ENERGY-EFFICIENT PLANT DESIGN: COST-BENEFIT ANALYSES OF TREATMENT PROCESS OPTIONS AT DIFFERENT WESTERN CAPE WASTEWATER TREATMENT WORKS

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ABSTRACT

Constraints around security and affordability of energy are increasingly driving planning decisions in municipal water and sanitation service provision. This paper reviews, at a preliminary level of accuracy, the technical and economic potential of reducing energy demands by implementing different design configurations for five wastewater treatment works within the Western Cape, ranging from small, regional scale works (1 Mℓ/d), up to the major metropolitan scale works (150 Mℓ/d).

A broad spectrum of wastewater treatment technologies was assessed from a simple base-case scenario (biological treatment, surface aerators and sludge disposal) to a more sophisticated scenario (biological treatment, fine bubble diffused aeration, advanced digestion with energy recovery and direct application of digested sludge) for each of the treatment works considered within the study.

For each case study, projections were made of future flows as well as organic and nutrient loads. The associated key treatment plant design parameters (optimal sequencing of phased upgrades, sizing of equipment and reactor volumes, energy demands and waste sludge volumes) were then determined using steady-state biological treatment process models. The outputs from the technical models were then used to develop a comparative economic model, to assess the lifecycle costs (or Net Present Value, NPV) of the different options at each wastewater treatment works.

The results of the study indicate that an optimum energy-efficient process configuration is achieved for the smaller regional treatment works (less than 5 – 10 Mℓ/d) when they are designed to allow for (as a minimum) fine-bubble diffused aeration, primary settling, and composting of sludge to achieve a stable biosolid suitable for application to fallow land. For the larger works, the optimum is achieved by incorporation of further advanced process technologies, including sludge pre-treatment and energy recovery from anaerobic digester gas. The array of results presented in this paper provide some generalised guidance as to how wastewater treatment plants of different scales may be optimally designed to practically and affordably reduce energy demands over the lifetime of the works, provided that any extrapolation of results appropriately accounts for local constraints.

INTRODUCTION

Background

This study incorporates work undertaken for the City of Cape Town and the Swartland Local Municipality during two different planning studies for upgrades to five wastewater treatment works (WWTWs) within the Western Cape.

Aims and objectives

In recent years, South Africa has experienced a shortage in base load electricity supply due to inadequate and aging power generation and distribution infrastructure and rapid increase in demand resulting from electrification and economic growth (Goeller, 2008). In order to finance new capital expansion projects, South Africa's public utility (ESKOM) has demanded significant increases to the bulk price of electricity (by as much as 25% p.a.) (Moolman, 2015).

Wastewater treatment is typically one of the most energy intensive activities mandated to local municipalities. This is due primarily to the high energy inputs associated with aeration in biological treatment processes such as the Activated Sludge process (Henze, et al., 2008). As the electricity price in South Africa increases, some local authorities have begun to explore ways to reduce energy costs through enhancements to treatment infrastructure.

In recent years, the trend at wastewater treatment works (WWTWs) in industrialised nations has been to reduce energy costs through the implementation of technologically complex energy-efficiency or energy recovery solutions that achieve significant reduction in net energy use, but which are associated with high upfront capital investments and onerous operating and maintenance requirements.

To date there has been much debate in the municipal engineering sector regarding the realistic potential of implementing energy efficiency objectives in wastewater treatment. On one side, there is an expectation that, as more energy-efficient process technologies achieve maturity in South Africa (such as anaerobic digestion and power generation from digester biogas), competition in the technology supplier market will drive capital costs (CAPEX) down, and drive potential for energy savings up, resulting in reduced operating expenses (OPEX). There is also a somewhat conflicting belief amongst municipal planners and engineers that more energy-efficient process technologies are technically impractical and cost-prohibitive at a small scale.

This study therefore aims to test the technical and economic potential of different energy-efficient solutions across a range of scales of Western Cape WWTWs (from small-scale, decentralised, rural works to large-scale metropolitan works) and determine what process enhancements (if any) could be feasibly implemented at each scale.

METHOD

Study area and treatment works

The City of Cape Town operates seventeen WWTWs throughout the metropolitan area, of which the third largest is Zandvliet WWTW,

TABLE 1 Description of WWTWs investigated

WWTW	Authority	Technology	Rated Capacity *(2015/16)*	Status
Zandvliet	City of Cape Town	MBR and BNR/SST	72 Ml/d	Upgrade underway (capacity limited)
Malmesbury	Swartland LM	MBR	10 Ml/d	Upgraded 2013
Riebeek Valley	Swartland LM	BNR/SST	2 Ml/d	Upgraded 2016
Darling	Swartland LM	BNR/SST	1.5 Ml/d	Due for upgrade (capacity limited)
Moorreesburg	Swartland LM	Extended aeration / SST	1.5 Ml/d	Due for upgrade (ageing infrastructure)

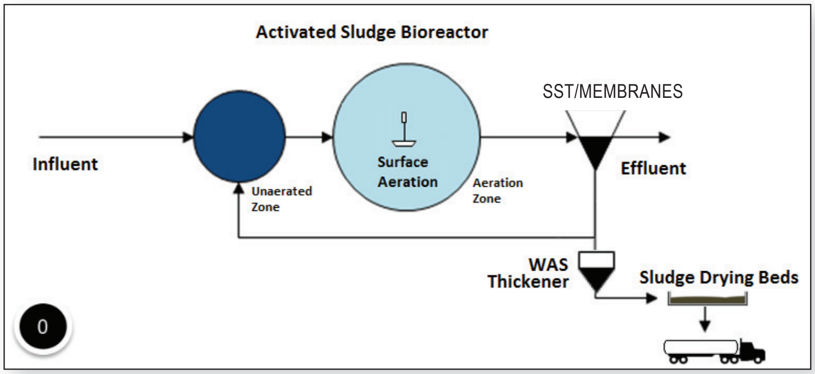

FIGURE 1 Baseline configuration – raw wastewater Activated Sludge system with SST/Membranes, surface aeration, and direct WAS discharge to sludge drying beds

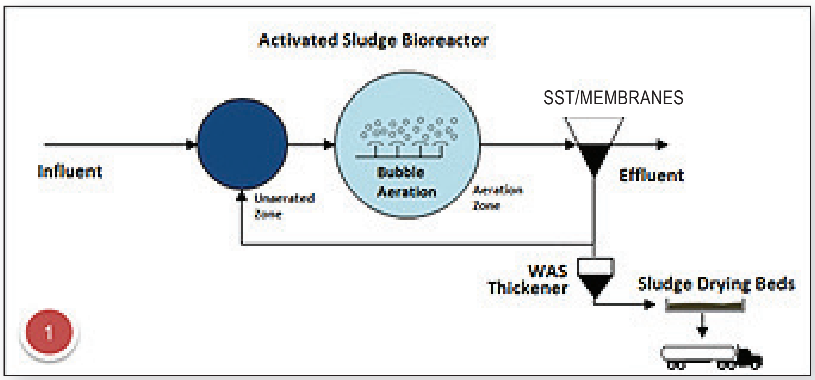

FIGURE 2 **Option 1** Raw wastewater AS system with SST/Membranes, bubble aeration, and direct WAS discharge to sludge drying beds

