CTCN Technical Assistance

Development of a technical and economic feasibility study for anaerobic digestion of the organic fraction of solid waste from households, hotels and markets in Mauritius

Output 4: Identification of best available and appropriate technologies and of suitable sites

Deliverable 4 (4.1, 4.2 and 4.3)

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Overview of Deliverable 4

Deliverable 4 consists of three components namely:

- An overview of identified technologies and processes
- An overview of identified sites
- Meeting report including selected technology and site

The report on the overview of identified technologies considers the different types of anaerobic digestion systems that exist based on the total solids (TS) content of the wastes processed, the mode of operation and the number of stages employed. The sizes of the digesters, the estimated costs of the technologies as well as the existing biogas storage systems are also overviewed, as far as practically possible. The report on the overview of identified sites lists potential sites for the eventual commissioning of a biogas plant in Mauritius and considers several aspects including site accessibility, land extent available, waste supply and connection to the grid network. The final report under Deliverable 4 consists of a meeting report that summarises the discussions held between all relevant stakeholders in connection with the choice of the anaerobic digestion technology and the site to set up the biogas plant.

1. Introduction

As mentioned in previous deliverables, anaerobic digestion refers to the degradation of organic matter in an environment deprived of oxygen to produce biogas comprising mainly methane and carbon dioxide and a digestate of high nutrient value. The biogas, after cleaning (if needed) to remove the impurities such as water vapour, hydrogen sulphide and siloxanes, amongst others, can be combusted to produce electrical energy while the digestate can be used as an organic fertiliser or can be composted with fresh organic wastes and then, used as a soil conditioner. Several anaerobic digestion technologies have been developed over the years based on the TS content of the wastes processed, the number of stages employed and the mode of operation, amongst others. Deliverable 4 will thus focus on the different anaerobic digestion technologies and processes that are currently commercialised and make recommendations as to the technique most suitable for Mauritius. Furthermore, this deliverable will also consider potential sites for the setting-up of a biogas plant in Mauritius after consultations with all involved stakeholders and make recommendations as to the most appropriate site for the commissioning of a biogas plant in Mauritius.

2. Identification of appropriate Technologies and Processes for Anaerobic Digestion (Deliverable 4.1)

2.1 Identification of appropriate technologies for anaerobic digestion based on solid content, stages to be employed and preferred operating temperature

2.1.1 Total solids concentration

Anaerobic digestion systems can be classified based on the TS contents of the wastes that are processed. The common ranges of TS concentrations that are cited in the literature are low solids or wet systems (TS content <15%) and high solids or dry systems (TS content >15%) (Rapport et al., 2008; Williams, 2012; Kothari et al., 2014). It is not uncommon to find other ranges whereby wet systems refer to systems processing wastes with a TS content of <10% (Cesaro et al., 2010). Low solids anaerobic digestion systems tend to produce lower biogas volume per volume of the reactor, require more water to reach the desired TS content and treats a lower amount of wastes as opposed to a high solids system (Shapovalov et al., 2020). Furthermore, depending on the ultimate use of the digestate produced, low solids anaerobic digestion systems have higher treatment costs of the digestate due to the excessive amount of water present. However, low solids anaerobic digestion systems are less complex in terms of handling waste materials (Williams, 2012).

2.1.2 Number of stages

Besides the TS content of the wastes processed, anaerobic digestion systems may also be classified based on the number of stages employed and are termed as either single-stage or multi-stage systems. As mentioned in previous deliverables, the anaerobic digestion system consists of four phases namely hydrolysis, acidogenesis, acetogenesis and methanogenesis. If the four phases of anaerobic digestion are carried out within a single reactor, this is referred to as a single-stage system. On the other hand, if the different phases are carried out in at least 2 separate reactors, this is referred to as a multi-stage system. The rationale behind one and multi-stage systems is to sequence the biochemical reactions that do not necessarily share the same optimal environmental conditions. The common practice in multi-stage systems is that the hydrolytic, acidogenic and acetogenic phases are carried out in one reactor while the methanogenic phase is carried out in a separate reactor. Single-stage systems are less complex to design, build and operate and also less expensive than multi-stage systems owing to the use of a single reactor (Rapport et al., 2008; Williams, 2012). However, single-stage systems are limited by the organic loading rate of the digester due to the potential accumulation of volatile fatty acids during the acidogenic and acetogenic phases that may inhibit the methanogenic phase and methane production (Rapport et al., 2008). Consequently, multi-stage systems are more able to optimise the different phases of anaerobic digestion and thus, methane production is enhanced (Williams, 2012).

2.1.3 Mode of operation

Biogas plants may be operated either as batch or continuous systems and are often classified based on the number of stages employed and the TS content of the wastes processed.

2.1.3.1 Batch systems

Batch systems operate under the principle that the feedstocks are all fed at the beginning of a cycle and once digested, everything is removed at the end of the cycle, following which, the cycle is repeated. Batch anaerobic digestion systems can be classified into two main types namely single-stage batch and multi-stage batch, as further explained:

- **Single-stage batch systems:** These comprise only one reactor wherein the percolate (or liquid fraction of the digestate) is recirculated to the top of the digester. Examples of single-stage batch systems include the Biocel process, the BEKON system and the BioConverter digester (Rapport et al., 2008; Williams, 2012; Jain et al., 2015; Fu et al., 2018).

- **Biocel Process**

The Biocel process, owned by Orgaworld, operates as a high solids batch system under mesophilic conditions and allows the conversion of organic wastes into biogas and compost (Brummeler, 2000; Rapport et al., 2008). There is currently one large scale Biocel biogas plant in Lelystad, Netherlands treating 30,000 tonnes per annum (tpa) of organic wastes, including yard wastes (Orgaworld, 2014).

- **BEKON Process**

In the BEKON anaerobic digestion system (developed by BEKON GmbH)), fresh wastes (of high solids content) are mixed with digested waste to provide the inoculum source and the waste mass is digested without any mixing process. Percolate is collected from the bottom of the digester and recirculated to the top of the digester system (BEKON GmbH, 2016a). There are currently 46 BEKON biogas plants worldwide (majority in Europe) treating source-segregated organic wastes, organic fraction of municipal solid wastes, with plant capacities ranging from 3,500 tpa to 60,000 tpa (BEKON GmbH, 2016b). As per a report from GIZ (2019), a 25,000 tpa BEKON biogas plant had an investment cost of USD 8.85 Million.

- **BioConverter**

The BioConverter digester operates as a single-stage sequential batch system and was developed by McElvaney Associates Corporation (Williams, 2012; Jain et al., 2015). However, the use of an equalisation tank prior to the digestion process results in the separation of the hydrolysis phase from the other three phases of digestion, implying that this could instead be classified as a multi-stage system (Rapport et al., 2008).

- **Multi-stage:** multi-stage processes make use of two or more reactors for the different phases of anaerobic digestion. More often, methanogenesis is carried out in a separate reactor while hydrolysis, acidogenesis and acetogenesis are carried out in another reactor. An example of a multi-stage batch anaerobic digestion system is the hybrid batch-upflow anaerobic sludge blanket (UASB) system whereby the methanogenic phase is carried out in the UASB reactor (Verma, 2002). Another example of a multi-stage batch anaerobic digestion system is the anaerobic phased solids (APS) digester, commercialised by Onsite Power Systems, wherein rapid volatile fatty acids production is promoted in sequential digesters while methanogenesis is carried out in a separate reactor (Rapport et al., 2008; Williams, 2012; Jain et al., 2015). The APS digester operates as a high-solids system (CleanWorld, 2015) and biogas yield in this system ranges from 400 to 500 m^3/tonne volatile solids (Rapport et al., 2008). A pilot APS digester has been commissioned at the University of California at Davis (Zhang and Rapport, 2011).

Batch systems offer the benefit of being simple to operate, robust and less expensive than continuous systems (Monnet, 2003; Kothari et al., 2014). Besides, in batch systems, pre-treatment of the substrates is often not a requirement (Fu et al., 2018). However, these systems are relatively large and require a huge extent of land for commissioning as opposed to continuous systems (Monnet, 2003). Furthermore, control over the biological process is difficult in batch systems and process failures may be difficult to remediate in between cycles (Rapport et al., 2008).

2.1.3.2 Continuous systems

In continuous systems, feedstocks are constantly fed to the digester and digestate is continuously removed from the system. Similar to batch systems, continuous anaerobic digestion systems may operate either as single-stage systems or multi-stage systems and also based on the TS content of the wastes being processed. As opposed to batch systems, continuous systems can be more complex to operate, maybe more expensive but require less land for commissioning. Based on the number of stages and the TS content of the wastes, continuous anaerobic digestion systems may be sub-classified as single-stage low solids (SSLS), single-stage high solids (SSHS), multi-stage low solids (MSLS) or multi-stage high solids (MSHS). For each of these different systems, commercialised technologies have been designed and commissioned, as further detailed out:

- **Single-stage low solids (SSLS)**

SSLS systems operate on the low solids content and comprise only one reactor or bio-digester for the four phases of anaerobic digestion. Some examples of SSLS systems that have been commercialised include the Waasa process and the BIMA process, as further explained.

