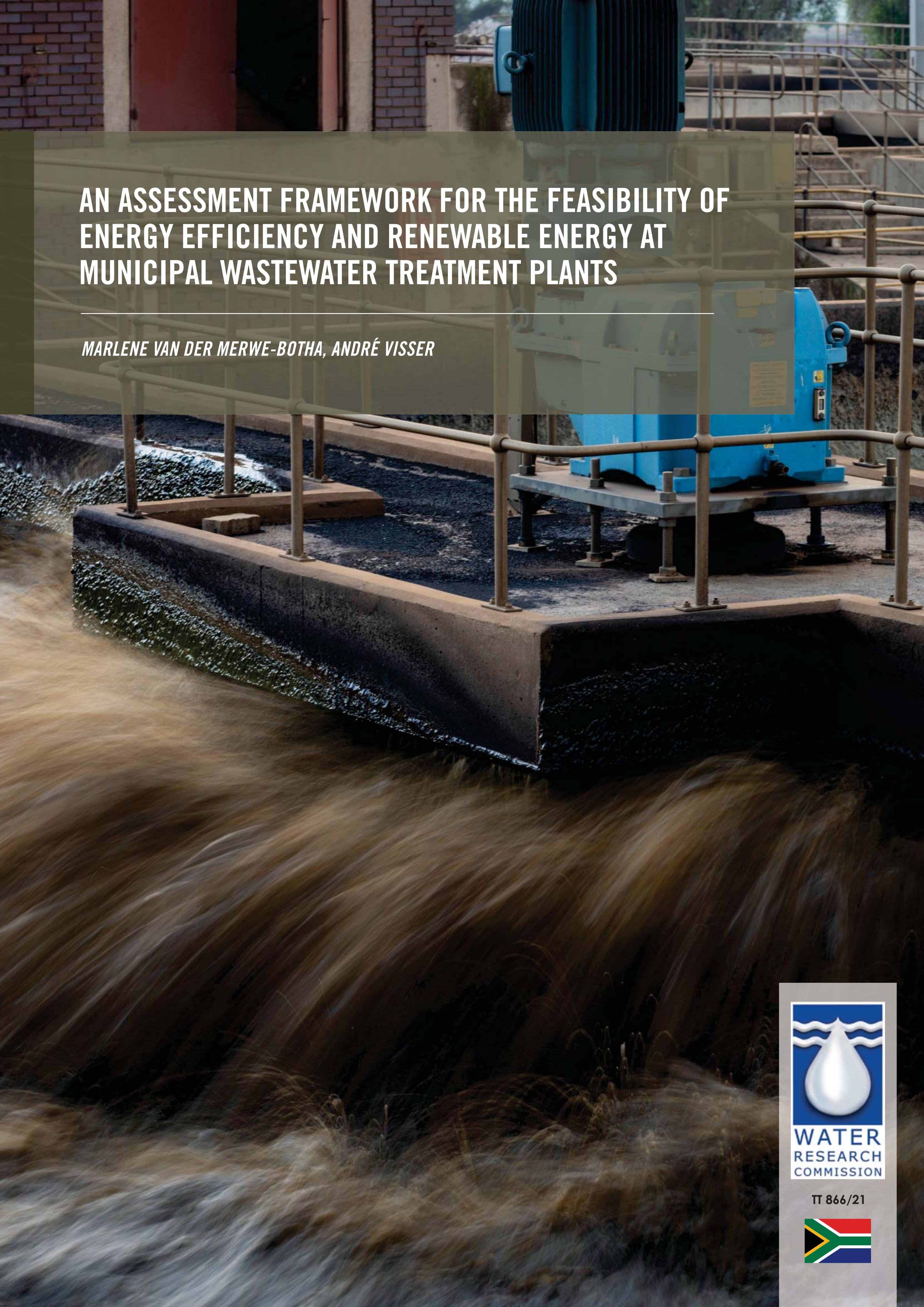

AN ASSESSMENT FRAMEWORK FOR THE FEASIBILITY OF ENERGY EFFICIENCY AND RENEWABLE ENERGY AT MUNICIPAL WASTEWATER TREATMENT PLANTS

MARLENE VAN DER MERWE-BOTHA, ANDRÉ VISSER

WATER RESEARCH COMMISSION

TT 866/21

An Assessment Framework for the Feasibility of Energy Efficiency and Renewable Energy at Municipal Wastewater Treatment Plants

Report to the

WATER RESEARCH COMMISSION

by

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WATER GROUP HOLDINGS (Pty) Ltd

WRC Report No. TT 866/21

ISBN 978-0-6392-0302-7

November 2021

Obtainable from
Water Research Commission
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Gezina
Pretoria, 0031

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This report is based on the WRC project no. C2019-2020-00109.

Cover photo: *GIZ-SAGEN*

EXECUTIVE SUMMARY

Introduction

Energy awareness has been growing in all sectors of industry, both public and private, mainly as a result of factors such as increased electricity and fuel costs, interrupted power supply risks, as well as a growing environmental awareness and the impact of energy inefficiency. This awareness and the need for energy efficiency (EE) and Renewable Energy (RE) recovery (co-generation) prompted an investigation into the key drivers and factor that impact on the feasibility of EE and RE projects at municipal wastewater treatment facility, known for its significant energy conservation and generation potential.

This project aimed to identify and assess the cross-functional aspects that impact on EE and RE at municipal wastewater treatment works from global and local perspectives; to develop and test a framework to assess EE and RE at three case sites; and to build a picture of how the learnings from this study could benefit the uptake of EE and RE at SA municipal plants.

Development of assessment framework

The key factors identified from literature were incorporated into an excel-based 'measurement instrument' that determines the extent to which a plant is feasible for EE and RE, i.e. highly viable, viable, low viable. A viable or highly viable 'score' would serve as a ''go'' indicator that the EE or RE project receive further attention and project scoping:

1. *Management Commitment:* The tool measures the commitment of the wastewater management as well as the operational culture of the organisation, as a key driver and indicator towards successful EE and RE projects.
2. *Technical Aspects for EE*: The metric tool determined the key technical criteria as part of the assessment approach, and weigh the unit process technologies, operational aspects, SPC and EE measures, and subsequently estimate the EE savings potential and viability for a particular facility.
3. *Technical Aspects for RE:* These criteria 'qualifies' if a particular WWTW is feasible for different RE technologies, and generates a go or no-go outcome (feasible or not feasible). The qualifying criteria address the availability of primary settling tanks and anaerobic digesters, space for solar photovoltaic panels, organic load for CHP, energy available for hydro turbine generation, etc.

Case Studies

The assessment tool were tested and refined at three case studies. The sites were chosen based on their dynamics of having knowledgeable managers and process controllers, as well as having the required level of technical data available as input to the metric tool. The sites also represented different geographical regions, technologies and capacities (20 Ml/d to 85 Ml/d).

Case study 1 summary: The high score for demonstrated management EE commitment indicates a high probability of successful implementation of EE and RE projects for this case study, while the high single score assessment indicates an exceptionally high SPC at 1234 kWh/Ml (benchmark 412 kWh/Ml), reflecting a large potential for EE measures. The most promising EE measures are related to the aeration system including upgrade to fine bubble diffused aeration, installation of VSD for aeration drives with an aeration control system based on ammonium. The potential energy savings is estimated at 32% of total energy consumption. Solar photo voltaic renewable energy is feasible for this site and would on average, be capable of producing 24% of the plant power consumption.

Case study 2 summary: The high score for demonstrated management EE commitment of 87% indicates a high probability of successful implementation of EE and RE projects for this case study, while the single score assessment indicates an exceptionally low SPC at 181 kWh/Ml (benchmark 276 kWh/Ml), reflecting a low potential for EE savings. It is indicated that up to 37% of the current plant energy consumption can potentially be saved through various EE measures. The most promising EE measures are related to the aeration system including upgrade to fine bubble diffused aeration, installation of VSD for aeration drives with an aeration control system based on ammonium. The potential aeration energy savings is estimated at 20% of total energy consumption. CHP is feasible for this site. Solar photo voltaic renewable energy is also feasible and would on average be capable of producing 24% of the plant power consumption. In addition, there is hydropower potential to generate approximately 4% of the total energy consumed.

Case study 3 summary: The average score for demonstrated management EE commitment of 43% indicates an average probability of successful implementation of EE and RE projects for this case study, while the single score assessment indicates an exceptionally low SPC at 117 kWh/Ml (benchmark 259 kWh/Ml), reflecting a low potential for EE savings. It is indicated that up to 51% of the current plant energy consumption can potentially be saved through various EE measures. The most promising EE measures are related to regional/module load optimisation with a potential 15% saving and the aeration system including upgrade to fine bubble diffused aeration, installation of VSD for aeration drives with an aeration control system based on ammonium. The potential aeration energy saving is estimated at 18% of total energy consumption. CHP is feasible for this site. Solar photo voltaic renewable energy is also feasible and would on average be capable of producing 24% of the plant power consumption.

Key Findings

The following generic list is ordered to highlight the key aspects that is expected to have the biggest impact on EE and RE viability, as outcome of *Management Commitment* assessment (aspects with highest impact listed at the top):

- Plant should be regularly benchmarked and status formally reported
- EE training should be done
- Energy audit or balance should be done
- PCs should be sensitised to energy cost and implications
- Low profile EE projects should be implemented (from plant budget)
- Process Controllers should be aware of SPC value and actively manage same
- Regular estimation, recording and reporting of SPC (specific power consumption)

From a *Technical Assessment for EE*, interventions having the largest EE impact are listed at the top, with diminishing returns toward the bottom of the list:

- Manual control upgradable to automated ammonium control?
- Can low efficiency electric motors be replaced with high efficiency motors?
- Aeration system upgradable to variable aeration control (VSD)?
- Pump motors upgradable to VSD control to enable load matching?
- Can RAS/recycle/process flows and/or head be reduced/optimised?
- Current aeration system upgradable to fine bubble diffused aeration?
- Operationally flexible modules for load optimising possible?
- Can pump systems be optimised: duty point, throttling, efficiency, etc.?
- Manual aeration control upgradable to automated DO control?
- Regional load optimisation among plants viable?
- Can anaerobic/aerobic sludge digestion, mixing, aeration, etc. be optimised?

The *Technical Assessment for RE* indicated as follows:

- Two of the 3 case studies indicated that primary and secondary sludge to anaerobic digesters are available and that the plants are good candidates for CHP. In the context of SA, CHP can supply up to approximately 75% of an activated sludge plant electrical energy consumption for plants treating typical municipal organic loadings. Higher than typical organic loadings and co-digestion with suitable organic waste will improve the renewable energy fraction.
- Solar photo voltaic solar arrays were feasible for all 3 case studies. In the SA context, pay-back periods of 5 to 8 years are expected with appropriately sized solar arrays (i.e. supply matched to instantaneous WWTW demand), capable of supplying approximately 25% of WWTW electrical energy consumption.
- One of the 3 case studies was identified for a possible viable hydropower project which is recommended for investigation regarding feasibility. The feasibility of hydropower is related to the topography of the WWTW location and the plant capacity.
- Although thermal energy is always available in the treated effluent, no suitable client for thermal energy in close proximity could be identified for any of the 3 case studies.

The design approach for new WWTWs and the refurbishment of existing WWTWs should pro-actively re-focus on the following high impact aspects:

1. EE and RE design objectives have to be determined and specified **from concept/feasibility stage** and monitored through the design stages, moving into the commissioning stage with specific measurable targets. The establishment of a national SPC benchmark database will be of assistance towards achieving higher efficiencies.
2. The process configuration of extended aeration AS and BNRAS plants render these technologies simple to operate, less capital intensive, and capable of producing the required effluent and bio-solids quality. However, these low capital cost type plants are significantly more energy intensive and typically consume 40% more aeration energy than AS or BNRAS plants that treat settled wastewater. **Extended aeration plants should not be recommended** without an appropriate life

cycle cost analysis. Application should be limited to small plants with capacity less than 2 to 5 Ml/d.

3. Extended aeration AS and BNRAS plants also preclude the option of anaerobic digestion and energy generation through CHP facilities. For this reason, new WWTWs or extensions, specifically larger capacities based on extended aeration AS plants must be avoided. **Process options that include primary settling immediately unlocks the option of energy recovery** via anaerobic digestion and CHP.
4. Fully-fledged BNRAS process configurations are not always required to achieve the licensed effluent quality. **Activated sludge plants should, as a minimum, always include a denitrification step in order to utilise oxygen released during denitrification**. The benefits being the significant energy saving associated with denitrification, as well as the reintroduction of alkalinity for enhanced pH stability, particularly in areas with low alkalinity water. Typically the oxygen demand, or alternatively the aeration energy, will be approximately 25% more if a denitrification step is not included in the process configuration, effectively using more energy to produce a lower quality effluent (i.e. higher effluent nitrates).
5. **Fine bubble diffused aeration is significantly more energy efficient** than mechanical surface aeration. The known maintenance challenges can be mitigated by appropriate design, whereby energy efficiency outweighs the operational challenges. The transfer efficiency of fine bubble diffused aeration systems are typically 40% higher than low speed mechanical surface aerators. The transfer efficiency of high speed surface aeration systems is significantly less than low speed surface aerators and therefore high speed aerators should be avoided if possible.
6. **Effective aeration control systems** have a major impact on wastewater treatment works EE. In this regard there is a recent trend towards ammonia control rather than conventional dissolved oxygen control. Ammonia control would imply lower operation dissolved oxygen levels (0.5 to 0.8 mg/l instead of ±2.0 mg/l) while achieving better effluent quality.
7. Relatively short payback periods are expected for grid tied solar photovoltaic systems that harvest solar energy which is directly supplied into the WWTW distribution system. **Augmentation of WWTW power supply should pro-actively be investigated** for implementation, particularly in prime solar radiation areas such as the Northern Cape.
8. The feasibility of **hydropower generation** is mainly related to the WWTW site topography and is typically expected to be limited to 50 kW or less. WWTWs with capacities of 20 Ml/d or more and utilisable topographical drops upstream or preferably downstream, of 15 meters or more may be a viable contender for a hydropower project. Hydropower should be investigated for these cases.
9. The amount of **thermal energy available** in the treated effluent discharged from a WWTW is significant. The feasibility of thermal energy extraction is completely driven by the availability of a suitable thermal energy user (industry requiring heat energy) in close proximity to the WWTW.

Future research and initiatives:

1. Establish a **national SPC benchmark database** for municipal WWTWs in SA
2. Share and **influence the agenda** of specific stakeholders and funding agencies in policy and financing space – e.g. SALGA interested in benchmarking, DWS in incentive regulation, DMRE in climate fund initiatives, SANEDI in reducing C, NT in reduced Opex, etc.

3. Wider application of the **Assessment Framework** to determine EE and RE feasibility at more WWTWs, using the metric tool to establish a baseline from where progress can be monitored and reported
4. Develop a **guideline of design considerations** towards energy efficient wastewater treatment technology and processes – bring in green technologies and climate change imperatives
5. Wider EE **knowledge sharing** and best practice via platforms such as Wader, WINSA, DSI, TIA, WISA
6. **EE and RE toolboxes** for practical application by WWTW superintendents and process controllers.

ACKNOWLEDGEMENTS

The research team acknowledges the following people and institutions for their contributions towards this WRC project:

- The Reference Group members for their guidance during the study, in particular:
    - Dr John Ngoni Zvimba – WRC Research Manager and Chairperson
    - Louise Klapprott – Silulumanzi
    - Karl Juncker – WEC Projects
    - Jason Gifford – SABIA
    - Ayesha Laher – Independent
    - Dr Michelle Kruger – Independent
    - Gugu Tywabi – Ilembe Local Municipality
    - Roda Lidzhade – ERWAT
    - Stephen van der Merwe – City of Tshwane Metropolitan Municipality
    - Thabo Mahlatsi – City of Johannesburg Metropolitan Municipality
    - Ronald Brown – Drakenstein Local Municipality
    - Brenda Phahlamohlaka – Department of Mineral Resources & Energy
    - Oliver Stotko – City of Cape Town Metropolitan Municipality
    - Dr Sven Sotemann – City of Cape Town Metropolitan Municipality.
- Municipalities and wastewater champions that tested the Energy Framework and participated in the case studies:
    - City of Cape Town Metropolitan Municipality – Dr Werner Rössle
    - Silulumanzi – Louis Klapprott
    - ERWAT – Fortune Mabunda.

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ACRONYMS

Abbreviation	Description
ABAC	Ammonia Based Aeration Control
AD	Anaerobic Digestion
AEL	Atmospheric Emission Licence
ASP	Activated Sludge Process
AT	Appropriate Technology
AVN	Ammonia Versus Nitrate
BIOS	Bioprocess Intelligent Optimisation System
BNRAS	Biological Nutrient Removal Activated Sludge
BOD	Biological Oxygen Demand
CANDO	aerobic-anoxic nitrous decomposition
CFA	Carbon Footprint Analysis
CHP	Combined Heat and Power (generation)
CNG	Compressed Natural Gas
COD	Chemical Oxygen Demand
CoGTA	Department of Cooperative Governance and Traditional Affairs
CSIR	Council for Scientific and Industrial Research
DAF	Dissolved Air Flotation
DAFF	Department of Agriculture and Fisheries
DBSA	Development Bank of Southern Africa
DEA	Data envelopment analysis
DMRE	Department of Mineral Resources and Energy (previous DoE)
DO	Dissolved Oxygen
DoE	Department of Energy (currently DMRE)
DS	Dry Solids
DWS	Department of Water and Sanitation
EE	Energy Efficiency
EEA	Economic efficiency analysis
EEDSM	Energy Efficiency and Demand Side Management
EIR	Environmental Impact Reporting
ERWAT	East Rand Water Care Company
FBDA	fine-bubble diffused aeration
GHG	Green House Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Co-operation)
GNR	Government Notice Regulations
GWh	Gigawatt Hours
HVAC	Heating, ventilation, and air conditioning
ICDG	Integrated City Development Grant
IEA	International Energy Agency
IPP	Independent Power Producer
iREEET	Integrated Renewable Energy and Energy Efficiency Technology
IRP	Integrated Resource Plan
ISO	International Organisation for Standardisation
kWh	kilowatt hours
LCA	Life Cycle Analysis

LED	Light-emitting diode
LGCCSP	Local Government Climate Change Support Programme
LNG	Liquefied Natural Gas
MAD	Mesophilic Anaerobic Digestion
MEC	Microbial Electrolysis Cell
MFC	Microbial Fuel Cells
MGD	Megalitres per day (also known as Ml/day)
NBR	National Building Regulations
NDPG	Neighborhood Development Partnership Grant
NEMA	National Environmental Management Act
NEM:WA	National Environmental Waste Act
NEM:AQA	National Environmental Air Quality Act
NEM:BA	National Environmental Biodiversity Act
NEM:PAA	National Environmental Protected Areas Act
NERSA	National Energy Regulator of South Africa
OSEC	Overall Specific Energy Consumption
PCS	Polymeric Carbon Solid
PE	Population Equivalent
PS	Primary Sludge
PV	Photovoltaic
RAS	Return Activated Sludge
RBC	Rotating Biological Contactor
RBIG	Regional Bulk Infrastructure Grant
RCA	Regulatory Clearing Account
RE	Renewable Energy
SABIA	South African Biogas Industry Association
SABS	South African Bureau of Standards
SALGA	South African Local Government Association
SANAS	South African National Accreditation Systems
SANS	South African National Standard
SBNR	shortcut biological nitrogen removal
SCADA	Supervisory control and data acquisition
SDG	Sustainable Development Goals
SPC	Specific Power (Energy) Consumption
STP	standard temperature and pressure
TDS	Total Dissolved Solids
TGP	Top Green Planner
TH	Thermal Hydrolysis
TSS	Total Suspended Solids
TWh	Terawatt-hour
UK	United Kingdom
USA	United States of America
USDG	Urban Settlements Development Grant
UV	Ultraviolet
UVT	UV transmittance
VFD	Variable frequency drives
VSD	Variable Speed Drive
WAS	Waste Activated Sludge
WEF	World Economic Forum

WISA	Water Institute of Southern Africa
WRC	Water Research Commission
WSI	Water Services Institutions
WSIG	Water Services Infrastructure Grant
WWTW	Wastewater Treatment Works

Chapter 1 - Introduction

1.1 Background

Energy awareness has been growing in all sectors of industry, both public and private, mainly as a result of factors such as increased electricity and fuel costs, interrupted power supply risks, as well as a growing environmental awareness and the impact of energy inefficiency. This awareness and the need for energy efficiency (EE) and Renewable Energy (RE) recovery (co-generation) will increase as Eskom continues to request and apply escalation rates far above the inflation rate.