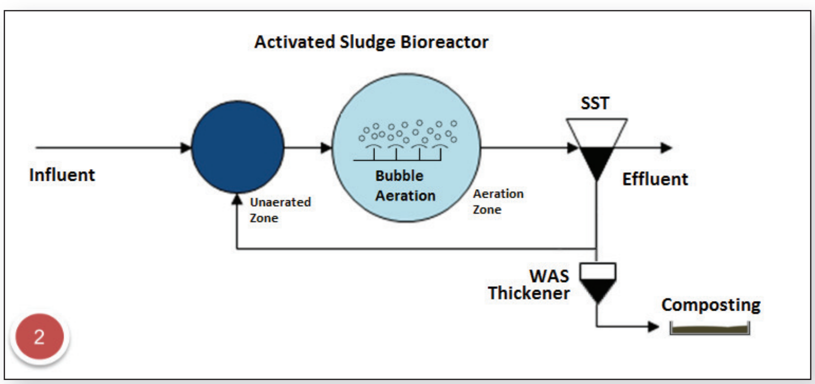

FIGURE 3 **Option 2** Raw wastewater AS system with SST/Membranes, bubble aeration, and WAS composting

treating residential wastewater from the Khayelitsha, Blue Downs, Delft and Mfuleni areas in two parallel streams: one membrane bioreactor (MBR) stream and one conventional biological nutrient removal / secondary settling tank (BNR/SST) stream. Treated effluent from the Zandvliet WWTW is discharged to the Kuils River and dewatered biosolids are transported offsite for application to fallow land. This works is currently being extended to accommodate increasing wastewater runoff driven by growth and development in the catchment.

The Swartland Municipality is situated directly north of Cape Town. There are four significant WWTWs that are operated by the Swartland Municipality (Malmesbury, Moorreesburg, Darling and Riebeek Valley), the capacities of which are presented in Table 1.

Malmesbury is a larger works, treating predominantly residential wastewater in a BNR/MBR system. Treated effluent is reused for irrigation, and dewatered biosolids are transported offsite for application to fallow lands. The other Swartland WWTWs (Moorreesburg, Darling and Riebeek Valley) are all designed as a BNR/SST activated sludge process configuration.

Determination of treatment process energy savings

The determination of energy savings achieved by improvements to the treatment processes at each WWTW involved the following sequential modelling and calculation steps:

- Conceptual design of incremental improvements to treatment process configurations
- Analysis of historical influent data and projections of future flows and organic and nutrient loads expected at each WWTW
- Activated sludge modelling of each WWTW considering capacity upgrades and different treatment configurations
- Sludge handling and beneficiation modelling at each WWTW considering: biogas generation potential and energy recovery, net electrical energy use, fuel energy for sludge transportation

Conceptual design of incremental process improvements

The treatment process configuration has a significant impact on the overall energy-efficiency of the WWTW, most significantly due to aeration requirements of biological treatment processes for removal of organics and nutrients, as well as pumping of wastewater flows, and sludge handling and beneficiation. The following paragraphs describe a range of case-study treatment process configurations considered at each treatment works:

- **OPTION 0:** For the purpose of this investigation, a baseline treatment system (Option 0) was selected, against which the energy-efficiency of the treatment processes could be evaluated under various enhancement scenarios. This baseline process configuration comprises of a conventional raw wastewater biological nutrient removal (BNR) activated sludge system with mechanical surface aeration, solid-liquid separation by secondary settling tanks (SSTs) or membranes and direct discharge of waste activated sludge (WAS) to sludge drying beds from where it is transported to a landfill for disposal. This configuration is shown in Figure 1.
- **OPTION 1:** Reductions in energy demand can be achieved by installing a fine-bubble diffused aeration (FBDA) system instead of a surface aeration system (Option 1). This system improves the oxygen transfer efficiency in the aerobic reactor, resulting in reduced mechanical energy requirements. The Option 1 process configuration is illustrated in Figure 2.
- **OPTION 2:** An alternative treatment option that is theoretically more energy-efficient involves on-site windrow composting of the

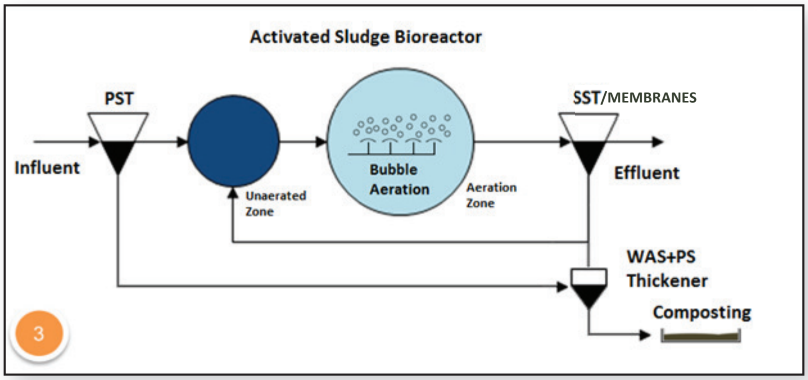

FIGURE 4 **Option 3** Settled wastewater AS system with SST/Membranes, bubble aeration, WAS and PS composting

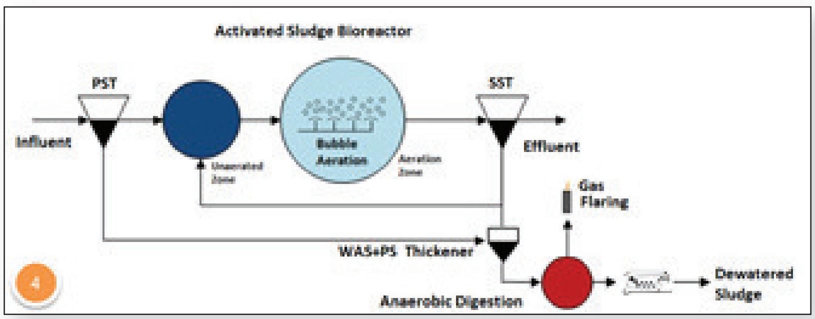

FIGURE 5 **Option 4** Settled wastewater AS system with SST/Membranes, bubble aeration, WAS and PS anaerobic digestion with gas flaring

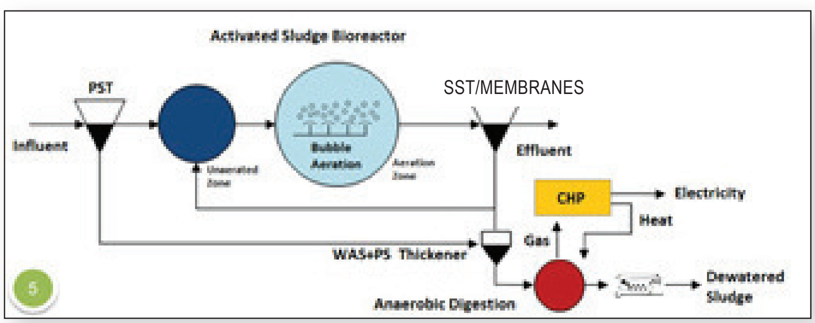

FIGURE 6 **Option 5** Settled wastewater AS system with SST/Membranes, bubble aeration, WAS and PS anaerobic digestion with combined heat and power recovery