- **Waasa Process**

The Waasa process originated in Finland in the late 1980s and was initially developed by the company Citec, Finland (Rapport et al., 2008). The Waasa process comprises primarily a pulping stage followed by the anaerobic digestion process (Cesaro et al., 2010). Organic fraction of municipal solid wastes (OFMSW) are initially homogenized and water is added to adjust the TS content during the pulping stage (TS content of 10% to 15%) (Nichols, 2004). The pre-treated MSW is then fed to a continuously stirred vertical tank reactor (biodigester) for the anaerobic digestion process operating under either mesophilic or thermophilic conditions (Verma, 2002; Nichols, 2004; Williams, 2012). The vertical reactor is sub-divided internally into the main reactor and a pre-digestion chamber (Nichols, 2004; Nayono, 2009). The pre-digestion chamber allows for inoculation of the feedstock and prevents the loss of feedstock through shorter retention times (which may be common in continuously stirred tank reactors) (Nayono, 2009; Williams, 2012). Biogas production in the Waasa process is estimated at 100 to 150 m^3/tonne of added waste (Williams, 2012). According to Rapport et al. (2008), more than 10 biogas plants are using the Waasa process worldwide, with plant capacities ranging from 3,000 tpa to 230,000 tpa.

- **BIMA Process**

The Biogas Induced Mixing Arrangement (BIMA) process is commercialised by Entec Biogas GmbH (Austria) (Rapport et al., 2008). As the name implies, mixing is brought about by the biogas produced in the biodigester. Essentially, the BIMA process comprises a reactor with an upper and a lower chamber connected by a central tube (Reddy, 2016a). The pressure difference caused by the biogas produced in the upper chamber causes the feedstock (slurry) to move to the lower chamber through the central tube while the removal of biogas from the digester likewise causes the slurry to rise through the central tube, thereby creating the mixing effect (Rapport et al., 2008; Reddy, 2016a). Over 40 BIMA digesters are operational worldwide (Entec Biopower, n.d.), with few available data reporting plant capacities ranging from 30 tonnes per day (tpd) to 235 tpd (Reddy, 2016b)

- **Single-stage high solids (SSHS)**

SSHS systems are similar to SSLS in terms of the mode of operation but the main difference is that these operate using a feedstock having a high TS content. The three main commercialised SSHS technologies are the DRANCO process, the Kompogas process and the Valorga process, as further detailed out.

- **DRANCO Process**

The DRANCO (DRy ANaerobic COmposting) process was designed in 1983 and is commercialised by Organic Waste Solutions (OWS) from Belgium (Rapport et al., 2008; Maleki-Ghelichi and Sharifi, 2017; Fu et al., 2018). The DRANCO technology consists of a vertical cylindrical digester with a conical bottom used for the collection of the digestate and a pre-mixing unit. The fresh wastes are mixed with inoculum/digestate in the mixing unit, fed to the top of the digester and moves downward as a plug flow (Williams, 2012). Digested wastes are removed at the bottom of the digester, with part of the digestate mixed with fresh wastes and recirculated to the top of the digester while the remaining digestate can be used to produce compost. As for the biogas produced, this is collected and stored separately in a biogas holder. With the mixing of fresh wastes and digestate being carried out in the mixing unit, no mixing is thus carried out in the digester (Maleki-Ghelichi and Sharifi, 2017). The DRANCO process can operate under both mesophilic and thermophilic conditions and can treat organic wastes up to a TS content of 40% (OWS, 2021a). Biogas yields from the DRANCO process range from 103 to 147 m^3/tonne wastes (Rapport et al., 2008), although Nichols (2004) reported a yield of up to 200 m^3/tonne wastes. The hydraulic retention time in DRANCO digesters range from 15 to 30 days depending on the feedstocks used (Nichols, 2004) and OWS reports having single DRANCO digesters up to a digestion capacity of 60,000 tpa (OWS, 2021a). There are 36 biogas plants using the DRANCO technology worldwide, with plant capacities ranging from 3,000 tpa to 320,000 tpa and digester sizes reaching 6,000 m^3 (OWS, 2021b).

- **Kompogas Process**

The Kompogas process commercialised by the company Hitachi Zosen Inova is another SSHS anaerobic digestion system (Hitachi Zosen Inova AG, 2020a). The Kompogas process is similar to the DRANCO process in that it operates as a plug-flow system but the difference is that the Kompogas process employs a horizontal cylindrical reactor as the digester (Cesaro et al., 2010). The Kompogas process also comprises an agitator with a rotor inside the digester for mixing and degassing purposes (Rapport et al., 2008; Williams, 2012). Fresh wastes are introduced to one end of the reactor and move horizontally to the other side of the reactor through which the digested wastes are removed after a retention time of 15-20 days (Nichols, 2004; Rapport et al., 2008). The digestate is passed through a press to separate the solid and liquid digestate. The solid digestate is used as organic fertiliser while the liquid digestate is used as liquid fertiliser, sent to a wastewater treatment plant for further treatment or part of the liquid digestate is recirculated to the digester (Hitachi Zosen Inova AG, 2020a; Maleki-Ghelichi and Sharifi, 2017). The Kompogas digester systems can be used on modular basis (depending on the amount of wastes to be treated and retention time) and one Kompogas digester can reach 1,200 m^3 in size (Hitachi Zosen Inova AG, 2020a). The Kompogas process operates under thermophilic conditions, with a TS content of 23% to 28% and the biogas yield ranges from 110 to 130 m^3/tonne of wastes processed (Nichols, 2004; Maleki-Ghelichi and Sharifi, 2017). There are over 38 Kompogas plants worldwide (Rapport et al., 2008), with capacity throughputs reaching 83,000 tpa (Hitachi Zosen Inova AG, 2020b).

- **Valorga Process**

The Valorga process, commercialised by Valorga International, comprises a vertical cylindrical digester but is designed to produce a horizontal plug-flow system which is made possible through an inner wall inside the digester on two-thirds of its diameter (Valorga International SAS, 2006a). The feed inlet and digestate outlet from the reactor are located on the bottom of the digester but either side of the inner wall. Once fresh wastes are fed into the digester, these are compelled to move around the inner wall (Valorga International SAS, 2006a). Furthermore, part of the biogas produced is recirculated to the process through nozzles located at the bottom of the digester. The pressurised biogas thus pushes up the waste materials and ensures constant mixing in the digester (Rapport et al., 2008). The digested wastes undergo a dewatering process prior to being composted. The Valorga process operates under both mesophilic and thermophilic conditions using a TS content of 25% to 35% and a retention time of 18 to 25 days (depending on wastes processed), thereby resulting in a methane yield of 80 to 160 m^3/tonne wastes (Nichols, 2004; Williams, 2012). There are 27 biogas plants worldwide using the Valorga process, with capacities ranging from 10,000 tpa to 268,500 tpa and digester size reaching 4,500 m^3 (Valorga International SAS, 2006b).

- **Multi-stage low solids (MSLS)**

MSLS systems operate on the low solids content and comprise more than one reactor or bio-digester for the four phases of anaerobic digestion. The methanogenenic phase of anaerobic digestion is most commonly separated from the other three phases. Some of the main MSLS systems that have been commercialised include the BTA process and the Linde-KCA process, as further discussed.

- **BTA Process**

The Biotechnische Abfallverwertung (BTA) process, commercialised by BTA International GmbH through different licensees to several parts of the world, is essentially a mechanical-biological waste treatment process (BTA International GmbH, 2021a). When commingled MSW is fed to the process, the main recyclables and rejects are removed through a dry pre-treatment system. The remaining waste fraction then undergoes the BTA hydro-mechanical pre-treatment which comprises a waste pulper and a grid remover. In the waste pulper, the wastes are mixed with water to reach a TS content of 10% and the waste pulper produces three fractions namely a light fraction comprising plastics and textiles, a heavy fraction consisting of bones and stones and a digestible organic fraction (Williams, 2012; BTA International GmbH, 2021a). The light and heavy fractions are removed from the system as residual wastes while the third fraction (digestible organic fraction) is sent to a grit removal system for removal of small particles such as sand. The digestible organic fraction is then sent to a screw press whereby the liquid generated is sent directly to a methanogenic reactor for biogas production (Rapport et al., 2008). The organic solids from the screw press are mixed with water to achieve a TS content of 25% and then sent to a hydrolytic reactor for 4 days (Rapport et al., 2008). The hydrolysate is then sent to the methanogenic reactor for biogas production (Verma, 2002). The digestate produced from the BTA process is dewatered prior to being composted. The BTA process is operated under mesophilic conditions (35-38°C) (BTA International GmbH, 2021a), with a biogas yield ranging from 120 to 150 m^3/tonne wastes (Rapport et al., 2008). There are over 50 plants worldwide operating on the BTA process, with plant capacities ranging from 2,500 tpa to 190,000 tpa (BTA International GmbH, 2021b). For a 40,000 tpa capacity plant, the investment costs are estimated at USD 46 Million (GIZ, 2019).

