EXECUTIVE SUMMARY

BIOGAS FEASIBILITY STUDY

Zeekoegat Wastewater Treatment Works

Report for: Zeekoegat WWTW, City of Tshwane

Commisioned by: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Prepared by: Consortium AKUT/AD Solutions UG

T Burkard[1], M van der Merwe-Botha[2]

[1,] CONSORTIUM AKUT/AD Solutions, Berlin

[2] Water Group Holdings (Pty) Ltd, South Africa

December 2017

AKUT Partner, Wattstr. 10, 13355 Berlin, Germany mail@akut-umwelt.de

TABLE OF CONTENTS

1. PROJECT SUMMARY

The detailed feasibility study on the production of power to reduce the electricity purchase of Zeekoegat WWTW Wastewater Treatment Works determined the technical and economic baselines for this specific case. Different scenarios of Biogas to Energy production have been evaluated. The study present recommendations for further consideration by the City of Tshwane Municipality:

First step: Starting with a CHP-project of 350 $kW_{e,}$ using the sludge from Zeekoegat WWTW only, requires a moderate investment 12.8 m ZAR, will replace 21% or 2.55 m kWh/year of consumed power, the static payback period is shown with 8.9 years. A more detailed stochastic financial modelling shows a discounted payback period between 8.2 and 9.3 years and an IRR between 22.5 and 23.2%. The existing practice whereby methane is directly released to the atmosphere will be discontinued, which will safe 30,767 t CO_2 equivalents (reduction of 72 %).

Extension steps: In addition to the sludge from Zeekoegat WWTW, additional sludge from Baviaanspoort WWTW could be used, thereby utilizing of the full capacity of the existing digesters. Such an extended project would require an additional investment of approximately 16 m ZAR, creating a payback period of 4.9 yrs. The detailed stochastic analysis shows a discounted payback period between 5.4 and 5.9 years, and an IRR between 30.4 and 31.8%. The power production will replace about 80% or 11 187 000 kWh yearly of consumed power. During the study an existing potential of 225 to/d sludge could be identified.

A successive implementation is recommended whereby in Step 1 already an upgrading should be foreseen. This would include premature installation of some components (e.g. the gas treatment, gas pipes) while the main investment in the CHP will be split into several units.

Two **Business Models** are proposed. The recommendations are to outsource the sludge treatment process to a PSP or a BOT/BOOT model for the proposed CHP system while the WSA remains responsible for the balance of the WWTW. The decision should be based on the financing possibilities or intentions.

The Feasibility Study provides sufficient information and data to enable the asset owner, Tshwane Municipality, to make a sound decision on the future of power from Biogas on the Zeekoegat WWTW based on facts.

Some **general recommendations** are highlighted:

1. Combustion of already produced Biogas in a flare to reduces methane emissions and risk of explosions. This can be implemented asap.
2. Implement Water Conservation Demand Management to reduce the water losses to the Zeekoegat plant and studies on reducing waste water inflow in canalisation.

   The measured inflow volume is exceeding the expected volume (based on inflowing COD load) by 80% (50 ML/d instead of 27.7 ML/d). This reflects in a high specific power consumption of 75.2 kWh / P.E.COD (30 kWh/P.E. being tolerable for a German WWTW of this size). A reduction of inflow volume will be not only reduce power consumption and extend the lifespan of the pumps, but will enable Zeekoegat WWTW to make full use of its treatment capacity. The plant's licence allows treatment of 85 ML/d. The, currently operational flow is 50 ML/d (at 58% of the plant's capacity). It is estimated that this flow

could be reduced to 28 ML/d (33% of the plant's capacity). Currently 154,000 persons are connected to the plant, and the treatment capacity is 472,000 persons.
The project should focus on water consumption patterns / habits as well as intrusion of external water into sewer lines. It needs a sound analytical part as well as detailed and practicable recommendations.

3. Energy efficiency measures should be investigated to reduce the electricity demand of the plant further. Water and energy saving efforts have often been more efficient then the introduction of renewable energy. However this is not replacing the introduction of RE.

2. BACKGROUND

South Africa faces challenges in the security- and cost of supply of energy. In the subsector of biomass the usage of wet waste streams, next to solid waste and wood-based biomass, offers significant opportunities to produce biogas and generate electricity. Unlike foreign markets, this source of energy is under-represented in South Africa. Unlike other renewable energies, biogas can be stored and balance peak loads and support load management.

This project aims to develop a Feasibility Study for the generation of electricity and heat from the biogas produced during the anaerobic digestion (AD) of sewage sludge at the Zeekoegat WWTW. This project forms part of the initiatives under the SAGEN "Biogas Market Development" component implemented by GIZ and financed by BMZ German Federal Ministry for Economic Cooperation and Development.

3 STATUS QUO ASSESSMENT

3.1 Design Capacity, Flow Regimes and Loading

The City of Tshwane Metropolitan Municipality is situated in the Gauteng province. It is the single-largest metropolitan municipality in the country, serving a population of approximately 2 921 500 people and 911 500 households, with a growth rate of 3.1% per annum.

The Zeekoegat plant is one of the City of Tshwane's wastewater treatment plants and is located to the north-east of the city centre near the Roodeplaat Dam. The plant is owned, managed and operated by the Tshwane Metro.

The plant is registered as a Class A facility with the Department of Water and Sanitation (DWS). The initial 30 Ml/d plant was constructed in 1991, followed by various upgrades thereafter to its current design capacity (ADWF) of 85 Ml/d.

Diagrammatically, the water phase treatment train can be illustrated as below:

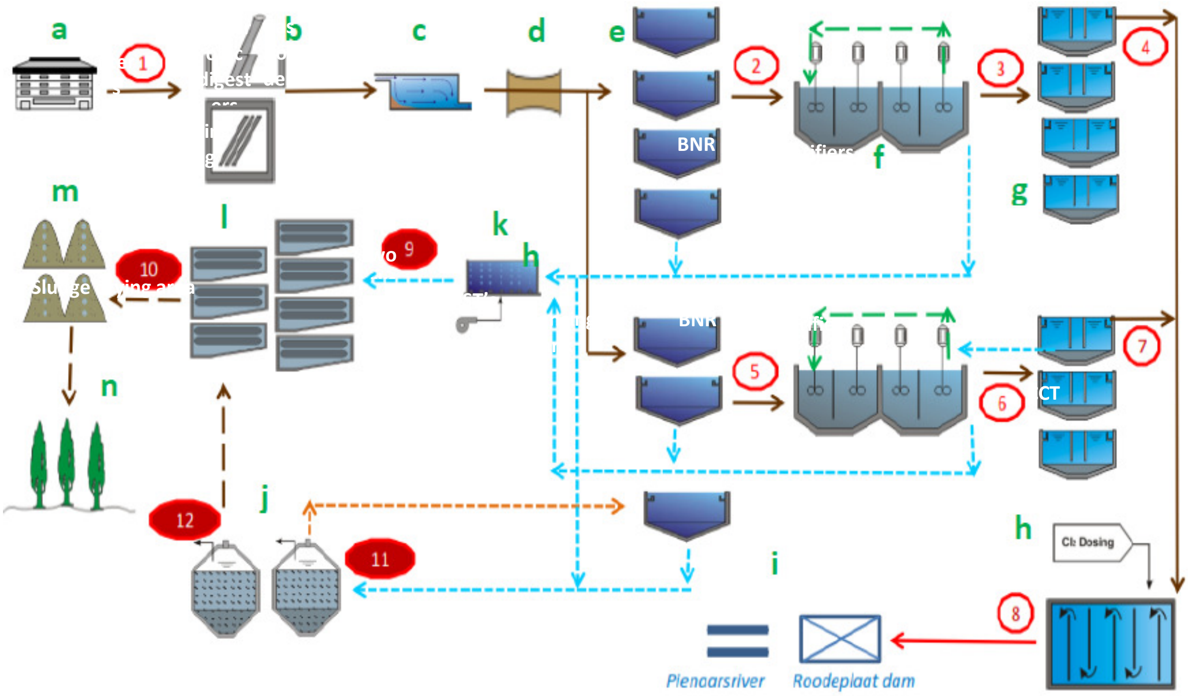


Figure 1: Simplified Zeekoegat process flow diagram

3.2 Flow and load dynamics

The following inflow and COD load patterns were extracted from the data available (zkg flow 1601, 1602, 1603 and LabInfo Data 2013 – 2017). The results are presented in the sections following

The raw sewage character is that of a medium strength sewage, which is unexpected given the 20% industrial contribution to the plants influent. Due to the low organic loading of the plant, the PST's are not operated in the conventional fashion. The PST's are used as fermenters and settled sludge is retained and allowed to ferment for a period of approximately four days. After four days, the sludge is discharged into the balancing tank (in a sequential order) in an effort to provide adequate concentrations of readily biodegradable COD to maximize biological phosphorus removal.

Table 1: Comparison between actual load profile and the water use license specifications

Discharge Licence	Design capacity	ML/d	85
	spec. consumption	l/P,d	180
	P.E. licence/water		**472.222**
ZKG flow data 16 01-03 and LabInfo Data 2013 - 2017	Inflow volume	ML/d	50
	Inflow COD	mg/l	370
	Organic load COD	kg/d	18.500
	specific COD	g/P,d	120
	P.E. inflow/COD		**154.167**

3.3 Status of the Anaerobic Digesters

The two 6000 m^3 digesters were commissioned in 2016 and are in an excellent condition. The digesters are high rate units with pumped mixing and heated to operate in the mesophilic range using gas fuelled hot water boilers and heat exchangers. The biogas collection system is equipped with the normal fittings such as over/under pressure valves, flame arresters, sediment and drip trap, etc. Unused gas is stored in two 2000m^3 holding tanks while excess biogas is flared. At time of the site assessment, the flare was not in operation and the storage tank was commissioned but not operational.

Operational recommendations: The following recommendations will improve process stability and efficiency:

1. The flare should be taken in operation with immediate effect.

2. At the present loading it is recommended that only one digester is used. Alternatively, one digester can be used as a high rate heated (there will probably not be enough heat energy to heat both digesters anyway) and mixed digester with discharge to the second digester which can be used unheated and unmixed. The second digester can then also be used for digestate thickening before dewatering. This operational mode is recommended up to the point where the digester loading increases beyond the capacity of one digester at which time the two digesters can be operated as two parallel high rate digesters.

3. The feed sludge should be managed to ensure the highest solids concentration achievable by the existing process units.

4. The temperature of the digester content should be kept as stable as possible and temperature variation of more than 1°C per day should be avoided.

5. Biogas flow meters and recorders/loggers on each anaerobic digester will assist the operator to understand the condition of the digesters and under what operating conditions maximum biogas is produced. Maximum biogas production will in turn indicate maximum volatile solids destruction which in turn will produce the most stabilised sludge and ensure minimum sludge mass for disposal. A high degree of stabilisation will ensure a Stability Class 1 in terms of the Sludge Guidelines.

6. Reducing the BNR sludge age (while maintaining the minimum sludge age for nitrification) has been reported to improve biological phosphorus removal. This strategy has the further advantages that a shorter sludge age will reduce oxygen consumption in the BNR and will simultaneously improve the digestibility and biogas potential.

3.4 Energy Audit of Plant Demand

Zeekoegat WWTW has provided several sources of data on energy consumption:

- Access to the online power metering system (period 1st Feb 2016 to 25th Jan 2017)
- Energy Audit 2015 EA 2015 (period Nov 2014 to Oct 2015)
- Power bills (period July 2015 to June 2016) PB 2016
- Own data collection (May 2017).

Analysis of the municipal electricity bill of the plant indicates an average cost for 2016/17 of R1.218 per kWh. This translates to 1,037,245 kWh/month or 12,445,941 kWh per year. Various scenarios were run for off- and on peak usage, as well as use of electricity in standard and standby tariff ranges. The results shows that the majority of usage takes place in off peak and standard tariff ranges, with a 90 percentile peak demand of 1 728 kVA.

The next table summarizes data used for the purpose of the feasibility study. The consumption is based on values from 2015/16 and rates from 2016/17 are used to estimate average costs.

Table 2: Average Tariffs

	Consumption [kWh/yr]	Aver. Cost 16/17 [SRA]	kVA
OffPeak	5 921 373	R 0.863	
OnPeak	1 758 984	R 2.030	
Standard	4 490 659	R 1.165	
Stand-by	275 925	R 4.67	
Peak demand 90 percentile			1728

3.5 Feed-stock for Co-Digestion Case

No suitable feedstock from agricultural activities for co-digestion within the geographical reach of the Zeekoegat plant has been identified. The City of Tshwane laboratory is continuing its efforts to investigate potential sources.

Importing sludge from Baviaanspoort and Rooiwal: Because the organic loading of the Zeekoegat digesters is so low, the option of importing sludge from surrounding wastewater treatment plants was considered. The existing anaerobic digesters at Zeekoegat would be able to handle approximately 36 000 kg DS per day at a solids concentration of 5.3% or higher. The Rooiwal plant is a significantly larger plant than Baviaanspoort but the distance to Zeekoegat is nearly double that of Baviaanspoort (Rooiwal ±38 km and Baviaanspoort ±20 km). The cost of transport from Rooiwal would therefore be double the cost from Baviaanspoort.

Zeekoegat is producing approximately 6000 kg DS/d of WAS so an additional 30 000 kgDS/d is required from an external source to load the digesters to capacity. Baviaanspoort is the closest so that would be the obvious source to select. From provisional figures sludge availability is estimated as follows:

Table 3: Analysis of sludge from Baviaanspoort and Rooiwal

Plant	PS kl/d	PS % %	PS kg/d	WAS kl/d	WAS % %	WAS kg/d	Total kg/d
Baviaanspoort	800	3.3	26 400	3 000	0.4	11 550	37 950
Rooiwal	1 330	3.3	43 890	1 085	0.7	7 866	51 756

From the above table it is clear that Baviaanspoort should have more than enough sludge to fully utilise the digester capacity Zeekoegat, although a small portion of this sludge may be WAS. The estimated daily cost to transport approximately 30 000 kg of primary and waste activated sludge from Baviaanspoort to Zeekoegat is R 144 000 per day (at solids concentrations currently available). If sludge is dewatered to 8% solids before transport to Zeekoegat, the daily cost can be reduced to approximately R 30 200 per day. This cost is based on a transport rate of R 19.95 per km for a 10 m^3 tanker truck and a 40 km round trip per load.