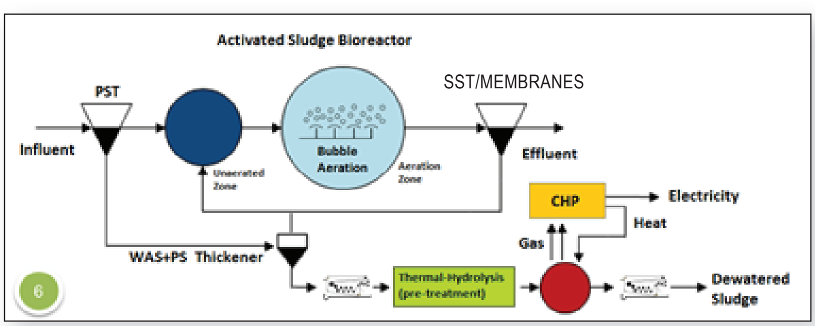

FIGURE 7 **Option 6** Settled wastewater AS system with SST/Membranes, bubble aeration, WAS and PS anaerobic digestion with thermal hydrolysis pre-treatment and combined heat and power recovery

WAS (Option 2). Once composted on-site, the WAS is sufficiently stabilised that it meets the sludge reuse classification for application to land nearby (on fallow fields during crop rotation), reducing the energy demand associated with transporting the sludge to a landfill further away. This process configuration is illustrated in Figure 3.

- **OPTION 3:** The most significant change to the process configuration is the addition of primary settling and conversion of the raw wastewater system to a settled wastewater system.
  The addition of a primary settling tank (PST) results in a diversion of organic and nutrient loads from the activated sludge system. On a mass basis, this accounts for approximately 30-40% of the organics measured as chemical oxygen demand (COD), 15-20% of the Total Kjehldahl Nitrogen (TKN), and 15-20% of the Total Phosphorus (TP), and 50% of the Suspended Solids. This reduction in organic and nutrient load changes the process requirements of the activated sludge system, typically requiring a smaller reactor volume, and lower oxygen demands.
  By reducing the oxygen demands of the biological system in this way, the associated aeration energy demand is proportionally reduced.
  With primary settling, an unstable primary sludge (PS) waste stream is produced. This sludge requires additional treatment before it can be safely applied to land. This scenario considers composting the WAS and PS together to produce a stable biosolids stream for application to fallow land nearby. The overall process configuration is shown in Figure 4.
- **OPTION 4:** To improve the treatment process further, mesophilic anaerobic digestion of WAS and PS can be implemented instead of the WAS and PS composting system. Mesophilic anaerobic digestion involves treating the sludge in an oxygen-starved environment at a temperature of 20-45°C for a retention time of 15 to 30 days (Henze, et al., 2008). By digesting the sludge, 50-70% of the volatile solids (VS) is converted to a methanerich digester gas which is flared to the atmosphere. This reduction in waste sludge mass results in significant savings in sludge transport energy.
  However, anaerobic digestion comes with additional operation complexities and may require more qualified maintenance technicians and operators. The process configuration for this option of enhancement is shown in Figure 5.
- **OPTION 5:** If the methane-rich digester biogas is dehumidified and cleaned of impurities, it can be burned in a gas engine to generate electricity for use within the WWTW, thereby reducing the works' net energy demand. If a combined heat and power (CHP) engine is used, the waste heat from the engine and exhaust can be recovered to preheat the sludge feed and maintain an elevated temperature in the digester, which enhances the efficiency of the digester (faster breakdown of sludge, faster conversion of biogas).

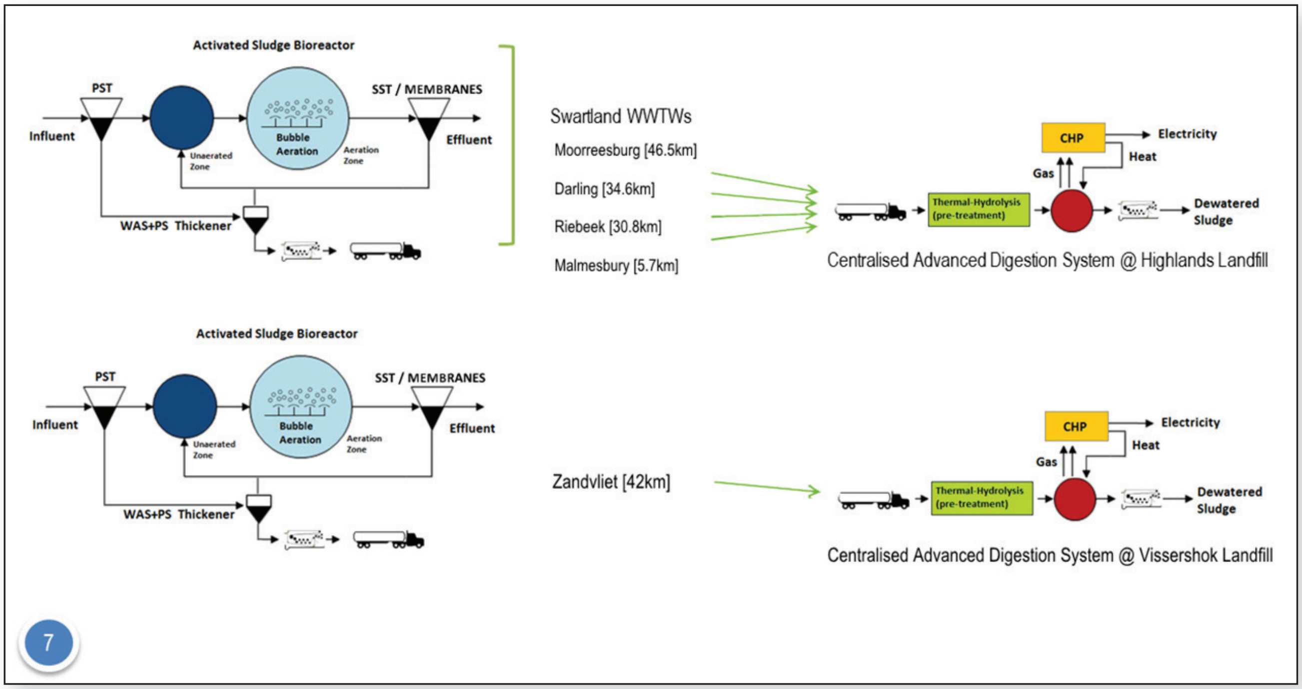

FIGURE 8 **Option 7** Settled wastewater AS systems, bubble aeration, centralised advanced digestion (at Highlands/Vissershok) with CHP energy recovery facility

The integration of the CHP unit to the sludge system is shown in Figure 6.