- **Linde-KCA Process (Wet system)**

The company Linde-KCA has designed multi-stage digesters for both wet and dry systems. The wet system operates like the waste pulper stage of the BTA process. Following the pulping and screening stage, the organic waste suspension is sent to a hydrolysis and suspension buffer tank, following which, it is sent to the methanogenic reactor for biogas production (Williams, 2012). The digestate is sent to a dewatering press and can then be subjected to a composting process. The Linde-KCA wet system has been employed under thermophilic conditions for wastes with high grease content (Nichols, 2004).

- **ArrowBio Process**

The ArrowBio process, developed by Arrow Ecology Ltd. (Israel), employs a waste sorting system whereby all undesirable materials are removed, similar to the BTA and Linde-KCA wet system (Williams, 2012). The organic solid suspension is then sent to an acidogenic reactor for the production of volatile fatty acids. The effluent from the acidogenic reactor was screened, heated to 40^{o}C and sent to a UASB reactor for methane production under mesophilic conditions (Williams, 2012). Arrow Ecology Ltd. has 4 plants operating or under construction worldwide, with capacities for anaerobic digestion reaching 300 tpd (Arrow Ecology, n.d.). A typical 80,000 tpa capacity plant operating on the ArrowBio process could have an investment cost of USD 12 M (Williams, 2012).

- **Multi-stage high solids (MSHS)**

MSHS are similar to MSLS in terms of their mode of operation but the main difference is that these operate at a higher TS content. Some of the main MSHS systems that have been commercialised include the Biopercolat process and the Linde-KCA process, as further explained.

- **Biopercolat Process**

The Biopercolat process developed, by Wehrle Umwelt GmbH, is a two-stage system, employing a separate hydrolytic phase and a methanogenic phase (Rapport et al., 2008). As the waste mass enters the hydrolytic reactor, which is essentially a rotating tunnel, water percolates at the top of the waste mass (Rapport et al., 2008). The leachate produced from the waste mass then moves to the methanogenic reactor (a UASB with attached growth system) for digestion into biogas over a retention time of seven days (Verma, 2002). The solids from the percolator are removed at two to three days intervals and sent to a screw press. The liquid part from the screw press is sent to the methanogenic reactor while the solid fraction is sent to a composting unit (Rapport et al., 2008). As for the water from the methanogenic reactor, this is partly recirculated as process water while the remaining is treated as wastewater (Rapport et al., 2008). Information on the Biopercolat process is scanty in literature, with Rapport et al. (2008) reporting that there is only 1 operational plant using the Biopercolat process of capacity 100,000 tpa.

- **Linde-KCA Process (Dry system)**

The Linde-KCA dry process operates as a two-stage aerobic and anaerobic phase. In the aerobic phase, hydrolysis of the waste mass takes place following which, the hydrolysed matter is then sent to a plug-flow methanogenic reactor comprising internal rotors or agitators to ensure mixing and flow of the waste through the reactor to the outlet (Rapport et al., 2008). Similar to the wet system, the digestate from the Linde-KCA dry process is sent to a dewatering press and can then be subjected to a composting process. The Linde-KCA dry system has been employed under both mesophilic and thermophilic conditions (Nichols, 2004) and has a biogas yield of 100 m^3/tonne waste (Nichols, 2004; Rapport et al., 2008). There are at least 8 plants worldwide, with capacities ranging from 15,000 to 150,000 tpa, operating under the Linde-KCA wet/dry anaerobic digestion technology (Rapport et al., 2008).

2.1.4 Selection of anaerobic digestion technology

The selection of the anaerobic digestion technology suitable to the Mauritian context was made based on a multi-criteria decision analysis (MCDA) using the Simple Multi-Attribute Rating Technique (SMART). A series of attributes or criteria were chosen to allow for the selection of the most suitable anaerobic digestion technique for Mauritius. These criteria were selected from Kigozi et al. (2015), based on factors considered as being primordial to the setting-up, operation and maintenance of a biogas plant. Each criterion was also assigned a ‘weight’ based on its importance as opposed to the other criteria. For each attribute, a score of 0 to 2 was assigned. Table 1 summarises the different criteria, the weights assigned and how the score could be allocated.

Table 1– Criteria selected for MCDA using SMART for technology selection

Criteria	Description	Weight	Score		
			0	**1**	**2**
Waste Suitability (A)	This determines the suitability of the technique chosen for processing the organic solid wastes in Mauritius (i.e. with high solids content)	0.15	Not Suitable	Suitable	Highly Suitable
Investment Costs (B)	The investment costs often determine the choice of a technique and the willingness of potential promoters to invest	0.15	High	Medium	Low
Operating and Maintenance Costs (C)	Operating and maintenance costs help determine the profitability of a project	0.11	High	Medium	Low
Land Requirement (D)	With limited land availability in Mauritius, a plant with the lower land requirements will be more favourable	0.13	High	Medium	Low
Complexity of Construction, Operation and Maintenance (E)	If a plant is easy to construct, local labour can be available and this reduces the investment costs. If the plant is simple to operate and maintain, highly qualified personnel will not be required and this reduces the operating and maintenance costs.	0.10	High	Medium	Low
Control on the Digestion Process (F)	Control over the digestion process ensures that any issues in digestion can be remediated to prevent process failures.	0.11	Low	Medium	High
Capacity Scalability (G)	This determines whether the plant is available in different sizes that can be customised for the Mauritian context	0.10	Poor	Good	Excellent

Temperature Regulation Ability (H)	Temperature is an important parameter of the digestion process to ensure optimum biogas production. As such, it is important to regulate the temperature inside the digester.	0.08	No	Can be customised	Yes
Presence of Agitation System (I)	Similar to temperature, constant mixing inside the reactor ensures maximum biogas production. As such, agitation inside the digester is preferable.	0.08	No	Can be customised	Yes

For each criterion listed in Table 1, the scores were assigned for each type of anaerobic digestion system reviewed. These results are listed in Table 4.

Table 2 – Scores for each criterion for each anaerobic digestion system

Anaerobic digestion system	**Criteria**								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Batch – Single Stage (High solids)	2	2	2	0	2	0	1	2	2
Batch – Multi Stage (High solids)	2	1	1	0	2	1	1	2	2
Continuous – SSLS	0	1	1	2	1	1	2	2	2
Continuous – SSHS	2	1	1	2	1	1	2	2	2
Continuous – MSLS	0	0	0	1	0	2	2	2	2
Continuous – MSHS	2	0	0	1	0	2	2	2	2

A – Waste Suitability; B – Investment Costs; C – Operating and Maintenance Costs; D – Land Requirement; E – Complexity of Construction, Operation and Maintenance; F – Control on the Digestion Process; G – Capacity Scalability; H – Temperature Regulation Ability; I – Presence of Agitation System

Based on the scores assigned in Table 4 and the weightage for each criterion as listed in Table 3, the weighted scores for each criterion for each anaerobic digester system are then determined and the results are summarised in Table 6, with the ranks of each digester system also included.

Table 3 – Weighted scores and ranking for each criterion for each anaerobic digestion system

Anaerobic digestion system	Criteria (Weights)									Total	Ranking
	A (0.15)	B (0.15)	C (0.11)	D (0.13)	E (0.10)	F (0.11)	G (0.10)	H (0.08)	I (0.08)		
Batch – Single Stage (High solids)	0.29	0.29	0.23	0.00	0.19	0.00	0.10	0.16	0.16	1.42	2
Batch – Multi Stage (High solids)	0.29	0.15	0.11	0.00	0.19	0.11	0.10	0.16	0.16	1.27	3
Continuous – SSLS	0.00	0.15	0.11	0.26	0.10	0.11	0.19	0.16	0.16	1.24	4
Continuous – SSHS	0.29	0.15	0.11	0.26	0.10	0.11	0.19	0.16	0.16	1.53	1
Continuous – MSLS	0.00	0.00	0.00	0.13	0.00	0.23	0.19	0.16	0.16	0.87	6
Continuous – MSHS	0.29	0.00	0.00	0.13	0.00	0.23	0.19	0.16	0.16	1.16	5

A – Waste Suitability; B – Investment Costs; C – Operating and Maintenance Costs; D – Land Requirement; E – Complexity of Construction, Operation and Maintenance; F – Control on the Digestion Process; G – Capacity Scalability; H – Temperature Regulation Ability; I – Presence of Agitation System

Based on the results from Table 3, the continuous SSHS anaerobic digestion system is most suitable for the Mauritian context. Under this digester system, there are three highly commercialised technologies operational worldwide namely the DRANCO process, the Kompogas process and the Valorga process. While any of these techniques could be implemented in Mauritius, these are patented technologies, are highly automated systems and require a high level of expertise and skilled staffs. Furthermore, these techniques, being patented technologies, are also expensive although they are cheaper that multi-stage one. As such, although it is recommended that a continuous SSHS anaerobic digestion system be implemented in Mauritius, the technology to be selected will eventually depend on the investment costs.