Table 4: Cost to transport sludge from Baviaanspoort and Rooiwal to Zeekoegat

Plant	PS kl/d	Cost R/kl	Cost R/annum	Total R/annum
Baviaanspoort	800	42.65	53.7m	
Rooiwal	1 330	43.85	37.8m	R91.5m

4. BIOGAS PLANT TECHNICAL DESIGN

4.1 Description of possible biogas use

Biogas can be used in many different ways including:

- decentralised combined heat and power production,
- direct heat utilisation or distribution via heating networks,
- application in gas-powered household appliances,
- processing and feeding into the natural gas grid and
- utilization as fuel for cars, tractors and trucks.

Biogas can also be stored in the gas network, in decentralised gas storage facilities or by means of heat storage facilities over longer periods of time.

For Zeekoegat WWTW, the most viable option would be to use the gas in a combined heat and power (CHP) station for the following reasons:

- Value creation through production of electricity is higher than using biogas for heat production only;
- Absence of heat-consumer or gas-consumer in the vicinity to make it worthwhile to consider a heating or gas distribution network;

- To feed biogas into a gas grid or to use it as fuel in cars, it has to be converted into CNG. This means that all components (except methane) such as CO_2, humidity and other substances have to be removed. The gas need to be pressurized up to 200 bar. The technology for this application is new and expensive.

4.2 Investigated CHP scenarios

Various alternatives were investigated with regard to economic feasibility of a combined heat and power installation with respect to the following reflections:

- **Substrate for biogas production:** WWTW solids only or additional substrates from 3rd party (co-digestion)
- **Energy use profile:** consistent supply throughout the day or focusing on peak-time-periods
- **Sizing:** CHP and biogas treatment equipment
- **Additional technologies:** equipment to heat and mix the sludge, devices to prepare co-substrate.

Options I include the use of sludge from WWTW, whilst Options II consider the addition of co-substrates. Key characteristics and figures of the options are given below.

- **Option IA – High rate digester, WAS only**: For this alternative the sludge production was based on the current plant loading of 50 Ml/d, a COD concentration of 370 mg/l and a sludge production of 180 m^3/d (at 3% solids), waste activated sludge only. All primary sludge is returned to the primary settling tank effluent. For this option the digesters are operated as high rate units, heated and mixed. A biogas yield of 1 204 m^3/d was estimated and a 150 kW generator is proposed.

- **Option IB – High rate digester, primary and WAS**: For this alternative the sludge production was based on the current plant loading of 50 Ml/d. Primary sludge of 154 m^3/d (at 3% solids) together with waste activated sludge of 180 m^3/d (at 3% solids) is routed to the anaerobic digester. For this option the digesters are operated as high rate units, heated and mixed. A biogas yield of 2 986 m^3/d was estimated and a 350 kW generator is proposed.

- **Option IIA – High rate digester, primary WAS and co-substrate**: For this alternative the sludge production was based on the current plant loading of 50 Ml/d. Primary sludge of 154 m^3/d (at 3% solids) together with waste activated sludge of 180 m^3/d (at 3% solids) is routed to the anaerobic digester. In addition to this load it was assumed that an external source of 98 m^3/d (at 23% solids) co-substrate was available to increase the loading to 3 kgVSS/m^3.d. For this option the digesters are operated as high rate units, heated and mixed. A biogas yield of 15 823 m^3/d was estimated and a 1 500 kW generator is proposed.

- **Option IIB – High rate digester, primary WAS and co-substrate**: For this alternative the same assumptions according sludge and co-substrate volume and biogas-production were made. The difference to IIA is a bigger CHP to provide electricity mainly in high price periods. Therefore an ultimate 1 850 kW generator capacity is proposed.

- **Option IIC – High rate digester, primary WAS plus centralised treatment**: For this alternative the sludge production was based on the current plant loading of 50 Ml/d. Primary sludge of 154 m^3/d (at 3% solids) together with waste activated sludge of 180 m^3/d (at 3% solids) is routed to the anaerobic digester. In addition to this load dewatered WAS will be imported from Baviaanspoort - 225 m^3/d WAS at 18% solids to increase the loading to 2.7 kgVSS/m^3.d. For this option the digesters are operated as high rate units, heated and mixed. A biogas yield of 12 021 m^3/d was estimated and a 1 350 kW generator is proposed.

4.3 Summary of discussed scenarios

Key figures for the evaluated scenarios are reflected in the Table below:

Table 5: Summary of investigated scenarios

Zeekoegat		Option IA	Option IB	Option IIA	Option IIB	Option IIC
Description		as it is now; only WAS All tariffs	with PST Sludge and WAS All tariffs	optimized to Digester capacity max DM 8% All tariffs	optimized to Digester capacity max DM 8% Large generator; max savings through providing peak time	Centralized sludge treatment max DM 8% All tariffs
Digester Volume	m³	*2 *6000*	*2 *6000*	*2 *6000*	*2 *6000*	*2 *6000*
Input	m³/d	**WAS**: 180 with DM: 3 %	**Sludge PST**: 154 with DM: 3 % **WAS**: 180 with DM: 3 %	**Sludge PST**: 180 with DM: 3 % **WAS**: 180 with DM: 3 % **Organic Waste**: 141 with DM: 23.1%	**Sludge PST**: 154 with DM: 3 % **WAS**: 180 with DM: 3 % **Organic Waste**: 141 with DM: 23.1%	**Sludge PST**: 154 with DM: 3 % **WAS**: 180 with DM: 3 % **Baviaanspoort WAS**: 225 with DM: 18%
Digester load	kg oDM/ m³,d	0,3	0,5	3	3	2,7
HRT	d	70,2	37,8	23,6	23,6	20,1
Biogas-yield	m³/d	1.204	2.986	15.823	15.823	12.021
Size of CHPS	kW	150	350	1500	1850	1350
Net Electricity produced	kWh/a	1.063.485	2.554.102	11.187.337	11.187.337	10.012.354
Net Electricity produced ratio to own consumption	%	9%	21%	89%	89%	80%

Depending on the scenario, CHP sizes of 150 to 1,850 KW_{el} would be applicable. Net electricity ranges between 1.07 M kWh and 11.2 M kWh per year.

Approximately 21 % of the total electricity demand of the WWTW could be produced in-house using only own sludge. If digesters are loaded to full capacity, up to 89 % of the total energy demand can be produced in-house.

4.4 Connection point of CHP

The substation which is powering the BNR was considered as connection point, as a constant energy demand is expected at this point. The CHP could therefore be placed nearby this station. The final positioning will have to be clarified during the detailed planning phase.