- **OPTION 6:** Advanced anaerobic digestion involves the addition of a thermal hydrolysis pre-treatment step in which the sludge is treated at high temperature and pressure conditions before being fed to the digester. This pre-treatment process sterilises the sludge (destroying parasites and helminth ova) and converts fibrous material into a fermentable substrate, improving the conversion and efficiency of the anaerobic digestion process (higher conversion of solids to methane gas at a shorter retention times).

  In addition to this performance improvement, the final residual solids (digestate) can be more easily dewatered reducing the volume to be transported. The sterilised sludge is also suitable for direct and unrestricted application to soils as a bio-fertiliser, meaning that suitable disposal land might be sourced closer to the WWTW.

  This system demands a highly-skilled team of WWTW operators and staff (to an even greater extent than Option 4 and 5). The advanced treatment system is shown in Figure 7.

- **OPTION 7:** The last option considers a single centralised advanced digestion system, as shown in Figure 8 (sludge treatment stream only). With this option the PS and WAS produced from the regional WWTWs is transported to a centralised facility where the combined sludge is pre-treated and digested to produce biogas for energy recovery in a CHP.

In doing so, the staff and operation requirements are economised by having one centralised sludge treatment facility for all of the WWTWs. The capital cost of constructing such a scheme also enjoys better economies-of-scale.

Option 7 was evaluated for each WWTW separately, assuming the centralised scheme would be situated at the Highlands landfill site (for Swartland WWTWs) or at the Vissershok landfill site (for Zandvliet WWTW). The evaluation for each WWTW therefore considered only the contribution of each WWTW on its own to the centralised scheme (so that it could be considered against the decentralised options 0 – 6).

Not all options were considered for each treatment works. For instance, the larger works (Zandvliet and Malmesbury) are already equipped with Fine-Bubble diffused aeration systems. For these plants, Option 1 is therefore adopted as the 'Baseline'. The options to compost sludge were also not considered in the case of Zandvliet WWTW, where close proximity to residential neighbourhoods and heavy winter rainfall would

TABLE 2 Matrix of options considered at each WWTW

		Zandvliet	Malmesbury	Moorreesburg, Darling & Riebeek Valley
Option 0	Surface aeration and WAS landfill	n/a	n/a	Baseline
Option 1	FBDA	Baseline	Baseline	✓
Option 2	WAS Composting	n/a	✓	✓
Option 3	Primary settling and WAS and PS composting	n/a	✓	✓
Option 4	WAS and PS mesophilic anaerobic digestion and gas flaring	✓	✓	✓
Option 5	Biogas cleaning and energy recovery (CHP)	✓	✓	✓
Option 6	Advanced digestion (pre-treatment & additional dewatering)	✓	✓	✓
Option 7	Centralised advanced anaerobic digestion (pre-treatment and additional dewatering)	✓	✓	✓

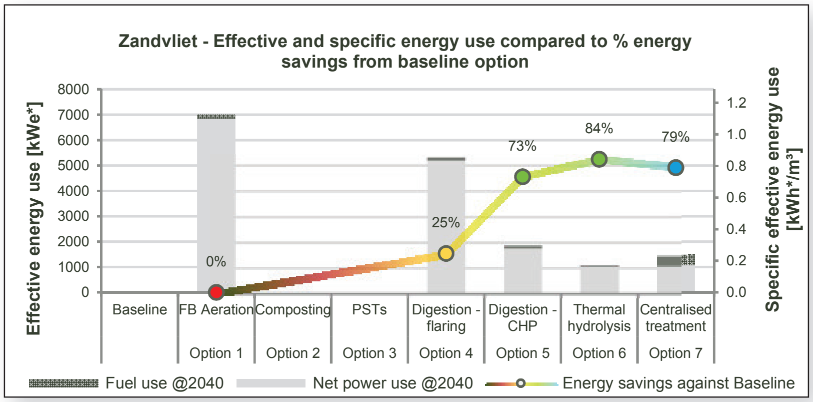

FIGURE 9 Zandvliet - Effective and specific energy use compared to percentage energy savings against baseline option

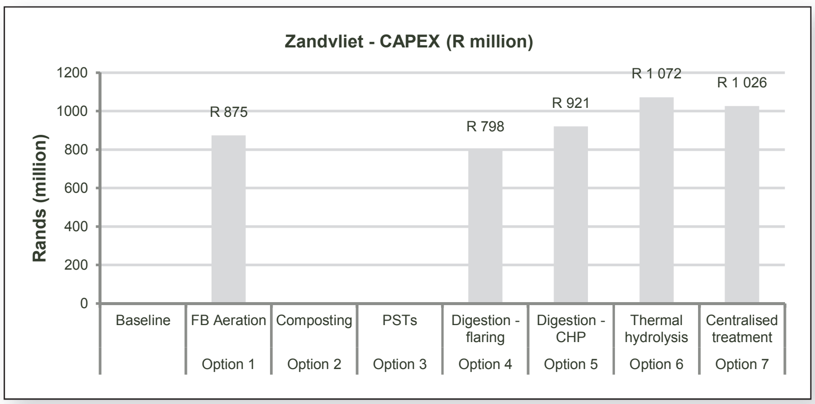

FIGURE 10 CAPEX estimates for treatment options at Zandvliet WWTW (for final capacity @ 2040)

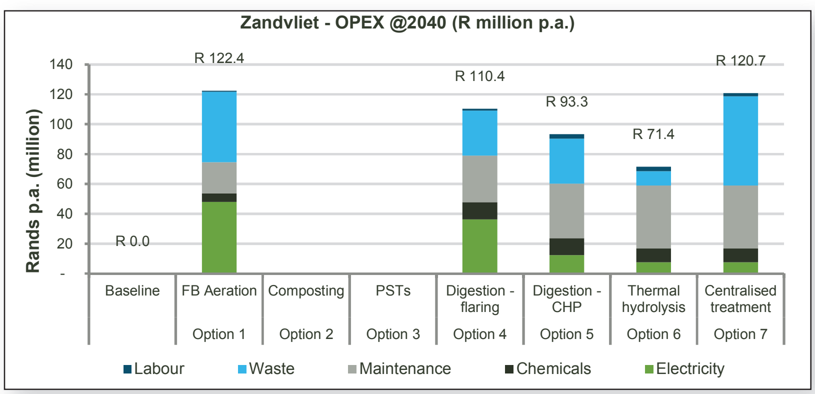

FIGURE 11 OPEX estimates for treatment options at Zandvliet WWTW (at final capacity @ 2040)

make such a technology impractical. Table 2 presents a summary of the treatment process options considered for each of the WWTWs.

Projections of future flows, organic loads and capacity upgrades

Both the flowrate and characteristics of the influent wastewater have a direct impact on the energy demand of the treatment process (energy used for conversion of organics and nutrients). Both the City of Cape Town and Swartland Municipality have comprehensive data records for raw influent wastewater flows and composition at most of their treatment works. This study therefore involved a thorough analysis of historical data to establish representative wastewater characteristics at each WWTW.

The expected flows and organic and nutrient loads were projected for each WWTW over different planning horizons. The City of Cape Town preferred a study period of twenty-five years (2015-2040), while Swartland considered a period of thirty years (2015 to 2045). Based on the projected increase in loads over the 25-30 year planning horizons, it will be necessary to upgrade the WWTWs to meet future demand. Table 3 presents the projected capacity upgrades required at each WWTW.