2.2 Biogas storage systems

Biogas can be generally combusted (after cleaning) for the production of electrical energy. However, biogas is also temporarily stored for later usage particularly to meet peak loads. Biogas storage systems are classified into two main types namely internal storage systems and external storage systems (Zafar, 2020). Internal biogas storage systems are essentially incorporated in the biodigester system while external biogas storage systems are independent and separate from the biodigester unit (Zafar, 2020). The different types of biogas storage systems that are commonly used have been designed based on the pressure they can sustain and include low pressure, medium pressure and high-pressure biogas storage systems (Deublein and Steinhauser, 2008). The type of biogas storage system will be discussed in Deliverable 5.

2.2.1 Low-pressure biogas storage systems

Low-pressure biogas storage systems are the most commonly employed biogas storage systems and are designed to sustain a pressure of 0.05 mbar to 50 mbar (Deublein and Steinhauser, 2008). Low-pressure biogas storage systems are employed as either internal storage systems integrated into the biodigester or as external storage systems. Internal storage low-pressure storage systems exist as floating drums or as thermoplastic foils acting as the bioreactor cover (Krich et al., 2005; Deublein and Steinhauser, 2008). External low-pressure biogas storage systems commonly exist as double-membrane gasholders, plastic biogas bags and enclosed thermoplastic foil gasholders (Deublein and Steinhauser, 2008). Low-pressure biogas storage systems are much larger in size than the high-pressure ones and can reach up to 2,000 m^3 capacity (Deublein and Steinhauser, 2008).

2.2.2 Medium and high-pressure biogas storage systems

Medium pressure biogas storage systems can sustain pressures varying from 5 to 20 mbar while high-pressure biogas storage systems are designed for a pressure up to 300 bar (Deublein and Steinhauser, 2008). Both medium and high-pressure biogas storage systems are made from steel and exist as pressure tanks and pressurised flasks respectively (Deublein and Steinhauser, 2008). The maximum size of medium pressure biogas storage systems can reach up to 100 m^3 while that of high-pressure flasks is up to a maximum of 0.5 m^3 (Deublein and Steinhauser, 2008).

3. Identification of Suitable Sites for the Biogas Plant (Deliverable 4.2)

Proper site selection is essential during the planning stage for the implementation of anaerobic digestion. The main criteria that decides the choice of a suitable site for construction of a biogas plant are the distance of the biogas plant from the waste source (or supply), its proximity with the grid network, current and future land use, land ownership, available space, accessibility to the site, site characteristics, use of digestate and sufficient buffer from existing residential areas (Kigozi et al., 2015). Two approaches may be followed for the identification of suitable sites:

1. **A Multi-Criteria Decision Analysis (MCDA) Approach**: The MCDA process will score and rank a number of criteria to be utilised in the site selection process (Annex 1). See also the additional explanation at the end of this report.
2. **A Geographic Information Systems (GIS) Approach**: GIS is a powerful spatial analytical tool which can be utilized in conjunction with the MCDA process for site selection. Like any computational based platform, the relevance depends on the QUALITY of the data used (i.e., 0.5m resolution Digital Terrain Modelling data is better than publicly available ~30m resolution data). For the GIS approach, a list of required GIS information is provided to assist the SWMD in future site selections. For the local context, the GIS data can be obtained from the Government of Mauritius (or more specifically the local authorities who will have a better understanding of the local context). Some local governments or local authorities may also have good quality data on hand, if not, this has to be purchased (where available) or surveyed (this may not be practical given the budget limitation and time constraints of the project).

3.1 Site selection criteria

Some of the aforementioned criteria which can be used for both the MCDA and the GIS hybridised approach are further detailed out as a guide for the eventual selection of a site for the commissioning of a biogas plant.

3.1.1 Waste supply

The point of waste generation determines the radius within which a biogas plant could be set up. However, this also depends on the waste to be processed by the biogas plant. For instance, processing sewage sludge or animal manures implies the biogas plant needs to be located close to the point of generation as these waste materials cannot be transported over long distances in view of the foul smell and limitations presented for handling this semisolid wastewater during transportation. A radius of 5 km from the point of generation is often recommended for biogas plants processing liquid agricultural feedstock (animal manures) or sludge (Epp et al., 2008).

However, for biogas plants processing the organic fraction of MSW, the distance could be increased as this waste mass has a less foul smell and generates less water (if any) during transportation. A radius of 15 km from the point of generation is often recommended for biogas plants processing organic fraction of MSW (Epp et al., 2008). Distance greater than the 15 km radius will increase transportation costs and decrease the profitability of the project.

The current feasibility study focuses on solid organic wastes generated from hotels, fresh produce markets and households. With all these wastes transiting through one of the five transfer stations prior to disposal at the landfill (except for wastes from the south and south-east), the transfer stations and the landfill (for south/south-east) could be considered as the points of waste generation. As such, a radius of 15 km from each transfer station/landfill could limit the potential areas in which a future biogas plant could be located, as illustrated in Figure 1.

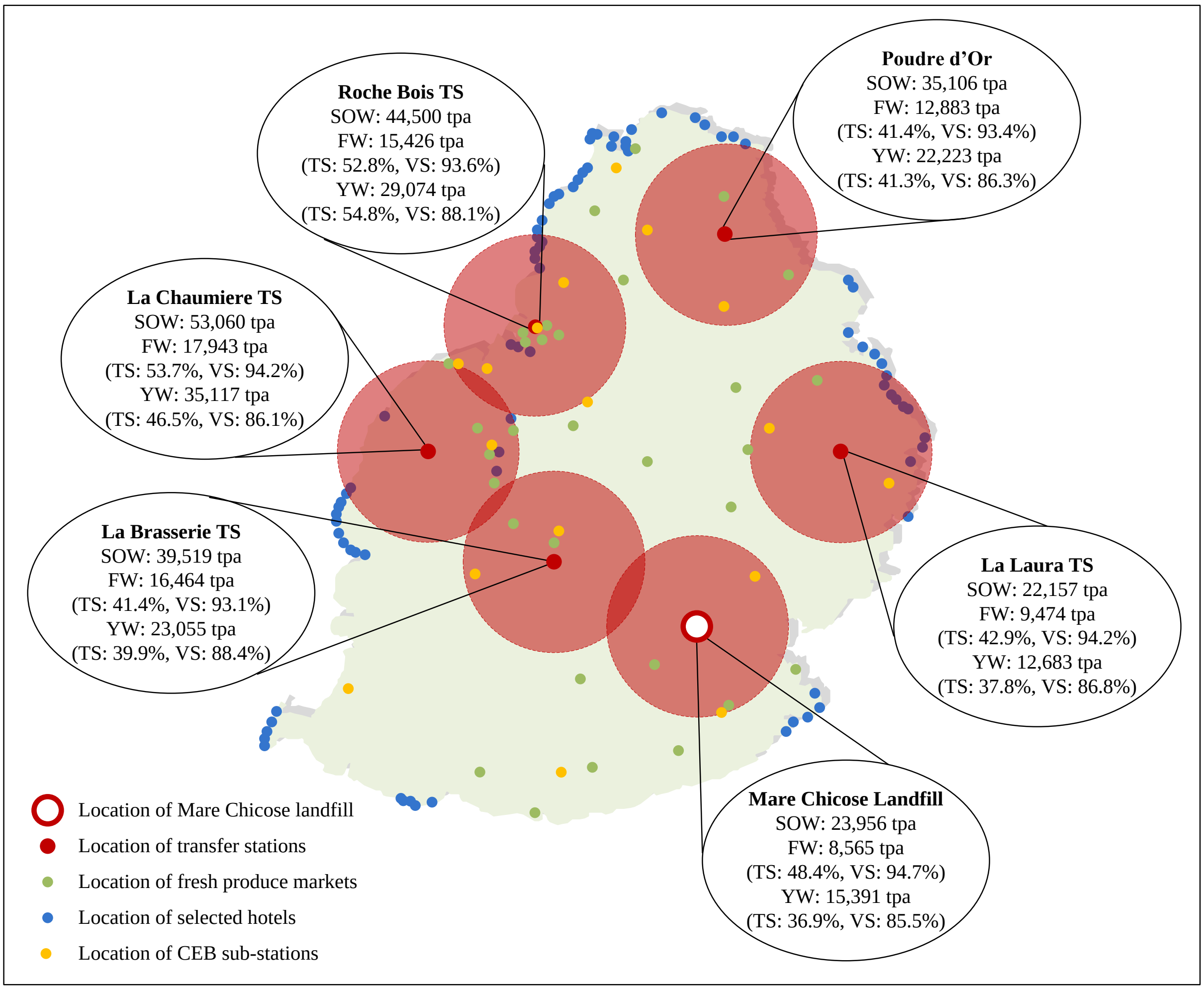

Figure 1 – Location of solid organic wastes generation points and sub-stations of the Central Electricity Board (Source for sub-stations: CEB, 2019)