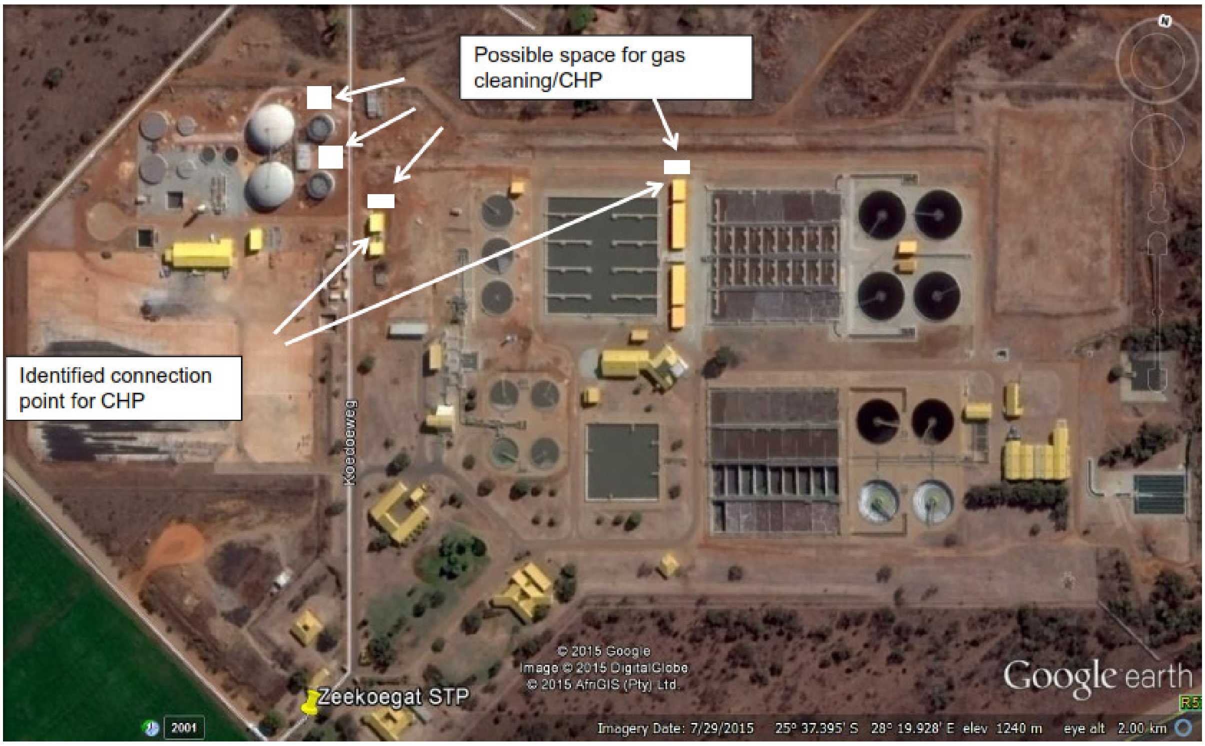


Figure 2: Proposed location of the CHP plant

5. FINANCIAL MODELLING AND COST BENEFIT ANALYSIS

5.1 Estimation of Investment Costs CAPEX, Running Costs OPEX and Benefits

The estimation of Investment Costs has been conducted with varying degrees of accuracy. The accuracy varies with depth of the present preliminary designs of the discussed options. As example the estimates for CHP and gas treatment are based on existing guiding price quotations. The power control system will need to be refined during the detailed planning process therefore its estimate is based on available prices with no specific quotation. The table below summarizes the various types of used cost estimates.

Table 6: Types of Cost Estimates

Item	Estimate Type
Digester Equipment, including gas pipes connections, gas pipes, trenches, earth work	Price estimates
Gas treatment, including civil work, engineering, installation, put in operation and shipment from Germany if necessary	Guiding price quotations

CHPS, Gas-engine, generator, gas mixer, gas control path, voltage and Cos-Phi regulator, synchronization, control system with remote monitoring, silencer, heat-exchanger, emergency cooler, preinstalled in container, engineering, installation, put in operation and shipment from Germany if necessary	Guiding price quotations
Substrate preparation unit in option II, including civil work, engineering, installation, put in operation and shipment from Germany if necessary	Guiding price quotations and price estimates
Electrical connection, incl. cabling, control systems, security systems, junction boxes, possible modification of connection point	Price estimates

The CAPEX is split into Technical and Constructive Devices to allow different depreciation rates. Most items include both types of cost groups. For further details please see the tables cost estimations for all selected options as Annexure.

The operational expenditures summarize the reoccurring costs of an investment. These include in particular costs for operation of gas-treatment, effluent handling, wages of employees, maintenance and annual inspection cost of the CHPS, insurance policy for the CAPEX. We did not include effluent handling, and wages of employees involved in sludge handling, because these cost are inevitable cost even when there is no CHP running. Maintenance costs of the CHP are determined as percentage of the CHP´s CAPEX. Additionally a capital interest rate (14%) of the total CAPEX has been included into the OPEX.

In options II operational cost respective power consumption for substrate preparation was taken into account. In option IIC sludge transport from Baviansspoort was set to be R 42.65 /kl.

The depreciation has been determined using three depreciation rates:

- 16.6 % (life span 6 years) for the CHP
- 12.5 % (life span 8 years) for other technical equipment and accessories
- 5 % (life span 20 years) for structural investments.

In general a biogas plant with added CHP has three main outputs:

- Electrical Energy
- Thermal Energy
- Effluent.

In all options the produced power is solemnly used to satisfy the in-house power consumption of the WWTW. The benefits are calculated as saving on costs of electricity provided and in-house produced power through diesel generators.

One has to note that this biogas system is **not** creating any monetary income, but <u>savings</u> on energy. Economically this savings are regarded as income even not creating any physical cash-flow.

5.2 Economic modelling and economic evaluation

This study considered two approaches for economic evaluation: Static economic evaluation and dynamic economic modelling.

5.2.1 Static economical evaluation

Approach: This calculation uses static, single point values to show the feasibility of discussed options in terms of Payback time period. PBT-Period was calculated using surplus versus investment costs when surplus will be calculated being total benefit minus OPEX minus depreciation. Main question here is: Will there be a payback of invested capital within life span of implemented technology.
Results are shown in the following table.

Table 7: Results static economical evaluation

Zeekoegat		Option IA	Option IB	Option IIA	Option IIB	Option IIC
Measurements to be implemented		New CHP 150 kWel Gas cleaning 50 m³/h Gas connection Digester-CHP Electrical connection CHP-internal grid	New CHP 350 kWel Gas cleaning 150 m³/h Gas connection Digester-CHP Electrical connection CHP-internal grid	New CHP 3x500 kWel Gas cleaning 690 m³/h Gas connection Digester-CHP Electrical connection CHP-internal grid Substrate preparation and feeding	New CHP 850+2x500 kWel Gas cleaning 690 m³/h Gas connection Digester-CHP Electrical connection CHP-internal grid Substrate preparation and feeding	New CHP 850 +500 kWel Gas cleaning 500 m³/h Gas connection Digester-CHP Electrical connection CHP-internal grid
Investment costs	ZAR	7.524.000	12.848.000	42.699.000	46.273.000	28.328.000
Depreciation	ZAR/a	1.032.550	1.801.450	6.065.750	6.631.250	4.170.750
Operational cost	ZAR/a	1.155.508	1.683.230	6.532.875	6.749.015	7.322.121
Benefits	ZAR/a	1.304.031	3.131.806	13.717.763	14.158.801	13.134.286
Surplus	ZAR/a	-884.026	-352.874	1.119.138	778.536	1.641.415
Cash Flow	ZAR/a	148.524	1.448.576	7.184.888	7.409.786	5.812.165
PBT	a	no	8,9	5,9	6,2	4,9

It is clearly shown that a scenario with use of only WAS sludge as described in option IA, will not show a feasible payback time period. All other option seems to be viable. Options II with better use of existing digester capacity are better than options without co-digestion.