Wastewater Treatment Works (WWTWs) are one of the largest energy consumers within the municipal sector. Water supply and WWTWs use approximately 17% of the total energy consumed by South African municipalities. When only electricity consumption is considered, this value increases to 25% with electricity consumption representing up to 30% of the total operating cost of an activated sludge type WWTW. Optimising the energy efficiency of these facilities could therefore result in a significant carbon footprint reduction, as well as operating cost savings.

As part of best practice, Process Controllers use asset condition and age analysis to inform a methodology to assess equipment replacement or refurbishment. A 20/80 ratio is used as rule of thumb to determine the preventative/reactive maintenance of infrastructure from a cost perspective.

Many South African WWTWs are fairly old, using equipment that was installed a number of years and even decades ago. Driven by strict effluent quality standards, energy intensive treatment technology had become common practice, but now demands serious reconsideration. Compounded by environmental imperatives, and strengthened regulatory requirements, new and emerging technologies are ready for an accelerated uptake in the municipal wastewater sector. Several opportunities are presented by taking this discourse, which precipitated a relook at South Africa's approach to wastewater treatment and how energy can be conserved and/or generated via energy efficiency measures and technologies.

Recent work done by the Water Research Commission and a number of sector partners has covered feasibility of co-generation, guideline development for conducting energy audits, energy demand optimisation through efficiency measures, and development of energy compendiums and benchmarks with international partners. Of note are recent developments in the establishment of a progressive Water Reuse Programme by the Development Bank of Southern Africa (DBSA) and the roll out of the iREEET and EEDSM programme by the Department of Mineral Resources and Energy (DMRE). The Water Institute of Southern Africa (WISA) is providing accredited training and train-the-trainer courses in building capacity at local government level to develop and upscale RE and EE at their WWTWs. These initiatives imply that a tipping point has been reached in closing the gap in the water-energy nexus, with energy saving having captured the interest of the water sector. However, much still need to be done to organise the key actors, share information and publish results and lessons learnt on this subject. A framework for energy efficiency and renewable energy will go a long way to unite and organise the wastewater-energy fraternity towards conceptualising, developing and scaling energy projects at municipal wastewater treatment facilities.

One of the challenges most likely hampering the introduction of energy efficiency measures and technologies is the compliance with the licensed effluent quality and biosolids standards. The study approach therefore has to test the probability of this impact. Furthermore, the project will identify various management, operational, financial, environmental and human capacity considerations, practices and technologies capable of reducing energy consumed during the transport and treatment of wastewater liquid and solids. Potential pressure points will be researched in the Literature Study, in order to inform the development of a framework for EE and RE. The Assessment Framework will be used to build a high-level picture of the potential and benefits of EE and RE in the SA municipal wastewater industry.

1.2 Aim of Project

The aim of this project is:

1. Conduct a literature review of cross-functional aspects that impact on energy efficiency and generation, and assessment of such criteria, and to map the SA landscape regarding EE and RE costs, operations, technology, legal, skills, and other aspects;
2. Development of a framework to assess EE and RE, using input from the literature study and selected case studies;
3. Apply and test the framework against the case studies;
4. Use the framework to build a picture of the benefits and potential of EE and RE at SA municipal plants.

1.3 Methodology

The research study was executed according to the following methodology:

1. *Literature Review*

Various aspects impact on the feasibility of an energy efficiency and/or energy generation at a wastewater treatment plant. These drivers are cross- and multi-functional and include financial, technical, skill, legal, environmental, etc. aspects. For example, it is generally accepted that anaerobic treatment, passive treatment systems (such as wetland, reeds beds, oxidation ponds, etc.) and certain equipment is more energy efficient than others, but that final effluent quality may be compromised compared to sophisticated systems with higher energy demand. A literature review of local and global technologies, energy use, energy efficiency and effluent quality would highlight these differences and inform the further research. The review included a review of benchmarks from local and international reports, e.g. kWh/m^3 treated and kWh/kg COD, for further use in the formulation of the energy framework.

2. Developing a framework to assess energy efficiency and energy generation at WWTWs

The literature study identified a range of cross functional aspects that influence the feasibility of energy efficiency and co-generation at a WWTW. These aspects were used to design an excel-based energy framework and metric tool that measures the potential feasibility of EE and RE, and identify the improvement opportunities on organisational, technological and operational levels for enhanced EE or RE readiness and viability.

3. Testing the Assessment Framework for Energy Efficiency and Energy Generation

The set of criteria or requirements contained within the Assessment Framework were tested at 3 sites, which serviced as case studies. This activity served to refine the metric tool and determine the suitability of the framework to assess EE and RE viability and potential at a WWTW.

4. Building a picture of the benefits and potential of RE and EE in South Africa

The principles of the framework, case study results, industry estimates and EE/RE benchmarks were considered in building a picture of the municipal water sector and map the improvement opportunities and benefits of energy efficiency and co-generation in South Africa.

5. Findings and recommendations

Recommendations, focus areas and further research were provided.

The outputs from this research study were:

- Final WRC Report;
- Feasibility Indicator (excel-based feasibility assessment tool);
- WINSA short report (lesson series).

Chapter 2 - Literature study

2.1 The international perspective on energy consumption by wastewater treatment plants

After water is used by consumers, energy is required to collect, transport and treat it so that it can be safely discharged to minimise adverse environmental and human health impacts. Globally, wastewater treatment consumes about 1% of total energy consumption (IEA, 2016). In developed countries, wastewater treatment is the largest energy consumer in the water sector. Similarly, the energy needs for wastewater treatment can be very important at the local level. For some municipalities in the USA, the energy consumed by water and wastewater utilities can account for 30-50% of their energy bill (IEA, 2016). Five factors influence the energy consumption for wastewater treatment:

1. the fraction of wastewater collected and treated;
2. the level of groundwater infiltration and rainfall into the sewage system (reducing the water inflow that does not need treatment is one way to significantly reduce energy consumption);
3. the contamination level;
4. the treatment level;
5. the energy efficiency of the operations.

Saving energy through energy efficiency improvements can cost less than generating, transmitting, and distributing energy from power plants, and provides multiple economic and environmental benefits. Energy savings can reduce operating costs for local governments, freeing up resources for additional investments in energy efficiency and other priorities. Energy efficiency can also help reduce air pollution and GHG emissions, improve energy security and independence and create jobs.

The globally endorsed Sustainable Development Goals (SDGs) include action on SDG 6: Clean Water and Sanitation as well as SDG 7: Affordable and clean Energy.

Figure 1: The globally endorsed Sustainable Development Goals (SDGs)

SDG 6: Ensure availability and sustainable management of water and sanitation for all. Targets include for improvement of water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

SDG7: Ensure access to affordable, reliable sustainable and modern energy for all. The sustainable energy goal has ambitious 2030 targets for access to modern energy, improvement on energy efficiency and increasing the share of renewable energy in the energy mix.

Feng et al. (2012) states that electricity cost is usually between 5 to 30% of the total operating cost for water and wastewater utilities. The share is generally higher in developing countries and can go up to 40% or more in some countries. Such energy costs often contribute to high and unsustainable operating costs that directly affect the financial health of water and wastewater utilities. Improving energy efficiency (EE) is at the core of measures to reduce operational cost at water and wastewater plants, since energy represents the largest controllable operational expenditure of most plants and many EE measures have a payback period of less than five years. Investing in EE supports quicker and greater expansion of clean water access for the poor by making the system cheaper to operate while reducing pressure on power generation capacity with associated emissions of pollutants.

Case studies by Feng et al. (2012) indicate that cost-effective measures can bring up to 25% overall EE improvements at water and wastewater plants in developing countries. Using a 5 to 25% range, the global energy savings of the sector at its current level of operation, could be in the range of 34 to 168 TWh per year. The increase in demand for energy to move and treat water and wastewater in developing country cities is likely to be significant in the next 20 years or so.

In addition, Feng et al. (2012) states that, based on trends in developed countries, water and wastewater treatment may become more energy intensive in the next two decades due to stricter health and pollution regulations, which often require additional or more sophisticated treatment that uses more energy. Greater efforts to improve EE in municipal water supply and wastewater treatment for both existing and new systems would have a number of positive effects, including lower costs to consumers, the ability to serve new urban populations, greenhouse gas mitigation, and help to ensure the long-term fiscal stability of this vital municipal service.

Maktabifard et al. (2018) found that kWh/m^3 was the most commonly use indicator to assess the energy performance of wastewater treatment plants of the four typical energy key performance indicators. The second most frequent indicator reported in the literature shows the electricity consumption in relation to the population equivalent (PE) per year as kWh/PEyear. Furthermore, a reference to the amount of pollutants removed from wastewater expresses the electricity consumption related to the removed loads of BOD_5 as $kWh/kgBOD_{removed}$ and COD as $kWh/kgCOD_{removed}$.

2.2 The relevance of energy consumption by wastewater treatment plants in South Africa

2.2.1 Historical approach to the current energy consumption situation

Water and wastewater infrastructure is one of the major consumers of energy within municipal operations and service delivery environment. Indications are, that on average, water and wastewater accounts for some 17% of total energy consumption in a South African metro. In terms of electricity consumption alone (i.e. excluding other forms of energy such as liquid fuel for vehicles), the proportion is as much as 25% of the entire municipality's electricity bill. Electricity is a critical input for delivering municipal water and wastewater services, usually representing around 30% of the costs of running the water and wastewater services. This sector has been shown to hold the greatest electricity savings potential within municipal operations and is thus a high priority for energy efficiency investment by municipalities. Energy efficiency measures can achieve savings of up to 25% within this area (SEA, 2017).

Operational cost savings are even more critical when considering growth and future demand for water and wastewater services. New technologies, aimed at meeting stricter water treatment quality requirements, are often more energy intensive. Energy efficiency offers an important opportunity to achieve greater levels of long-term environmental and fiscal sustainability (SEA, 2017).

Musvoto & Ikumi (2016) states that similar to the global industry, the South African wastewater sector has historically focused on achieving the primary objective of wastewater treatment of protecting the environment and compliance with the regulatory effluent standards. Energy costs have been viewed as simply part of the cost of doing business and no significant focus has been placed on mitigating cost increases. However, with the sharp increases in Eskom electricity rates, which are predicted to continue increasing well into the foreseeable future, energy will continue to be a significant operating cost.

Because of the relatively low and stable cost of fossil fuels and electricity pre-2007, the use, recovery and management of energy was generally not of high importance during the design and operation of wastewater treatment plants. Fluctuation and uncertainties with regard to cost and the future of fossil fuel supplies, capacity challenges with regard to power generation, related unreliability of power supply and the increasing awareness of the impacts of greenhouse gas emissions has led to a greater concern with both private and public entities. The principal driving forces for achieving more efficient management of energy in wastewater treatment are:

- Potential for energy cost savings, including the possibility of becoming a net energy supplier: With electrical energy cost typically being the second largest (following labour cost) expense item on the municipal wastewater treatment plant budget, energy management has the potential to significantly reduce operating cost. Examples of energy saving opportunities include the use of energy efficient equipment, optimised process design and control and the selection of alternative cost effective energy sources.

- Considerations for sustainability, including the greenhouse gas reduction goals: The impact of the increasing anthropogenic greenhouse gas emissions in the atmosphere and the global climate change has been scientifically confirmed. It has consequently become necessary to manage the inevitable climate change impact through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity. It has also become necessary to contribute to the global effort to stabilise greenhouse gas concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system within a timeframe that enables economic, social and environmental development to proceed in a sustainable manner. The costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment. The South African government is of the view that imposing a tax on greenhouse gas emissions and concomitant measures such as providing tax incentives for rewarding the efficient use of energy will provide appropriate price signals to help nudge the economy towards a more sustainable growth path. The Carbon Tax Act, 2018, therefore came into operation on 1 June 2019. Although the Carbon Tax Act does not directly impact the operations of wastewater treatment plant from the date of implementation, it is expected to impact the operations of wastewater treatment plant within the foreseeable future and it would therefore be prudent to take cognisance of the expected implications.

- Potential for an improved energy supply reliability: The reliability of energy supply for wastewater treatment facilities is an important consideration taking note of area blackouts and energy disruptions due to natural disasters as well as load shedding due to capacity constraints. Typically, wastewater treatment facilities are equipped with emergency generators to operate critical equipment during power supply disruptions. During this limited power supply periods with only critical equipment operational, the process is generally incapable of maintaining the required discharge standard. In recent years, it has been recognised that wastewater theoretically contains more energy than that required for treatment. It is also recognised that wastewater treatment plants could become net exporters of energy if the energy contained in the incoming wastewater could be recovered effectively. Becoming self-sufficient with regard to energy would significantly improve treatment plant reliability.

2.2.2 Energy consumed for wastewater treatment

Wastewater treatment uses about 55% of the energy consumed in the South African water sector (Musvoto & Ikumi, 2016). About 50 to 75% of this energy is used for aeration at the widely employed biological nutrient removal activated sludge plants in order to meet the strict final effluent discharge standards. Musvoto & Ikumi (2016) further found that aeration at a plant with surface aeration accounted for 74% of total energy consumption compared with 42% for a plant with a more efficient fine-bubble diffused aeration (FBDA) system.

Maktabifard et al. (2018) states that wastewater treatment plant data from across the world reflect specific energy consumption (SPC) figures ranging from 260 Wh/m^3 up to 1 600 Wh/m^3. Many factors influence the energy consumption for wastewater treatment. The energy demand depends on the plant location, plant size, type of a treatment process and aeration system employed, effluent quality requirements, age of a plant, and knowledge and skills of the Process Controllers. Specific energy consumption figures exceeding 1 000 Wh/m^3 could be considered to be high according to the literature. High SPCs might be caused by several factors, such as high load of industrial wastewater influent, stricter effluent requirements, complex technology, etc. Typical distribution of consumption on a wastewater treatment site is reported to be as follows:

Aeration	Sludge treatment	Pumping	Other
13% to 77%	5% to 31%	4% to 30%	5% to 38%

Frost and Sullivan (WRC, 2011) reported a specific energy consumption for a limited number of South African wastewater treatment plants varying from 200 up to 1800 kWh/Ml, with reduced energy efficiency for smaller capacity plants. The reported specific energy consumption for the reticulation systems varied from 0 to 350 kWh/Ml and is excluded from the stated wastewater treatment SPC figures. Frost also reflects on international benchmarks, referring to the New York figure of 391 kWh/Ml while the USA national average is reported as 317 kWh/Ml, both figures exclude collection systems. In California, the specific energy consumption for wastewater collection and treatment varied from 290 up to 1214 kWh/Ml. Energy consumption by different processing steps was allocated as follows:

Aeration	Sludge handling	Pumping	Other
80%	9%	10%	1%

The Water Energy Nexus report by the International Energy Agency (IEA, 2016) concluded that the typical energy consumption allocation in a wastewater treatment facility is as follows:

Primary	Secondary	Tertiary	Pumping	Sludge
8%	51%	10%	16%	10%

The grouping above is based on the following definitions:

- Primary treatment: The removal of solids via screens, filters, sedimentation tanks and dissolved air flotation tanks.
- Secondary treatment: Biological processes to remove biodegradable organic matter using both fixed film (e.g. trickling filters) and suspended growth (activated sludge) systems, followed by settling tanks for liquid-solid separation.

- Tertiary (advanced) treatment: Additional treatment to remove nutrients, such as nitrogen, phosphorous and suspended solids through technologies including sand filtration or membrane filtration. Disinfection is often the final step before discharge.

Basic treatment is typically limited to primary treatment while a higher effluent specification requires secondary or even tertiary treatment in order to achieve the required specification. About half of the energy used in advanced wastewater treatment and collection is consumed in secondary treatment, notably to satisfy the requirement for aeration in the biological step. Tertiary treatment is typically a less significant energy consumer, but increasingly stringent water quality standards in developed countries have already led to higher energy consumption for tertiary treatment. The energy input in sludge treatment is in general far outweighed by energy recovery in the form of heat and/or electricity from biogas production.

The biological process, which is the most energy intensive within the secondary treatment train, offers the largest savings potential (IEA, 2016). The wider deployment of variable speed drives, fine bubble diffused aeration, better process control and more efficient blowers are among the most important efficiency measures, which together has the potential to reduce energy consumption in the biological step by up to 50%. Further efficiency savings are realised in sludge treatment, via improved methods for dewatering and in wastewater pumping through more efficient pumps, pipe maintenance and the deployment of variable speed drives. In addition, reducing run-off and groundwater infiltration through better infrastructure maintenance decreases the water inflow and consequently the energy necessary for pumping.

The Energy Centre of Wisconsin (ECW, 2003) found that within an activated sludge treatment plant, approximately 70% of the total energy costs for the plant are associated with treatment. About 55% of the total energy costs are associated with mainstream liquid treatment, mainly aeration.

Main processes	Sludge treatment	Pumping	Buildings
55%	15%	20%	10%

Depending on the size and topography of the catchment as well as the elevation of the treatment plant, the cost of energy associated with pumping in the collection system may also be significant. It is concluded that opportunities with the highest return involve aeration, sludge treatment and pumping. The utility objectives listed below should however take precedence over energy saving initiatives:

- Meeting daily flow requirements;
- Maintaining the required final effluent discharge quality requirements;
- Minimising capital investment.

Energy saving opportunities can be created by demand side management. Demand side measures include:

- Shift consumption from peak to off-peak periods. Additional storage may facilitate off-peak pumping. Efficient pumping programs can save energy by reducing peak demand as well as total energy consumption;
- Use premium efficiency motors and variable speed drives;
- Effective instrumentation and control;
- Effective use of available storage and high efficiency pumping units;
- Investigate use of generators for peak-clipping.

Feng et al. (2012) states that advanced wastewater treatment with nitrification can use more than twice as much energy as the relatively simple trickling filter treatment. Pond-based treatment is low energy but requires large land area. In general, larger systems (to a limit) tend to be less energy intensive than smaller ones. The estimated energy intensity for typical large wastewater treatment facilities (about 380,000 m^3/day) in the United States are (Feng et al., 2012):

- 0.177 kWh/m^3 for trickling filter;
- 0.272 kWh/ m^3 for activated sludge;
- 0.314 kWh/ m^3 for advanced treatment; and
- 0.412 kWh/ m^3 for advanced treatment with nitrification.

The ascending energy intensity of the above latter three different treatment options is due mainly to aeration and additional recycles and pumping requirements for more advanced treatment of the wastewater. In fact, for activated sludge treatment, a commonly used process in newer municipal wastewater treatment plants, aeration alone often accounts for about 50% of the overall treatment process energy use.

Feng et al. ((2012) estimates the following typical allocation of energy consumed in United States activated sludge wastewater treatment systems:

Wastewater collection.	Pumping.	10%	Dependent on share of gravity based collection.
Treatment.	Aeration and related processes and buildings.	55%	Mostly aeration.
Sludge treatment and disposal.	Dewatering, pumping, storage, buildings.	35%	RE can be produced.

