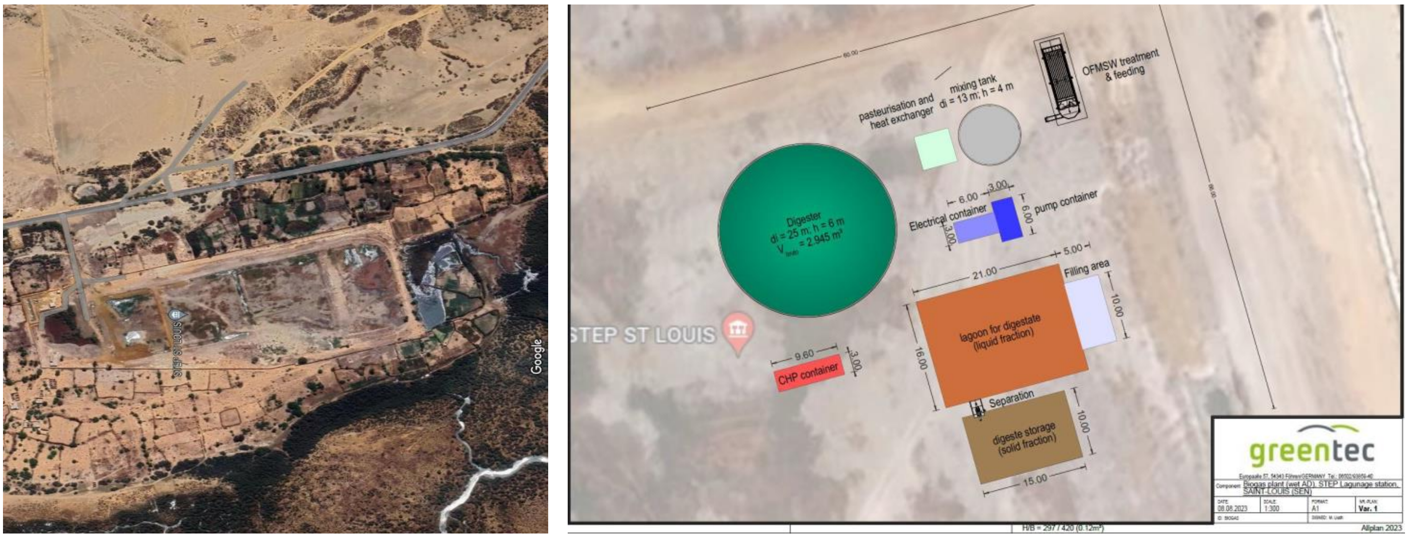


Figure 25 | | Aerial View of STEP Location and Layout Design of Wet AD Biogas Plant, (© ÖKOBIT GmbH)

For the dry AD, the chosen technology for Saint-Louis, the location of Gandon landfill (CET) was chosen because it offers significant advantages, including ample space near the landfill road and its location within an industrial zone. Situated 7 km from the entrance at Sor and 16 km from the northernmost point in Langue de Barbarie, it serves as the primary disposal point for Municipal Solid Waste (MSW), ensuring minimal impact on existing waste transportation logistics. The site's strategic position allows direct disposal of the residual fraction in case organic waste is not sorted at households. Securing the land at no cost or through a long-term lease from authorities would be highly beneficial. Additionally, anticipated synergies due to logistics/waste disposal with the biogas plant are expected, enhancing both waste reception and disposal requirements for the biogas plant.

4.3 Economic Analysis

The technical evaluation concluded that the dry anaerobic digestion is a more viable option for Saint-Louis compared to wet AD. The financial requirements for wet AD, especially when adding an additional sorting facility, are significantly higher. These additional costs are not covered by the earnings from electricity production. Therefore, this section will focus solely on the dry AD model.

This chapter offers a financial viability assessment of the Gandon Landfill facility. The ensuing analysis aims to assist in understanding the economic potential of a biogas plant using the advanced dry anaerobic digestion method. Additionally, it sheds light on the potential risks and opportunities of the suggested project, drawing from data gathered in this study, established standards, and hands-on experience.

4.3.1 Economic Feasibility of Dry AD

The total investment of the dry AD with all the necessary components as explained in Table 7 amount to €2,585,000. This amount does not include the basic waste sorting and the digestate post-processing as they are suggested as optional measures.

Table 7 | List of Investment Costs CAPEX

ITEM	*MAIN INVESTMENT PACKAGE*	*INVESTMENT COSTS, €*
1	Basic waste sorting (optional)	220,000 €
2	Drive-in silo chambers	635,000 €
3	Equipment for nine drive-in silo chambers	630,000 €
4	Further equipment and services	242,000 €
5	Gas utilization (300 kW_{el} CHP, flare, transformer)	600,000 €
6	Other on-site services (earthworks, foundations, roads, storage areas, etc.)	315,000 €
7	Engineering, services, experts, approval/permits	163,000 €
8	Digestate post- processing (optional)	180,000 €
	Total	**2.585.000 €***

*** Not including basic waste sorting and digestate post-processing.**

The dry anaerobic digestion plant will be connected to a CHP unit. Several CHP manufacturers have been assessed. The summary of the findings is showcased in Table 8. The selected CHP unit chosen for this study is the 300 kW_{el} power from a German manufacturer which provides a good combination of electrical efficiency and cost effectiveness. The possible output of this biogas plant is displayed in Figure 26.