Focussing savings only during peak time consumption seems not to have a positive effect on PBT: Option IIB is worse than option IIA.

Option IIC is better than Option IIA, based on co-substrate potential in the form of sludge from another WWTW. The CAPEX for substrate preparation and feeding devices is very small, however, transport costs are high and need to be taken into account.

Options IB and IIC were selected for further detailed calculations.

5.2.2 Dynamic economical modelling

The modelling is presented in the full study report.

A total of 4 scenarios were evaluated to determine the most economically feasible configuration. As noted above, for each main scenario defined, an additional sensitivity scenario was compiled to evaluate the effect of adding revenue streams, additional to the baseline assumption of electricity only.

Table 8: Summary of the main economic factors for the project's different scenarios:

Scenario:	I B EXCL	I B INCL	II C EXCL	II C INCL
Variables:				
IRR	22.50%	23.20%	30.40%	31.80%
MIRR	18.00%	18.10%	20.20%	20.90%
NPV_20	R 10m	R 11.9m	R 44.2m	R 51.7m
Discounted Payback Period	9.3 yr	8.2 yr	5.9 yr	5.4 yr
Estimated Capital cost incl. VAT & duties	R 13.1m	R 13.1m	R 29.5m	R 29.5m
DSCR debt service coverage ratio	1.97	2.07	2.54	2.85
NPV / CAPEX	75.8 %	90.2 %	150.0 %	175.1 %

An IRR between 22.5% and 31.8% can realistically be expected with NPV range of between R10.0 mil and R51.7 mil. The discounted payback period is between 5.4 and 9.3 years. Option IIC INCL provides the highest earnings per Rand spent with a median value of R1.75 NPV per R1.00 CAPEX. When assuming a 50% loan for the project with interest rate equal to the assumed WACC of 14%, the Net DSCR is between 1.697 and 2.85.

For the Zeekoegat CHP project, all scenarios had favourable economics, i.e. IRR (and MIRR) were above WACC, etc. However, only certain scenarios (Option IIC) performed above typical hurdle rates.

6. ENVIRONMENTAL CONSIDERATIONS AND ROLEPLAYERS

6.1 Overview of the South African Legislative Environment

Policy: The framework set out for the energy sector is implemented by the Department of Energy which is primarily commanded by the National Development Plan (2011), the 2003 White Paper on

Renewable Energy; the Electricity Regulation Act (2006), the Integrated Resource Plan (2010) and the Integrated Energy Plan (2013).

Legislation: In the absence of a dedicated legislative framework for biogas, a number of Acts and Regulations need to be consulted prior to the approval for the development of a biogas project. These include:

- National Environmental Management Act (NEMA)
- National Environmental Waste Act (NEM;WA)
- National Environmental Air Quality Act (NEM:AQA)
- National Environmental Biodiversity Act (NEM:BA)
- National Environmental Protected Areas Act (NEM:PAA)
- National Heritage Act
- National Gas Act
- National Water Act
- Spatial Planning and Land Use Management Act
- Municipal planning regulations.

The relevant national government departments include the Department of Environmental Affairs (DEA), Department of Water and Sanitation (DWS), Department of Agriculture and Fisheries (DAFF), and the Department of Energy, and the National Energy Regulator of South Africa, NERSA. Facilities are also subject to local municipal bylaws and strategic planning documents that have jurisdiction.

The main activities that are regulated include:

1. Environmental authorisation for establishment, construction and/or upgrading;
2. Waste licence for treatment of sewage sludge;
3. Atmospheric emission licence;
4. Water use licence authorising the management and disposal of wastewater;
5. Registration of energy generation facility;
6. Licensing of energy generation connected to the grid;
7. Storage of biogas; and
8. Beneficial use of digested sludge as a fertiliser.

6.2 Status Quo of Zeekoegat Wastewater Treatment Plant

The Zeekoegat WWTW has a water use licence dated 19 July 2011 which is valid for 15 years. The authorisation allows the disposal of an average 84,932m^3/d and maximal 272,000 ML/d of waste water to the maturation pond.

The treatment of abattoir waste (blood, paunch content) or any other waste affecting the function of the works is excluded from treatment in WWTW (point 8.3 of discharge licence). It is assumed this includes treatment of co-substrates in the anaerobic digestion.

All sludge must be treated, dewatered and disposed of onto a licensed solid waste site or used for agricultural beneficial purposes. Sludge must be quantified, analysed and classified and dealt with in accordance with the requirements of the Waste Act (No. 59 of 2008) and the WRC guidelines. The classification of the sludge is not known.

The current municipal electricity bylaws do not include provisions for the renewable energy projects connected to the grid.

Based on the status quo with regard to authorisation of the existing plant and the proposed biogas project, the processes that will be required to fully comply with the environmental legislative framework are summarised in the following Table.

Table 9: Summary of the legislative requirements for a biogas project at Zeekoegat

Activity	Legal Framework	Legislative Requirement	Process Required	Action Required
Sludge treatment	National Waste Management Act (No. 59 of 2008)	Category B listed waste activity Waste licence required	Anaerobic digesters installed in 2016 and would have been authorised according to EIA regulation under NEMA. Confirm no further authorisation required.	Yes, 3 months
Biogas utilisation	Electricity Regulation Act (No. 4 of 2006) National Gas Act (No. 48 of 2001)	Registration with NERSA Registration with NERSA	Register electricity generation and on-site use Register biogas project and on-site use	Yes, 3 months
Biogas combustion	Air Quality Act (No. 39 of 2004)	Gas combustion listed activity Air quality licence required	Scoping and EIR process Air quality licence application	No No, but need to be confirmed
Water management	National Water Act, 1998 (No. 36 of 1998)	Discharge of waste that may impact on water resource Water use licence required	Notification of amendment to sludge management and disposal to DWS	No, covered in existing authorisation
Beneficial use of sludge	Fertilisers, Farm feeds, Agricultural remedies and Stock Remedies (No. 36 of 1947). WRC Guidelines for	Sale and disposal of fertiliser to be registered Sludge disposal methodology	Determine ultimate disposal of digested sludge and register with DAFF if product is to be sold as a fertiliser Classify digested sludge and confirm disposal route is	No, unless biosolid is to be sold as fertilizer, etc. Yes, covered under

Activity	Legal Framework	Legislative Requirement	Process Required	Action Required
	utilisation and disposal of wastewater sludge	guided by classification of sludge	appropriate	existing Authorisation
Municipal framework	Strategic planning frameworks Bylaws	Project to align with municipal strategic direction Conditions for biogas projects defined	Include project in strategic planning and budgeting framework Existing bylaws do not make provision for renewable projects and will be updated for future application	Yes Yes
Institutional Arrangements	Water Services Act 108 of 1997	Contractual requirements between WSA and WSP	Formal service level agreement between WSA and any service provider appointed to support with service delivery	Yes, depending on business model and use of PSP

TBC = to be confirmed by the relevant authorities

6.3 Stakeholder Map and Responsibilities

The *Municipality* is pivotal in project implementation. The municipality will be implementing the project from project preparation to operation phase. The municipality will own the infrastructure, will contract out and manage service contracts for operation of the facilities. The municipality contribute significantly to the project by making available existing wastewater facilities and fixed assets to the projects where possible, while taking responsibility for the long term financial commitment associated with the operation and maintenance of the projects. The municipality is also responsible for sludge management and is the owner of the sludge and its end destination.