Swartz et al. (2013) report that at the time their information was gathered, South Africa has not been actively pursuing and implementing energy savings projects on a large scale, mainly as a result of the abundance of readily available and cheap electricity in the country during the pre-2007 period. This means that case studies and operational data on energy saving measures are not readily available. In cases where energy savings applications have been made, the data was poorly recorded and not verified.

NEWRI (NEWRI, 2010) provides the overall specific energy consumption (OSEC) values in plants in a number of regions and shows differences in energy consumption arising from the differences in specifics at the various locations:

Region	**OSEC, W/m^3**
Australia (Gold Coast)	265
Australia (Melbourne)	298
Australia (Sydney)	118
Austria	300
Canada (nitrifying)	405
Canada (non-nitrifying)	305
China (Beijing)	258
Iran	300
Japan	320
Sweden	475
USA (San Francisco, HPO, 20 MGD inflow)	604
USA (San Francisco, HPO, 63 MGD inflow)	373
USA (San Francisco, non-nitrifying, >10 MGD inflow)	447
USA (Wisconsin, > 5 MGD inflow)	605
USA (Wisconsin, 1-5 MGD inflow)	661

Table 1: Overall Specific Consumption for WWTW per region (NEWRI, 2010)

For overall specific energy consumption figures for various regions that range from 258 Wh/m^3 (China) to 475 Wh/m^3 (Sweden), the aeration energy range from 148 Wh/m^3 (China and Japan) to 231 Wh/m^3 (Iran). More detail allocation of energy consumption is given below:

Preliminary	Main processes	Sludge treatment	Pumping
13-136 W/m^3	148-231 W/m^3	12-59 W/m^3	13-59 W/m^3

NEWRI (NEWRI, 2010) further make the following observations and recommendations:

- Treatment processes and plant configurations affect energy consumption;
- Application of centrifugal blowers and fine bubble diffusion, and mixer location are important (lowest specific energy consumption–China);
- Oversized plants may significantly increase specific energy consumption (Iran);
- Energy consumption in sludge treatment processes can be reduced by employment of gravity thickening and belt filter presses, internal and external sludge heating systems, gas and mechanical mixing and polymer addition China);
- Application of CHP generators (Strass) to achieve energy self-sufficiency;
- Chemicals addition to improve anaerobic digestion (Japan).

UKWIR (UKWIR, 2010) case studies indicate that energy savings from pumping vary widely depending on the circumstances, but overall savings of between 5 and 30% of current energy demand appear achievable. Specific measures for specific pumping aspects revealed the following saving opportunities:

Saving measure	**Saving**
Variable speed drives (VSDs)	12% to 30%
Duty point	3% to 63%
Intrinsic pump	6% to 11%
Duty change	10%
Waste water	8%
Duty range	3%

Hamilton et al. (2009) reports that in 2006 about 4% of total annual USA electricity consumption is used for water and wastewater supply and treatment and the typical operating and maintenance cost distribution for a wastewater treatment plant is as follows:

Cost category	**% of cost**
Labour	40% to 50%
Energy	25% to 40%
Solids disposal	10% to 15%
Chemicals	3% to 5%
Maintenance materials	3% to 5%
Other	5% to 10%

Hamilton et al. (2009) allocates energy consumption to processing steps as follows:

	Aeration	Sludge handling	Pumping	Other
Activated sludge	50 to 60%	25 to 30%	10 to 20%	5 to 10%
Trickling filter	-	40 to 45%	50 to 55%	5 to 10%

Hamilton et al. (2009) reports on projects which incorporate virtual real-time pump efficiency data into the operations control systems. By incorporating real-time pump power consumption data into the SCADA system and matching it to water flow and pressure data, a close approximation of instantaneous pumping energy intensity (i.e. kWh/Ml) can be derived. This data can assist in decision making with regard to the efficiency of pump operations.

Hamilton et al. (2009) further concludes that energy saving opportunities should also be linked to aspects such as increased process reliability, improved water quality, and reduced labour and maintenance costs. The identification of such multiple benefits will help to prioritise EE projects and accelerate project approval and implementation, ultimately resulting in greater and quicker energy savings.

2.2.3 Eskom electrical energy generating capacity

From a time of electrical energy overcapacity in the 1980s, the years since 2007 have been difficult for South Africa's power sector when demand outstripped supply in terms of generation, transmission and distribution capacity. With an installed capacity of approximately 42,000 MW and production of only 36,500 MW there has been a need for load shedding (WRC, 2011). This situation was instrumental in the re-evaluation of energy efficiency in South Africa in general, but also in the wastewater treatment industry and will remain so in the medium term. In addition to capacity restrictions in South Africa, key drivers for the focus on energy efficiency are disproportionate electrical energy cost hikes, greenhouse gas emissions, climate impact and looming carbon tax.

2.2.4 Cost of electrical energy

The DoE document "South African Energy Price Statistics – 2018" reflects an Eskom price increase for bulk supply from 23.29 c/kWh in 2008/9 to 82.94 c/kWh in 2017/18. This represents an average increase of **15% per annum** over the period. This excessive increase in energy cost creates new opportunities with regard to alternative energy sources, which were previously not feasible, that now become financially more viable as electrical energy cost continue to increase.

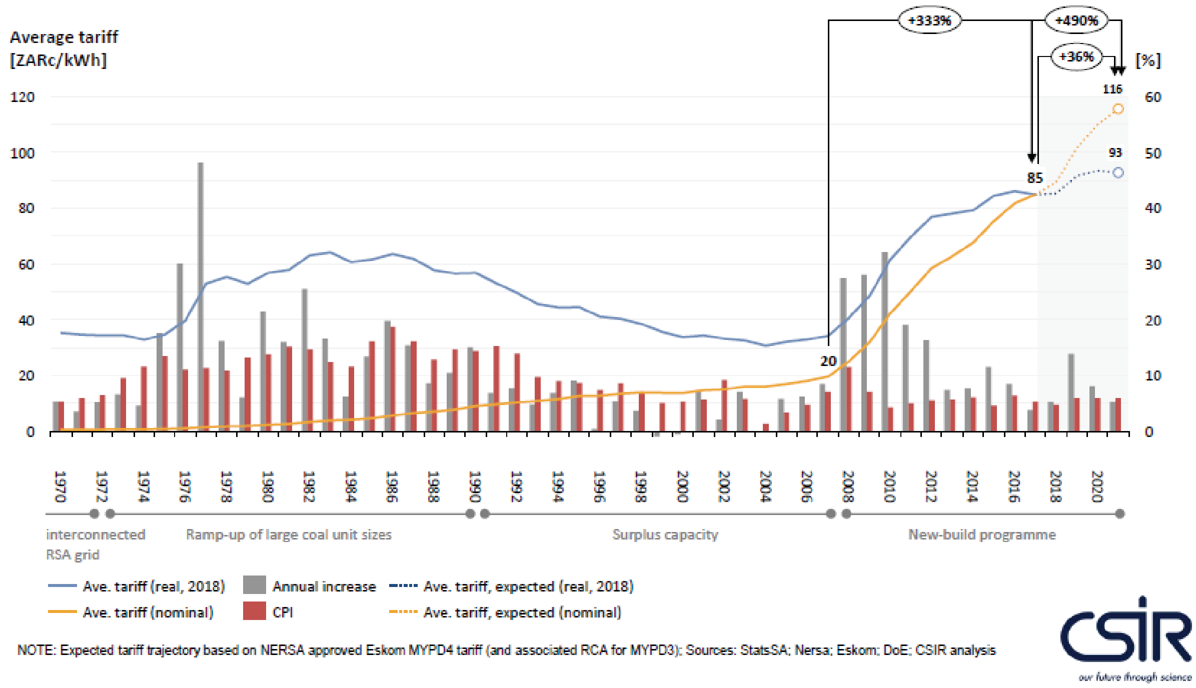


Figure 2: The evolution of real and nominal average Eskom tariffs over the past five decades in South Africa

The nominal average tariff has experienced an extraordinary increase of 333% over the period 2007 to 2017, with a projected increase of 490% over the period 2007 to 2021 (CSIR, 2019). Electricity prices in South Africa have dramatically outpaced inflation since the 2008 electricity supply shortage crisis. After a brief respite in 2017 when an increase of only 2.2% was granted by the National Energy

Regulator of South Africa (NERSA), tariff hikes far in excess of the consumer price index has been approved.

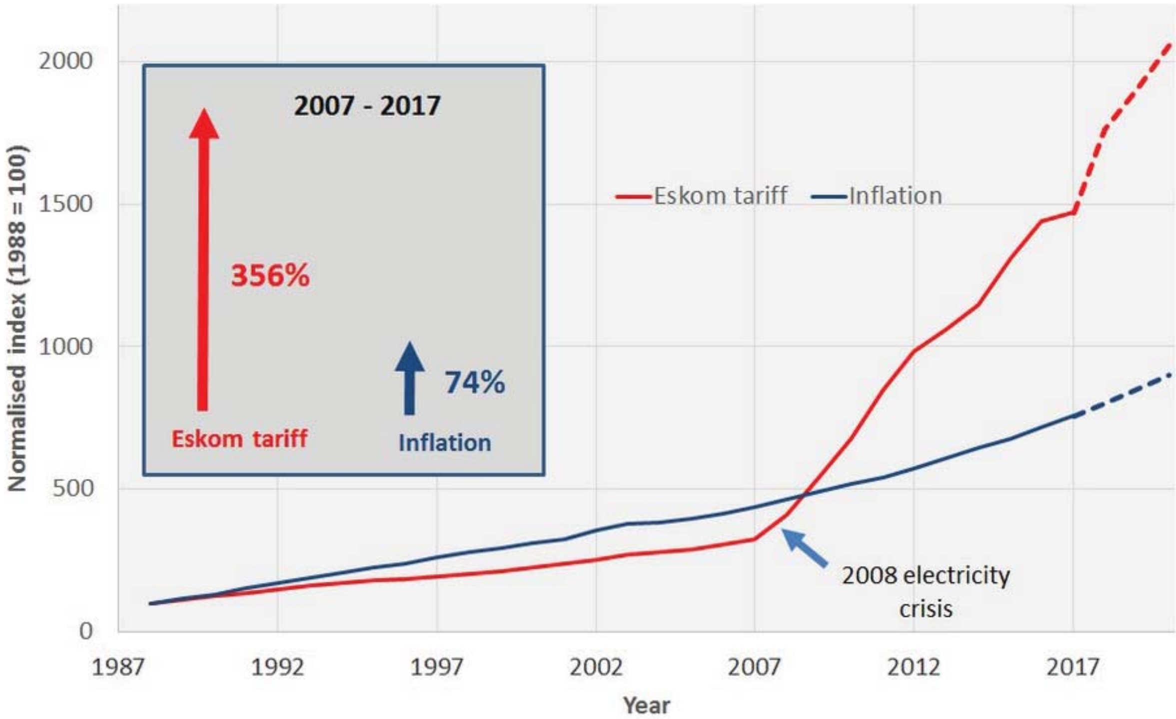


Figure 3: Eskom average tariff versus inflation (CPI) over past three decades

On 9 March 2020, the National Energy Regulator of South Africa approved Eskom's allowable revenue from standard tariff customers to be increased by 8.76%. (Eskom, 2020). Recently, Eskom has won a court case allowing it to recover historical 'losses' or under-recoveries (the so-called regulatory clearing account or RCA) which could lead to the 20/21 tariff hike further increasing from 8.67% to a crippling double digit increase expected to be more than 14%, at a time the South African economy can least afford it.

Year	Tariff Adjustment %	CPI %
2005	4.10	3.42
2006/7	5.10	4.40
2007/8	5.90	7.10
2008/9		10.30
2008/9, 01 April	14.20	
2008/9, 01 July	34.20	
2009/10		6.16
2009/10, 01 July	31.30	
2010/11	24.80	5.40
2011/12	25.80	4.50
2012/13	16.00	5.20
2013/14	8.00	6.00

Year	Tariff Adjustment %	CPI %
2014/15	8.00	6.00
2015/16	12.69	5.70
2016/17	9.40	6.59
2017/18	2.20	5.30
2018/19	5.23	4.50
2019/20	13.87	4.20
2020/21	8.76	4.5 (forecast)

Table 2: Eskom's average tariff adjustments for the last 15 years (Eskom, 2020)

The incessant and disproportionate Eskom tariff hikes impose increasing pressure on wastewater treatment energy budgets and reinforces efforts to improve energy efficiency and renewable energy drives. Design approach and philosophy is evolving and reflects new energy sensitivity resulting in more energy efficient designs. Increasing Eskom tariffs will accentuate energy awareness and drive new technologies into economically feasible terrain.

In spite of some energy efficiency gains over recent years, the South African economy is still generally inefficient in its use of energy, leading to higher production costs and reduced economic competitiveness (SEA, 2012).

2.2.5 GHG emissions, climate change and decarbonisation

According to the WRC report (WRC, 2011), coal is the most abundant source of energy in South Africa as most of the coal is low quality with a low heat value and high ash content. This makes it suitable for cheap power generation and Eskom produces approximately 90% of its electricity through coal fired power stations. Eskom uses over 90 million tons of coal per annum and approximately 325 million cubic meters of water per annum to produce this energy (WRC, 2011).

South Africa is a relatively high global warming gas emitter, and will increasingly be obliged to reduce such emissions as global warming takes place (SEA, 2017):

World	5 tonnes CO_2 per capita
Africa	1 tonnes CO_2 per capita
South Africa	9 tonnes CO_2 per capita

The reason South Africa is the world's 12th-biggest CO_2 emitter is largely due to the heavy dependence on coal (carbon-dirty), which supplies 92% of our electricity. Furthermore, research indicates (World Bank, 2016) that air pollution kills 20 000 people in South Africa every year, costing the economy nearly R300-million per annum.

2.2.6 Energy consumption versus compliance

Global electricity consumption for wastewater collection and treatment is expected to require over 60% more electricity in 2040 than in 2014, as the amount of wastewater in need of treatment increases. Two trends concerning the energy intensity of wastewater treatment on a worldwide basis counterbalance each other: developing countries move towards treating wastewater to a higher level, increasing the global energy intensity, while efficiency improvements in treatment mitigate this growth. Wastewater treatment is projected to become 7-27% (depending on the region) more efficient by 2040, compared with 2014. This is achieved partly through more efficient wastewater pumping but also through efficiency gains in secondary treatment. Increased water quality standards, especially in developed countries (e.g. standards requiring the removal of pharmaceutical substances) will increase energy consumption in the future, but only to a limited degree (IEA, 2016).

Musvoto et al. (2012) applied modelling to investigate energy-saving operational measures at nitrifying activated sludge plants in the United Kingdom with design capacities of 158 Ml/d and 350 Ml/d, and reported energy cost savings as high as 50% without compromising final effluent quality within the required standard. The implementation of EE measures at two BNRAS case study plants investigated by Musvoto & Ikumi (2016), revealed that advanced process control strategies resulted in optimal process and aeration control which improved both denitrification and enhanced biological phosphorus removal. The two case study plants were:

- Zeekoegat WWTW with a capacity of 85 Ml/d with fine bubble diffused aeration, and
- JP Marais WWTW with a capacity of 15 Ml/d with surface aeration

The applied model predicted final effluent nitrate/nitrite and Ortho Phosphate values that were significantly lower than the baseline measured values as well as licence discharge limits.

Many technologies, to meet more stringent regulations, tend to be more energy intensive than prevailing technologies. Examples of these newer technologies include ultraviolet disinfection, ozone treatment, membrane filtration, and advanced wastewater treatment with nutrient removal (Feng et al., 2012).

Miller et al. (2019) states that with ammonia based aeration control a lower than typical operating DO concentration (2 mgO_2/l) can be achieved thus lowering the total aeration requirements and eliminating excess aeration. Additionally, operating at very low DO concentrations (0.2-0.5 mgO_2/l) promotes simultaneous nitrification and denitrification resulting in lower effluent total nitrogen and reduced alkalinity consumption. The study makes no reference with regard to the impact of the low DO operating environment on the generation of nitrous oxide (N_2O), a major GHG contributor.

Metcalf and Eddy (M&E, 2014) confirms that when lower DO concentrations are maintained in the aeration basin, less energy is needed because of the higher driving force between the saturated DO concentration and the aeration basin DO concentration. However, if the DO concentration is too low, filamentous organisms may predominate and the settleability and quality of the activated sludge may be poor. In general, the dissolved oxygen concentration in the aeration tank should be maintained at about 1.5 mg/l to 2.0 mg/l in all areas of the aeration tank. A minimum DO concentration of about

0.7 mg/l is required to initiate nitrification. Operating at DO levels below 1.0 mg/l can save energy and is done in some designs to induce simultaneous nitrification and denitrification. However, the aerobic biological reaction rates are lower, requiring larger tank volume. Higher DO concentrations between 2.0 and 3.0 mg/l provide small additional increase in nitrification rates. Values of DO above 4.0 mg/l result in little or no improvement in performance, but do increase aeration costs significantly and can potentially result in the growth of foaming organisms. Operating at higher DO concentration will also impact negatively on the performance in the anaerobic and anoxic zones of biological nutrient removal reactors due to the higher DO in the recycle streams.

Based on a case study, Rieger et al. (2014) found that aeration control based on ammonia may be used to limit aeration to reduce operating costs, and potentially improve performance. The approach is used to partially limit nitrification while maintaining a target effluent ammonia concentration below the permit value. The potential benefits include energy savings, increased denitrification, reduced external carbon dosage, and improved bio-P performance.

2.3 Current treatment technologies from an energy perspective

2.3.1 Energy in wastewater

Wastewater contains a significant amount of chemical, thermal and hydrodynamic energy:

- Chemical energy: mostly from COD but also inorganics such as ammonia – always available at a wastewater treatment plant and recovery needs to be maximised;
- Thermal energy: by heat extraction from water – not readily available at wastewater treatment plant. Recoverable in exceptional cases with higher water temperatures and applicable users of low quality heat energy;
- Hydraulic energy: potential, kinetic and pressure is recoverable by hydro-turbine technology. Applicability of energy recovery is the exception rather than the rule. Specific cases where large elevation drops and/or high pressures are available would apply.

Maktabifard et al. (2018) states that the estimated total energy embedded in wastewater was estimated as high as 9 700 Wh/m^3 which includes 2 700 Wh/m^3 (28%) of the extractable energy. The highest specific energy consumptions reported by WWTPs in most cases are below 1 000 Wh/m^3 which is still far less than the reported potentially extractable energy content of wastewater. Biosolids typically contain approximately 4 to 6 kWh/kg on a dry weight basis, which is similar to the energy content of low-grade coal. Wastewater treatment plant data from across the world reflect specific energy consumption (SPC) figures ranging from 260 Wh/m^3 up to 1 600 Wh/m^3.

Burton et al. (2009) estimated the energy potential from municipal WWTP in South Africa with a total capacity of 7 600 Ml/d, an average COD of 860 mg/l and an energy content of 15 MJ/kg COD at 1 134 MJ/s or 1 134 MWth. This equates to a specific energy content of 3 500 Wh/m^3. This specific energy content is optimistic because of the fact that it considers only the total chemical energy available and does not account for the technology used to harvest the energy or the associated transformation and other losses.