Table 8 | Comparison of the Commercial CHP Units Assessed

CHP UNIT	*ELECTRICAL EFFICIENCY*	*THERMAL EFFICIENCY*	*INDICATIVE COST*
CHP: German manufacturer A			
300kW_{el} / 308 kW_{th} (at 83% load)	41.6%	42.7%	
Selected option in this study as per rated power* 360 kW_{el} / 345 kW_{th} (at 100% load)	42.5%	40.7%	475,000 €
CHP max. capacity **			
CHP: EU Manufacturer B			
300 kW_{el} / 322 kW_{th} (100% load)	40.48%	42.15%	410,000 €
CHP: EU Manufacturer C ***			
2 units 166 kW_{el} / 217 kW_{th}	37.7%	49.3%	525,000 €

* 360kW_{el} CHP unit throttled down to 300 kW_{el}

** Equivalent to an expansion of about two additional fermenter chambers (eleven chambers in total)

*** Manufacturer active in Senegal

Commercial framework*		
Year of commissioning	year	2024
	month	January
Equity share		0,00%
Equity (less subsidy)		0 €
Funding		0 €
Borrowed capital		2.585.000 €
Interest rate of debt		7,60%
Total term of the loan		15,0 years
Grace years		1,0 year
Inflation		3,10%

Overview gas yield substrate input	volume [t/a]	gas yield [m³/t FM]	gas yield [Nm³/a]
OFMSW 29% TS	11.100	89,2	990.000
Total	**11.100**		**990.000**

Possible output based on input materials		
Total gas yield	990.000	m³/year
Methane content	60,00	%
Capacity utilisation CHP	8.237	Full load hours/a
Electrical efficiency of CHP unit (according to manufacturer's data s	41,60	%
Thermal efficiency of CHP unit (according to manufacturer's data sh	42,70	%
Possible kWh electric	2.471.000	kWh elec.
Possible kWh thermal	2.537.000	kWh therm.

Figure 26 | Commercial Framework of the Biogas Plant and the Possible Output of the CHP Unit, (© ÖKOBIT GmbH)

Using a dry anaerobic digestion process coupled with a Combined Heat and Power (CHP) unit, excess electricity generated is sold to the grid at a feed-in tariff rate of 15 ct/kWh. This presents a significant revenue stream for the operation. Additionally, the digestate produced as a byproduct from the digestion process is monetized as high-quality fertilizer, with a price of 6.86 €/t (Figure 27). When combining these revenue streams, the total average annual earnings, including the commissioning year, amount to 442,000 €/a. A detailed list of all operational costs is exhibited in Figure 28, which amounts to €7,217,400 . With average annual operational costs amounting to 346,000 €/a, this garners a notable profit of 96,000 €/a, showcasing the economic viability of this energy production scenario as presented in Figure 27.

Feed-in tariff	15,00	ct/kWh

Revenues		
	Full load year	Total (20 years)
Revenues (excess electricity of the CHP at grid feed in point)	359.600 €	7.499.200 €
Revenues (heat sales)	- €	- €
Revenues (self consumption of heat)	- €	- €
Revenues (fertiliser value of digestate 6,86 €/t)	61.800 €	1.728.700 €
Total revenues	**421.400 €**	**9.227.900 €**

*according to your specifications for the sale of heat or own use of waste heat

Figure 27 | Revenues Obtained from Selling Excess Electricity and Digestate, (© ÖKOBIT GmbH)

OPEX*		
	1. full load year	total (20 years)
Analytical process support	500 €	13.900 €
Accounting, legal/tax advice, general administrative expenses	250 €	7.000 €
Wheel loader	14.200 €	399.700 €
Annuity** acc. 15 Y. Financing (Ø year commissioning + 20 years)	203.500 €	4.273.100 €
Personnel costs (unskilled) and supervision	2.000 €	58.000 €
Maintenance / repair biogas plant	25.900 €	729.000 €
Raw materials incl. Transport	- €	0 €
Desulfurization	5.000 €	140.000 €
CHP maintenance	25.100 €	702.800 €
Electricity costs (plant's own consumption)	- €	0 €
Insurance	12.900 €	363.100 €
Provisions for recurring tests and appraisals	- €	0 €
Provisions for minor and major overhauls CHP	19.400 €	530.800 €
Total operating costs	**308.750 €**	**7.217.400 €**

For the operating costs, all costs were taken into account that are based on empirical values, estimations and/or information has been obtained from you.
*Year of commissioning + 20 years of operation
** The annual annuity was considered per operating year in the plan calculation. The resulting over-/under-recovery can be taken from the liquidity graph under the profitability calculation.

Overview transport costs*	volume [t/a]	costs [€/t]	costs [€/a]
OFMSW 29% TS	11.100	0,0	0
Total	**11.100**		**0**

*for 1st full load year

Figure 28 | Summary of Operating Costs, (© ÖKOBIT GmbH)

Profitability (mean values for year of commissioning + 20 years of operation)	
Revenues	442.000 €/a
Costs	346.000 €/a
Results	96.000 €/a

In the average value analysis, a period of 20 operating years including the year of commissioning is considered.