From Figure 1, it can be observed that based on the waste generation points (location of hotels, markets and transfer stations), the northern, eastern and western regions of Mauritius represent the areas with the highest potential for commissioning of a biogas plant. Based on the waste amount, the western area is the most appropriate. However, it must also be factored in that the Solid Waste Management Division is embarking on the setting-up of regional composting plants in the Northern or Western regions of Mauritius (SWMD, personal communication, May 2021). This could represent both an advantage and a drawback. The advantage is that a future biogas plant could be annexed to the composting plant planned to be constructed by the Solid Waste Management Division and this would imply that the digestate from the biogas plant could be treated at the annexed composting plant. The drawback of having a biogas plant in the region of the composting plant is that there could be "competition" for feedstocks depending on the capacity of the composting plant and the biogas plant. This point will need to be carefully considered. The GIS locations for the following infrastructure is required for a GIS analysis:

- GIS Points of future waste management infrastructure (composting facilities)
- GIS Points of all 5 transfer stations
- GIS Points of all Fresh produce markets
- GIS Points of Hotels on the island generating significant food waste

3.1.2 Grid network

The second criterion that determines the selection of a site for setting-up of a biogas plant are the possibility for connection to the grid network. Unless the biogas produced is not intended for electricity production, a biogas plant must be located within a reasonable distance from the grid. The electricity produced from a biogas plant is normally at low voltage and transportation of this low voltage over long distances results in high losses (Epp et al., 2008). As such, the low voltage needs to be stepped up at a transformer site (at a station in the vicinity of the biogas plant) prior to sending over high voltage lines to a transmission sub-station (Epp et al., 2008). At the transmission substation, the voltage is stepped down prior to sending to a distribution substation where the voltage is further stepped down to the required voltage for transmission to households through low voltage electric distribution lines (Brain, 2002). While there is no mention of any distance limit between a biogas plant and the step-down sub-station, minimising this transmission distance reduces transmission losses. As observed in Figure 1, the sub-stations of the Central Electricity Board (CEB) are well scattered around the island, implying that transmission losses due to long distances will not be an issue. For a GIS Analysis, the following information is required:

- The location data of CEB substations is a requirement of the GIS analysis.
- The location of existing electrical grid (transmission) servitudes

3.1.3 Available space

Space availability or land extent is another important criterion for setting up a biogas plant. Land requirement for a biogas plant is dependent on the size of the biodigester and other unit operations in the biogas plant such as the substrates preparation tanks, buffer tanks, shredder, conveyor belts, biogas storage system, biogas cleaning unit, combined heat and power unit and digestate management unit (e.g. a composting area if digestate is composted). All these unit operations are typically size based on the amount of wastes processed while the size of the biodigester is also dependent on the mode of operation and the number of stages of anaerobic digestion and the hydraulic retention time selected for digestion. The space required for the setting-up of the biogas plant will be worked out in Deliverable 5 "Schematic design of the biogas plant". On an indicative basis, a 500 kW_{el} biogas plant requires 4,000 m^2 of land, excluding the area for storage of biomass and digestate processing (Epp et al., 2008). This information will be used to identify suitable cadastral. For a GIS Analysis, the following information is required:

- Land parcels / Cadastral
- Land Parcel Ownership (i.e. government versus private sector)
- Aerial Photos / Satellite imagery

3.1.4 Site accessibility

A suitable site for the setting-up of any infrastructures must consist of appropriate access. Access to waste infrastructures such as biogas plants must make provision for either two-way traffic or if one-way traffic is provided, there must be one entrance to the site and another exit from the site. The access roads must also be large enough and provide good turning radii for large trucks to easily enter and leave the facility. The roads must also give direct access to main roads (Epp et al., 2008). The site should also not be too steep. For a GIS Analysis, the following information is required:

- Existing Road Networks (including speed limits for the different classes of roads)
- Digital Terrain Mapping (DTM) at preferably 0.5m contour intervals.

3.1.5 Digestate use

The use of the digestate is another parameter that may decide the location of a biogas plant. If the digestate is intended to be used as organic fertiliser or composted to be used as soil conditioner, the organic fertiliser or compost should be applied on fields or other cultivated areas in the vicinity of the biogas plant so as to reduce transportation costs of the compost or biofertiliser. As such, siting a biogas plant in the vicinity of fields or other cultivated areas is privileged. For a GIS Analysis, the following information is required:

- The GPS points of the location of any local government supported community gardens or projects that could benefit from the use of the digestate.
- The GPS points for any commercial private sector enterprises which could potentially make use of the digestate.

3.1.6 Buffer

A biogas plant must be located in such a region that will not cause any unacceptable impacts to the nearby residents. The building and land use permit require that any polluting activity must be located at least 1 km from an existing residential area (Ministry of Local Government and Outer Islands, 2017). Considering that waste materials will be handled and processed at the biogas plant, it should be sited at least 1 km from an existing residential area. Furthermore, attention needs to be given to wind directions and whether any foul smell from the waste mass will impact the closest residential area. Furthermore, biogas plants must not be constructed near or at environmentally sensitive areas such as wetlands and wildlife habitats. For a GIS Analysis, the following information is required:

- Town planning land use layers (specifying industrial areas or residential cadastrals)
- Environmentally sensitive areas (i.e. rivers and wetlands, parks, etc.)
- Natural or Scenic areas to be excluded
- National Parks
- Conservancies
- Green corridors
- Wind direction maps (showing prevailing winds especially close to residential or industrial areas)

3.1.7 Site characteristics

The site characteristics including the soil conditions are important parameters that determine whether a biogas plant can be constructed or not. A typical digester in a biogas plant of a capacity 100 tpd and a hydraulic retention time of 30 days weighs more than 3,000 tonnes on a daily basis. As such, geotechnical investigations will be required for any site earmarked for housing a biogas plant and the physical properties of the soil will have to be determined. The site must also not be located in a region prone to flooding. Also, excessively steep slopes will require extensive earthworks which could also contribute to the costs for the development of the selected site. Where slopes are more than 3:1 (or 18 degrees), these areas will need extensive earthworks (increased costs) as opposed to sites which have more gentle slopes, thereby adding to the capital costs for the project. For a GIS Analysis, the following information is required:

- Underlying soil mapping designating any areas which may be unsuitable for the location of the infrastructure (i.e. sandy areas or areas prone to geotechnical faults lines, volcanic areas, fracture zones, etc.)
- 1:100-year flood lines.
- Environmentally sensitive areas (i.e. dams, rivers and wetlands, parks, etc.).
- Digital Terrain Mapping (DTM) at preferably 0.5m contour intervals.

3.1.8 Bulk Water Supply Points

Where the plant will need to tap into or draw water from existing water supply infrastructures, a coverage of bulk water supply available for use close to the proposed site will need to be known. For a GIS Analysis, the following information is required:

- Bulk Water Supply Points.
- Reticulation water supply lines.
- Water supply networks.
- Water Sources (boreholes and dams)

3.1.9 Wastewater Treatment infrastructure and associated networks

If effluent needs to be pumped or discharged to sewer where this cannot be stored onsite, the location of local tie in points (and the reticulation network) is important for the project. For a GIS Analysis, the following information is required:

- Waste water treatment facilities.
- Waste water networks.

3.1.10 Areas prone to sea level rise.

Mauritius is known to be an island state particularly susceptible to sea level rise. As such, the location of areas particularly susceptible to sea level rise will need to be excluded from selection of potential sites. For a GIS Analysis, the following information is required:

- Location of any areas prone to sea level rise.

3.1.11 Summary of GIS data required

In summary, the following GIS information will be required from the Mauritian authorities for selection of a site for construction of a biogas plant. This information is useful for the GIS exclusion mapping and site selection process and could assist the SWMD for site selection in the future:

- GIS Points of future waste management infrastructure (composting facilities)
- GIS Points of landfill site
- GIS Points of all 5 transfer stations
- GIS Points of all Fresh produce markets
- GIS Points of Hotels on the island generating significant food waste
- This location data of CEB substations is a requirement of the GIS analysis.
- The location of existing electrical grid (transmission) servitudes
- Land parcels / Cadastral
- Land Parcel Ownership (i.e. government versus private sector)
- Aerial Photos / Satellite imagery
- Existing Road Networks (including speed limits for the different classes of roads)
- Digital Terrain Mapping (DTM) at preferably 0.5m contour intervals.
- The GPS points of the location of any local government supported community gardens tor projects that could benefit from the use of the digestate.
- The GPS points for any commercial private sector enterprises which could potentially make use of the digestate.
- Town planning land use layers (specifying industrial areas or residential cadastrals)
- Environmentally sensitive areas (i.e. rivers and wetlands, parks, etc.)
- Natural or Scenic areas to be excluded
- National Parks
- Conservancies
- Green corridors

- Wind direction maps (showing prevailing winds especially close to residential or industrial areas)
- Underlying soil mapping designating any areas which may be unsuitable for the location of the infrastructure (i.e. sandy areas or areas prone to geotechnical faults lines, volcanic areas, fracture zones etc.)
- 1:100 year flood lines.
- Environmentally sensitive areas (i.e. dams, rivers and wetlands, parks, etc.).
- Digital Terrain Mapping (DTM) at preferably 0.5m contour intervals.
- Bulk Water Supply Points.
- Reticulation water supply lines.
- Water supply networks.
- Water Sources (boreholes and dams)
- Wastewater treatment facilities.
- Wastewater networks.
- Location of any areas prone to sea level rise.