Attempts to correlate COD and chemical energy have come up with values ranging from 14.7 to 17.8 kJ/gCOD (Metcalf and Eddy/AECOM, 2014). In wastewater treatment, part of the chemical energy is removed from the liquid stream in the form of sludge during preliminary and primary treatment. During the biological treatment process, some of the chemical energy is transformed into biomass and reaction products such as carbon dioxide and methane, or released as heat through metabolism of microorganisms. The transformation of chemical energy occurs primarily during two major treatment processes: the biological treatment of the liquid stream and the treatment of sludge. The fate of chemical energy is reflected in Figure 4, as adapted from Metcalf and Eddy (Metcalf & Eddy, 2014). Actual values will depend on wastewater characteristics and actual process unit performance. It should be noted that a considerable portion of chemical energy is diverted to the biological treatment unit where additional energy is required to convert chemical energy into CO_2, H_2O, N_2, N_2O, heat and other by-products that cannot be utilised as an energy source.

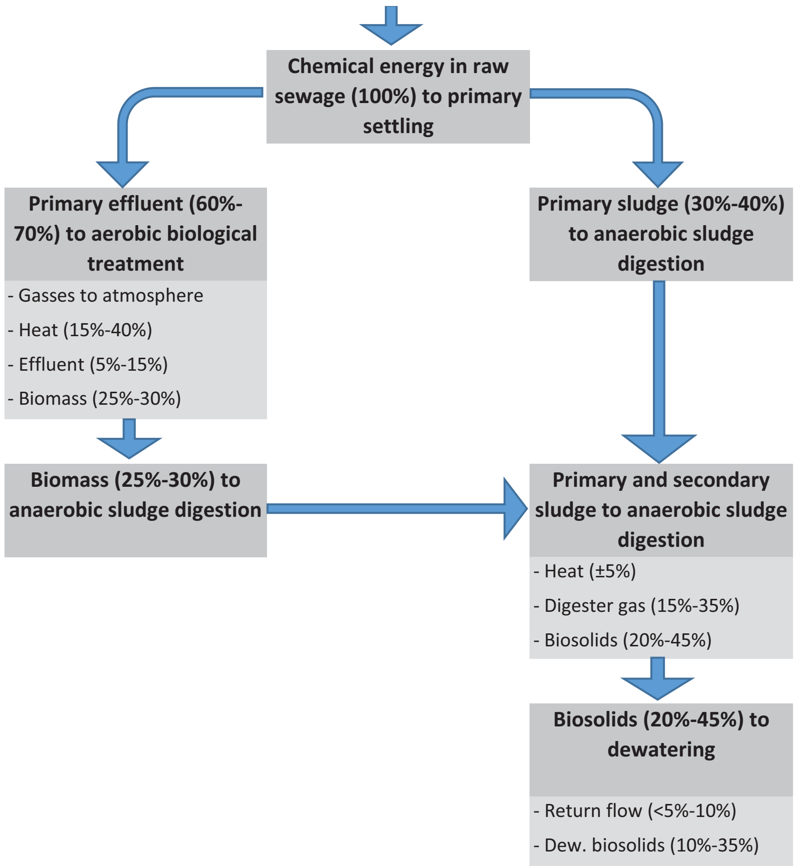


Figure 4: The fate of chemical energy in a typical wastewater treatment plant adapted from Metcalf and Eddy, 2014

Historically wastewater treatment plants were not designed with the intent to maximise the flow of chemical energy to the process stream that is capable of energy recovery. The actual value of chemical energy and its fate in a wastewater plant depends on:

- The organic load and characteristics.
- Actual process selection.
- Efficiency of each specific process.
- Operating parameters such as desludging procedure, operating sludge age, etc.

2.3.2 Aerobic versus anaerobic treatment

Anaerobic treatment processes have the potential to be net energy producers instead of energy users as in the case for aerobic processes, although the effluent quality from an aerobic process is generally superior. The COD load and, to a lesser degree, water temperature are major considerations around the energy balance between aerobic and anaerobic processes. Higher water temperatures would favour anaerobic processes in terms of energy efficiency. Assuming a water temperature of 20°C and an anaerobic operating temperature of 30°C (without effluent heat recovery) the anaerobic process and the aerobic process would use approximately the same amount of energy at a feed COD concentration of 1270 mg/l (Metcalf & Eddy, 2003). For higher COD loadings the anaerobic process would therefore be more energy efficient and will eventually become a net producer of energy at increasing COD loadings.

Although anaerobic treatment is the preferred option with regard to energy efficiency and has many other advantages such as lower sludge production, lower nutrient requirement and higher volumetric loading rates (smaller reactors), the negative aspects are more difficult start-up, alkalinity issues and the general requirement for an aerobic polishing step to ensure effluent compliance. Because of the relatively low organic loading in domestic sewage, anaerobic treatment is generally not a feasible process option and has therefore not been implemented in South Africa. However, technologies involving enhanced separation and redirection of organic load via an anaerobic route is an option worth investigating.

2.3.3 Contribution of each unit/operation process with regard to energy consumption, cost of energy and compliance

Scheepers, R et al. (Scheepers, R et al., 2012) reported on the technology counts for a total of 975 WWTPs in South Africa. Activated sludge plants and variations thereof was the most frequently applied technology at 395, followed by pond systems at 368 and biofilters at 145 plants. A further 100 counts were made in total for remaining technologies such as Pasveer ditch, RBC, various package plant types including unknown or poorly specified processes. A trend was identified that favour energy-intensive technologies such as BNRAS and extended aeration activated sludge systems, in preference to lower energy intensive processes such as pond systems, for the establishment of future wastewater treatment capacity. The influence by the consulting engineer, strict effluent standards, as well as the lack of energy considerations in feasibility studies are considered pivotal issues in the effort to redress energy efficiency of future wastewater treatment capacity. From data evaluated the following electrical energy consumption figures (kWh/Ml) were derived:

Plant capacity, Ml/d	<0.5	2	10	25	100
Trickling filter, kWh/Ml	478	478	251	177	160
Activated sludge, kWh/Ml	590	590	374	318	294

Table 3: The energy requirement of common secondary treatment technologies at varying design capacities

Metcalf and Eddy (Metcalf & Eddy, 2014) indicate that there is a significant difference with regard to energy requirements of the activated sludge process with nitrification (417 kWh/Ml) and a trickling filter process (175 kWh/Ml) for plants with capacities more than approximately 150 Ml/d. For plants with capacities less than 150 Ml/d there is a gradual increase in power requirement for both technologies from capacities 150 Ml/d towards 50 Ml/d, while for capacities less than 50 Ml/d there is an exponential increase in electrical energy requirement as the capacity decreases. Small, decentralised WWTWs will therefore be less energy efficient than larger, centralised plants. This is a clear indication that decentralisation of wastewater treatment should be thoroughly evaluated from an energy perspective in order to facilitate an energy efficient solution. Decentralisation may still be the most energy efficient solution for remote areas with long outfall sewers and/or excessive pumping.

Metcalf and Eddy (Metcalf & Eddy, 2014) state that the review of energy usage in wastewater treatment plants is important because the cost of energy ranges between 15% and 40% of the total operation and maintenance costs for wastewater treatment. WEF confirms that the cost of energy for wastewater treatment ranges from 15% to 40% of the total operating and maintenance cost, second only to labour cost which is normally the largest cost item on the operation and maintenance budget for a wastewater treatment facility (WEF, 2009).

The information collected for the development of a regional treatment capacity strategy for South African plants operated by a regional utility, was assessed in terms of electrical energy cost relative to all direct budget items. Overhead expenses were excluded. All the activated sludge plants assessed were designed for nitrification and most were designed for full biological nutrient removal. The WWTWs were categorised with regard to main secondary treatment technology with associated electrical energy consumed by each and expressed in 2012 rand. The percentage of electrical energy cost in relation to the total of all other direct costs were as follows:

Trickling filter	10% - 25%
Activated sludge and trickling filter	14% - 39%
Activated sludge	27% - 47%
Activated sludge, extended aeration	29% - 44%

Considering the disproportionate increases of electrical energy since 2012 (database date), it is expected that the percentages could presently be significantly higher than indicated above.

Metcalf and Eddy (2014) estimate power consumption by various unit process operations as the following table:

Process description	Energy consumption range Wh/m³		
Influent pumping	32	to	45
Screens	0.3	to	0.5
Grit removal (aerated)	3	to	13
Trickling filters	61	to	93
Trickling filter solids contact	93	to	93
Activated sludge for BOD removal only	140	to	140
Activated sludge for nitrification/denitrification	230	to	230
Membrane bioreactor	500	to	1000
Return sludge pumping (RAS)	8	to	13
Secondary settling	3	to	4
Dissolved air flotation	30	to	40
Tertiary filtration	30	to	80
Chlorination	0.3	to	0.8
Ultraviolet disinfection	10	to	50
Microfiltration/ultrafiltration	200	to	300
Reverse Osmosis without energy recovery	500	to	650
Reverse Osmosis with energy recovery	460	to	600
Electro-dialysis (TDS 800 to 1200 mg/l)	1100	to	2200
UV photolysis (advanced oxidation)	50	to	100
Sludge pumping	0.8	to	0.8
Gravity Thickening	0.3	to	1.6
Aerobic digestion	130	to	320
Mesophilic anaerobic digestion (PS&WAS)	93	to	160
Mesophilic anaerobic digestion (PS&WAS) with thermal hydrolysis	15	to	20
Centrifuge dewatering	5	to	13
Belt press dewatering	0.5	to	1.3

Table 4: Energy consumption ranges for various treatment processes (Metcalf & Eddy, 2014)

From the table above there is a clear trend of increased energy consumption for technologies producing higher effluent quality, for example an increasing energy consumption trend from trickling filters, to activated sludge, to biological nutrient removal activated sludge and to membrane bioreactor. Tertiary technologies required to improve effluent quality to even stricter quality requirements, for example: microfiltration, ultrafiltration, reverse osmosis and electro-dialysis require significantly increased energy consumption. It is also clear that processes based on aerobic principles require significantly higher energy input than processes based on anaerobic principles. There would be little or no benefits from selecting aerobic sludge digestion as opposed to anaerobic sludge digestion.

Typical performance data for selected aeration devices as reported by the EPA (Ireland) (1997), Stenstrom, M.K. and Rosso, D. (2010), and WEF (2017) is as tabled below. Variability of SOTR values and technology improvement over time is illustrated:

Aeration Device	**SOTR (EPA, 1997)** kgO_2/kWh	**SOTR (S&R 2010)** kgO_2/kWh	**SOTR (WEF, 2017)** kgO_2/kWh
Fine bubble diffusers	2.0-2.5	3.6-4.8	2.0-3.3
Coarse bubble diffusers	0.8-1.2	0.6-1.5	1.0-2.0
Vertical shaft aerators (low speed)	up to 2.0	1.5-2.1	2.5-3.5
Vertical shaft aerators (high speed)	-	0.9-1.3	1.8-2.3
Horizontal shaft aerators	up to 2.0	-	1.5-3.6

2.3.4 The potential role of EE in wastewater treatment

Water and wastewater facilities can often achieve a 20 to 30% reduction in energy use through energy efficiency upgrades and operational measures (EPA, 2013). Maktabifard et al. (2018) reports that the results of energy audits already carried out show that despite the capacity, each WWTP has potential for energy savings. Such savings can range from 20 up to 40% and in some specific cases even more (there are examples where even 75% were attained).

Best practices adoption can deliver energy efficiency gains of between 5% and 25% in the water cycle while up to 15% of wastewater energy demand can be offset by energy generation from sludge (power and/or combined heat and power) (Zvimba & Musvoto, 2020). In this study, aeration energy consumption and cost savings of 9% to 45% were demonstrated through implementation of energy conservation measures without compromising final effluent regulatory compliance. The study further indicated significant potential future energy savings as high as 50% and 78% through implementation of simple and more aggressive aeration energy conservation measures respectively. Generally, the model-predicted energy savings suggest that adoption of energy efficiency should be coupled with electricity generation from sludge in order to achieve maximum energy consumption and cost savings within the South African wastewater services sector.

The report by the UK Water Industry Research Ltd. (UKWIR, 2010) on energy efficiency in the British water and wastewater sector concluded that overall energy efficiency gains of between 5 and 15% may be achieved, with up to 25% energy efficiency improvement in wastewater treatment processes (mainly activated sludge processes). The report further indicates that renewable energy, mainly in the form of combined heat and power (CHP) from sludge gas, could contribute significantly to the net energy demand of the water industry.

Feng's review (Feng et al., 2012) of existing literature concluded that most of the commonly applied technical measures to address EE issues at water and wastewater generate 10 to 30% energy savings per measure and have 1 to 5 year payback periods. Financially viable energy savings depend on the vintage and conditions of facilities, technologies used, effective energy prices, and other factors affecting the technical and financial performances of individual utilities.

According to Feng et al. (2020), there is evidence that significant energy savings at water and wastewater utilities in developing countries can be attained cost effectively. Recent energy audits at 12 water and wastewater utilities across the Latin America/Caribbean region, reveal energy savings potential ranging from 9 to 39% at utility level with an average payback period of 1.5 years. These energy audits also highlight the main EE problems (interpreted as savings opportunities) with pumps and motors across utilities due to inadequate pump specifications, change in operating conditions as well as lack of regular and structured maintenance. An energy assessment study (including limited energy audits) of 5 water and wastewater utilities in China identifies multiple improvements with 10 to 25% energy savings and 1.7 to 5.9 years of payback periods. A recent assessment of water and wastewater utilities in developed economies of Europe and North America concludes that system wide EE gains between 5 to 25% appear to be financially viable under prevailing operation and financial conditions. The areas of opportunity and their relative importance in terms of the magnitude of energy savings do not differ substantially from findings from developing countries. Key energy-saving opportunities and viable saving potential in wastewater utilities are:

Pumps and pumping, with a general savings potential range of 5-30%

- 5 to 10% by improving existing pumps
- 3 to 7% through improved pumping technology
- Up to 30% by improved maintenance and closer matching of pump duty to actual duty (such as, using VSDs)
- Complex/large-scale savings are feasible but often show marginal payback

Aerobic sewage treatment, with a general savings potential of up to 50%

- Simple gains of up to 50% are possible on some aerobic systems by aligning control parameters with the discharge standard
- Up to 25% in activated sludge systems

Other opportunities, with a general savings potential of up to 15%

- Up to 15% by improving building services

In a case study by Musvoto & Ikumi (2016), the following feasible aeration energy conservation measures were identified at an 85 Ml/d BNR plant with a fine bubble diffused aeration system. The fine bubble diffused aeration system was responsible for 42% of the plant electrical energy consumption:

- Simple measures utilizing existing process and aeration equipment: Optimal process and aeration control resulting in potential cost savings of 9%;
- Low to medium capital investment: Upgrading the current aeration control strategy from traditional dissolved oxygen based control to ammonia based control with potential cost saving of 17%. Preliminary financial analysis indicates a payback period of 1.7 years;
- Complex high capital investment: Replacing the existing Module 1 single stage centrifugal blowers with more efficient turbo blowers. Potential savings of 19-23% can be achieved with payback periods of 5.2 to 5.5 years.

The second case study by Musvoto & Ikumi (2016), revealed the following feasible aeration energy conservation measures at a 15 Ml/d BNR plant equipped with slow speed surface aerators. The surface aeration system was responsible for 74% of the plant electrical energy consumption:

- Simple measures utilising existing process and aeration equipment: Optimal process and aeration resulting in potential cost savings of about 14%.
- Low to medium capital investment measures utilising the existing aeration equipment: Fully automating aeration control and implementing advanced process control with ammonia based aeration control. Potential cost savings of 21% and a payback period of 1.1 years.
- High capital investment – replacing existing surface aerators: This measure requires a complete redesign of the aeration system and replacing the surface aerators with either fine bubble diffused aeration, hybrid aerator/mixers or dual impeller surface aerators. Potential cost savings of 31 to 39% can be achieved with payback periods ranging from 5.8 to 6.4 years.
- High capital investment – installing an influent balancing tank: Installing a balancing tank combined with an efficient aeration system will yield maximum energy savings greater than 40%. Flow balancing also results in simplified more efficient process and aeration control systems.

Musvoto & Ikumi (2016) recommend that, before practically implementing aeration energy conservation measures identified from desktop studies, the following is observed:

- A more detailed investigation of market available options for aeration technologies as well as process and aeration control technologies. The quality and costs including maintenance requirements are of critical importance to the success of the aeration energy conservation measures;
- Application of a superior economic evaluation technique such as life cycle cost analysis, which takes into account all the costs incurred during the project life, so that the most cost effective measures can be selected for implementation;
- Detailed engineering design support for medium to high capital measures that require significant modifications to existing infrastructure as well as new treatment units and equipment.

2.3.5 The potential role of RE in wastewater treatment

Zvimba & Musvoto (2020) find that the implementation of energy efficiency with generation within the South African wastewater sector has a significant potential of reducing future energy consumption and cost for wastewater utilities, ultimately translating into significant greenhouse gas emission reduction in support of climate change mitigation.

Combined heat and power (CHP) systems using biogas from anaerobic sludge digestion, a well-established means of generating energy, can provide up to % of the power requirements at wastewater treatment plants using activated sludge process (Feng et al., 2012).

Fersi et al. (2014) assessed the total cost of energy recovery from sewage sludge with AD and CHP and found that the generated thermal energy meets the needs of the entire WWTW and guaranteed self-sufficiency in heat. The surplus of renewable heat produced by CHP was not a primary factor to improve the economic viability of the process, and the sales of electricity output represented about 76% of the operating cost of the AD process.

Sludge is considered a renewable energy resource as it contains organic material that has a fuel value. Under properly engineered and controlled environment, energy recovery from sludge is considered top of the hierarchy of beneficial use, due to the increased cost of energy and more stringent air quality regulations (Van der Merwe-Botha et al., 2016). Sludge from wastewater can be processed to generate energy by (Metcalf & Eddy, 2014):

- CH_4 production from anaerobic digestion;
- Thermal oxidation;
- Syngas production through gasification and/or pyrolysis;
- Oil and liquid fuel production.

Recovery of energy is a mature technology and has been practiced at wastewater treatment facilities primarily by producing biogas from sludge with anaerobic sludge digestion. Typical biogas production rates achieved are between 0.75 and 1.12 m^3/kg VS destroyed. Biogas contains 55%-70% methane, 30%-40% CO_2 and small amounts of N_2, H, H_2S, water vapour and other gases. The energy content of digester gas is typically in the range of 22 to 24 MJ/m^3. Gas production can also be estimated crudely on per capita basis, where the norm yield is 15-22 m^3/1000 persons/day for primary treatment plants and up to 28 m^3/1000 persons/day in secondary treatment plants (Metcalf & Eddy, 2014). Methane gas at standard temperature and pressure (20°C, 1 atm) has a heating value of 35 800 kJ/m^3, which gives approximately 22 400 kJ/m^3 for biogas at 65% CH_4 content.

Wastewater contains significant amounts of embedded energy and capitalising on this resource has the potential to provide over 55% of the energy required for municipal wastewater treatment by 2040 (IEA, 2016). The greater use of biogas can also help manage variable renewable energy resources in a network. While there is significant potential to recover embedded energy and to pair it with other waste via co-fermentation, increased use of waste-to-energy technologies will require both the right regulatory framework and at least initially, fiscal incentives.

2.3.6 Energy performance management

Maktabifard et al. (2018) states that energy audits and energy benchmarking are fundamental tools in assessing energy consumption and energy conservation potential, including implementation of new processes and technologies. It is expected that the proposed upgrades are energy and cost efficient, while still maintaining the effluent discharge limits. As the wastewater treatment paradigm shifts towards sustainability, the environmental impact in a life cycle has become another challenge in a WWTP optimisation. The following tools are recommended for sustainability management:

1. ***Economic efficiency analysis (EEA):*** EEA is based on the capital costs, operating costs and economic benefit in WWTPs. It is mainly related to energy aspects in terms of reducing operating

costs by advanced control systems and increasing economic benefit by increasing energy recovery.