Figure 29 | Profits of Dry Anaerobic Digestion Scenario, (© ÖKOBIT GmbH)

4.3.2 Economic Risk Assessment

Following the positive outcome of the economic feasibility of the dry AD scenario, an economic risk assessment becomes an essential step to do before decision-making. ÖKOBIT has undertaken this assessment to pinpoint potential financial risks emerging from a range of internal and external determinants. These risks have been segmented into categories such as policy, technology, operation, production, market, and natural phenomena. Table 9 provides a detailed breakdown of these categorized risks and introduces preventative measures to avoid their impacts.

Table 9 | Risk Assessment of Dry AD

RISK DESIGNATION	*CATEGORY*	*PREVENTION MEASURES*
Delays in approval processes	Political	• Intensive legal research • Early beginning of approval procedure • Involvement of relevant authorities • Preliminary research for Saint-Louis suggests very low risk regarding approval
Sales of fertilizer	Market	• Pasteurization of critical materials to eliminate pathogens. • Information of agricultural actors regarding the fertilization benefits • Market campaign in advance • Long-term purchase agreements
Sales of electricity	Market	• Price guarantees • Long-term purchase agreements • Diversification of customer
Incomes organic waste disposal	Market	• Long-term supply agreements with • Long-term price structure • If applicable, relevant for investment in sorting facilities
General price increase	Market	• Conservative planning
Increasing electricity costs	Market	• Price guarantees • Long-term supply agreements
Disappearance of substrates	Production	• Diversification of input materials • Long-term supply agreements • Low for Saint-Louis. Research indicates higher waste production rates
Power blackouts	Production	• Not of high importance for drive-in silo chambers (feeding with loader, no agitation, etc.) • Backup battery for system control
Technical defects	Technical	• Use of high-quality products • Stockpiling of sensitive spare parts • Lang-term service agreements
Flooding	Natural phenomenon	• Planning of flood protection measures • Insurance • Stockpiling of affected spare parts
Fire & Explosion	Fire & Explosion	• Complying with safety standards and recommendations in planning and construction • Comprehensive safety training of staff • Insurance
Overfeeding	Operating errors	• Extensive employee training • Frequently monitoring of biological parameters • Provision of required laboratory facilities • Modular approach, digesters in parallel as proposed
Loss of key personnel	Human resources	• Appropriate measures for staff retention • Fair contracts

5 Potential of Organic Fertilizer in Agriculture

In the rural outskirts of Saint-Louis, agriculture is the primary activity, and most people rely on fertilizers, both synthetic and natural, to improve their harvest due to poor soil conditions. Despite the availability of local options, there is a notable demand for imported fertilizers, indicating a strong market. Local farmers also show interest in using cow manure and chicken litter as fertilizers.

The digestate generated during the production of biogas in a biogas facility showed remarkable fertilizing qualities, making it a great asset in farming. Whether employed as a liquid or solid fertilizer, this digestate proves advantageous, particularly in revitalizing depleted soils. The digestate fertilizer is rich with vital macro- and micro-nutrients, which results in improved crop yield. Significantly, its use showcases effectiveness in nutrient distribution and has a positive influence on soil microbial activity, promoting overall soil fertility and sustainability in agriculture.

Figure 30 illustrates the growth of maize plants when fertilized with digestate compared to those without any fertilizer or treated with alternative fertilizers. The findings revealed significant growth in plants treated with digestate fertilizer, nearly on par with those treated with chemical fertilizers. This suggests that digestate serves as a bio-fertilizer of high value, contributing positively to the economic viability of the biogas plant.

The quantitative and qualitative characteristics of the digestate depend on both the input materials and the anaerobic digestion process employed. Regarding storage and transportation, digestate produced via wet anaerobic digestion can be separated into liquid and solid fractions due to its pumpable nature, thereby mitigating costs. Conversely, digestate from batch anaerobic digestion (Dry AD) exists in a solid form, making it stackable. The type of digestate varies depending on the anaerobic digestion technology used and can be classified as follows: pumpable digestate with a liquid consistency (wet anaerobic digestion, particularly in continuous process), paste-like digestate (common in plug flow continuous dry anaerobic digestion), and stackable digestate in solid form (typical of batch dry anaerobic digestion).

Figure 30 | Growth Comparison of Maize Plant[7], (© ÖKOBIT GmbH)

[7] From left to right: maize plant with no fertilizer used as control, using manure as fertilizer, using digestate as fertilizer, and using a chemical fertilizer.

During the fact-finding mission to Saint-Louis in Senegal that took place on the 25th of February 2022, visits to shops selling fertilizers were scheduled. After conducting interviews with the mangers of these shops, data was collected and summarized in Table 10 below. The fertilizers are provided on quota by the government, which subsidizes 60% of the price, leaving 40% to be covered by the farmers. The government is the one responsible for regulating the selling prices.