The *Department of Energy* (DoE) is a key driver in both the development and the implementation of Renewable Energy programmes.

Financing Agencies has a role to consider and fund projects under their Renewable Energy units, and if required, to management, monitor and evaluate. A comprehensive list of financing institutions is available from GIZ on request. In the case of municipal infrastructure financing, the Department of Cooperative Governance and Traditional Affairs (CoGTA) and National Treasury may have defined roles to (co)fund the CHP project.

The *SA Local Government Association* (SALGA) is responsible for representing municipal interests in parliament, comment on legislation, facilitate knowledge exchange between municipalities and in general facilitate the improvement of waste management services at municipalities.

Various *Government Departments* have a role biogas projects which may be from the perspective of regulation, monitoring or as synergies with their own Renewable Energy initiatives. These may include Provincial Government Department, the Department of Environmental Affairs (DEA), Department of Trade and Industry (DTI), Department of Science and Technology (DST), Department of Agriculture (DoA), Department of Water and Sanitation (DWS).

Organised Business and *Private Service Providers* (PSPs) such as SABIA and other project developers will have commercial interest and expertise to offer. PSPs will be invited to bid and will be contracted to operate facilities. PSPs will contribute to the monitoring and evaluation of the programme, taking on responsibilities with regard to reporting on different technologies.

Third party consultants will be invited to bid and will take on responsibilities in technical assistance for due-diligence and business plan development, project preparation, transaction advisory services, construction service supervision and technical assistance during operation.

Parastatals such as ESKOM will have an interest from a strategic supply point of view and taking note of the need for pricing strategies and incentives to municipalities on biogas projects in future.
Research, Technology, Development and Innovation Institutions has a role to play in terms of sourcing, developing, and communicating technologies and performance achieved via the treatment of sludge, the use of biosolids and generating information that inform the sustainable futures of Renewable Energy and Sludge Treatment in future.

Organisations and institutions such as GIZ, SANEDI, SABIA, etc. are involved in the development and support of various projects, depending on their respective mandates.

Research and technology partners, such as the Water Research Commission, universities and technical colleges, who are responsible to advance and disseminate research and emerging technologies in the water sector.

7. INSTITUTIONAL ARRANGEMENTS AND BUSINESS MODELLING

7.1 Background for the Business Model

The asset ownership and project execution strategy is an important consideration and will ultimately depend on financing model, the appetite for risk, business strategy, responsibility allocation, contract period, skills base, regulatory requirements and governmental factors and drivers. Different preferential models which suit the specific needs of the municipality and the WWTWs should be considered.

In the table and figure following, different business models are explored. These models may not be exhaustive, but may serve as springboard for more discussion within the municipality on the suitability of the models or hybrids thereof.

For the purpose of this section, it is assumed that a proposed CHP facility may include aspects such as feed sludge thickening and rehabilitation/upgrading of the anaerobic digesters. The illustrative table below shows a range of management options whereby business model number 1 renders the highest level of ownership and operational responsibility to the municipality or WSP, in contrast to the higher number options which leans towards lesser ownership by the WSP and/or more outsourcing of operation and maintenance responsibilities to a Professional Service Provider (PSP).

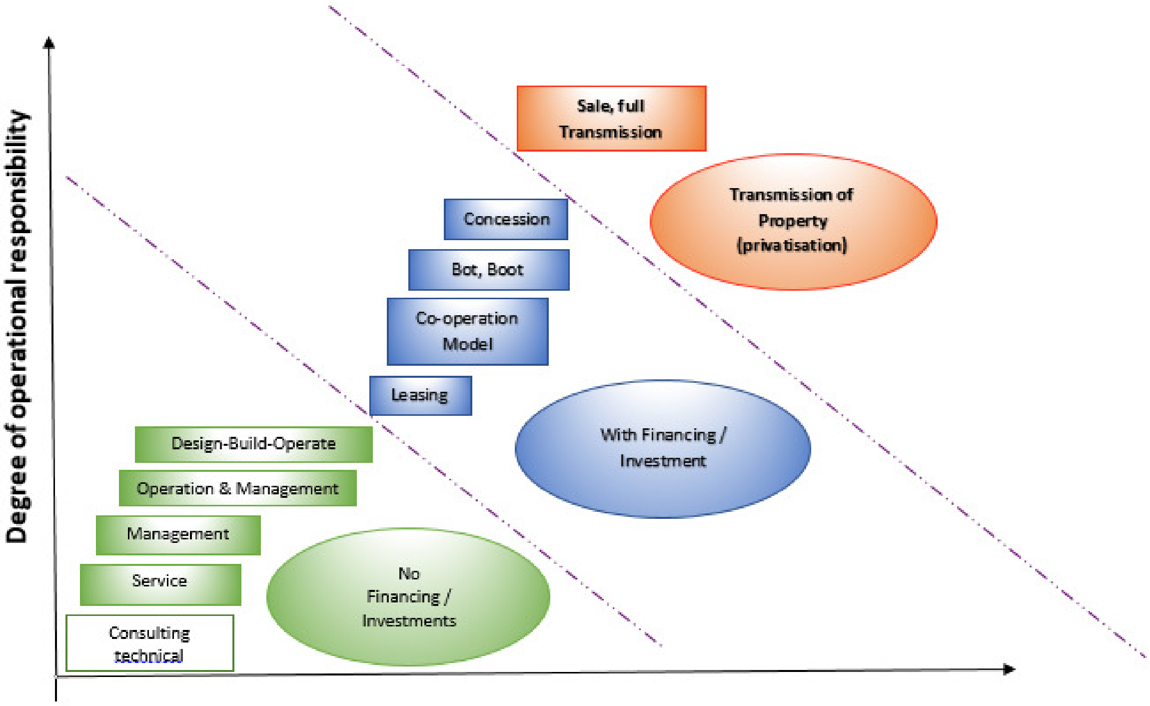
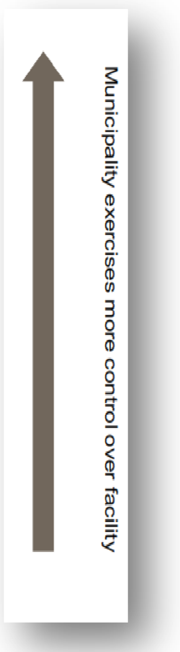


Figure 4: A schematic representation of business models versus responsibility and contract period (GIZ, 2016)

Possible models are:

1. Investment and operation by the municipality with maximal participation.
2. Outsourcing of the energy production, based on a monthly operation fee and a tariff per kWh. Thermal energy used for digester heating and electricity for the on-site use.
3. Outsourcing the sludge treatment from post thickening process steps, anaerobic digestion and energy production, based on a monthly operation fee and a tariff per kWh. Thermal energy used for digester heating and electricity for the on-site use. Digested sludge returned to WSA.
4. BOT/BOOT* model for the proposed CHP system while WSA remains responsible for the balance of the WWTW.