2. ***Carbon footprint analysis (CFA):*** CFA can measure the total GHGs released by WWTPs. Increasing aeration efficiency and reducing energy consumption by on-site energy recovery would help reduce the carbon footprint of WWTPs.

3. ***Life cycle analysis (LCA):*** LCA is a standardized procedure applied for analysing environmental aspects in WWTPs. Several studies have adopted LCA to analyse energy related aspects such as AD and biogas production.

4. ***Data envelopment analysis (DEA):*** DEA is a technique that is widely applied for eco-efficiency assessment (useful when there is limited available data). The economic cost, energy consumption, pollutant removal, and global warming effect during the treatment processes are integrated to interpret the eco-efficiency of WWTPs

5. ***Plant-wide modelling:*** Simulation tools allow to predict performance of WWTPs and analyse detailed information in terms of the influent and effluent quality, and energy consumption. Modelling also makes comparison of different strategies to achieve energy neutral condition much more feasible. A multi-objective performance assessment of WWTPs combining dynamic process model including GHG, detailed energy models, operational cost and LCA is also proposed.

2.4 Emerging technologies from an EE and RE perspective

Maktabifard et al. (2018) report that bio-electrochemical systems (BES), such as microbial fuel cells (MFC) and microbial electrolysis cell (MEC), are generally regarded as a promising future technology for the production of energy from organic material present in wastewater. BESs are aimed at bio-energy generation in the form of methane and bio-hydrogen while treating wastewater in an anodic chamber. The MFC is capable of converting the chemical energy of dissolved organic materials directly into electrical energy, while MEC is capable of generating a product (e.g. hydrogen) from dissolved organic materials using a low level electrical energy input.

Other emerging technologies include:

- CANDO: The direct energy recovery from waste nitrogen has recently proven feasible using the coupled aerobic-anoxic nitrous decomposition (CANDO) process. The chemical energy of nitrogen compounds in wastewater is estimated at approximately 300 Wh/m^3.

- Micro algae system: Microalgae can grow in wastewater and can play the dual role of bioremediation of wastewater treatment and generation of biomass for biodiesel production. Although still not commercially viable at the current fossil fuel prices, a niche opportunity may exist where algae are grown as a by-product of high rate algal ponds operated for wastewater treatment. An annual average of 540 Wh/m^3 of wastewater, electricity production from biogas cogeneration is estimated.

Gude, VG, (2015) is of the opinion that current wastewater treatment processes, especially aerated systems, are energy intensive. However, wastewater is considered a rich energy source. This energy, if properly extracted, can exceed the treatment energy requirements by up to 10-fold. In order to recover this energy and move towards energy neutrality, three approaches are proposed:

1. Approach 1 includes anaerobic digestion of sludge collected from primary and secondary treatment units to meet the treatment energy expenses. However, this approach alone may not be adequate to generate all the energy required for wastewater treatment due to technological and scientific barriers that prevail in these systems. Instead integration of other organic wastes for co-digestion can be considered. Current wastewater treatment plants (larger than 37 850 m^3/d) relying on this technology are able to achieve energy recovery up to 50%. Anaerobic digestion can only become energy positive when other organic wastes such as food waste, brewery and dairy wastes are included in the feed. This process is called co-digestion.

2. Approach 2 involves wastewater treatment with mixotrophic systems (i.e. bacteria and algae) to enhance carbon utilisation (biomass production as opposed to oxidation and release of carbon dioxide), nutrient removal and biomass production.

3. Approach 3 is to use secondary effluents from the wastewater treatment plants to cultivate algae for biofuel production through thermo-chemical processes.

Several technologies are available for sludge management/energy recovery which include anaerobic digestion, thermochemical processes such as super- and sub-critical water (hydrothermal) processes, pyrolysis, incineration and gasification (Gude, 2015).

Energy recovery is essential for the long-term sustainability of wastewater operations. Musvoto et al. (2018) reports on the evaluation of one innovative/emerging and two established sludge-to-energy technologies that have not yet been implemented in South Africa. The selected technologies were:
1. Emerging enhanced hydrothermal carbonisation polymeric carbon solid (PCS) technology
2. Established advanced anaerobic digestion using thermal hydrolysis (TH) as the sludge disintegration technology followed by mesophilic anaerobic digestion (MAD)
3. Gasification technology which is established for coal and woody biomass conversion.

Key findings reported on the Musvoto study on the sludge to energy technologies were:

- Both the PCS technology and advanced TH-MAD are more economically attractive than conventional MAD.
- The PCS technology is the most economically attractive technology with the highest positive NPV. Apart from being the most economically attractive, the PCS technology offers other unique advantages to the South African water sector over established technologies, such as:

- ability to process a wide range of biomass including screenings
- ability to integrate with existing technologies such as conventional MAD, advanced TH-MAD or gasification. A positive NPV was obtained for the 35 tDS/d retrofit to conventional MAD case study
- potential to destroy contaminants of concern such as endocrine disrupting compounds
- Beneficial use of residual sludge or ash is more economically attractive than disposal to landfill.

2.5 EE as mitigation measure

Improving the energy efficiency on a plant is one of the most effective ways for WWTPs to manage costs and help ensure the long-term operational sustainability. Maktabifard et al. (2018) state that methods of minimizing the electricity consumption can be divided into two major categories. The first one focuses on the operational modifications (operational adjustments and equipment upgrades) and the second involves innovative processes for wastewater treatment with less energy demand compared to the traditional technologies. Operational measures include:

- Pumping operations: Pump life cycle cost is dominated by operational energy cost and it therefore makes sense to invest more initially to save on operational cost, or to replace when inefficiency becomes apparent. Flow control by VSD is often a cost effective measure, but must be evaluated against the system curve response. VSD upgrades typically have short payback periods of between six months to 5 years. Motors and pumps should be appropriately sized.
- Aeration devices: Fine bubble diffused aeration is significantly more energy efficient than low speed surface aerators. Low speed surface aerators are more efficient than high speed surface aerators. New developments with regard to mechanical surface aerators are the inclusion of multiple impellers which are reported to improve efficiency.
- Aeration control: Effective aeration control systems can save 25% to 40% on energy as opposed to manually controlled systems. A number of aeration control strategies are available:

    - Aeration control based on airflow modulation and oxygen demand.
    - Intermittent aeration is reported to result in 10% to 15% energy saving while improving on effluent TP and TN concentrations.
    - Ammonia based aeration control (ABAC): Maintaining a selected DO concentration while ammonia concentrations approach zero could result in unnecessary aeration. The feed-back approach is simpler than the feed-forward approach. The feed-forward control is a more complex system but has potential to be more energy efficient. It is reported that the benefit of the feed-forward cannot be justified due to the higher complexity.
    - Ammonia versus nitrate (AVN) control: This control system is based on the approach that nitrification is only allowed to the extent that the denitrification capacity is not exceeded. Lower effluent nitrogen levels are achieved with lower oxygen demand compared to the ABAC approach.

- Bioprocess intelligent optimisation system (BIOS): BIOS is an intelligent feed-forward simulation system based on on-line measurements of temperature, ammonia, nitrate and flowrate. The system simulates a continuous DO set point and has the potential to minimise energy consumption.

The conventional biological nitrification-denitrification processes, require high amounts of oxygen for nitrification and organic carbon for denitrification. To reduce the energy required for nitrogen removal, shortcut biological nitrogen removal (SBNR), also called the nitrite shunt, has been developed. The process steps are as follows:

$$NH_3 \rightarrow NO_2 \rightarrow N_2$$

The SBNR process implies a reduction of oxygen consumption during the aerobic phase by 25% as a result of skipping oxidation of nitrite to nitrate and consequently reduces the total energy required by 60%.

Deammonification and Anammox: Ammonia-rich wastewater can be treated with the very economic autotrophic deammonification process, which requires no organic carbon source and less than half of the aeration energy compared to the conventional nitrification-denitrification. Anaerobic ammonium oxidation (Anammox) is an autotrophic process for ammonium removal which has widely been studied for its potential application. The anammox process requires less energy but anammox bacteria grow very slow. The Anammox process was typically applied in a side-stream configuration in the past, but recent developments is moving towards better integration with the mainstream process.

It is internationally recognised that saving one unit through energy efficiency is cheaper than producing one unit of energy. Energy efficiency is the quickest, cheapest and most direct way of addressing the climate change imperative, high electricity costs and the electricity supply constraints facing the country (SEA, 2015). The importance of energy efficiency has been highlighted at the global level, by the World Energy Council, and at the South African national level through various policies, particularly the national Energy Efficiency Strategy (DME, 2005, 2008, 2011) and further reinforced in the State of the Nation Address (The Presidency, 2015). Wastewater/energy experts are of opinion that the implementation of these policies and monitoring of the outputs should be fast-tracked (Brown, Drakenstein Local Municipality, 2020). One way would be for the state to impose implementation thresholds or targets for EE by a specific timeline. This is being done via the National Energy Efficiency Strategy of 2015 that commits South Africa to show a 29% reduction in energy consumption by 2030 based on EE improvements. This 29% is made up, amongst others, by the municipal sector to target 37% reduction in energy consumption and 20% improvement from municipal services.

Energy efficiency has far-reaching benefits in terms of financial savings, economic efficiencies, job creation, reduced demand and (indirectly) lower carbon emissions. Yet, despite these benefits, energy efficiency remains underutilised in South Africa's energy portfolio, upfront capital costs being identified as one of the major barriers (SEA, 2015).

Before describing the methods and technologies for decreasing the energy consumption in wastewater treatment processes, the main energy consumers in WWTPs should be identified. Regardless of the WWTP size, most of the energy is consumed during biological treatment (can be up to 77% of total consumption). More than 60% of the investigated WWTPs consume more than a half of their energy just for aeration in the biological stage of the plant. Logically, the most consistent energy savings in the treatment line can be achieved there. Other important contributions may be derived from the optimisation of primary settling efficiency and pumping operations, provided that the necessary amount of biodegradable organic compounds to achieve biological nutrient removal is guaranteed.

NERSYDA (NERSYDA, 2010) recommends a number of energy saving best practice measures with regard to wastewater treatment processes. UKWIR (UKWIR, 2010) present a summary of case studies on energy interventions with outcomes in terms of savings achieved from the British Compendium (Appendix A).

NEWRI (NEWRI, 2010) propose the following approaches and technologies towards improving energy efficiency in the wastewater treatment sector:

- Fine bubble air diffusion (15-40% higher oxygen transfer efficiency).
- Dissolved oxygen control (30-60% saving in energy consumption).
- Variable frequency drives (VFDs) (up to 50% savings for pumping energy consumption).
- Utilisation level vs. design capacity (Iran).
- Anaerobic digestion and biogas production (20-61% energy production in surveyed countries).
- Equipment renewal/upgrading.
- Application of CHP generators (Strass WWTP, Tabirz WWTP).
- Feedstock pre-treatment.

A study by Zvimba & Musvoto (2020) illustrate the significant potential energy savings available to the South African wastewater sector through focusing on and prioritising implementation of aeration energy conservation at BNR activated sludge plants. It is concluded that the use of technically superior tools such as mathematical modelling and simulation that enable evaluation of both aeration conservation measures and process control strategies, yields additional benefits that would not be realised through just aeration equipment changes. The most significant benefit of this approach is that final effluent compliance with regulatory requirements is not compromised through implementation of aeration EE measures, thereby satisfying the primary wastewater treatment objective of protecting the environment. Other additional benefits include cost-efficiency through desktop evaluation of options and better understanding of process performance under various process and aeration control strategies before practical implementation. The following steps are recommended before the implementation of EE measures:

- Detailed investigation of available aeration and control technologies.
- Application of techniques such as life cycle cost analysis.

- Engineering support for medium to high capital cost measures.

A modelling study by Miller et al. (2019) investigated three aeration control approaches on a MLE process and found the following:

1. Manual control (baseline): The target DO concentration was 2 mgO_2/l. Although true manual DO control is difficult to replicate, it was assumed that a Process Controller would check the DO every four hours and adjust the airflow rate based on the DO at that time. This resulted in large swings in the DO from 0.5 to 3.5 mgO_2/l. It is expected that the model controller likely did better at maintaining the DO near 2 mgO_2/l than what would occur in reality. For the manual DO control scenario (baseline), the average energy demand for the blowers was 590 kWh/MGD (±156 kWh/Ml).
2. Automated DO control: Using a target set point of 2 mgO_2/l, it was found that 3% less aeration energy was required than the baseline scenario, while it was expected for the difference to be closer to 10-20%. That is, the controller likely did better at maintaining the DO near 2 mg-O2/L than what would occur in reality.
3. Feedback ammonium based aeration control (ABAC): ABAC was modelled assuming a target effluent ammonia concentration of 1 mg/L. This resulted in approximately 30% additional energy savings for a total of 33% compared to the baseline scenario.

2.6 RE as mitigation measure

Pioneering efforts, led by some municipalities in the EU and US, have shown that improving energy efficiency and harnessing embedded energy can move their operations towards “energy neutrality”, where energy needs are entirely satisfied with own generation. The path to this self-sufficiency comes in two parts: first, is energy savings through efficiency gains and the second is electricity generation from biogas. Capitalizing on energy recovery could provide over 55% of the electricity required for municipal wastewater treatment by 2040 (IEA, 2016), but without greater attention from policymakers and municipalities this potential risks being unfulfilled.

Maktabifard et al. (2018) states that there are several types of technologies to recover energy from wastewater. Energy recovery can be classified into three groups: chemical, thermal and hydro energy. The calorific energy of average wastewater is estimated at 1 500 W/m^3, i.e. more than typically required for treatment.

NYSERDA (2010) recommend the following best practices with regard to RE:

1. Biogas produced in an anaerobic digester can be used to generate electricity with reciprocating engines, micro-turbines, turbines, or fuel cells. The thermal energy generated by these systems can often be used to meet digester heat loads and for space heating. Alternatively, the biogas can be used directly as boiler fuel for the production of heat. A commonly used rule is that the biogas generated from each 16.7 Ml/d of influent can potentially generate approximately 100 kW of electricity.

2. Recover excess heat from wastewater prior to treatment or discharge to use at or near the wastewater treatment facility. Some industrial wastewater systems have a large volume of low grade heat available in their wastewater, although the use of low grade heat remains a challenge. The distance between the heat recovery source and the application determines the economic feasibility.

3. Assess the availability of renewable energy resources (wind, solar, biogas or hydro) at the facility site. If available, investigate the technical and economic feasibility of installing equipment to harvest these resources to meet part or all of the facility's electric and heating needs. Typically, payback periods for renewable energy technologies range from three to seven years.

In the forthcoming years, the focus within the wastewater management sector will expand into the additional utilisation of other sustainable energy sources and the recovery of raw materials (Stamatelatou and Tsagarakis, 2015). The following advances are envisioned:

- Further development of technologies to reduce energy consumption and increase energy yield (Cold Anammox, fuel cells, gasification, supercritical gasification).
- Conversion of biogas to transport fuel (Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG)) to expand sustainability gains into the transportation sector.
- Energy supply from renewable sources (wind turbines and solar panels) to STPs.

Renewable energy is more suitable for decentralized use, with the energy converters located close to consumers and providing supplies at concentrations far lower than those obtainable with non-renewables (Wisconsin Focus on Energy, 2016). Among the renewable resources with technical and economic viability to meet the typical demands of sewage treatment plants, are mainly micro hydro, solar photovoltaic and wind power. Each source should be assessed, site-specifically, for feasibility and life-cycle cost. A combination of renewable resources may even be appropriate for a site. For example, a combination of solar and biogas may be appropriate: a solar system can offset some energy requirements during the daylight hours and a biogas system can offset the energy requirements during the evening hours or on cloudy days.

2.6.1 Chemical energy recovery

Maktabifard et al. (2018) reports that anaerobic digestion is one of the well-established mature technologies for the recovery of chemical energy. Anaerobic digesters are more common for plants with a capacity of 22 Ml/d or more. The anaerobic membrane bioreactor (AnMBR) is a more recent development in anaerobic digestion with a reported volume reduction of 65% to 80% (Kanai et al., 2010). Electrical energy recovery from AnMBR is reported to be in the order of 150 W/m^3 to 300 W/m^3 for typical wastewater.

Chemically enhanced primary treatment improves the performance of the settling tank with chemical coagulants. The advantages include that the biodegradable organic material diverted to the ADs are increased while the oxygen demand in the aerobic reactor is decreased. This measure has potential to increase energy recovery via biogas while reducing the aeration energy. Possible disadvantages could be inhibition of the methanogens by increased coagulant (i.e. aluminium) concentrations. Güler Türkoğlu Demirkol et al. (2020) investigated several coagulants and coagulant aids for the enhanced removal of COD and suspended solids in the primary settling tanks and possible inhibitory effect on biogas production in the anaerobic digester. Ferric chloride and certain coagulant aids made a positive contribution while aluminium sulphate and coagulant aids based on acrylamides and acrylic acid derivatives indicated inhibition of biogas production.

Sludge pre-treatment by physical, chemical, thermal or mechanical means before anaerobic digestion can improve volatile solids destruction and improve biogas production and energy recovery. Sludge pre-treatment can be by various means:

- The thermal hydrolysis process can improve biogas production by 20% to 30%, but the net energy benefit was found to be modest;
- Chemical pre-treatment by free nitrous acid (renewable chemical) free ammonia indicates improved biogas production rates from WAS of 16% and 22% respectively;
- Combined chemical and heat pre-treatment improved biogas production by 25%;
- Ultrasound and microwave pre-treatment showed inconsistent biogas gains between 8% and 50%.

2.6.2 Thermal energy recovery

The thermal energy in wastewater is dependent on the flow rate and the water temperature. Wastewater heat recovery via heat exchangers and heat pumps constitutes an environmentally friendly, approved and economically competitive, but often underestimated technology. This low quality heat energy has limitations with regard to the location of the potential user relative to the source.

2.6.3 Hydro energy recovery

Hydropower relies on water passing through turbines to generate electricity. Effective energy recovery requires consistent flow and a reasonable head loss. Due to the limited head losses typically available at plants, recovery opportunities are not common and the recovery of hydropower energy in wastewater infrastructure is relatively new. The hydro power recovery is directly proportional to the flow rate and the available pressure drop or head loss. Due to potential issues with the debris in raw wastewater, the recovery of hydropower from treated effluent is preferable.

2.6.4 External renewable energy

Photovoltaic: Maktabifard et al. (2018) reports that photovoltaic (PV) panels provided only 0.1% of the total global electricity generation in 2010. This share is projected to increase to 5% of the global electricity consumption by 2030, rising to 11% in 2050. Economic analysis revealed that photovoltaic systems could be a viable RE source, with an estimated payback time of less than 7.4 years.

A report by Harper (2017) describes a novel application of a solar farm on the surface of an overflow pond at the East Lismore WWTP, Australia. This solar farm can produce 180,000 kWh of electricity per year which covers 12% of the total energy consumption of the plant.