For the baseline scenarios, it was assumed that, in future, the treatment systems would be upgraded 'likeforlike'. For Zandvliet and Malmesbury, the upgrades will therefore involve membrane bioreactor activated sludge systems, while at Darling and Riebeek Valley, the upgrades would be an extension of the existing BNR/SST activated sludge systems. It was similarly assumed that Moorreesburg (due to be completely overhauled) would also be upgraded as a BNR/SST conventional activated sludge system as the baseline scenario.

Steady state biological activated sludge process modelling

The activated sludge system was modelled for each treatment works using steady state process models in order to determine several key process parameters. Each WWTW was modelled at the different stages of upgrades (Current, Upgrade I, Upgrade II and Final) at the projected flows and loads in that year. Each of the works was modelled under raw and settled configurations in order to determine the optimum sludge age, unaerated mass fractions for effective nitrification/denitrification, reactor volume required, aeration energy demand, mass flow rates and activity of primary and/or waste-activated

Waste Water Treatment Works	Rated capacity (Ml/d)	Upgrade I (Ml/d)	Upgrade II (Ml/d)	Upgrade III (Ml/d)	Final Capacity (Ml/d)
Zandvliet	72	18 @ 2015	30 @ 2018	30 @ 2029	150 @ 2040
Malmesbury	10	11.5 @ 2020	-	-	21.5 @ 2045
Riebeek Valley	2	1 @ 2025	-	-	3 @ 2045
Darling	1.5	0.6 @ 2015	0.9 @ 2030	-	3 @ 2045
Moorreesburg	1.5	2 @ 2015	0.8 @ 2030	-	2.8 @ 2045

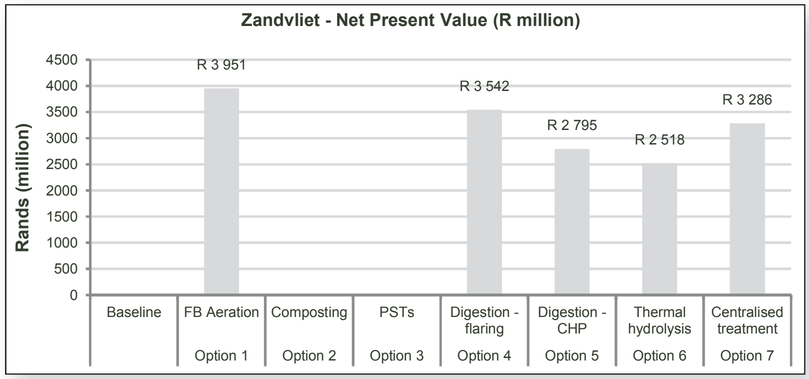

FIGURE 12 NPV cost estimates for treatment options at Zandvliet WWTW over 25 year planning period

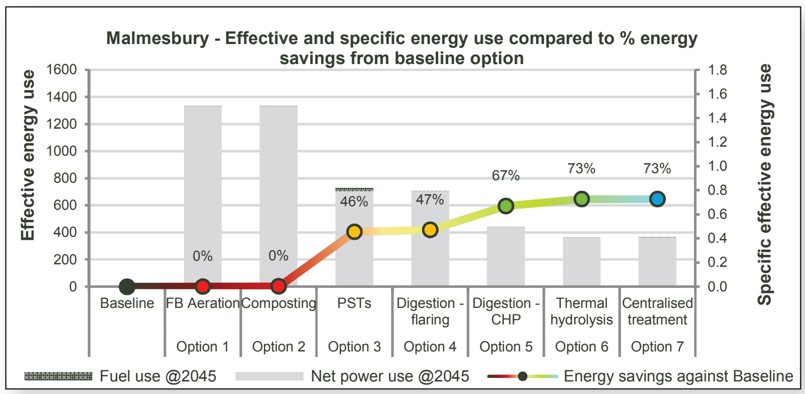

FIGURE 13 Malmesbury - Effective and specific energy use compared to percentage energy savings against baseline option

sludge. For all the improvement options considered, the activated sludge models were checked to ensure that quality of effluent was not negatively affected by the process change proposed.

Sludge handling and beneficiation modelling

The flow rates of primary and/or waste activated sludge, calculated by the activated sludge models, were then incorporated into a sludge handling model to determine (for each process option) the thickening/dewatering equipment requirements (gravity belt thickeners / belt presses), the chemical and wash water demand, Primary Settling Tank (PST) equipment requirements, composting requirements (footprint / implement energy use), as well as impacts of anaerobic digestion (solids reduction, biogas production, CHP energy generation), impacts of advanced digestion (heat energy integration, biogas yields, dewatering volumes) and sludge transportation fuel energy requirements.

Energy use modelling

Each of the scenarios was assessed in terms of overall energy use, accounting for electrical power demand, recovered power from CHP, as well as transport energy requirements (diesel) for transporting biosolids and for operating composting implements.

To compare these different forms of energy (power/fuel), energy figures were calculated as 'effective energy use' with kWe* units. This requires that transport energy demands are converted to an electrical kilowatt equivalent (assuming a 30% conversion efficiency).

For all scenarios, both absolute energy demands (in kWe*) and specific energy demands (in kWh*/m^3) are reported as well as the relative energy savings (in %) enjoyed against the Baseline scenario.

Economic modelling

Estimates were made for each treatment works, under each process technology option, of total capital and operating expenses required at the ultimate capacity, accounting for fixed capital investment (assumed to be 100% financed upfront), design and planning fees, variable operating expenses (power, chemicals, sludge disposal), and fixed operating expenses (labour and maintenance). The capital cost estimates were based on local historical costs of construction for different WWTW equipment, as well as quotes from technology suppliers.

Operating expenses were based on real prices of power, chemicals, sludge disposal and labour paid by the two different authorities, as well as estimates of maintenance based on a factor of the CAPEX of installed equipment. Cash flows were projected over the planning period for each scenario, accounting for ramp-up in flows treated, scheduled upgrades, price inflation, escalation in power prices, and replacement of mechanical and electrical equipment.