5. Outsourcing the total sludge treatment from post thickening process steps, anaerobic digestion and energy production, based on a monthly operation fee and a tariff per kWh. Thermal energy used for digester heating and electricity for the on-site use. Digested sludge dewatered and disposed by PSP.
6. Outsourcing of operation of the complete plant.
7. Transfer of ownership/privatisation with complete take-over by PSP.

7.2 Potential business model for Zeekoegat WWTW/CHP

A 1st order SWOT analysis, present the following strengths and weaknesses for the City of Tshwane. The Metro serves both as the WSA and WSP in the treatment of wastewater:

Tshwane - Zeekoegat WWTW: Strengths	Tshwane - Zeekoegat WWTW: Weaknesses
1. Competent and experienced staff 2. Strong skills/experience base in wastewater treatment 3. High level of commitment to green technologies 4. Reasonable appetite for CHP 5. Ability to conceive, procure, manage CHP project 6. Involved in research and new technology 7. Bylaws and strategies ready for uptake of embedded technology.	1. No spare capacity of technical staff 2. No CHP skills/experience 3. Cost/benefit not clear 4. Limited knowledge of PSPs in field 5. Medium appetite for risk 6. Difficulty to attract skilled CHP resources 7. Procurement response time for maintenance repair services 8. Funding uncertain 9. Deficit in revenue leaves limited ability to fund capital project of secure loan.

The recommended business models for the WWTW are as follows:

Business Model 3: If Tshwane Metro takes a decision to extend its competency to include CHP technology, business model 3 is the preferred model:

- Capital investment funded by WSA, grant funding, or a combination.
- The WSP remains responsible for the complete WWTW, excluding CHP and directly related aspects.
- The successful Design Build Operate PSP will be responsible for design, build and operation of the supplied plant and equipment.
- The PSP will be responsible for skills transfer during the operating period and there should preferably be an option to renew the operational period should the WSA prefer this option at the time. The operation duration should be agreed with WSA.
- The WSA will pay the PSP an agreed amount per month for the execution of plant management as well as operation and maintenance functions regarding infrastructure and equipment for which the PSP assumes responsibility.

- The WSA will pay the PSP an agreed tariff per kWh generated and supplied into the site reticulation for consumption by the WSA on site. The tariff will be lower than model 4 due to the fact that the PSP did not contribute to capital investment.
- The PSP will pay the WSA for site utility services.
- The PSP accepts an agreed mass of sludge at agreed solids content from the WWTW with responsibility for further thickening, anaerobic digestion and related equipment, returning supernatant and digested sludge to the WWTW.
- The PSP will also assume responsibility for the operation and maintenance of **existing** WSA infrastructure as allocated, as well as digester feeding, mixing and heating. The purpose of this allocation is to enable the PSP maximum opportunity and flexibility with regard to biogas production. This will also enhance digested sludge quality.
- The PSP is responsible for all aspects related to biogas collection, treatment, conditioning, analysis, flow measurement, boosting and utilisation as fuel, power generation and control, heat recovery and distribution to digesters.

Business Model 4: If the WSA is adverse to the extension of competency to include CHP technology, business model 4 is the preferred model. The contracting principles will essentially be the same as for business model 3 above as described below:

- Capital investment for CHP facility funded by PSP.
- The WSP remains responsible for the complete WWTW, excluding CHP and related aspects.
- The successful Design Build Operate PSP will be responsible for design, build and operation of the supplied plant and equipment. The PSP will retain ownership of plant and equipment supplied and installed.
- The WSA will pay the PSP an agreed amount per month for the execution of plant management as well as operation and maintenance of **existing** infrastructure and equipment for which the PSP assumes responsibility in addition to the new plant.
- The WSA will pay the PSP an agreed tariff per kWh generated and supplied into site reticulation for consumption by the WSP on site. The tariff will be higher than model 3 to compensate the PSP for capital investment.
- The PSP will pay the WSA for utility services.
- The PSP accepts an agreed mass of sludge at agreed solids content from the WWTW with responsibility for further thickening, anaerobic digestion and related equipment, returning supernatant and digested sludge to the WWTW.
- The PSP will also assume responsibility for the operation and maintenance of **existing** WSA infrastructure as allocated, digester feeding, mixing and heating. The purpose of this responsibility allocation is to enable the PSP maximum opportunity and flexibility with regard to biogas production.
- The PSP is responsible for all aspects related to biogas collection, treatment, conditioning, analysis, flow measurement, boosting and utilisation as fuel, power generation and control, heat recovery and distribution to digesters.

Whichever business model is implemented, the exact scope of the contract and allocation of responsibilities should be carefully considered during the execution of the technical feasibilities.

8. RECOMMENDATIONS

The recommendations aim to target aspects that would assist the municipality to advance the project by addressing gaps or sensitivities identified during the feasibility phase of this project.

8.1 Appraisal

According to the structure of a SWOT-Analysis the impact or possible impact of implementing a CHP project can be summarized as follows:

Strengths	**Weakness**
• Reduction of operational costs • PBT-period <10 years • Reliable source of energy • 70 % reduction of CO_2 emissions • Improvement of Green Footprint • Reduced peak demand from ESKOM grid	• Investment in additional technology • Increased requirements on operations of biogas treatment and CHP • Pressure on existing human resource capacity
Opportunities	**Risk**
• Knowledge Hub for RE Renewable Energy and EE Energy Efficiency within Zeekoegat and RSA • Set-up of center for treatment of sludge from WWTW through co-digestion	• Permanently low electricity price • Long decision-making processes

Figure 5: Possible impact of CHP project

Reduction of operational costs: Using only own sludge the total demand of the plant could be covered up to 21 % with own production of electricity. Savings will lead to a payback time period for CAPEX of about 8.9 years. If sufficient co-substrate become available to feed the digester to full capacity, then about 89 % of own consumption could be covered through CHP.

Improved sludge quality: In order to produce as much as possible electrical and heat energy, the PSP will need to stabilise the sludge. Stabilising is essentially the destruction of volatile suspended mass. The degree of stabilisation required to produce biogas implies that the digested sludge will comply with the Sludge Guideline stabilisation requirement, allowing classification as a Class 1 in terms of stability. This will reduce restrictions in terms of disposal with positive cost implications for the WSP. Well-digested sludge will also lead to a better microbiological quality, although the improvement may not be as well defined as in the case of stability. This will result in a further improved sludge classification, reduced restrictions and reduction in disposal costs.

Reduced sludge mass and related disposal cost: As described above the stabilisation of sludge implies the destruction of volatile solids. Typical solids destruction expected for well controlled anaerobic digesters is in the order of 37% to 44% resulting in a significant mass reduction for Zeekoegat WWTW. This implies a considerable reduction in sludge disposal cost based on mass to be disposed only.

Freeing up of Eskom generating capacity: The generation of electrical energy on the proposed sites implies that energy produced on site displaces the energy consumption by the WWTW resulting in the freeing up of Eskom generating and transmission capacity, thus delaying capital investment in power generating capacity.

Opportunity for additional revenue streams: A CHP project will serve as trigger to explore additional revenue streams that will further boost the economics of the energy generation project.