3.2 Identification of suitable site options

Based on some of the aforementioned criteria (distance from point of waste generation and location of grid networks), several options exist and may be considered by the Solid Waste Management Division, as follows:

3.2.1 Commissioning of a biogas plant in a transfer station or at the landfill

With the Ministry not having any suitable site within the earmarked regions in Figure 1, a first proposal is to commission a biogas plant at one of the 5 transfer stations or the landfill. In this context, a MCDA was employed using the Simple Multi-Attribute Rating Technique (SMART) to determine the most suitable site for housing of a biogas plant among the 6 aforementioned waste disposal sites. A series of attributes or criteria were chosen to allow for the selection of the most suitable site and these included the distance of the biogas plant from the waste source (or supply), its proximity with the grid network, current and future land use, land ownership, available space, accessibility to the site, site characteristics, use of digestate as compost, sufficient buffer from existing residential areas and location of wastewater treatment points. Each criterion was also assigned a ‘weight’ based on their importance as opposed to the other criteria. The weights for each criterion were decided during a meeting held with the Solid Waste Management Division and other key stakeholders in this project namely the Ministry of Energy and Public Utilities, the Central Electricity Board, the Ministry of Housing and Land Use Planning and the Food and Agricultural Research and Extension Institute under the aegis of the Ministry of Agro-Industry and Food Security.

For each attribute, a score of 0 to 2 was assigned. For this exercise, the Solid Waste Management Division was requested to provide the scores considering that they are more familiar with the sites. Table 1 summarises the different criteria, the weights assigned and how the score could be allocated.

Table 4 – Criteria selected for MCDA using SMART for site selection

Criteria	Description	Weight*	Score		
			0	**1**	**2**
Proximity of waste supply (A)	A biogas plant needs to be located within 15 km from the waste generation point	0.08	Too distant	Distant	Close
Current and future waste supply (B)	Waste availability in the short and long term is important to ensure that the plant has the minimum guaranteed tonnage to process. As such, any future strategy from the Government needs to be considered	0.12	Poor	Good	Excellent
Proximity with grid network (C)	The closer to the grid network, the less the transmission losses	0.06	Too distant	Distant	Close
Current and future land use (D)	The current and future land use often dictates the selection of a site. If the site is currently not developed but is planned for another project, then it is not worthwhile investigating the site	0.10	Current and future land use planned	Currently used but could be redeveloped for the project	No current and future land use planned
Land ownership (E)	The property rights of a site are primordial in the determination of site selection. With privately-owned site, negotiations can be tough while the site acquisition can be a lengthy and costly process	0.06	Private	Private but negotiable	State-land

Available space (F)	The available space or area on a site is also factor that decides the choice of a site	0.12	Low	Medium	High
Accessibility to site (G)	Site accessibility is important to reduce costs of land acquisition for development of road networks	0.11	Low	Medium	High
Site characteristics (H)	Site characteristics including the physical properties of the site are important parameters to consider prior to commissioning a biogas plant	0.10	Not suitable	-	Suitable
Use of digestate as compost in proximity to the biogas plant (I)	If the use of digestate as compost can be made in close proximity to the biogas plant, this reduces transportation costs	0.05	No	-	Yes
Sufficient buffer from residential areas (J)	A future biogas plant needs to be located at least 1 km from nearest existing residential areas	0.12	No	-	Yes
Wastewater treatment points and associated infrastructures (K)	If effluent needs to be pumped or discharged to sewer where this cannot be stored onsite	0.08	Too distant	Distant	Close

** Determined by stakeholders on 25.08.21 at the premises of the Solid Waste Management Division during the stakeholders meeting*

For each criterion listed in Table 4, the scores were assigned for each of the 6 potential sites (5 transfer stations and landfill) by the Solid Waste Management Division. These results are listed in Table 5 and the justifications for providing each score are summarised in Table 6.

Table 5 – Scores for each criterion for each site (Provided by the Solid Waste Management Division)

Site	Criteria										
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
La Chaumière transfer station	2	0	2	2	2	0	2	2	2	2	2
Roche Bois transfer station	2	0	2	2	2	0	1	0	0	0	2
Poudre d'Or transfer station	2	1	2	2	2	0	2	2	2	2	1
La Laura transfer station	2	2	2	2	2	2	2	2	2	2	0
La Brasserie transfer station	2	1	2	0	2	0	2	0	1	0	1
Mare Chicose landfill	2	2	2	0	0	1	2	2	2	2	0

A – Proximity of waste supply; B – Current and future waste supply; C – Proximity with grid network; D – Current and future land use; E – Land ownership; F – Available space; G – Accessibility to site; H – Site characteristics; I – Use of digestate as compost in proximity to the biogas plant; J – Sufficient buffer from residential areas; K – Wastewater treatment points and associated infrastructure

Table 6 – Justifications for each score for each criterion (Provided by the Solid Waste Management Division)

Criteria	Description	Justification
A	Proximity of waste supply	A score of 2 is given for all disposal sites as the biogas plant is within close proximity to the waste generation point
B	Current and future waste supply	The Ministry is planning on implementing regional composting plants and sorting units in the Western and Northern regions of Mauritius. These waste management facilities will

		cater for the wastes received at La Chaumiere and Roche Bois transfer stations and part of the wastes at La Brasserie and Poudre d'Or transfer stations. As such, the future waste supply at La Chaumiere and Roche Bois transfer stations will be minimal (thus the score of 0) while that at La Brasserie and Poudre d'Or transfer stations will still have some future waste supply (thus the score of 1). Only the future waste supply at La Laura transfer station and from the South (directly to the landfill) will have potential for exploitation in the future (thus the score of 2)
C	Proximity with grid network	With the CEB mentioning that the sub-stations are well-dispersed over the island, the proximity with grid network is thus not an issue and a score of 2 is given for all the disposal sites.
D	Current and future land use	There is no planned future land use for La Chaumiere, Roche Bois, Poudre d'Or and La Laura transfer stations and a score of 2 is thus given. For La Brasserie transfer station, there is a possibility of the site being relocated. Due to this uncertainty, a score of 0 is given. As for the landfill, this is being vertically expanded and it is not envisaged to have land available on this site in the near future, justifying the score of 0.
E	Land ownership	All the land for the 5 transfer stations are state-land (thus a score of 2). The land at the landfill is privately-owned and is being rented to the Ministry. It will be difficult to acquire the land in the future for commissioning a biogas plant, thereby justifying the score of 0.
F	Available space	With the exception of the landfill and La Laura transfer station, all the other disposal sites have a smaller land extent and thus, the available space to construct a biogas plant is insufficient, thereby justifying a score of 0. For La Laura transfer station, a land extent of

		2 Ha justifies the score of 2. For the landfill (despite having an extent of 50 Ha), a score of 1 is attributed due to the vertical expansion works that will be taking place, thereby limiting the available space for a biogas plant.
G	Accessibility to site	All the sites are easily accessible, thereby justifying the score of 2. Only for Roche Bois transfer station, the score is 1 due to heavy traffic in the morning and afternoon (near the capital of Port-Louis).
H	Site characteristics	Roche Bois and La Brasserie transfer stations are old dumpsites and the site may not be appropriate to withstand huge load, thus a score of 0 is attributed.
I	Use of digestate as compost in proximity to the biogas plant	In the vicinity of Roche Bois transfer station, vegetation is low, thereby decreasing the potential for use of compost (thus a score of 0). Same reasoning applies to La Brasserie transfer stations which nevertheless has some more vegetation, thereby being attributed a score of 1. For the other sites, there is a good level of vegetation and plantation in close proximity, thereby justifying the score of 2.
J	Sufficient buffer from residential areas	For Roche Bois and La Brasserie transfer stations, there are residents nearby the sites and thus a score of 0 is being attributed. For the other sites, there are sufficient buffer, thus warranting the score of 2.
K	Wastewater treatment points and associated infrastructure	Most of the major wastewater treatment plants are located in the western to north-western regions of Mauritius making them closer to Roche Bois and La Chaumière transfer stations (thus a score of 2 for these 2 sites).

Based on the scores assigned in Table 5 and the weightage for each criterion as listed in Table 4, the weighted scores for each criterion for each site are then determined and the results are summarised in Table 7, with the ranks of each digester system also included.