TABLE 4 Economic model assumptions (based on 2015 values)

Assumption	Unit	Zandvliet	Swartland
Price of power	R/kWh	0.80	0.44
Price of coagulant	R/kg	45.00	45.00
Price of sludge disposal (Landfill)	R/m^3	390.00	390.00
Price of sludge disposal (Application to fallow land)	R/m^3	73.00	103.50
Maintenance costs (Civil)	% CAPEX p.a.	0.5%	0.5%
Maintenance costs (Mech/Elec)	% CAPEX p.a.	6%	6%
Operator salary	R.p.a	300 000.00	300 000.00
Supervisor salary	R.p.a	700 000.00	700 000.00
Discount rate	% p.a.	8%	8%
CPI Inflation	% p.a.	6%	6%
Power price escalation	% p.a	12%	11%

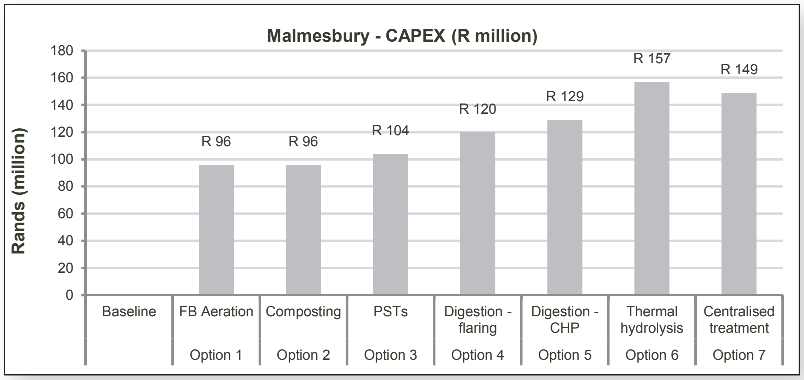

FIGURE 14 CAPEX estimate for treatment options at Malmesbury WWTW (at final capacity @ 2045)

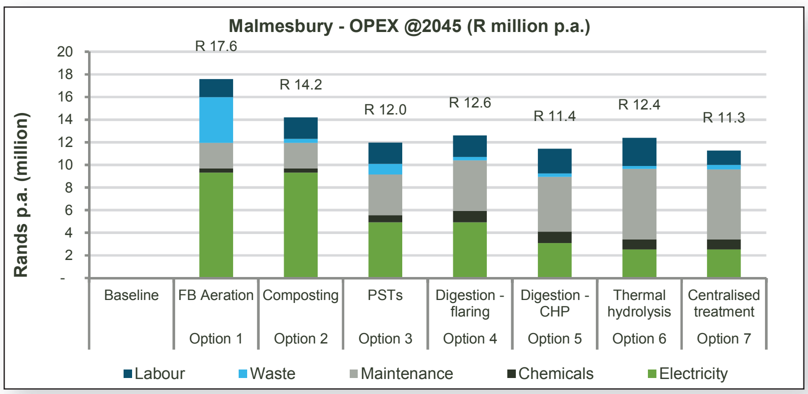

FIGURE 15. OPEX estimate for the different treatment options at Malmesbury WWTW (at final capacity @ 2045)

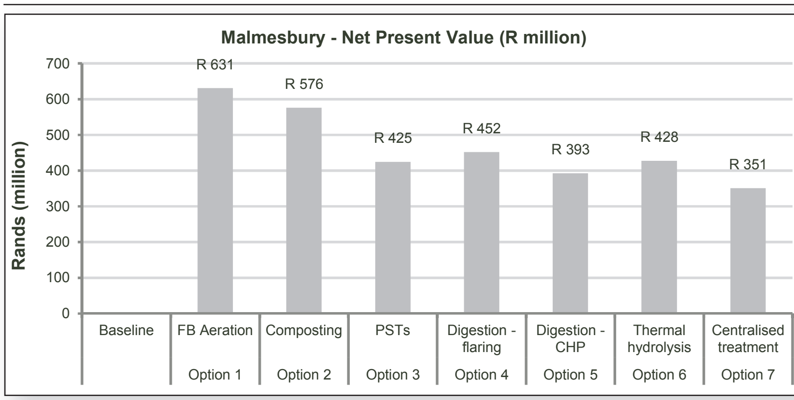

FIGURE 16 NPV cost estimates for treatment options at Malmesbury WWTW over 25 year planning period

Table 4 presents a summary of the key assumptions that informed the economic modelling process.

RESULTS & DISCUSSION

Zandvliet WWTW

The results from Zandvliet WWTW indicate that significant energy savings can be enjoyed by adopting more sophisticated treatment options. Given the size of the Zandvliet works, any marginal savings equate to significant energy savings in absolute terms (megawatts).

Figure 9 presents the net effective energy use of each of the treatment process options at Zandvliet WWTW, at the final estimated capacity of 150Mℓ/d (in the year 2040). While composting options were not considered for Zandvliet WWTW, Option 4 (primary settling and digestion of primary sludge and WAS) demonstrates significant reduction in overall plant energy consumption, primarily because installing PSTs will liberate capacity in the existing conventional BNR stream, which is less energy intensive than the existing and proposed MBR streams, reducing the energy required for membrane pumps as well as for aeration.

By recovering energy from the digester biogas (Option 5), the plant can achieve a net saving of over 70% against the baseline scenario, and by including pre-treatment and advanced digestion (Option 6) this can be augmented further to over 80% (due primarily to increased biogas yield, but also in part to the reduced transport energy required for sludge disposal).

Option 7 (centralised treatment at a regional sludge beneficiation works) incurs a significant energy penalty associated with the transportation of dewatered sludge.

Figure 10, Figure 11, and Figure 12 present the results of the economic models completed for Zandvliet WWTW.

These figures confirm that, while the 'business-as-usual' scenario (Option 1) and installing PSTs and mesophilic digestion (flaring gas) are the most affordable in terms of capital expenses, they are expensive in terms of OPEX, due mostly to high energy and sludge disposal costs.

In contrast, the options that involve recovery of energy (by combusting digester biogas in CHP engines) are expensive in terms of CAPEX (over R1bn), but are significantly cheaper to operate (due to the savings from reduced net energy demand).

The relative influence of CAPEX and OPEX on overall economic feasibility is evaluated using NPV calculations. Figure 12 confirms that, for the case of large WWTW such as Zandvliet, the more sophisticated solutions (Options 5 and 6) are economically optimal when assessed over a twenty-five year planning period. The figure also demonstrates that, for larger treatment works, the overall economic performance of the works is influenced more by the cumulative effects of operating expenses (including energy and sludge disposal costs) over time than by the initial capital outlay.

Malmesbury WWTW

The results from Malmesbury WWTW confirm that, at larger works that use MBR technology (as with Zandvliet), significant energy savings can be enjoyed by adopting more sophisticated treatment options.

Figure 13 presents the net effective energy use of each of the treatment process options at Malmesbury WWTW, at the final estimated capacity of 21Mℓ/d (in the year 2045). By installing PSTs (Option 3), the plant's energy demand can effectively be halved, while recovering energy from the digester biogas (Options 5/6/7) can achieve a net saving of over 70% against the baseline scenario.

Figures 14, 15, and 16 present the results of the economic modelling of options at Malmesbury WWTW.

These figures confirm that the additional CAPEX required for more complex options results in process efficiency and reduced OPEX, due primarily to reduced costs of sludge disposal and reduced energy costs

Figure 16 indicates that, in terms of long term feasibility, the economically preferred options are Options 3 (PSTs), 5 (digestion with CHP) and 7 (centralised advanced treatment). This confirms the major influence of energy costs on overall economic feasibility for larger plants.

The economic feasibility of centralising the sludge treatment plant at the nearby Highlands landfill site (Option 7) is further confirmed for Malmesbury WWTW. However, for this option to be viable, it needs to be proven for all of the Swartland WWTWs.

Smaller Swartland WWTWs (Darling, Riebeek Valley and Moorreesburg)

The smaller of the WWTWs in Swartland (Moorreesburg, Darling and Riebeek Valley) exhibit similar technical results to one another, all achieving relatively large reductions in energy demand; however, given the scale of these plants, this does not relate to significant reduction in absolute terms (10s of kilowatts).