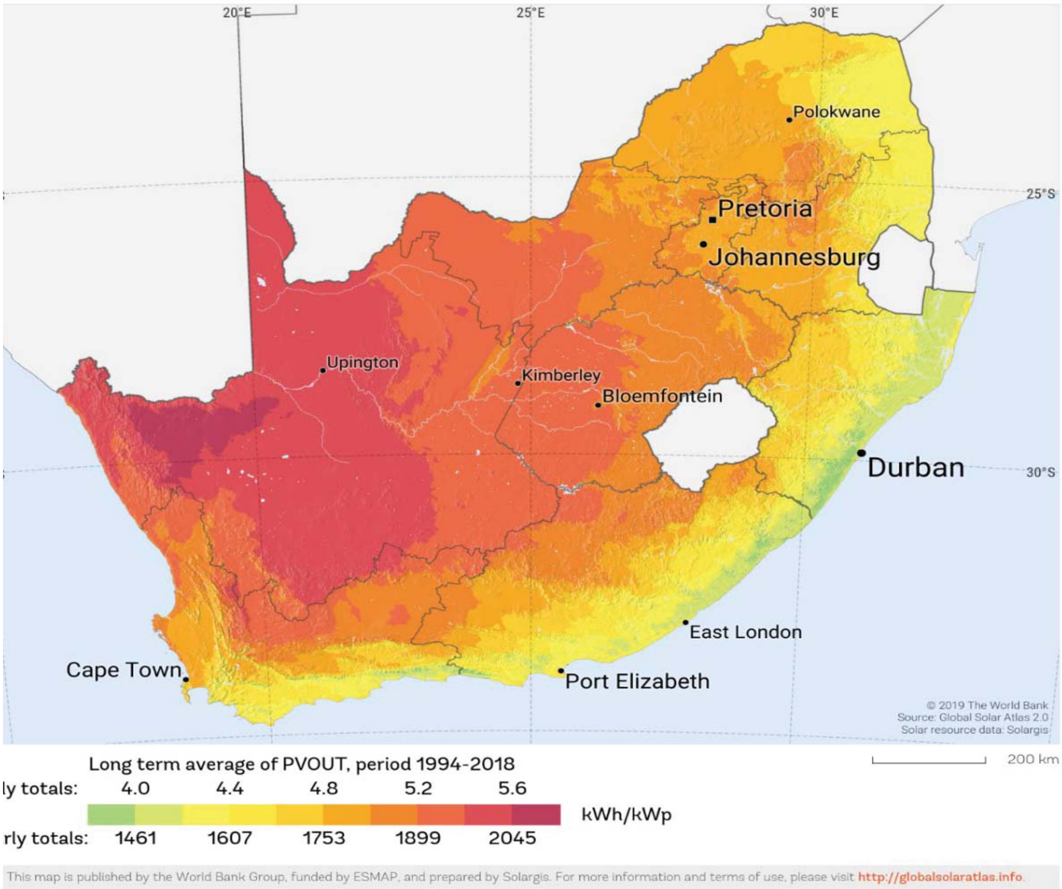


Figure 5: Photovoltaic power potential in South Africa (World Bank, 2019)

From the map above it is clear that the return on a similar capital investment in a photovoltaic system located in the north-western Cape will be up to 40% more effective than a similar system located in the Durban vicinity.

Solar energy has also been successfully deployed for sludge drying.

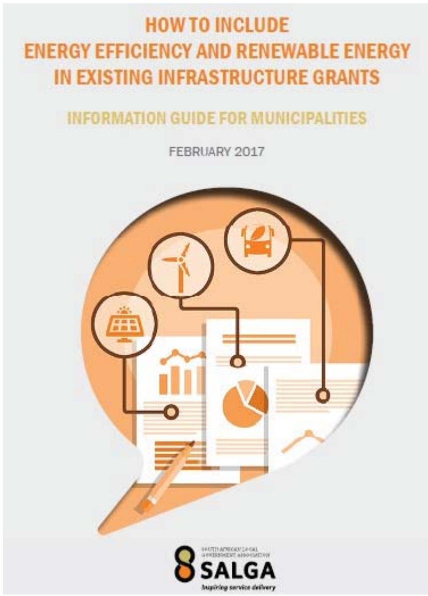
Co-digestion: The process of co-digestion can be performed by adding small amounts of co-substrates which will not affect significantly the designed hydraulic retention time. The typical co-substrate addition rates in sludge digesters are between 5 and 20%. Food waste is more readily biodegradable than municipal wastewater solids. Consequently, the anaerobic digestion of food waste can be achieved at a shorter hydraulic retention time (i.e. 5 or 10 days) in comparison with sewage sludge requiring up to 20 days. In other words, the feed rate of food waste to ADs can be 2 to 3 times higher than sewage sludge. More importantly, food waste has a higher specific energy content than sewage sludge. Food waste digestion results in a nearly 3 times higher biogas production rate in comparison with sludge digestion. Substrates rich in lipids yield the highest methane potential, followed by carbohydrates and proteins.

The potential contribution food waste towards self-sufficiency of WWTPs was investigated by Koch et al. (2016). The biogas production doubled with the addition of only 1000 m^3 of food waste, while the amount of thickened raw sludge treated remained roughly the same at the level of 9000 m^3. A comparison of 176 German WWTPs revealed that 44% of them achieved energy neutrality with a strong correlation to the fact that co-substrates were used.

2.7 Cost and financing of EE and RE projects in South Africa

Burkard & van der Merwe-Botha (2017) published a list of financing institutions as cited from the GIZ-SAGEN programme. In the case of municipal infrastructure financing, the Department of Cooperative Governance and Traditional Affairs (CoGTA) and National Treasury have defined roles with regard to funding or co-funding CHP projects.

The main stumbling block to the adoption of green projects remains the low level of funding available in local and district municipalities (GIZ, 2015). The implementation of energy efficiency drives do not always require funding for implementation. There are a number of EE measures that could be implemented via the normal operating and maintenance budgets, i.e. the replacement of motors that need extensive repair should not be repaired but replaced by new energy efficient motors. The difference in cost is minimal and the payback period could be two years or less depending on rating and duty cycle. There are other EE measures that require no capital investment and have significant impact which and are based on how equipment is operated and controlled.



The following grants have EE and RE opportunities at water and wastewater facilities. The document "How to include EE and RE in existing infrastructure grants – Information guide for municipalities" can be referred for further detail, is available and can be applied for at SALGA (SALGA, 2017):

- The **Energy Efficiency and Demand Side Management (EEDSM) Grant** provides funds for retrofitting existing infrastructure to become more energy efficient. Improved efficiency is the most cost-effective, least-polluting and readily-available energy resource. More than half of the electricity-sector related carbon emissions reduction target in the coming twenty years could be achieved through energy efficiency. Administered by the Department of Energy.

- The **regional bulk infrastructure grant** (RBIG) is designed to fund large bulk water and wastewater projects within a municipality or projects that cut across several municipalities. It is intended for use to develop infrastructure that connects water resources to reticulation infrastructure, thus providing water and sanitation services to individual households. It is administered by the Department of Water and Sanitation (DWS). The grant is well placed to fund EE interventions in the water and wastewater sector where new infrastructure is purchased or ageing infrastructure is replaced. Both cases present opportunities to install EE pumping technology or other interventions.

- The **water services infrastructure grant** (WSIG) is a consolidation of the municipal water infrastructure grant (MWIG), the rural household infrastructure grant and the water services operating subsidy. The grants were merged to rationalise, overlap, and ensure greater alignment between water and sanitation projects. It is administered by the Department of Water and Sanitation (DWS). Similar to the RBIG, the WSIG can be spent on more energy efficient technology in the water sector, when investing in new or replacing old infrastructure.

- The **neighbourhood development partnership grant** (NDPG) is designed to help cities (metropolitan municipalities and secondary cities) develop and implement urban network plans. The grant is intended for planning and investment in targeted locations to catalyse, attract and sustain third party capital. This grant is administered by National Treasury. The NDPG's objective make it a suitable source of funding for EE and RE interventions in the water sector, municipal buildings and vehicle fleets.

- The **urban settlements development grant** (USDG) is designed to support the national human settlements development programme in the eight metropolitan municipalities. This grant is administered by National Treasury. The USDG is a suitable source of funding for EE and RE interventions in the metropolitan water as well as lighting sectors.

- The **integrated city development grant** (ICDG) is a financial incentive provided to metropolitan municipalities to achieve a more compact urban spatial distribution. This grant is administered by National Treasury. Similar to the USDG, the ICDG is a suitable source of funding for EE and RE interventions in the water as well as lighting sectors.

The SEA (SEA, 2015) reports that in parallel with national energy efficiency policy development, local government policy and initiatives have advanced considerably. Most cities are undertaking a range of energy efficiency interventions, including public building audits and lighting retrofits. These are financed through the national DOE's Energy Efficiency Demand Side Management (EEDSM) Programme. This programme has been a catalyst for energy efficiency within municipalities, and covers street lights, traffic lighting, building lighting, heating, ventilation and air conditioning systems, and (lately) water pumps in the water and wastewater treatment plants. Some of the larger cities and metros have also undertaken energy efficiency campaigns and established forums to promote implementation.

A growing number of municipalities are undertaking their own, internal efficiency retrofits, through the national DOE EEDSM programme, which began in 2009 and is now in its second three-year funding phase. The programme funds the implementation of municipal efficiency measures and has, in response to municipal needs, expanded from public lighting to building and wastewater treatment pump retrofits (SEA, 2015).

2.8 EE and RE barriers in South Africa

Since 2015 GIZ-SAGEN (GIZ-SAGEN, 2018) regularly investigates and reports on how many municipalities have incorporated sustainable energy and climate change elements and themes into their planning using an indicator defined as Top Green Planner. In order to qualify as a Top Green Planner (TGP), using their wider scope of projects TGP definition, the number of TGPs increased from 22% (60 out of 278) in 2015, to 46% (117 out of 257 municipalities) in 2018. Although sustainable waste management and energy efficiency projects were the most prevalent among IDP plans, followed by sustainable water and renewable energy projects, wastewater related projects remains limited. This limited wastewater treatment uptake is evident despite the fact that wastewater treatment consumes a major portion of municipal electrical energy. The lack of financing mechanisms for local government to directly access funding for the wider scope of sustainability-focused projects was identified as a serious concern and needs to be addressed.

GIZ-SAGEN (GIZ-SAGEN, 2018) reports that in 2016, the Department of Environmental Affairs (DEA) in partnership with the South African Local Government Association (SALGA) and GIZ began implementing the Local Government Climate Change Support Programme (LGCCSP) across the country. One of the strategic objectives of the programme was to support the mainstreaming of climate change adaptation into municipal planning processes and documents, such as the IDPs.

According to Feng et al. (2012), a number of typical barriers can inhibit proactive measures to address EE issues at wastewater treatment plants:

1. Institutional and regulatory issues:
   - Politicising of wastewater tariffs
   - Constraints of public sector budgeting
   - Electricity subsidising/low tariffs
   - EE is not a performance evaluation criteria
   - Divided responsibilities with regard to energy procurement and plant operational efficiency
   - Operational staff are allocated specific responsibilities which discourages EE awareness

2. Knowledge and know-how:
   - Inadequate knowledge regarding EE opportunities, solutions, costs, benefits, savings, etc.

- Limited capacity to undertake EE measures

3. Access and availability of financing.
    - Low credit rating of WWTW owner
    - Unattractive quantum of EE projects for commercial lenders
    - Underdeveloped EE financing market

4. General EE policy and market conditions.

The World Energy Outlook 2016 Excerpt (IEA, 2016) reflects an outlook that is far from exploiting the full potential for energy efficiency and energy recovery from wastewater. A range of barriers remain, including but not limited to:

- The electricity consumption of different parts in the system is often not quantified, contributing to a general lack of awareness about the potential for efficiency improvements;
- Energy efficiency measures require upfront investment, which can deter action if financing is associated with an increase in water tariffs;
- Larger wastewater facilities are rarely considered as an integrated system to be optimised as a whole;
- Efficiency projects save electricity but their adoption can interrupt processes or increase maintenance requirements;
- Some energy-savings measures are not easily replicated from one facility to another, as the layout and water quality at each facility may differ.

Feng et al. (2012) cites the commitment of top management to EE as the most critical factor for effective and sustained EE efforts at wastewater treatment plants. Without an institutional environment that demands good performance and financial accountability, an EE improvement drive is unsustainable. From a management perspective, strengthening the incentive for taking up EE interventions by political, regulatory and financial means and increasing the flow of quality information on EE solutions, costs and benefits are essential for successful EE projects.

Feng et al. (2012) encourages good management practice based on the following approach:

- ***Establish organisational commitment and an energy management team****:* Commitment must come from top-tier management via the establishment of an energy management team that can work effectively with different units within a utility, such as operations, engineering, and accounting departments. The energy management team needs to have clear responsibilities and resources to support viable initiatives.

- ***Conduct facility energy assessment****:* A basic understanding of energy use and cost must be obtained to help identify energy cost reduction opportunities and measures, and prioritize measures for implementation. The initial baseline analysis may only involve a walkthrough audit of the facilities or even just one facility, staff interviews, and desk analysis of metering and billing data to reveal areas for immediate improvement and those for further investigation. Limited-scale energy audits may be conducted if a plant wishes to confirm key EE opportunities.

- ***Develop an energy management plan**:* As data gathering and analyses progress and key opportunities and options are identified and prioritized, a plan should be developed to guide the energy management efforts with specific targets; underlying measures and activities; budgets; implementation arrangements (internal versus contracted services); financing options; procurement schedule; etc. It is important to make sure that the proposed program is within the utility's implementation capacity and do not overleverage the utility's technical, financial, and management resources. For EE investments identified for implementation, investment grade energy audits may be conducted either by the EE service provider or an entity acceptable to the financier, depending on the financing options and implementation arrangements.

- ***Implement planned activities, monitor progress, and evaluate and verify results:*** An implementation plan is a living guide and should be adjusted to address issues as they arise during implementation. For example, a proposed financing option may fail and alternate sources of funding may be needed. Progress, changes, and results need to be communicated in a timely manner to staff and management, keeping them informed, engaged, and able to resolve any implementation issues promptly.

Amongst others, Swartz et al. (2013) make the following recommendations from the energy efficiency case studies and best practices reported:

1. The guidelines and best practices should be used as a basis for development of energy efficiency and energy conservation targets for the South African water sector. These targets can then be implemented, encouraged and regulated through the Department of Water Affairs' Blue Drop and Green Drop programs.
2. Municipalities should already start using the guidelines for energy conservation and energy generation in their strategic planning processes, and include specific targets for energy efficiency in their operations in the Water Services Development Plans (WSDPs). Energy audits should be undertaken on a yearly basis.
3. Energy efficiency should form a major criterion when planning new or upgrading existing water supply and sanitation projects, and funding programs should use specific targets in the decision-making process.
4. Wastewater treatment facilities should be encouraged to implement biogas energy production projects, and incentives should be provided for this purpose (e.g. assistance with feasibility studies and technical support).
5. "Toolboxes" should be developed to provide water and wastewater treatment plant supervisors and process controllers with technical solutions and support for improving energy efficiency in their facilities.

6. Investigate the feasibility of using alternative renewable energy technologies with relation to initial capital costs, site conditions, specific climate conditions and return-on-investment. Financial incentives should be provided for such investigations and projects.
7. Development of new or alternative wastewater treatment processes and systems (both centralized and decentralized) should aim towards low-energy processes, especially regarding the high energy requirements for aeration in biological systems.

Local experience indicates that barriers to EE and RE take-up include (Burkard & van der Merwe-Botha, 2017):

1. Limited knowledge and experience regarding the applicability and risks of various EE and RE technologies.

2. Limited experience with regard to appropriate procurement models. Typical procurement models for RE could be (arranged from maximal municipal participation/minimal PSP participation to minimal municipal participation/maximal PSP):

   2.1 Investment and operation by the municipality with maximal participation;
   2.2 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;
   2.3 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;
   2.4 BOT/BOOT model for the proposed CHP system while WSA remains responsible for the balance of the WWTW;
   2.5 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;
   2.6 Outsourcing of operation of the complete plant;
   2.7 Transfer of ownership/privatisation with complete take-over by PSP.

3. Ability to secure funding.

Chapter 3 – Framework elements

3.1 Management commitment to EE and RE

The commitment of management and personnel is essential framework element. Commitment to EE and RE is considered as essential for the successful implementation of EE and RE projects. Commitment to EE and RE is demonstrated by the extent to which the following can be observed:

- **Energy audit or balance has been done:** This could be anything from simple motor power survey and record (done by site personnel) to a fully-fledged energy audit. An energy audit is a preliminary procedure used to evaluate energy consumption in order to identify energy conservation measures. One of the aims of an energy audit is determination of an energy baseline regarding the reference consumption of individual devices and installations.

- **Regular estimation of SPC (specific power consumption**): Monthly energy consumption from electricity accounts in conjunction with monthly total received and treated flow.

- **Benchmarking of plant has been done:** Regular comparison of SPC values with benchmarks and other WWTWs. A demonstrated sensitivity towards energy efficiency and awareness of plant performance in relation to EE benchmarks by plant management will greatly enhance the probability of successful EE and RE projects.

- **Process Controllers aware of SPC value and actively manage:** From the energy audit or balance Process Controllers must be aware which equipment and why this equipment contribute most significantly to the electricity account bottom line. All staff members are familiar with electricity account and implications on operating cost. Energy budgets with targets and demonstrated impact of electrical energy cost on unit treatment cost will favour and assist getting EE and RE projects initiated and implemented. For WWTW managers and process controllers to become sensitive towards energy consumption and related cost, it is essential that they are exposed to the monthly electricity bill in order to play a constructive role in energy management. The handling of the electricity bill by the financial department only should be phased out in favour of an inclusive management procedure. One problem facing is rural municipalities is the lack of skilled Process Controllers and Managers to execute energy conservation projects, compounded by the lack of funding to sustain any improvements. Focussed effort should be made by government and its partners to identify and support these municipalities.

- **EE and RE training have been done:** Training to cover all aspect of EE and RE. Any form of EE and RE training is advantageous, from basic in-house training to formalised courses.

- **Small, low cost EE projects have been implemented:** The fact that small, low cost EE interventions has been implemented is clear demonstrators of commitment by management and staff. Interventions could include operational, maintenance, replacement, etc. activities. Typical interventions could be: optimal utilisation of treatment modules, replacement of unrepairable motors with high efficiency motors, reducing/optimising process flows, limiting the starting of large motors (manage maximum demand), etc. Evidence of EE and RE measures already implemented will indicate an existing awareness with regard to energy consumption and will enhance the probability of successful future projects. As implemented EE and RE measures progress, the remaining opportunity for further savings will reduce.

More skilled and experienced managers and process controllers will improve the probability that EE and RE projects are successfully driven through to implementation. The multidisciplinary nature of EE and RE (process, hydraulic, mechanical, electrical and financial) can be considered to be a major barrier and improved interdisciplinary relations and communication will further enhance the probability of successful EE and RE measures. Training with regard to the aspects listed below will support the implementation of energy saving measures:

- Monitoring and recording of EE and RE related performance indicators;
- Energy characteristics of processes;
- Energy characteristics of equipment;
- Impact of EE and RE on water and sludge quality and performance;
- Deployment of limited electrical energy generating infrastructure;
- Electricity billing structure (energy, on and off-peak, demand opportunities);
- Budget and contribution of energy cost to the unit treatment rate;
- Ability to identify, select and operate EE and RE technology;
- Understanding unsustainable reliance on fossil fuel as energy source;
- Climate change, impact on carbon and GHG emissions;
- Carbon Tax.

More than 90% of the world is still powered by fossil fuels. The understanding of the unsustainability of fossil fuel as a major energy source will support EE and RE as well as the initiation of EE and RE projects. The fact that the availability of fossil fuel is limited, together with an understanding of the devastating effect of GHG emissions on global warming serves as a wake-up call for the initiation of EE and RE measures.

3.2 Process configuration

Simple process configurations such as septic tanks, oxidation ponds, reedbeds without pumping or aeration have no or limited opportunity for EE or RE. Anaerobic ponds, primary settling tanks and anaerobic digesters is a definite requirement for RE projects.

3.3 Existing process capacity

The energy efficiency of smaller capacity plants tends to be lower than for larger plants. A plant of any capacity has potential for feasible EE projects with significant saving potential. The absolute saving at larger plants could be significantly more. Despite the capacity of a plant, each WWTP has potential for energy savings which can range from 20% up to 40% and even up to 75% have been attained. WWTWs with a capacity less than 5 Ml/d is unlikely to be a candidate for a RE project.