Table 10 | Data Collected from Local Shops from Onsite Interviews

TOPIC	NOTES
	DAP local fertiliser shop
About the shop / market:	• 60% subsidized by the government, 40% by farmers • The government regulates selling price published in the local HIM paper. • Local fertiliser is distributed, apparently frequently made in Senegal • Each district is equipped with a shop. Individuals eligible for purchasing from the shop are provided with a voucher. Not everyone benefits from subsidies, primarily benefiting small-scale and household farming. • A ceiling exists on the subsidised amount granted per eligible person. In cases of larger quantities, the non-subsidized price is applicable
Other fertilisers*:	• Products varies over time. Currently DAP fertiliser 18-46-0 in 50 kg bags • Occasional availability of Triple 15 (currently not subsidised) • Urine is also offered
Contacts:	• ASPHORD: Association des Productors Horticole du Delta • SAED Conseille des productens for crop-specific fertiliser guidelines and recommended quantities (rice, tomato, onions, melon, aubergine) • IP05 Interprofession Oingnon section Dagana • Company ICS: Industrie Chemiques du Senegal (Indian)
Recommended fertiliser quantities per crop:	• Max. for 1 ha: 350 kg Urine + 100 kg DAP (per ha) • In wintertime: 300 kg Urine + 100 kg DAP (per ha) • Tomato: 100 kg 9-23-30 + 150 kg Urine (per ha) • Onion: 250 kg 10-10-20 + 100 kg Urea (per ha)
Local inputs:	• According to the shop manager, cultivating plants in the local area without fertilisers is unfeasible. • Certain soils have high salinity levels, requiring farmers to fertilise during plant growth to mitigate salt-related issues. • In cases of typical soil, fertiliser application occurs primarily at the beginning. However, some farmers increase fertilisation as plants develop, such as an additional 200 kg when growth demands.
Construction store NS Les Niayes Sarraut	
Prices and inputs from the market*	• 25 kg bag NPK 20/20/20. It requires dilution or it is sprayed directly on leaves possible. Price: 35.000 CFA (previous price before pandemic: 25.000 CFA) • Currently, urea is unavailable; cow/chicken manure is recommended as an alternative. Due to its increased cost and scarcity, its price has surged from 12,500 CFA to 35,000 CFA due to pandemic. Urea is sourced from Russia, China, or India. • Liquid fertiliser, sold in 1-liter bottles, is priced at 4,500 CFA. • Peat or turf infused with fertiliser, packaged in 70-liter bags, is available for 12,500 CFA • Fertiliser prices are increasing significantly, largely due to dependency on Russia.

In the feasibility study, the planned biogas plant for each scenario considered the production of agriculture fertilizer for each technology. The wet AD scenario in Figure 31 will result in 25,526 m^3/a, which is divided into 5,605 t/a of solid fertilizer and 19,922 m^3/a of liquid fertilizer. As for the dry AD scenario in Figure 32, which is the recommended technology for Saint-Louis, approximately 9,000 t/a of fertilizer will be generated from all the 9 chambers. This could generate an annual revenue of €61,800 from selling the fertilizer at a unit price of €6.86 per tonne.

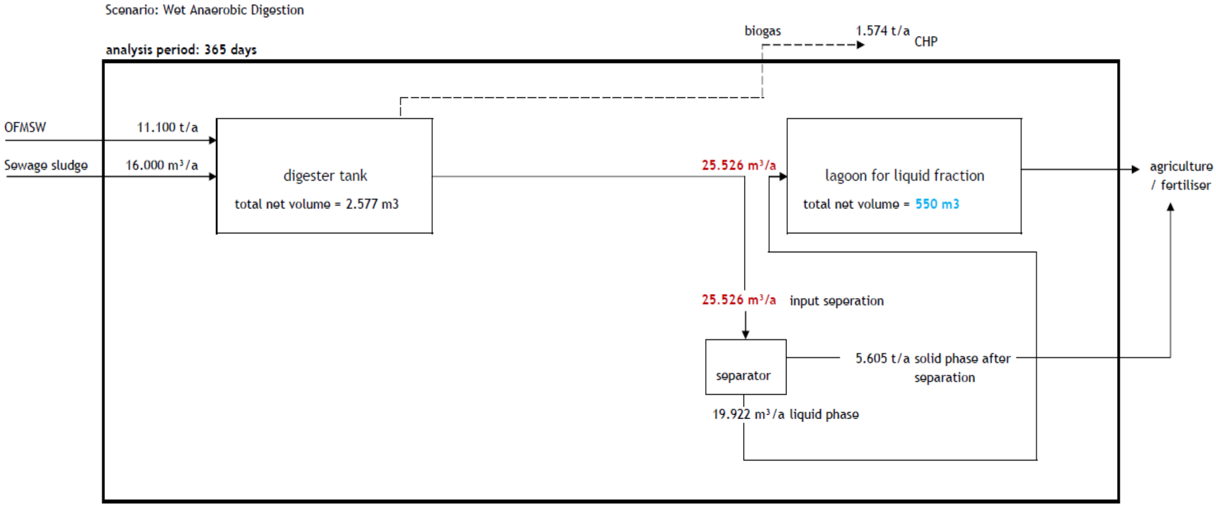


Figure 31 | Mass Balance of Wet AD Scenario, (© ÖKOBIT GmbH)