Figure 17, Figure 18, and Figure 19 present the net effective energy use of each of the treatment process options at the smaller Swartland Local Municipality WWTWs, at the final estimated capacity (in the year 2045).

These figures suggest that adopting more complex treatment technologies has the potential to reduce energy demand significantly when compared with the Baseline scenarios; however, there are practical limitations to implementing some of these technology options at this scale (CHP energy recovery and thermal hydrolysis technologies are not widely available at scales below 100-200kW). It is therefore only worthwhile to consider Options 1, 2, 3, 4 and 7 as being technically feasible.

The smaller Swartland WWTWs also exhibit similar economic results to one another. Figure 20 presents the estimated CAPEX required for the roll-out of each treatment option right up to the final capacity upgrade in 2045. Since Riebeek Valley has been upgraded recently (2015/16), it requires less capital expenditure for upgrading core treatment equipment (bioreactors, settling tanks, buildings, etc.).

This figure suggests that the additional capital costs required for improvement of the plant performance is not significant until advanced technologies (Options 5/6/7) are considered.

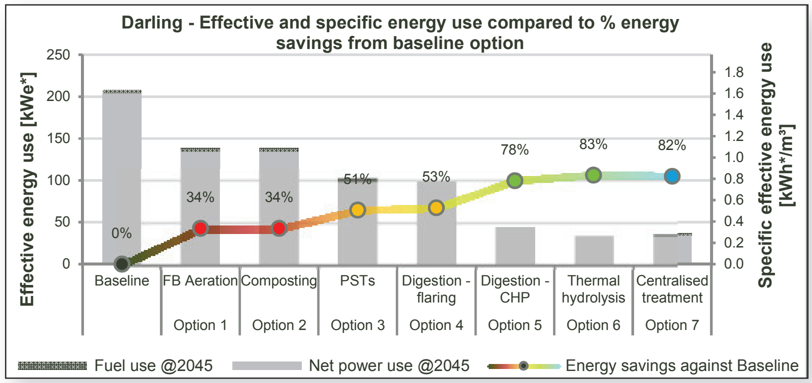

FIGURE 17 Darling - Effective and specific energy use compared to percentage energy savings against baseline option

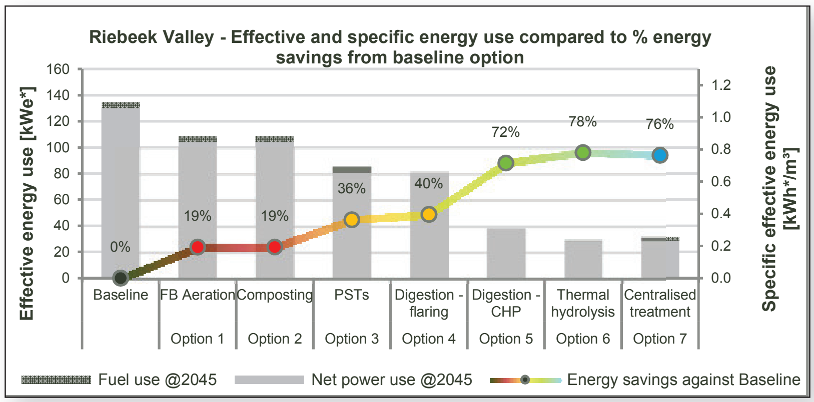

FIGURE 18 Riebeek Valley - Effective and specific energy use compared to percentage energy savings against baseline option

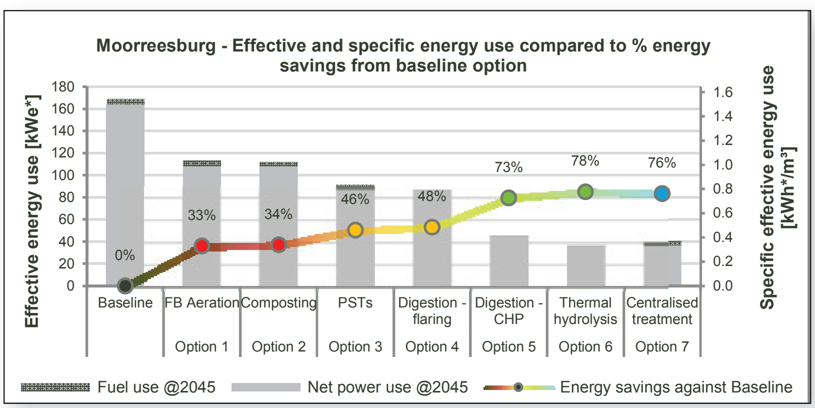

FIGURE 19 Moorreesburg - Effective and specific energy use compared to percentage energy savings against baseline option

Figure 21, Figure 22, and Figure 23 present estimates of OPEX for each treatment option at the smaller Swartland WWTWs (at final capacity). In comparison to the larger works assessed, these treatment works spend a greater proportion on maintenance, labour and sludge disposal than on energy. The relative benefit of implementing energy-efficient treatment technologies is therefore less pronounced. The figures also indicate that, at the smaller treatment works, savings in energy costs are almost perfectly offset by increased maintenance costs. While economically equivalent, this shift represents an opportunity for social and environmental benefit, as money is directed to the service sector of the economy (maintenance jobs), rather than on the extractive/energy sectors (mining).

Figure 24 presents the overall NPVs (lifecycle costs) of each treatment option at the different treatment works, measured over a twenty-five year planning period. This figure indicates that, for the smaller treatment works, the relative influence of CAPEX on overall

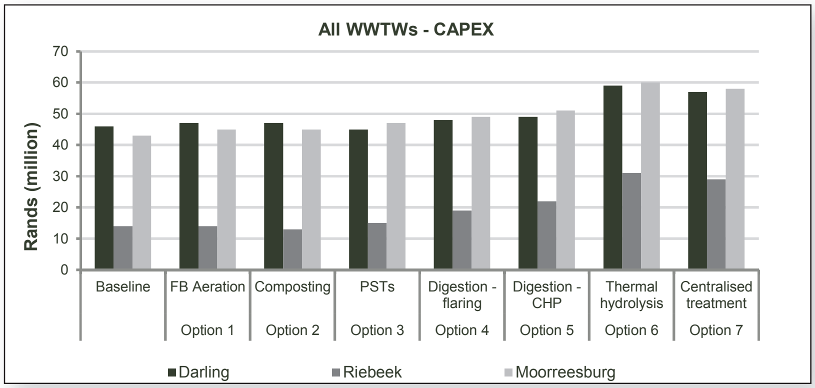

FIGURE 20 CAPEX estimates for smaller Swartland WWTWs (at final capacity @ 2045)