- The identification of organic sources for co-digestion will imply that the surplus capacity of the anaerobic digesters are productively used to increase biogas and energy generation. These waste streams will likely originate from an industrial and agricultural sources, which may see benefit in paying gate fees to the municipalities in exchange for their 'waste' problem.
- Different levels of refinement of the generated biosolids offers economic opportunities, i.e. soil enrichment, composting, and production of fertiliser. Technologies for the precipitation of struvite (MAP), brick making, etc. are available and documented.

Optimisation opportunities: The Zeekoegat site presents opportunities to optimise certain inefficiencies which would contribute to a sustainable CHP future, if addressed.

- The generation of electricity coupled with the reduction in energy demand of the plant will have benefits it terms of the economics and the carbon footprint of the plant.
- Correction of extraneous flows, i.e. water losses, excessive stormwater- and groundwater infiltration to the sewer system will free up capacity at the plant
- Correction to the water losses will reduce Non-Revenue Water, improve the revenue stream, improve the COD loading to the plant, and thereby, improve sludge quality and AD loading for optimal CHP generation.

Reputational value: The City of Tshwane considers its good name, reputation and brand as important. A CHP project which is rooted in good economics, job creation and environmental consciousness, will benefit the municipal brand and reputation up to being the Knowledge Hub for RE Renewable Energy and EE Energy Efficiency within RSA.

Climate impact potential: Current practice at the WWTW does use the biogas and the methane is released (un-flared) to the atmosphere. The replacement of methane by CO_2 by combustion in a CHP generator is associated with a positive effect concerning avoided greenhouse gas (GHG) emissions, as methane has a significantly higher (factor 25) global warming potential (GWP) than CO_2. The use of biogas as a fuel would substitute the baseline methane emissions (today) by CO_2 emissions in the CHP plant (future). Implementing a CHP project will save about 72 % GHG from baseline.

8.2 Recommendations according to the installation of CHP:

- From economic evaluation, Option IIC seems to suggest a shorter payback period if the assumed availability of co-substrate (Sludge from Baviaanspoort) can be achieved and maintained.
- Until co-substrate will be available Option IB should be focussed.
- The implementation can be phased in a modular fashion as the co-substrate supply is firmed up:
    - starting with 350 kW_e CHP,
    - upgrade with 350 / 500 kW_e generator on demand / when co-substrate and funds available, preferably with similarly sized modules.
- The suggested connection point of the CHP generator is LV blowers of Module 2.
- Further studies on co-digestion sources and optimized CHP configurations would be required to confirm this arrangement.
- Gas treatment plant should be situated nearby the digesters while CHP should be situated nearby of the connection point. Gas from Gas treatment could easily be conducted to the CHP via gas pipes.
- The tariff difference between off-peak, standard and peak was found to be insubstantial which render the implementation of a system sized to maximise savings during the peak tariff periods not feasible.

8.3 Recommendations according to the business model:

- Tshwane Council should take decision to extend competency to include CHP technology.
- Business model 3 (outsourcing the sludge treatment from post thickening process steps, anaerobic digestion and energy production, based on a monthly operation fee and a tariff per kWh) or Business Model 4 (BOT/BOOT* model for the proposed CHP system while WSP remains responsible for the balance of the WWTW) should be taken into account
- The precise exclusion of contractual obligations and allocation of responsibilities should be carefully considered during the execution of the technical feasibilities.

8.4 Recommendations according to anaerobic process stability and efficiency

- At the present loading it is recommended that only one digester is used. Alternatively one digester can be used as a high rate heated (there will probably not be enough heat energy to heat both digesters anyway) and mixed digester with discharge to the second digester which can be used unheated and unmixed. The second digester can then also be used for digestate thickening before dewatering. This operational mode is recommended up to the point where the digester loading increases beyond the capacity of one digester at which time the two digesters can be operated as two parallel high rate digesters.

- The digesters should preferably be operated on displacement mode. The volume of feed sludge should be as small and continuous as possible (as opposed to infrequent large volumes). This will have a significant positive impact on process stability and efficiency.
- The feed sludge should be managed to ensure the highest solids concentration achievable by the existing process units.
- The temperature of the digester content should be kept as stable as possible and temperature variation of more than 1°C per day should be avoided.
- Biogas flow meters and recorders/loggers on each anaerobic digester will assist the operator to understand the condition of the digesters and under what operating conditions maximum biogas is produced. Maximum biogas production will in turn indicate maximum volatile solids destruction which in turn will produce the most stabilised sludge and ensure minimum sludge mass for disposal. A high degree of stabilisation will ensure a Stability Class 1 in terms of the Sludge Guidelines.
- Reducing the BNR sludge age (while maintaining the minimum sludge age for nitrification) has been reported to improve biological phosphorus removal. This strategy has the further advantages that a shorter sludge age will reduce oxygen consumption in the BNR and will simultaneously improve the digestibility and biogas potential.

8.5 Recommendations with regard to the application of co-substrate:

- Identify sources with organic waste in the immediate vicinity of the plant as potential co-digestion source.
- Identify and resolve the underlying causes for the low COD to the plant. Ideally, all PST and WAS sludge must feed to the anaerobic digesters in order to reach their full potential.
- If the current low loading continues, consider running only one digester to optimise running costs and use energy more efficiently, as recommended above.

8.6 Recommendation in order to improve the energy efficiency of the plant:

- Replace old non-functional PLC’s with new PLC’s.
- Replace old non-functional instruments.
- Install solid state smart drives (VSD’s and Soft Starters) in all the motor starters from 22 kW and above.
- Supply and install in the control room a modern SCADA system for the overall system for performance monitoring and control.
- Supply and install a fibre Ethernet data communication ring network between all the new PLC’s, and between the PLC’s and the SCADA system.

8.7 Recommendations according additional value creation

The following additional streams of revenue need to be considered to optimise the returns on this project:

- Selling digested and prepared sludge as fertilizer to agriculture
- Waste gate fees for domestic, industrial, agricultural waste and landfill leachate from non-hazardous waste sites.
- Sale of effluent as compost for its Nitrate and Phosphate properties.
- Struvite recovery and precipitation processes could be investigated to recover MAP (Magnesium, ammonia, phosphate) from the sludge.
- Carbon credit trading (not common in SA yet but a strong economy internationally).
- Other tax incentives that could apply towards renewable energy projects.

9. WAY FORWARD

The Feasibility Study provides the basis for further actions to be taken by the City of Tshwane. The following high-level steps are recommended:

1. Council to take a decision to implement a CHP project, and add this project to the IDP and capital projects list (if positive decision taken)
2. The decision may be supported by the recommended Business Model
3. The point of departure may be to continue with the Zeekoegat WWTW, as an initiate project of this kind in Tshwane, and then to continue further work on the Road Map towards consideration of centralised sludge management strategies, exploring the beneficial aspects of sludge and biogas as part of the Rooiwal future upgrades, etc.
4. Set a detailed Project Plan for the Zeekoegat CHP project with responsibilities, timeframes, target dates to administer the project
5. Source and secure funds
6. Design, tender and adjudication Construction and commissioning
7. Optimisation of operation as per the recommendations from the Feasibility Study
8. Commence with sourcing of co-digestion phase, and explore fertilizer production

Note: GIZ will remain available in a support and facilitation role after close out of the Feasibility Study. The GIZ network may offer valuable opportunities to facilitate meetings between Tshwane and financing institutions, government departments, etc.

****