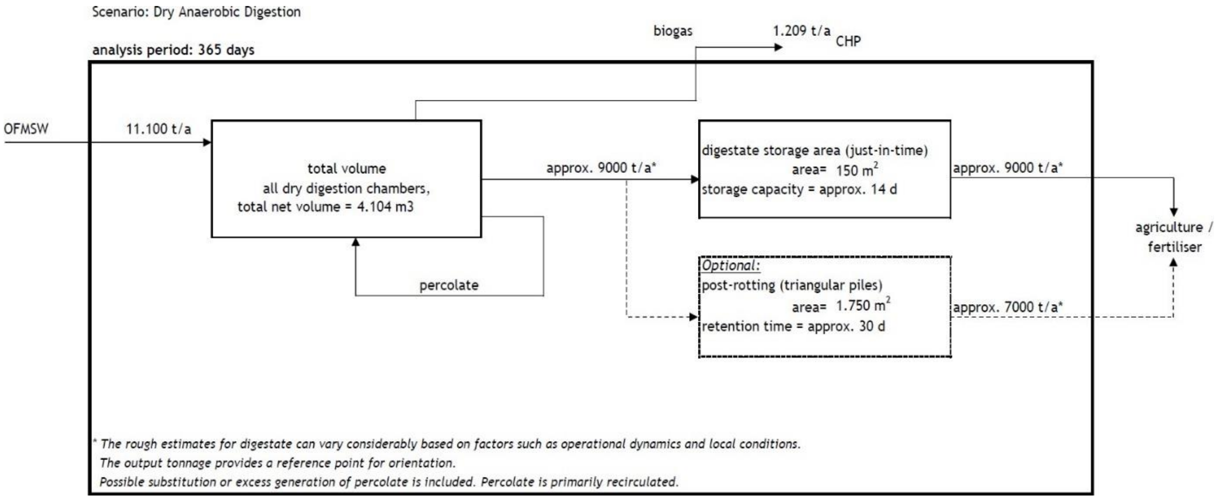


Figure 32 | Mass Balance of Dry AD Scenario, (© ÖKOBIT GmbH)

6 Limitations and Challenges

There are some critical factors to consider also to guarantee a successful project. Among which is the analysis of gas demand. It is important to determine the potential clients for the produced biogas. Moreover, it is necessary to know the income or economic situation of the targeted group to determine the convenient price which will cover the costs but at the same time can be afforded by the clients. And it is necessary to check if the materials needed for building the plant are available in the city of the installation (Afridi & Qammar, 2020).

On the operational level, it is required that the operators of the plant have enough background and knowledge about the operation of the plant. Operating the biogas plant can encounter many technical problems where a specialized intervention is needed to repair it. In the region of Saint-Louis, having the skilled and educated operators for the biogas plant is still one of the challenges and barriers to overcome. There is a significant lack of capacity building, which will be covered in in the chapter of Capacity Building of LoSENS's Master Plan. Saint-Louis has many biogas plants that were installed under the PNB program with the help of the Partenariat. However, most of them are not working because once there is a failure or a technical problem and there is no one who can fix it, the plant stops working and remains that way.

7 Adaptability to Needs and Future Scope

There are three major regulatory drivers forcing the development of biogas plants:

- Greenhouse gas (GHG) policies
- Recycling policies
- Renewable energy policies

Despite their biogas capture systems, landfill emits a significant amount of fugitive methane to the atmosphere, therefore contributing to greenhouse gas emissions. Additionally, landfilling of organic waste does not comply with typical recycling policies which state that waste should be reduced, reused, and recycled (3Rs) prior to final disposal. Due to these reasons, GHG and recycling policies generally ban organic landfilling therefore force composting and/or anaerobic digestion of organic waste[8].

Most of the renewable energy policies encourage the use of renewable energy sources instead of fossil fuels in order to reduce environmental pollution. In 2010, Senegal brought into force the Renewable Energy Law. This law aims at the following goals:

- Creating a legal framework for renewable energy installations projects
- Reducing dependence on fossil fuels
- Decreasing greenhouse gas emissions
- Ensuring energy supply security
- Diversifying the energy mix

In order to encourage this transition, the ministry proposed some incentives for renewable energy producers. According to the renewable energy law in Senegal that came into force in 2010, people investing in such projects will benefit from tax exemption and tax relief on the purchased materials and equipment related to biogas plant installation projects (*Renewable Energy Law*, 2013). This in addition to the important potential the country has of organic waste, a biogas plant seems to be one of the attractive options to generate biogas and electricity in a renewable and sustainable way.

Installing a biogas plant requires thorough study and analysis before starting the construction. The first step is to identify the potential of the feedstock in terms of quality and quantity and all the logistics related to it (collection, transport…). Then, comes determining the proper location for installing the biogas plant. There are certain regulations that need to be respected in the proposed site. For example, the site needs to be easily accessible by road so that the input material can come in and the digestate can be taken away without causing trouble or traffic. The site has to be away from any residential areas, rivers, or wells because the trucks can be noisy and when they open the doors to deliver the input material, some unpleasant odors can be released. To avoid this issue, it is best to install the plant near the place with the highest biomass potential but far from any household areas. Also, the biogas site needs to be close to an energy grid for an efficient export of biogas energy.