Table 7 – Weighted scores and ranking for each criterion for each site

	Criteria (Weights)												
Disposal sites	**A (0.08)**	**B (0.12)**	**C (0.06)**	**D (0.10)**	**E (0.06)**	**F (0.12)**	**G (0.11)**	**H (0.10)**	**I (0.05)**	**J (0.12)**	**K (0.08)**	**Total**	**Ranking**
La Chaumière transfer station	0.17	0.00	0.12	0.19	0.12	0.00	0.22	0.19	0.10	0.24	0.17	1.52	3
Roche Bois transfer station	0.17	0.00	0.12	0.19	0.12	0.00	0.11	0.00	0.00	0.00	0.17	0.88	5
Poudre d'Or transfer station	0.17	0.12	0.12	0.19	0.12	0.00	0.22	0.19	0.10	0.24	0.08	1.55	2
La Laura transfer station	0.17	0.24	0.12	0.19	0.12	0.24	0.22	0.19	0.10	0.24	0.00	1.83	1
La Brasserie transfer station	0.17	0.12	0.12	0.00	0.12	0.00	0.22	0.00	0.05	0.00	0.08	0.88	5
Mare Chicose landfill	0.17	0.24	0.12	0.00	0.00	0.12	0.22	0.19	0.10	0.24	0.00	1.40	4

A – Proximity of waste supply; B – Current and future waste supply; C – Proximity with grid network; D – Current and future land use; E – Land ownership; F – Available space; G – Accessibility to site; H – Site characteristics; I – Use of digestate as compost in proximity to the biogas plant; J – Sufficient buffer from residential areas; K – Wastewater treatment points and associated infrastructure

Based on the results from Table 7, La Laura transfer station is the most suitable for the commissioning of a biogas plant in Mauritius. However, the decision to convert this transfer station into a facility housing a biogas plant is dependent on the Solid Waste Management Division. This decision should be taken if no other suitable site is obtained after consultation with the Ministry of Housing and Land Use Planning or the private sector.

3.2.2 Vesting of land or land acquisition

Since the Ministry does not currently have any suitable site within the earmarked regions in Figure 1 (other than the sites at the transfer stations and the landfill), on-site investigations, as required in the response plan, could not be undertaken to determine the site suitability and whether the site meets all the aforementioned criteria. The Ministry of Housing and Land Use Planning could assist in investigating potential sites in the regions proposed (neighbouring La Laura transfer station) as to whether there are state-lands or not. If there are state-lands, further investigations (not within the scope of this feasibility study) should be carried out such as site accessibility and geotechnical investigations. It should be noted that where appropriate GIS information is available, this could be utilised as a pre-selection criteria for the project (it would be important to ground truth these findings on site when the preferred site is selected). The selected site could then be vested upon the Solid Waste Management Division. In the event that there is no state-land available, the potential for land acquisition from the private sector could be investigated in the region neighbouring La Laura transfer station. However, this option is not recommended in view of lengthy negotiations and cost implications that this may entail.

3.2.3 Commissioning of the biogas plant on build-own-operate basis

Alternatively, when the biogas plant is eventually implemented on a public-private-partnership basis, this could be routed towards a design-build-own-operate basis wherein a private promoter comes with his own land for the setting-up and operation of the biogas plant. However, the site proposed by any potential promoter must meet the aforementioned criteria and should preferably be located within the region neighbouring La Laura transfer station (i.e. the eastern part of the island).

4. Stakeholder Meeting on Identified Technologies and Site (Deliverable 4.3)

A stakeholder meeting was held on 25 August 2021, where the selected technologies based on literature and engagements with stakeholders in Mauritius were presented (see Section 2.1 above). A more detailed methodological approach was presented in Output 3 for this project, and proceedings contributing to Output 4 are annexed to this report (Annex 2.1 – 2.3). In addition, presentations by the project implementation team were shared with the stakeholders, and those reflected criteria for the MCDA and specific information requested for the GIS section of the project, intended to support the MCDA for site selection presented in this report.

5. Summary/Recommendations of Deliverable 4

Deliverable 4 of the Technical Assistance comprised 1) an overview of identified technologies and processes; 2) an overview of identified sites and 3) a meeting report on selected technology and site. Through deliverable 4, a series of anaerobic digestion systems has been reviewed together with their sizes, capacities and estimated costs, wherever practically possible. Through a MCDA using the SMART technique, it was possible to select one anaerobic digestion system more suited to the Mauritian context namely the SSHS system. Under this system, three commercial technologies are operational worldwide namely the DRANCO, the Valorga and the Kompogas processes. However, the ultimate choice of the technology will depend on the investment costs. Deliverable 4 also provided an overview of potential sites for the potential setting-up of a biogas plant in Mauritius. A list of GIS information required to assist the GIS process is also provided. Through another MCDA using the SMART technique and the inputs from the key stakeholders during a meeting held at the premises of the Solid Waste Management Division, the La Laura transfer station was determined to be the most suitable site for commissioning of a biogas plant in Mauritius. However, the decision to convert the La Laura transfer station into a biogas plant is dependent on the Solid Waste Management Division. In any case, alternative state-land can be investigated with the collaboration of the Ministry of Housing and Land Use Planning or the anaerobic digestion project can be implemented through a PPP route with the promoter also coming with his own plot of land in the region neighbouring La Laura transfer station or the eastern part of Mauritius. Nonetheless, the proposed site must meet the criteria as specified in Deliverable 4.

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Annex 1– Input from SWMD

Scores for Criteria for Site Selection for Biogas Plant

Disposal Sites	**Criteria**										
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
La Chaumière transfer station	2	0	2	2	2	0	2	2	2	2	2
Roche Bois transfer station	2	0	2	2	2	0	1	0	0	0	2
Poudre d'Or transfer station	2	1	2	2	2	0	2	2	2	2	1
La Laura transfer station	2	2	2	2	2	2	2	2	2	2	0
La Brasserie transfer station	2	1	2	0	2	0	2	0	1	0	1
Mare Chicose landfill	2	2	2	0	0	1	2	2	2	2	0

Justification for Scores

Criteria	Definition	Justification
A	Proximity of waste supply	A score of 2 is given for all disposal sites as the biogas plant is within close proximity to the waste generation point
B	Current and future waste supply	The Ministry is planning on implementing regional composting plants and sorting units in the Western and Northern regions of Mauritius. These waste management facilities will cater for the wastes received at La Chaumiere and Roche Bois transfer stations and part of the wastes at La Brasserie and Poudre d'Or transfer stations. As such, the future waste supply at La Chaumiere and Roche Bois transfer stations will be minimal (thus the score of 0) while that at La Brasserie and Poudre d'Or transfer stations will still have some future waste supply (thus the score of 1). Only the future waste supply at La Laura transfer station and from the South (directly to the landfill) will have potential for exploitation in the future (thus the score of 2)
C	Proximity with grid network	With the CEB mentioning that the sub-stations are well-dispersed over the island, the proximity with grid network is thus not an issue and a score of 2 is given for all the disposal sites.
D	Current and future land use	There is no planned future land use for La Chaumiere, Roche Bois, Poudre d'Or and La Laura transfer stations and a score of 2 is thus given. For La Brasserie transfer station, there is a possibility of the site being relocated. Due to this uncertainty, a score of 0 is given. As for the landfill, this is being vertically

		expanded and it is not envisaged to have land available on this site in the near future, justifying the score of 0.
E	Land ownership	All the land for the 5 transfer stations are state-land (thus a score of 2). The land at the landfill is privately-owned and is being rented to the Ministry. It will be difficult to acquire the land in the future for commissioning a biogas plant, thereby justifying the score of 0.
F	Available space	With the exception of the landfill and La Laura transfer station, all the other disposal sites have a smaller land extent and thus. the available space to construct a biogas plant is insufficient, thereby justifying a score of 0. For La Laura transfer station, a land extent of 2 Ha justifies the score of 2. For the landfill (despite having an extent of 50 Ha), a score of 1 is attributed due to the vertical expansion works that will be taking place, thereby limiting the available space for a biogas plant.
G	Accessibility to site	All the sites are easily accessible, thereby justifying the score of 2. Only for Roche Bois transfer station, the score is 1 due to heavy traffic in the morning and afternoon (near the capital of Port-Louis).
H	Site characteristics	Roche Bois and La Brasserie transfer stations are old dumpsites and the site may not be appropriate to withstand huge load, thus a score of 0 is attributed.
I	Use of digestate as compost in proximity to the biogas plant	In the vicinity of Roche Bois transfer station, vegetation is low, thereby decreasing the potential for use of compost (thus a score of 0). Same reasoning applies to La Brasserie transfer stations which nevertheless has some more

		vegetation, thereby being attributed a score of 1. For the other sites, there is a good level of vegetation and plantation in close proximity, thereby justifying the score of 2.
J	Sufficient buffer from residential areas	For Roche Bois and La Brasserie transfer stations, there are residents nearby the sites and thus a score of 0 is being attributed. For the other sites, there are sufficient buffer, thus warranting the score of 2.
K	Wastewater treatment points and associated infrastructure	Most of the major wastewater treatment plants are located in the western to north-western regions of Mauritius making them closer to Roche Bois and La Chaumière transfer stations (thus a score of 2 for these 2 sites).