3.4 Specific power consumption and energy neutrality

Specific power consumption (SPC) can typically be expressed in three formats kWh/m^3, kWh/kg COD or kWh/pe.a with kWh/m^3 being used most widely in South Africa. SPC is simple to estimate and will give an good indication of how energy efficient a plant is, what the EE potential at a plant is and how a specific facility is progressing in terms of EE projects. The Energy Neutrality of a wastewater treatment plant will reflect the degree to which RE has been implemented. Both these figures can be used to define a status quo, future targets with regard to EE and RE and to what degree targets are being met over time.

3.5 Implemented EE and RE measures and projects

Evidence of EE and RE measures already implemented will indicate an existing awareness with regard to energy consumption and will enhance the probability of successful future projects. As implemented EE and RE measures progress, the remaining opportunity for further savings will reduce.

An energy audit is a preliminary procedure used to evaluate energy consumption with the objective of identifying high impact process aspects and appropriate energy conservation measures. One of the aims of an energy audit is determination of an energy baseline regarding the reference consumption of individual devices and installations. Despite the capacity of a plant, each WWTP has potential for energy savings which can range from 20% up to 40% and even up to 75% have been attained.

3.6 Multiple plant catchments and load management

Large catchments with a central common outfall and multiple plants along the outfall sewer poses the opportunity to establish the most energy efficient plant and to divert most of the load to the energy efficient plants, referred to as load management.

Evaluate facility loadings and become familiar with the treatment systems in order to identify, plan and design the most efficient and effective ways to operate the system. Modifications are mostly limited to operational aspects with short payback time. When planning improvements, wastewater system personnel and designers should develop a team approach wherein they determine how modifications will effectively and efficiently meet current and projected conditions. Staging upgrades in capacity can help optimise system response to demand and also reduce energy costs (NERSYDA, 2010).

3.7 Topographically challenged catchments

Catchments that stretch across hills and valleys with a reticulation system that involves multiple pump stations will require special attention to pump efficiencies and system optimisation to keep specific energy consumption within acceptable ranges. The modelling of centralisation/decentralisation alternatives should be conducted in order to optimise energy consumption and cost while considering the trends and future cost of energy. Smaller plants tend to be less energy efficient than larger plants, but smaller plants may require shorter outfall sewers and less pumping cost.

3.8 Sewage characteristics

Sewage with low organic loading may be indicative of unwanted infiltration into sewer resulting in excessive pumping and treatment cost in terms of energy requirements. Higher total specific energy consumption will probably be an indication of a higher energy requirement due to pumping. Sewage with high organic loading will require more energy to treat aerobically. High organic loading will favour shifting load to anaerobic processes and be advantageous for CHP projects. High organic loading will enhance the feasibility of CHP projects for smaller capacity plants.

3.9 Regulatory environment

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). 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.
The main EE and RE related activities that are regulated include:

- Environmental authorisation for establishment, construction and/or upgrading;
- Atmospheric emission licence;
- Registration of energy generation facility;
- Licensing of energy generation connected to the grid; and
- Storage of biogas.

3.10 EE an RE incentives

Any incentive or competitive motivation based on specific energy consumption, while maintaining effluent compliance and treated sludge quality, will assist with the awareness to save energy. Incentives could be structured in many ways such as awards, performance bonus, etc. For example, the implementation of an EE improvement award (to coincide with WISA biennial conferences) similar to, for example, the Wilson Award, is expected to highlight the importance of EE and the implementation EE projects while maintaining effluent, sludge quality and optimising treatment cost.

3.11 Availability of funding

The main stumbling block to the adoption of green projects remains the low level of funding available in local and district municipalities (GIZ, 2015). The implementation of energy efficiency drives does not always require funding for implementation. There are a number of EE measures that could be implemented via the normal operating and maintenance budgets, i.e. the replacement of motors that need extensive repair should not be repaired but replaced by new energy efficient motors. The difference in cost is minimal and the payback period could be two years or less depending on rating and duty cycle. There are other EE measures that require no capital investment and have significant impact which and are based on how equipment is operated and controlled.

The following grants have EE and RE opportunities at water and wastewater facilities and are available and can be applied for at SALGA (SALGA, 2017):

- Energy Efficiency and Demand Side Management Grant;
- Urban Settlements Development Grant;
- Integrated City Developments Grant;
- Neighbourhood Development Partnership Grant;
- Regional Bulk Infrastructure Grant; and
- Water Services Infrastructure Grant.

Chapter 4 – Development of an Energy Assessment Framework

Due to the diverse and dissimilar approaches and technologies that need to be incorporated in the framework, EE and the various RE alternatives will be addressed separately. Framework elements will be based on three categories of criteria:

1. **Management criteria:** The commitment of the WWTW management as well as the operational team is considered to be a primary driver for successful EE and RE projects, but more specifically to EE projects.
2. **Technical criteria:** These criteria will apply to plants that comply with qualifying criteria where applicable. Framework elements are weighted and scored using the product of the proportion of energy typically allocated to a particular treatment stage (refer Table 5) and the typical energy savings achieved as reported in the literature.
3. **Qualifying criteria:** These are criteria that will determine go or no-go outcomes and will primarily apply to RE options. The qualifying criteria address the applicability of a particular RE technology to a particular WWTW. Typical elements would entail whether primary settling tanks and anaerobic digesters are available, whether adequate space is available for solar photovoltaic panels, minimum organic load for CHP, potential energy available for hydro turbine generation, etc. The final score may be enhanced by favourable conditions such as high COD concentrations, high solar energy area, high available effluent head loss, etc.

Reference	Aeration			Sludge treatment			Pumping			Other		
	min	ave	max	min	ave	max	min	ave	max	min	ave	max
Maktabiford, 2018	13	45	77	5	18	31	4	18	31	5	22	38
Frost & Sullivan, 2011	80	80	80	9	9	9	10	10	10	1	1	1
IEA, 2016	51	51	51	10	10	10	16	16	16	28	28	28
ECW, 2003	55	55	55	15	15	15	20	20	20	10	10	10
Newri, 2010	48	64	80	6	9	12	7	10	12	7	18	28
Hamilton, 2019	50	55	60	25	28	30	10	15	20	5	8	10
Feng, 2012	55	55	55	35	35	35	10	10	10			
Min, Average, Max	**13**	**57**	**80**	**5**	**17**	**35**	**4**	**14**	**31**	**1**	**12**	**38**

Table 5: Summary of typical energy allocation to various treatment stages

The diverse nature of RE technologies dictate that the framework approach should allow for specific framework sections, each section dedicated to a particular RE technology such as CHP, PV, hydro, thermal, etc. due to the specific nature and requirements related to each of the technologies.

4.1 Energy Efficiency

The viability of a successful EE project is more dependent on the management approach or mind-set than it is on a specific technology. The viability of EE interventions at a WWTW will be assessed on the basis of three main category headers, of which the first is a major contributor to expected successful implementation (also refer to Table 6):

1. **Demonstrated management commitment to EE:** Aspects such as estimation of SPC, benchmarking, awareness of SPC value and active management, energy audit or balance, training, understanding the implications of the electricity account and projects implemented are all quantified in order to assess commitment to EE. Each of the framework elements have been allocated a weighted score if a specific element is identified as appropriate. The scores for each of the elements are totalled for a final score for management commitment, which can total to a value between 0 and 1.5. Any score higher than zero indicates some level of commitment. The higher the score, the higher the probability of implementing a successful EE project is estimated to be.

2. **Single score enhancer based on SPC:** The single score enhancer is based on the assessment of an SPC value. SPC values higher than the benchmark for a particular technology indicate a good potential for energy savings by EE and vice versa. The single score enhancer allows for technologies utilising aeration which typically have a higher SPC (412 kW/Ml) as well treatment by fixed film technologies such as trickling filter and RBC that typically have lower SPC values (177 kW/Ml). The framework allows for the estimation of a weighted SPC for the WWTW. Plants with an actual SPC equal to the weighted average for the plant will score 1.0, while actual SPCs higher than the typical SPC will score more than 1.0, indication high probability for energy savings. WWTWs with an actual SPC lower than the typical benchmark will score less than 1.0, indicating a lower potential saving on energy consumption.

3. **Multiple EE score enhancer:** The multiple score enhancer considers multiple technical EE elements such as operationally flexible modules for load optimising, regional load optimisation among plants, current aeration system upgradable to fine bubble diffused aeration, air supply system upgradable to variable air flow system, manual aeration control upgradable to automated DO control, manual control upgradable to automated ammonium control, optimise anaerobic/aerobic sludge digestion, replacement low efficiency electric motors with high efficiency motors, upgrading pump motors to VSD control to enable load matching, optimise pump systems, reduction of RAS/recycle/process flows. Energy allocated to each treatment stage was derived from Table 5 and used for weighting framework elements together with the expected contribution to power saving by EE measure. A score is then calculated for each of these elements using the product of energy allocation fraction and the expected contribution to power saving by each, effectively prioritising high return interventions.

The outcome of the above three assessments serve as complimentary assessments. The commitment by management and personnel is expected to play a major role in successful implementation of EE projects. A demonstrated management commitment score of zero or close to zero could possibly indicate a lack of support from the WWTW management and personnel with regard to the initiation and execution of an EE project, while a full score of 1.5 or in the upper range of 0.5 to 1.5 would indicate good support and cooperation during the execution of EE projects. High scores in both the single score enhancer as well as the multiple score enhancer category reinforces both scores and the indication that a good potential exists to achieve significant energy savings through the implementation of EE measures.

In all the assessment frameworks given below the highlighted darker grey cells reflect the section heading and the green cells represent an input requirement that can either be an actual score value or a YES/NO selection. All white cells give information or output score values, while the two yellow cells next to the section heading reflect the interpreted and total score of the framework assessment for the specific section.

Operational Culture - Demonstrated management EE commitment:	VERY HIGH	(Score = 0.97/1.0)
Regular estimation of SPC (specific power consumption)	5/5 (of 0.17)	0.17
Benchmarking of plant has been done	5/5 (of 0.13)	0.13
Process Controllers aware of SPC value and actively manage	5/5 (of 0.13)	0.13
Energy audit or balance has been done	5/5 (of 0.20)	0.20
EE training has been done	4/5 (of 0.13)	0.11
PC's adequately sensitive to energy cost and implications	5/5 (of 0.10)	0.10
Low profile EE projects have been implemented (from plant budget)	5/5 (of 0.13)	0.13

Single score assessment -	EE saving potential based on SPC:	VERY HIGH	(Score = 3.0)
Aerated process: AS, SBR, MBR, etc.	Typical 412 kWh/Ml	Capacity:	24 Ml/d
Unaerated process, TF, RBC, etc.	Typical 177 kWh/Ml	Capacity:	0 Ml/d
Capacity weighted WWTW SPC	**Typical 412 kWh/Ml**	Tot.capacity	24 Ml/d
Estimated SPC allocated to non process, i.e. Head of works lift pumps			0 kWh/Ml
Actual recorded/estimated WWTW SPC over past 12 months			1234 kWh/Ml

Multiple score assessment - EE saving potential:	VIABLE	(Score = 0.46/1.0)
Operationally flexible modules for load optimising possible?	1/5 (of 0.15)	0.03
Regional load optimisation among plants viable?	2/5 (of 0.15)	0.06
Current aeration system upgradable to fine bubble aeration?	3/5 (of 0.13)	0.08
Aeration system upgradable to variable aeration control (VSD)?	5/5 (of 0.09)	0.09
Manual aeration control upgradable to automated DO control?	1/5 (of 0.09)	0.02
Manual control upgradable to automated ammonium control?	5/5 (of 0.13)	0.13
Can anaer/aerobic sludge digestion, mixing, aeration, etc be optimised?	0/5 (of 0.06)	0.00
Can low eff. electric motors be replaced with high efficiency motors?	2/5 (of 0.04)	0.01
Pump motors upgradable to VSD control to enable load matching?	1/5 (of 0.04)	0.01
Can pump systems be optimised: duty point, throttling, efficiency, etc?	0/5 (of 0.08)	0.00
Can RAS/recyle/process flows and/or head be reduced/optimised?	3/5 (of 0.04)	0.02

Table 6: Table reflecting management commitment and technical EE scoring

Operational Culture – Demonstrated management EE commitment: VERY HIGH, Score = 0.97/1.0, (range 0-1.0): The commitment by management and personnel is expected to play a major role in successful implementation of EE projects. A demonstrated management commitment score of zero or close to zero could possibly indicate a lack of support from the WWTW management and personnel with regard to the initiation and execution of an EE project, while a full score of 1.0 or in the upper range of 0.5 to 1.0 would indicate good support and cooperation during the execution of EE projects. The interpretation of scores in the assessment worksheet are based on the following assumptions:

Score interval	Score interpretation
0.0 to <0.2	Commitment level: NIL
0.2 to <0.4	Commitment level: LOW
0.4 to <0.6	Commitment level: VIABLE
0.6 to <0.8	Commitment level: HIGH
0.8 to 1.0	Commitment level: VERY HIGH

Single score assessment – EE saving potential based on SPC: VERY HIGH, (Score = 3.0), (range 0-unlimited): High scores in this category will indicate that a good potential exists to achieve significant energy savings through the implementation of EE measures and low scores would indicate poor potential for energy saving. The interpretation of scores in the assessment worksheet are based on the following assumptions:

Score interval	Score interpretation
0.0 to <0.4	EE saving potential: NIL
0.4 to <0.8	EE saving potential: LOW
0.8 to <1.2	EE saving potential: VIABLE
1.2 to <1.6	EE saving potential: HIGH
1.6 and more	EE saving potential: VERY HIGH

Multiple score assessment – EE saving potential: VIABLE, (Score = 0.46/1.0), (range 0-1.0):
High scores in this category will indicate that a good potential exists to achieve significant energy savings through the implementation of EE measures, while low scores would indicate poor potential for energy saving. Corresponding high or low scores for both the single score enhancer and the multiple score enhancer would reinforce the conclusion. The interpretation of scores in the assessment worksheet are based on the following assumptions:

Score interval	Score interpretation
0.0 to <0.4	EE saving potential: VERY LOW
0.4 to <0.8	EE saving potential: LOW
0.8 to <1.2	EE saving potential: VIABLE
1.2 to <1.6	EE saving potential: HIGH
1.6 and more	EE saving potential: VERY HIGH.

4.2 Combined Heat and Power

The CHP project feasibility assessment assumes that basic infrastructure is in place to optimally utilise the available organic load to generate biogas. Therefore, the plant is assumed to have primary settling tanks, sludge thickeners (as required) and high rate anaerobic digesters which are optimally loaded with an operational heating and mixing system. The organic loading of a plant (as mass loading) is the main driver of biogas and CHP potential. It is therefore logical that the CHP feasibility will improve for a given flow when the raw sewage organic concentration increases. Although primary sludge has a higher biogas potential than secondary sludge, the CHP feasibility for a given plant will be reduced if secondary sludge is not anaerobically digested. Treatment plants based on extended aeration technology only (no primary settling tanks or associated anaerobic digesters) will not qualify as potential CHP candidates. The portion of organic load treated by extended aeration modules on a specific plant site will impact CHP feasibility negatively and should be allowed for appropriately with regard to the total plant loading scenario. The graph below reflects the organic load expressed in terms of flow and organic load as Chemical Oxygen Demand. For the purpose of this assessment, the COD/SS ratio was assumed to be 2, i.e. for a chemical oxygen demand of 1000 mg/l the suspended solids is assumed as 500 mg/l.

From the equipment perspective, the feasibility of a CHP system is mainly dependent on the capital investment required, while the cost of a CHP system is primarily driven by the generating capacity and to a lesser extent by the funding model. Funding by the municipality, assuming no financing cost, would represent the most favourable feasible extreme while funding with normal commercial financing, the cost would represent the upper extreme. These two extreme financing cases are reflected in the graph below to demonstrate the sensitivity with regard to the impact of financing over the project life cycle.

For the purposes of this assessment, the "minimum feasibility requirement" is defined as ***a CHP project with an assumed lifespan of 15 years that will pay back the investment including financing cost over the project life cycle of 15 years.*** Any loading or condition better than this will result in the generation of a positive cash flow over the project life cycle. With reference to the graph below, any loading condition above and to the right of each of the four scenario curves has the potential to generate a positive cash flow over the project life cycle. The scenario graphs are based on the following assumptions:

- No financing cost for the scenario that is fully funded by municipality. The minimum generating capacity for this scenario is approximately 70 kWe.

- Commercial financing scenario at 7.5% per annum over a 10 year term. The minimum generating capacity for this scenario is approximately 230 kWe.

- Operating and maintenance cost over the CHP project life cycle is included, with allowance for escalation of 6% per annum. The operating cost includes for a full time Process Controller which has a progressively negative impact on feasibility the smaller the CHP capacity is. The Process Controller contribution would typically be up to 30 cent/kWh for a CHP plant with a capacity of 70 kWe. This cost per kWh reduces dramatically as the CHP capacity increases.

- Utility power cost escalation is based on best estimate (10% per annum for first three years followed by 8% per annum over the project life cycle.

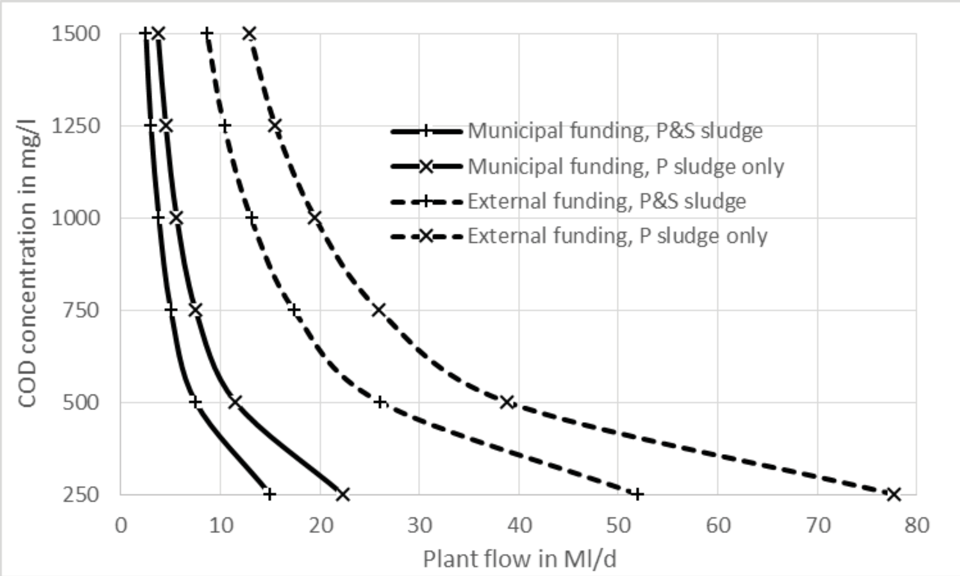


Figure 6: Minimum CHP feasibility requirement for a fifteen year payback period for various loading, sludge routing and financing scenarios

Interpreting the curves for clarification purposes:

1. For a plant with a flow of 5 Ml/d and a COD of 750 mg/l, funded by municipal funds, primary and secondary sludge are anaerobically digested, the estimated project payback period is 15 years, i.e. the project is feasible and would pay for itself. Any loading condition more than this would result in a positive cash flow over the project life cycle.

2. For a scenario based on commercial funding, a flow of 26 Ml/d with a COD of 750 mg/l and only primary sludge routed to anaerobic digesters, the estimated project payback period is 15 years, i.e. the project is feasible and would pay for itself. Any loading condition more than this would result in a positive cash flow over the project life cycle.