[8] Guide De Développement D'une Usine De Biogaz, Biogas World

8 Conclusions and Recommendations

Biogas technology, by converting OFMSW into energy, offers an eco-friendly solution for managing organic waste and minimizes harmful environmental impacts. Beyond energy, biogas processes also yield liquid fertilizer, adding value. Economic gains include energy and fertilizer self-reliance, job creation, and decreased external environmental effects and landfill burdens. The approach supports societal growth and bolsters the renewable energy industry.

Local politics in Saint-Louis might be open to these projects. However, research shows that there's no clear strategy currently, and prior biogas projects encountered challenges when negotiating power tariffs. This has led to existing setups in the area to use biogas mostly for heating purposes, such as cooking or slaughterhouse water heating. There was no significant electricity or heat consumers identified, and given the city's agricultural nature, distributing bottled gas might be the preferred business model. Yet, the amount of OFMSW in Saint-Louis doesn't match the requirements for such ventures. A new natural gas site, managed by BT since 2017, also poses competition. The city largely relies on agriculture and this recent gas venture for revenue. While power in Saint Louis comes primarily from charcoal and gas, solar energy is making new contributions, showcasing renewable potential.

Consequently, the favored model suggests generating electricity from a CHP unit. Storing biogas in commercial bags for household use could act as a backup or manage excess supply. The high potential acceptance and sale ability of the solid digestate, due to its nutrient richness, offers a sustainable alternative to synthetic fertilizers.

To utilize the organic component of municipal waste, a technical solution is essential. Dry AD sorting facilities are cost-effective in terms of both capital and operating costs. Economic assessments are promising; with electricity and digestate revenues, ROI could be achieved in just under 8 years. Critical economic factors include the concrete parts' investment and sales revenue.

Given the current data, moving forward with the project seems prudent. The framework suggests that a successful biogas plant is feasible and can be bolstered through additional commercial avenues. Beyond the primary scenario, if electricity prices increase to 20 ct EUR/kWh from 15, annual profits soar to €216,000, and ROI is reached in 5.6 years. Another scenario, which involves basic sorting and potential revenue from waste disposal fees, sees an average annual profit of €180,000, and a reduced ROI time of 6.5 years.

The dry anaerobic digestion technology proposed for Saint-Louis offers numerous benefits, including cost savings, efficient local resource use, simple equipment needs, water conservation, low energy demands, high resilience to contaminants, modular failure protection, and scalability.

To advance this initiative, the following actions are suggested:

- Introduce the concept to the government.
- Engage relevant government agencies for support.
- Identify potential investors and secure financing.
- Locate buyers for the heat and fertilizer outputs.
- Sort out infrastructure access points.
- Analyze waste characteristics, emphasizing decomposable organics.
- Establish a process for sourcing clean OFMSW.
- Secure a long-term power grid agreement.

- Conduct soil and static evaluations.
- Obtain concrete construction estimates.
- Proceed with detailed engineering, planning, and eventual construction.

9 Annex

This plan calculation relies on data collected during a fact-finding mission, research and estimated values or standardised values of the Kuratorium für Bau- und Landwirtschaftb(KTBL values). The profitability calculation serves as a first overview of the possible profitability of a biogas plant under the given conditions. The following tables shows the profitability of this plant over 20 years starting from 2024, which sums up to a total of 2.6 million euros.