Annex 2.1 Stakeholder Meeting

25 August 2021

High-level proceedings:

- **Purpose and background**

Discussion: Output 4 deliverables – site selection: stakeholder meeting, CTCN Mauritius project. The Mauritius TA assistance request to the CTCN and the signed Small Scale Funding Assistance request signed between the CTCN and the CSIR constitute the background to this work.

- **Participants**

Aubrey Muswema, John Khalo, Oscar Mokotedi, Jeffrey Baloyi, Ryneth Mbhele, Dinesh Surroop, Stanley Semelane, Valentin Rudloff, Rudy Oh-Seng, William Stafford, Shingi Mutanga, Suzan Oelofs, Bundhoo Zumar, B. Beerachee, Pooja Rago, Ballgobin Dokesh, Avinash Keesoony, Sanjay Sookhraz, Rakesh Dhununjoy, J. Espiegle, H. Multra.

- **Apologies**

Ragiv Garv (CTCN)

- **Proceedings**

- Meeting started at 14h00, Mauritius time as per agenda circulated before the meeting.
- The meeting was recorded and transcribed via MS Teams, and all participants should have access to the recordings, which constitute formal meeting minutes.
- The CTCN expressed content that the project is proceeding well, and there've been deliverables in line with the TA request by Mauritius.
- The Mauritian NDE emphasized acceptance of deliverables (i.e., reports) for Outputs 1 and 2 for the project. The CTCN requested a formal written confirmation.
- Mauritius will only consider the final Output 3 report, and not the draft report submitted by the deadline. The project implementing team indicated that the report will be submitted shortly after the meeting/workshop, to consider any other comments on the methodology that may emanate from the meeting's proceedings with the stakeholders.
- Meeting was well attended by stakeholders. Prof. Dinesh Surroop was present on site in Mauritius to engage directly with the Ministry and others, including facilitation of the Multi-Criteria Decision Analysis (MCDA) process.
- The project implementation team made three presentations, which were shared with the CTCN and the NDE of Mauritius – these highlighted Outputs 3 and 4 deliverables of the project, and were well received by the stakeholders.
- Inclusion of animal waste, especially pigs, emerged as a consideration for the project. The NDE, CTCN and project implementation team should consider this request, which was originally raised by the project' implementation team. Nevertheless, any additional work will have financial consequences that the project's implementation team may not

be able to absorb. To that end, additional proposals will be captured as recommendations for the project in general.

- The CTCN indicated that they will not be investing any further funds into the project (ends February 2022), which may be extended by up to two months at most (i.e.., by duration only).
- The project implementing team emphasized that they may be limited by funds to undertake work beyond the scope of the technical assistance.
- The NDE highlighted a project in Mauritius to sort out waste at house-hold level, which the implementation team may need to consider going forward. The CTCN requested the team to furnish written requests to the NDE for additional information, e.g., GIS information which will be used together with the MCDA outputs to inform forthcoming deliverables of the project.
- The CTCN requested the NDE to provide the project's implementation team, as well as the team to provide written requests based on the discussions.
- The project team requested Mauritius authorities to share in writing any further information that they have, which may enhance the impact of the project.
- Prof. Dinesh Surroop proceeded to engage the NDE and other stakeholders in Mauritius beyond the arranged time of the meeting, to complete the MCDA template, etc. The results are to be incorporated into Output 4 deliverables.
- The participant list from Mauritius as requested by the CTCN was as follows:

Name	Designation & Organisation	Email address
B. Beerachee	Director, Solid Waste Management Division	bbeera@hotmail.com
P. Rago (Miss)	Project Officer/Senior Project Officer, Solid Waste Management Division	yp.rago@gmail.com
Bundhoo Zumar	Project Officer/Senior Project Officer, Solid Waste Management Division	zumar.bundhoo@gmail.com
Dinesh Surroop	Associate Professor, University of Mauritius	d.surroop@uom.ac.mu
Ballgobin Dokesh	Town & Country Planning Officer, Ministry of Housing & Land Use Planning	dballgobin@govmu.org
Avinash Keesoony	Senior Research Scientist, Food & Agricultural Research & Extension Institute (FAREI), Ministry of Agro-Industry & Food Security	keesoonya@gmail.com
Sanjay Sookhraz	Senior Environmental Affairs Officer, Central Electricity Board	sanjay.sookhraz@ceb.intnet.mu
Rakesh Dhununjoy	Senior Engineer, Central Electricity Board	rakesh.dhununjoy@ceb.intnet.mu
J. Espiegle	Ministry of Energy and Public Utilities	-
H. Multra	Senior Engineer, Ministry of Energy and Public Utilities	hemant_multra@yahoo.co.uk

- The above met at the following venue in Mauritius: Conference Room, Solid Waste Management Division, 10th Floor, Emmanuel Anquetil Building, P. Louis

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Annex 2.2 – Post-Mortem of the stakeholder meeting

26 August 2021

Discussion: Output 4 – post-mortem of the stakeholder meeting held on 25 Aug 2021. CTCN Mauritius project

High-level proceedings:

- Purpose and background

The discussion noted the key messages from the stakeholder workshop held on **25 August 2021**, e.g., inclusion of the animal (pig) sludge in the project as originally proposed by the project team and brought forth to the CTCN. The key challenges to implement the latter include financial support (which the CTCN will not extend/provide) and human resources. The team aimed to reflect on the level of achievement of the stakeholder engagement meeting, particularly the site selection aspect which was the core of Output 4. In addition, the team concluded to also review the calculations made for Output 3, based on feedback received during the stakeholder meeting.

- Participants

CSIR: John Khalo, Oscar Mokotedi, Jeffrey Baloyi, Ryneth Mbhele, Dinesh Surroop, William Stafford, and Suzan Oelofse.

- Proceedings

- The meeting noted the **composting project** in Mauritius, including the sorting out of solid waste at house-hold level.
- The team presented three on-point presentations, well accepted by the CTCN, NDE focal point and other stakeholders in Mauritius.
- From the Ministry's input at the recent stakeholder workshop, **two composting sites** were identified for Mauritius. The Multi-Criteria Decision Analysis report/output, expected from the Ministry's office and other Mauritian stakeholders present at the meeting (see Output 4's final report), will inform better, the geo-location of a biogas plant for Mauritius.
- The inclusion of pig waste from other parts of Mauritius was noted as an emergent problem in Mauritius, and such projects (i.e., CTCN Mauritius TA) should aim to accommodate addressing the problem. This issue came up strongly during the recent stakeholder meeting.
- The proposals or ideas that emanated from the meeting with the stakeholders should perhaps be captured as recommendations, and not necessarily additional work for the implementing team. The bottom line is that the team should focus on the TA from Mauritius. Any other additional requests should inform the next phases of similar work, such as circular economy projects.
- Meeting concluded with updating outputs 4.1 and 4.2 before the general distribution to the CTCN, the Mauritian focal point and other stakeholders.
- Although Outputs 6 and 7 deliverables are downstream, the implementation team to start working on the economic aspects of the biogas plant to designed as part of Output 5, including developing a business model to attract the private sector into the PPP.
- Costs of such projects and their implementation are high and very important.

- The team should also note possible forthcoming projects, in the circular economy space for example, that would benefit from this project.
- Once outputs 3 and 4 deliverables are submitted by 30th August 2021, the project will be on track in terms of time.

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Annex 2.3 Discussion: Outputs 3 and 5 – way forward: CTCN Mauritius project

27 August 2021

High-level proceedings:

- Purpose and background

Preparation for next outputs – beyond Output 4.

- Participants

John Khalo, Oscar Mokotedi, Jeffrey Baloyi, Ryneth Mbhele and Dinesh Surroop

- Proceedings
- The team should start thinking about the training needed in Mauritius as part of the outputs for the project. Covid-19 regulations permitting, the CSIR should consider sending one or two project team members to Mauritius.
- Based on the information shared to date, there may be a need to **revisit the calculations** for methane production for Output 3?
- Plan the economic analysis aspect as part of the biogas plant design (include Prof. William Stafford and D. Stanley Simelane).
- Noted that the design of the biogas plant should be based on at least an average of 100 tons of municipal solid waste generated in Mauritius daily. There's a high level of impurities that may affect the quality of biogas generated.
- John, Jeffrey and Ryneth to lead the biogas plant design? (5.1) [*need to include inputs from GIS data collection…*]. Note the literature from Mauritius, e.g., building and infrastructure requirements, equipment, schematic diagram, logical infrastructure, pre-digestion and post digestion processes,
- Need to note the duration of Output 5. There's a lot to be done in ~2 months.
- Meeting concluded with updating outputs 4.1 and 4.2 before the general distribution to the CTCN, the Mauritian focal point and other stakeholders.
- Updates to be communicated to the CTCN and Mauritian authorities by 30 August 2021.

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