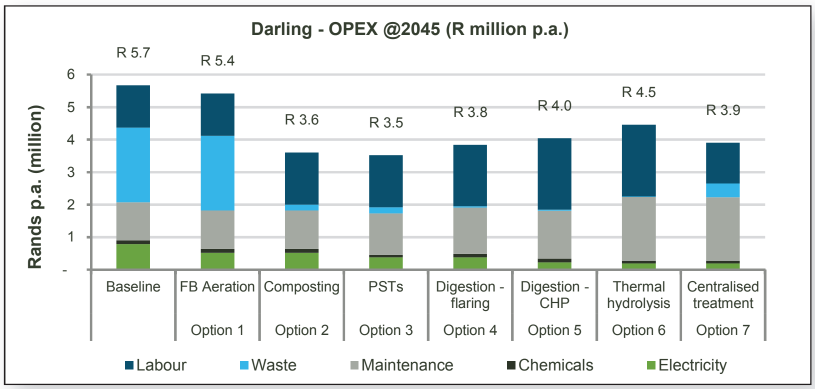

FIGURE 21 OPEX estimate for treatment options at Darling WWTW (at final capacity @ 2045)

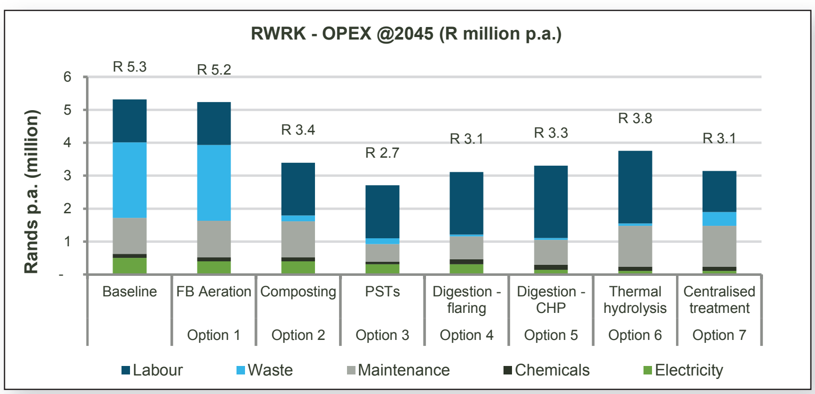

FIGURE 21 OPEX estimate for treatment options at Darling WWTW (at final capacity @ 2045)

lifecycle costs is greater than for the larger WWTWs. It is also apparent that, while installing fine-bubble diffused aeration, composting sludge, and installing PSTs are technically and economically beneficial in the long term, more advanced options (anaerobic digestion, energy recovery from biogas and thermal pre-treatment) are less promising economically.

Further discussion

In the South African development-driven context, smaller, wastewater treatment systems are not usually designed to meet long-term economic goals alone (minimum NPV), and the spending of capital on advanced technology projects for the sake of long term projected savings may not be appropriate when there exist other critical constraints, such as:

- Access to capital (usually apportioned between numerous critical basic infrastructure needs)
- Availability of skilled operators / maintenance technicians
- Reliability of mechanical equipment and risks of delays associated with servicing and maintenance

While improving energy efficiency at existing WWTW may be beneficial in the long term, it is difficult to motivate for government funding to achieve this goal when provision of basic sanitation services in underserviced areas has to be prioritised.

This raises the possibility of raising funds from alternative sources, such as Low-Emission Development grants/loans or pursuing Private/Public partnerships (PPP) where municipalities enter into an agreement with private firms to own and operate part of the treatment works (e.g. Municipality provides sludge to operator who recovers energy through digestion process and sells electricity back to municipality).

CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER WORK

This paper presents the results of a preliminary assessment of the feasibility of implementing energyefficient treatment technologies at different WWTWs in the Western Cape, ranging in size from remote 1Mℓ/d works, to 150Mℓ/d metropolitan works.

The results suggest that, in the Western Cape, smaller treatment works (less than 5 – 10 Mℓ/d) should be designed to allow for (as a minimum) fine-bubble diffused aeration, primary settling, and composting of sludge to achieve a stable biosolid suitable for application to fallow land.

At larger treatment works (above 10 – 20Mℓ/d), further gains are shown to be feasible by installing anaerobic digestion for sludge streams with recovery of energy from digester gas in CHP engines.

As the works approach metropolitan scale (>100Mℓ/d) results indicate that advanced treatment processes (pretreatment of sludge) can be adopted to further improve long-term technical and economic performance (resulting in A1a class biosolids and minimal energy demand).

Given the high costs associated with transporting dewatered sludge over long distances (>30km), the economic feasibility of centralising energy recovery within a single regional facility is limited, but still shown to be preferable to the baseline scenarios, where sludge is transported for disposal at landfill.

While the results and key conclusions were found to be consistent when tested against a simple sensitivity analysis (excluded from this paper for the sake of brevity), further work would enhance this study that gave greater consideration to the statistical uncertainty inherent in the key assumptions (power price, wastewater strength, CAPEX of advanced technologies, value of sludge/biosolids by-product).

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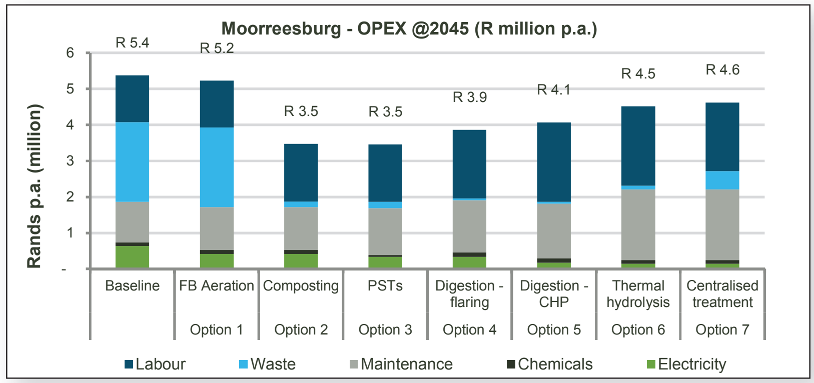

FIGURE 23 OPEX estimate of treatment options at Moorreesburg WWTW (at final capacity @ 2045)

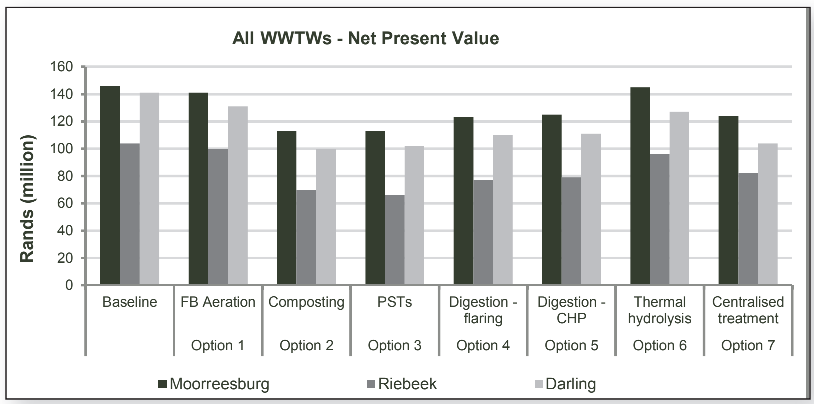

FIGURE 24 NPV cost estimates for treatment options at smaller Swartland WWTWs (over 25 year planning period)