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Biogas plant

Designation	Inflation	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Subtotal 10 years
Revenues (excess electricity of the CHP at grid fe	0,0%	307.158 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	3.543.558 €
Revenues(Electricity for own use in agricultural b	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Revenues (heat sales)	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Revenues (self consumption of heat)	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Revenues (fertiliser value of digestate 6,86 €/t)	3,1%	52.736 €	61.740 €	63.654 €	65.627 €	67.662 €	69.759 €	71.922 €	74.151 €	76.450 €	78.820 €	682.521 €
Operating performance		359.895 €	421.340 €	423.254 €	425.227 €	427.262 €	429.359 €	431.522 €	433.751 €	436.050 €	438.420 €	4.226.079 €
Personnel costs	3,1%	2.000 €	2.062 €	2.126 €	2.192 €	2.260 €	2.330 €	2.402 €	2.477 €	2.553 €	2.632 €	23.034 €
Personnel costs		2.000 €	2.062 €	2.126 €	2.192 €	2.260 €	2.330 €	2.402 €	2.477 €	2.553 €	2.632 €	23.034 €
Analytical process support	3,1%	375 €	500 €	516 €	531 €	548 €	565 €	582 €	601 €	619 €	638 €	5.475 €
Accounting, legal/tax advice, general administrative expenses	3,1%	250 €	250 €	258 €	266 €	274 €	282 €	291 €	300 €	310 €	319 €	2.800 €
Wheel loader	3,1%	14.200 €	14.200 €	14.640 €	15.094 €	15.562 €	16.044 €	16.542 €	17.055 €	17.583 €	18.128 €	159.048 €
maintenance and repairs	3,1%	25.900 €	25.900 €	26.703 €	27.531 €	28.384 €	29.264 €	30.171 €	31.107 €	32.071 €	33.065 €	290.095 €
Raw materials incl. Transport	1,0%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Desulfurization	3,1%	4.271 €	5.000 €	5.155 €	5.315 €	5.480 €	5.649 €	5.825 €	6.005 €	6.191 €	6.383 €	55.274 €
CHP maintenance	3,1%	21.440 €	25.100 €	25.878 €	26.680 €	27.507 €	28.360 €	29.239 €	30.146 €	31.080 €	32.044 €	277.475 €
Electricity costs (plant's own consumption)	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Insurance	3,1%	12.900 €	12.900 €	13.300 €	13.712 €	14.137 €	14.576 €	15.027 €	15.493 €	15.974 €	16.469 €	144.488 €
Provisions for recurring tests and appraisals	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Provisions for minor and major overhauls CHP	3,1%	19.400 €	19.400 €	19.400 €	20.001 €	20.621 €	21.261 €	21.920 €	22.599 €	23.300 €	24.022 €	211.925 €
Land rent/lease	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
0	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Depreciation		161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	1.615.625 €
Operating costs		260.298 €	264.813 €	267.412 €	270.693 €	274.076 €	277.564 €	281.160 €	284.868 €	288.690 €	292.631 €	2.762.205 €
Interest of the loan		0 €	186.586 €	179.129 €	171.106 €	162.473 €	153.184 €	143.190 €	132.436 €	120.866 €	108.416 €	1.357.387 €
Costs of capital		0 €	186.586 €	179.129 €	171.106 €	162.473 €	153.184 €	143.190 €	132.436 €	120.866 €	108.416 €	1.357.387 €
Total costs		262.298 €	453.461 €	448.667 €	443.991 €	438.809 €	433.078 €	426.752 €	419.780 €	412.109 €	403.680 €	4.142.626 €
Preliminary result		97.597 €	-32.121 €	-25.413 €	-18.764 €	-11.547 €	-3.719 €	4.770 €	13.971 €	23.941 €	34.740 €	83.454 €
EBT		97.597 €	-32.121 €	-25.413 €	-18.764 €	-11.547 €	-3.719 €	4.770 €	13.971 €	23.941 €	34.740 €	83.454 €
Cash - Flow		259.159 €	129.442 €	136.149 €	142.799 €	150.015 €	157.843 €	166.332 €	175.533 €	185.503 €	196.303 €	1.699.079 €
Repayment loan		0 €	98.163 €	105.620 €	113.644 €	122.277 €	131.566 €	141.560 €	152.314 €	163.884 €	176.334 €	1.205.362 €
Total		0 €	98.163 €	105.620 €	113.644 €	122.277 €	131.566 €	141.560 €	152.314 €	163.884 €	176.334 €	1.205.362 €
Excess/shortfall per year		259.159 €	31.278 €	30.529 €	29.155 €	27.738 €	26.278 €	24.772 €	23.220 €	21.619 €	19.969 €	493.717 €
Cumulative excess/shortfall		259.159 €	290.437 €	320.966 €	350.121 €	377.859 €	404.137 €	428.909 €	452.129 €	473.748 €	493.717 €	
0 €												

Financial forecast — Page 2 of 2

Biogas plant

Designation	Inflation	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	total TD€
Revenues (excess electricity of the CHP a	0,0%	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	359.600 €	7.499.158 €
Revenues(Electricity for own use in agric	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Revenues (heat sales)	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Revenues (self consumption of heat)	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Revenues (fertiliser value of digestate 6,	3,1%	81.263 €	83.782 €	86.380 €	89.058 €	91.818 €	94.665 €	97.599 €	100.625 €	103.744 €	106.960 €	110.276 €	1.728.692 €
Operating performance		440.863 €	443.382 €	445.980 €	448.658 €	451.418 €	454.265 €	457.199 €	460.225 €	463.344 €	466.560 €	469.876 €	9.227.850 €
Personnel costs	3,1%	2.714 €	2.798 €	2.885 €	2.974 €	3.067 €	3.162 €	3.260 €	3.361 €	3.465 €	3.572 €	3.683 €	57.974 €
Personnel costs		2.714 €	2.798 €	2.885 €	2.974 €	3.067 €	3.162 €	3.260 €	3.361 €	3.465 €	3.572 €	3.683 €	57.974 €
Analytical process support	3,1%	658 €	679 €	700 €	721 €	744 €	767 €	790 €	815 €	840 €	866 €	893 €	13.948 €
Accounting, legal/tax advice, general ad	3,1%	329 €	339 €	350 €	361 €	372 €	383 €	395 €	407 €	420 €	433 €	447 €	7.036 €
Wheel loader	3,1%	18.690 €	19.270 €	19.867 €	20.483 €	21.118 €	21.773 €	22.448 €	23.143 €	23.861 €	24.601 €	25.363 €	399.664 €
maintenance and repairs	3,1%	34.090 €	35.147 €	36.236 €	37.360 €	38.518 €	39.712 €	40.943 €	42.212 €	43.521 €	44.870 €	46.261 €	728.965 €
Raw materials incl. Transport	1,0%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Desulfurization	3,1%	6.581 €	6.785 €	6.995 €	7.212 €	7.436 €	7.666 €	7.904 €	8.149 €	8.402 €	8.662 €	8.931 €	139.998 €
CHP maintenance	3,1%	33.037 €	34.061 €	35.117 €	36.206 €	37.328 €	38.485 €	39.678 €	40.908 €	42.177 €	43.484 €	44.832 €	702.789 €
Electricity costs (plant's own consumptio	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Insurance	3,1%	16.979 €	17.506 €	18.048 €	18.608 €	19.185 €	19.779 €	20.392 €	21.025 €	21.676 €	22.348 €	23.041 €	363.075 €
Provisions for recurring tests and apprais	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Provisions for minor and major overhauls	3,1%	24.767 €	25.535 €	26.326 €	27.142 €	27.984 €	28.851 €	29.746 €	30.668 €	31.618 €	32.599 €	33.609 €	530.769 €
Land rent/lease	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
0	3,1%	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Depreciation		161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	161.563 €	0 €					2.585.000 €
Operating costs		296.694 €	300.883 €	305.202 €	309.655 €	314.246 €	318.979 €	162.297 €	167.328 €	172.515 €	177.863 €	183.377 €	5.471.245 €
Interest of the loan		95.021 €	80.608 €	65.101 €	48.415 €	30.462 €	11.145 €	0 €	0 €	0 €	0 €	0 €	1.688.139 €
Costs of capital		95.021 €	80.608 €	65.101 €	48.415 €	30.462 €	11.145 €	0 €	0 €	0 €	0 €	0 €	1.688.139 €
Total costs		394.429 €	384.290 €	373.188 €	361.045 €	347.774 €	333.286 €	165.556 €	170.689 €	175.980 €	181.435 €	187.060 €	7.217.357 €
Preliminary result		46.434 €	59.093 €	72.792 €	87.613 €	103.644 €	120.979 €	291.643 €	289.536 €	287.364 €	285.125 €	282.816 €	2.010.493 €
EBT		46.434 €	59.093 €	72.792 €	87.613 €	103.644 €	120.979 €	291.643 €	289.536 €	287.364 €	285.125 €	282.816 €	2.010.493 €
Cash - Flow		207.996 €	220.655 €	234.354 €	249.176 €	265.206 €	282.542 €	291.643 €	289.536 €	287.364 €	285.125 €	282.816 €	4.595.493 €
Repayment loan		189.729 €	204.142 €	219.649 €	236.335 €	254.288 €	273.605 €	1.890 €	0 €	0 €	0 €	0 €	2.585.000 €
Total		189.729 €	204.142 €	219.649 €	236.335 €	254.288 €	273.605 €	1.890 €	0 €	0 €	0 €	0 €	2.585.000 €
Excess/shortfall per year		18.268 €	16.514 €	14.705 €	12.841 €	10.918 €	8.936 €	289.753 €	289.536 €	287.364 €	285.125 €	282.816 €	2.010.493 €
Cumulative excess/shortfall		511.984 €	528.498 €	543.203 €	556.043 €	566.962 €	575.898 €	865.651 €	1.155.187 €	1.442.552 €	1.727.677 €	2.010.493 €	
0,00 €													

10 Glossary

AD	Anaerobic digestion (AD) is the biochemical decomposition of complex organic material. Organic materials are degraded by bacteria in the absence of oxygen converting it into biogas. The two main products of anaerobic digestion are the biogas and also the digestate, that is rich in nutrients, and it is used as an organic fertiliser.
Biogas	Combustible energy rich gaseous mixture of methane and carbon dioxide and other trace gases like hydrogen sulphide, ammonia and steam produced in anaerobic digestion process.
Biogas plant	A facility where organic waste, agricultural residues and animal by-products and/or energy crops are processed under anaerobic conditions with the aim to produce biogas and digestate.
CHP	Combined heat and power (CHP) or cogeneration, refers to the simultaneous generation of both heat and electricity.
Digestate	Digestate is what remains after biodegradable materials undergo anaerobic digestion. Its characteristics depend on factors such as the original materials and the type of anaerobic digestion used. It can exist in different forms, like solid, semi-liquid, liquid or paste. It's also called bio-slurry, bio-fertiliser or organic fertiliser.
Digester	Anaerobic digester, system where AD takes place. It is also known as "*fermenter*". It refers to a container or vessel used for fermentation, to facilitate the anaerobic digestion process where organic materials break down to produce biogas and digestate. In this study, both terms are used interchangeably.
Fermenter	Refer to digester.
Tank	Refer to digester. It refers to a container or vessel used for AD.
Chamber	This term is used in this study to refer to the space or compartment where dry batch AD takes place. Refer to digester or tank.
HRT	The Hydraulic Retention Time is the length of time for which a substrate is calculated to remain on average in the digester until it is discharged. Calculation involves determining the ratio of the reactor volume to the volume of substrate added daily. The hydraulic retention time can be calculated by dividing the digester working volume by the rate of flow of input materials into the digester: HRT [days] = digester volume [m^3] / influent flow rate [m^3 per day]. It is expressed in days.
OLR	The Organic Load Rate indicates how many kilograms of organic dry matter (oDM or volatile solids) can be fed into the digester per m3 of working volume per unit of time. It can be expressed as kg VS/(m^3 d).
Pumpable	Liquid to semi liquid, suitable to be pumped in a pipeline, characterized by solids content usually below 20%.
Substrate	Input material of a biogas plant, feedstock. It includes bio-waste, agricultural residues and other animal by-products.

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