CHP RE qualifier	**CHP readiness:**	**NIL**	**(Score = 0.0)**
WWTW has PST's and anaerobic digesters			NO
Is both primary sludge and WAS fed to the AD's?			NO
Actual COD loading of WWTW to exceed 5000 kg/d			12 985 kg/d

Table 7: Combined Heat and Power qualifier framework

CHP RE qualifier CHP readiness: NIL, Score = 0.0, (range 0 to unlimited): For a WWTW without primary settling tanks and anaerobic digesters the score will be zero and other inputs including loading will be ignored in terms of scoring. For COD loadings < 5000 kg/d the score is adjusted directly proportional to the loading, while for larger loadings the score is diluted by a factor of 10 to prevent excessively high scores. The score is enhanced by a factor of 1.3 for WWTW that anaerobically digest both primary and secondary sludge. A score of 1.0 or more should initiate a feasibility, and a higher scores will indicate increasing CHP potential. The interpretation of scores in the assessment worksheet are based on the following assumptions:

Score interval	Score interpretation
0.0 to <0.6	CHP readiness: VERY LOW
0.6 to <1.0	CHP readiness: LOW
1.0 to <1.2	CHP readiness: VIABLE
1.2 to <1.6	CHP readiness: HIGH
1.6 and more	CHP readiness: VERY HIGH.

4.3 Solar Photovoltaic

The standard solar panel collects around 1000 watts of solar power per square meter. The majority of solar panels available have an efficiency of around 15-20%. Therefore, a solar panel of one square meter in size would likely produce around 150-200 Wp in good sunlight. Inversely, 6.7 to 5.0 m^2 would be required to produce 1 kWp in good sunlight. If an area of 6.0 m^2 is assumed to produce 1 kWp and a factor of 1.2 is applied for inverter losses, then a panel area of 7.2 m^2 is required per kW WWTW utilised power. A grid tied solar PV systems could optimally be sized to produce all the energy required by a WWTW during good sunlight without the capital intensive requirement for energy storage. During periods of normal sunlight the plant will be fully powered by solar energy, gradually diminishing with failing sunlight while increasingly being supplied via the network, until fully dependant on the network during the night.

Referring to Table 8, a solar PV system in the Northern Cape would produce approximately 17% more energy than in Gauteng and 40% more energy than the coastal regions of KwaZulu-Natal with the same solar PV panel area. A solar photovoltaic system sized to match a specific WWTW power consumption rating (i.e. as Kilowatts), would be able to supply 28% of the energy requirement if located in the Northern Cape, 24% if located in Gauteng and 20% if located along the coast of KwaZulu-Natal.

PV RE qualifier	**Solar PV readiness:**	**VIABLE**	**(Score = 1.2)**
Estimate WWTW ave. power absorbed in kW			634 kW
Area available for erection of solar PV panels			150 000 sq.m
Site location solar intensity in kWh/kWp (refer Solar Map)			1753 kWh/kWp
Solar kWp installation required			761 kWp
Estimated area required for PV panel erection to match ave plant power draw			5 479 sq.m

Table 8: Solar photovoltaic qualifier framework

PV RE qualifier, Score = 1.2, (range 0-1.4): The estimated power requirement of the WWTW dictates the area of solar panels required for the specific WWTW. The PV RE qualifier score is directly proportional to the area available for the installation of the PV panels. A maximum area score of 1.0 is achieved if the minimum required area is available. Areas larger than the minimum do not contribute any further to the quantum of the score. The area score is multiplied by a factor that represents the solar energy intensity of the geographical location of the WWTW as represented by the kWh/kWp value obtained from figure 5. Scores of 1.0 and larger deserve further evaluation, although score lower than 1.0 cannot summarily be ignored. The interpretation of scores in the assessment worksheet are based on the following assumptions:

Score interval	Score interpretation
0.00 to <0.60	PV readiness: NIL
0.60 to <0.99	PV readiness: LOW
0.99 to <1.29	PV readiness: VIABLE
1.29 to 1.40	PV readiness: HIGH

4.4 Hydro power

Ideal conditions for hydropower harvesting is not routinely encountered at WWTW and will only become feasible if large pressure drops in pipelines or large head losses are obvious because of steep topographical site features. The generating potential for a given flow and available head can be estimated by:

$$P = 9.81 \times Q \times H \times n$$

Where:

P is the power potential in kW

Q is the flow through the turbine in m^3/s

H is the total absorbed head in metres

n is the efficiency factor, assumed to be 0.6 for this assessment.

If one assumes a turbine generator efficiency of 60%, the generating capacity of a 1 Ml/d flow with an utilisable head loss of 1 metre would be 68 watt. Typically the hydro power generating capacity could be quantified as below for exemplary purposes using the stated hypothetical system conditions:

Flow Ml/d	Utilisable head metres	Generating capacity kW
1	1	0.068
10	1	0.68
100	1	6.8
1	10	0.68
10	10	6.8
100	10	68

From the above hypothetical conditions it becomes clear that the harvesting of hydro power would be the exception rather than the rule and that feasible harvesting would only become possible for larger WWTWs located in sites with steep topographical features.

Hydropower RE qualifier	Hydropower readines:	NIL	(Score = 0.0)
Minimum hydropower generating capacity deemed feasible in kW			20 kW
Actual effluent stream head loss available/utilisable at WWTW			0 m
WWTW average outflow			12 Ml/d
Est.min required head loss for stated generating capacity and flow as above			24 m

Table 9: Hydropower qualifier framework

Hydropower RE qualifier, Score = 0.1, (range 0-unlimited): The framework assessment requires the minimum generating capacity considered feasible for the site, the average flow, together with the available head loss. The hydropower qualifier score is directly proportional to the ratio of (actual available head loss)/(minimum required head loss). Scores below 1.0 represent a non-feasible hydropower project, while scores of 1.0 and higher validate the execution of a feasibility study. The interpretation of scores in the assessment worksheet are based on the following assumptions:

Score interval	Score interpretation
0.00 to <0.60	Hydropower readiness: NIL
0.60 to <0.99	Hydropower readiness: LOW
0.99 to <1.29	Hydropower readiness: VIABLE
1.29 to <1.40	Hydropower readiness: HIGH
1.4 and more	Hydropower readiness: VERY HIGH.

4.5 Thermal energy

Extensive amounts of thermal energy is typically available in treated effluent, directly increasing with elevated effluent water temperatures. Industries discharging high temperature effluent into the catchment could significantly increase the potential for harvesting thermal energy from the effluent. A heat pump used to extract thermal energy is considered one of the most energy efficient forms of electric heating available.

With a specific heat of 4.18 J/g.°C for water (Metcalf and Eddy/Aecom, 2014), the thermal energy that can be harvested from an effluent stream by dropping the temperature by 1°C from an average flow of 10 Ml/d, would be 41.8 GJ/d, which is equivalent to a thermal capacity of 484 kW. It would require in the order of 20% to 30% of the output thermal power as electrical input power to drive the harvesting process. It would also generally not be feasible to transfer such low grade thermal energy over any significant distance. The technology for harvesting thermal energy from treated effluent is readily available, but would only be feasible if a potential user was located in close proximity of the WWTW. The driver for the harvesting of thermal power from the effluent would therefore not be the quantum of thermal energy available in the effluent, but rather the confirmed requirement by a potential user of the harvested thermal energy, which would also need to be located nearby to the thermal harvesting source.

Thermal power RE qualifier	Thermal power readiness:	NIL	(Score = 0.0)
WWTW average outflow			12 Ml/d
Is there a matched thermal power client adjacent or vey close to site?			NO
Envisaged temperature drop in degree C			1 C
Thermal power potential			599 kW

Table 10: Thermal power qualifier framework

Thermal power RE qualifier, Score = 0.0, (range 0 or 1.0): There are vast amounts of thermal energy available in treated effluent, but some a fraction of the energy to be harvested is required to harvest the energy. The availability of a potential user or client is therefore the primary driver for a feasible project. If no user/client has been identified, the thermal power qualifier score is zero. If a suitable user/client has been identified, the score will be 1.0. The quantum of thermal power can be estimated (noting possible effluent temperature limitations in the WUL) using the framework assessment and compared to the user/client requirement. If the available thermal power matches or exceeds the identified requirement, a feasibility can be done. The interpretation of scores in the assessment worksheet are based on the following assumptions:

Score	Score interpretation
0	Hydropower readiness: NIL
1	Hydropower readiness: VIABLE.

4.6 Interpretation of framework scores

The hypothetical case study assessment scores, using the framework as developed in this chapter, is summarised below for purposes of demonstration:

Section	Score	Interpretation	Range
Demonstrated management commitment to EE	0.97	VERY HIGH	(0-1.0)
Single EE score assessment based on SPC	3.00	VERY HIGH	(0-unlimited)
Multiple EE score assessment	0.46	VIABLE	(0-1.0)
CHP RE readiness	0.00	NIL	(0-unlimited)
PV RE readiness	1.20	VIABLE	(0-unlimited)
Hydropower RE readiness	0.1	NIL	(0-unlimited)
Thermal power RE readiness	0.0	NIL	(0 or 1.0)

The “Demonstrated management commitment to EE” score is primarily applicable to EE, but will also impact the RE projects. Low scores in this category should indicate low support from the WWTW management and team for the implementation of successful EE projects, while high scores will indicate good support and potential for successful EE projects. Scores of 1.0 or above for both “Single EE score Enhancer based on SPC” and “Multiple EE score Enhancer” will indicate increasing potential for significant EE savings as the score increases. High scores in this category will indicate EE projects with high potential energy saving impacts. Scores below 0.5 will indicate EE projects with lower potential.

Scores of 1.0 or more for each of the RE options generally indicate viable RE projects and should be evaluated on an individual basis for each RE option.

Chapter 5 – Application to case studies

5.1 Case study 1: Medium capacity activated sludge WWTW

5.1.1 Background

The 24 Ml/d plant was constructed on a green-fields site and completed in 2011. The extended aeration BNR activated sludge plant consists of an inlet works (mechanical screening & degritting), two full nutrient removal bioreactors with mechanical surface aeration treating unsettled wastewater, four secondary sedimentation tanks, maturation ponds and a UV disinfection facility. A mechanical dewatering installation (2 x filter belt presses) is provided to dewater the WAS produced onsite. Sludge cake is stored in storage hoppers, from where it is loaded into trucks and disposed of offsite.

Figure 7: Case study 1 WWTW site

The WWTW was constructed to treat effluent from rapidly developing, high growth areas. The WWTW receives mainly domestic wastewater and some Industrial areas. The catchment of the WWTW includes catchment areas that is served by another existing plant and therefore most of the flow to the other existing plant can be bypassed to the case study WWTW.

The average annual daily flow into the 24 Ml/d plant is 12.3 Ml/d with an average COD of 1 094 mg/l during the 2020 calendar year. The average daily electrical energy consumption over the same twelve month study period was 15 218 kWh/d, resulting in an average power absorbed of 634 kW.

Operational Culture - Demonstrated management EE commitment:	VERY HIGH	(Score = 0.97/1.0)	Comments
Regular estimation of SPC (specific power consumption)	5/5 (of 0.17)	0.17	Monthly reports on SPC, internal dailey
Benchmarking of plant has been done	5/5 (of 0.13)	0.13	City plants compared, on regular basis, contractual requirement
Process Controllers aware of SPC value and actively manage	5/5 (of 0.13)	0.13	PC get feed-back, record consumption, Continuous monitoring, power optimised
Energy audit or balance has been done	5/5 (of 0.20)	0.20	Energy balance, outsourced, "Smart facility" for energy consumption, cotractual requirement
EE training has been done	4/5 (of 0.13)	0.11	Informally discussed during meetings, instructions, Green Drop requirement
PC's adequately sensitive to energy cost and implications	5/5 (of 0.10)	0.10	Exposed to EE figures daily and informed
Low profile EE projects have been implemented (from plant budget)	5/5 (of 0.13)	0.13	Solar geysers, LED lighting or EE lighting, daylight switches

Single score assessment - EE saving potential based on SPC:		VERY HIGH	(Score = 3.0)	Comments
Aerated process: AS, SBR, MBR, etc.	Typical 412 kWh/Ml	Capacity:	24 Ml/d	Extended aeration activated sludge, 16-20 Rs
Unaerated process, TF, RBC, etc.	Typical 177 kWh/Ml	Capacity:	0 Ml/d	High organic load approximately at design capacity
Capacity weighted WWTW SPC	**Typical 412 kWh/Ml**	Tot.capacity	24 Ml/d	
Estimated SPC allocated to non process, i.e. Head of works lift pumps			0 kWh/Ml	
Actual recorded/estimated WWTW SPC over past 12 months			1234 kWh/Ml	Effective (estimated) treatment process SPC

Multiple score assessment - EE saving potential:	VIABLE	(Score = 0.46/1.0)	Comments
Operationally flexible modules for load optimising possible?	1/5 (of 0.15)	0.03	Upstream flow can be sent/bypassed as required to this plant
Regional load optimisation among plants viable?	2/5 (of 0.15)	0.06	3-4 plants monitored, maximise flow to FK, newest plant, FK more EE than other
Current aeration system upgradable to fine bubble aeration?	3/5 (of 0.13)	0.08	Reactor depth estimated at 4-5 metres, floor shape acceptable
Aeration system upgradable to variable aeration control (VSD)?	5/5 (of 0.09)	0.09	VSD for aerators being considered, requires panel replacement.
Manual aeration control upgradable to automated DO control?	1/5 (of 0.09)	0.02	On/off automated aerator control can be refined, Level control as well.
Manual control upgradable to automated ammonium control?	5/5 (of 0.13)	0.13	Ammonia and nitrate sensors available, control system upgradable
Can anaer/aerobic sludge digestion, mixing, aeration, etc be optimised?	0/5 (of 0.06)	0.00	No sludge digestion facility on site.
Can low eff. electric motors be replaced with high efficiency motors?	2/5 (of 0.04)	0.01	Unsure of currently installed motor efficiency class
Pump motors upgradable to VSD control to enable load matching?	1/5 (of 0.04)	0.01	Pump motors already on VSD but not controlled
Can pump systems be optimised: duty point, throttling, efficiency, etc?	0/5 (of 0.08)	0.00	No scope identified for improving efficiency
Can RAS/recyle/process flows and/or head be reduced/optimised?	3/5 (of 0.04)	0.02	Issues need attention: clarifier siphons, optimise RAS & recycles, inflow split

CHP RE qualifier CHP readiness:	NIL	(Score = 0.0)	Comments
WWTW has PST's and anaerobic digesters		NO	No AD's
Is both primary sludge and WAS fed to the AD's?		NO	
Actual COD loading of WWTW to exceed 5000 kg/d		12 985 kg/d	COD mass estimated from data

PV RE qualifier Solar PV readiness:	VIABLE	(Score = 1.2)	Comments
Estimate WWTW ave. power absorbed in kW		634 kW	Ave power concluded from energy consumption over past 12 month period
Area available for erection of solar PV panels		150 000 sq.m	Site for long term capacity extension
Site location solar intensity in kWh/kWp (refer Solar Map)		1753 kWh/kWp	Select from solar map
Solar kWp installation required		761 kWp	
Estimated area required for PV panel erection to match ave plant power draw		5 479 sq.m	

Hydropower RE qualifier Hydropower readines:	NIL	(Score = 0.0)	Comments
Minimum hydropower generating capacity deemed feasible in kW		20 kW	Feasibility justified taking into account all civil, mechanical and electrical costs
Actual effluent stream head loss available/utilisable at WWTW		0 m	
WWTW average outflow		12 Ml/d	Inffluent flowrate used.
Est.min required head loss for stated generating capacity and flow as above		24 m	Site flat, no viable headloss identified

Thermal power RE qualifier	NIL	(Score = 0.0)	Comments
WWTW average outflow		12 Ml/d	Actual effluent flowrate used.
Is there a matched thermal power client adjacent or vey close to site?		NO	No viable thermal energy users identified
Envisaged temperature drop in degree C		1 C	
Thermal power potential		599 kW	

Table 11: Case study 1 framework assessment

5.1.2 Discussion of case study 1 assessment

Operational Culture – Demonstrated management EE commitment: VERY HIGH (Score = 0.97/1.0)

The high score of 0.97/1.0 confirms a high awareness by management and operating personnel with regard to EE and RE. High scores in this section is essential for the implementation of any EE or RE project and increases the probability of a successful project implementation.

Single score assessment – EE saving potential based on SPC: VERY HIGH (Score = 3.0)

The plant SPC is very high at 1234 kWh/Ml, indicating a high potential for EE projects. In this case the high SPC is however driven by mainly two aspects: firstly the design stage decision to simplify the process and omit primary settling tanks (i.e. commit totally to aerobic process) and related infrastructure, and secondly, the higher than expected COD of the raw sewage. With the exception of retro-fitting primary settling tanks the high oxygen demand and related energy requirement is essentially fixed. Although this high score may suggest high EE saving potential, a major part of the

SPC was fixed at design stage and will require major intervention to mitigate. Minor EE savings may be possible as indicated by the multiple score assessment below.

Multiple score assessment – EE saving potential: VIABLE (Score = 0.46/1.0)
It can be concluded from the high contribution of each of the item scores listed below that these aspects are key to the highest potential savings at the plant. The focus of EE projects on the plant should therefore be on the following process aspects:

- The possibility of regional load optimisation among plants seems viable, although operation close to design load is a limiting factor.
- The current surface aeration system could be upgraded to fine bubble diffused aeration although basin configuration and depth may limit potential savings.
- The DO control is currently automated, but is based on an on/off control of the surface aerators. The installation of VSD on the surface aerator motors could significantly contribute to more stable operating DO levels and related energy savings.
- The current control system is upgradable to automated ammonium control. Ammonium control systems save energy by maintaining DO levels to ensure nitrification and has the potential to operate at lower DO levels while still maintaining nitrification.

CHP RE qualifier – CHP readiness: NIL (Score = 0.0)
The plant has no primary settling tanks or anaerobic digesters. Without major process interventions CHP is therefore not an option.

PV RE qualifier – Solar PV readiness: VIABLE (Score = 1.2)
There is adequate area available for the erection of solar panels to the extent that the solar panels can supply the average electrical energy consumed by the plant during peak sunlight hours of the day. The erection of a solar photovoltaic array in a grid tied system is feasible and should be investigated.

Hydropower RE qualifier – Hydropower readiness: NIL (Score = 0.0)
The plant terrain is relatively flat and there is no potential to harvest hydropower.

Thermal power RE qualifier – Thermal power readiness: NIL (Score = 0.0)
Although thermal power is available in the treated effluent, no suitable client for thermal energy in close proximity could be identified.

5.1.3 Assessment summary

The high score of 97% for demonstrated management EE commitment indicates a high probability of successful implementation of EE and RE projects for this case study, while the high single score assessment indicates large potential for EE measures. The most promising EE measures are related to the aeration system including upgrade to fine bubble diffused aeration, installation of VSD for aeration drives with an aeration control system based on ammonium. The potential energy savings is estimated at 32% of total energy consumption.

Solar photo voltaic renewable energy is feasible for this site and would on average, be capable of producing 24% of the plant power consumption.

5.2 Case study 2: Medium capacity Trickling filter and activated sludge plant

5.2.1 Background

The plant treats both domestic and industrial wastewater and serves a population of approximately 54 181 people. The first trickling filter extension was constructed in 1980. A BNR activate sludge module was commissioned in 1996. An activated sludge polishing plant to treat trickling filter effluent as well as sludge dewatering facility was completed in 2013. A new balancing tank will be commissioned in 2021 to receive pumped sewage from the head of works, after screening and degritting, from where effluent will be distributed to the main treatment plant.

The plant is registered as a Class B facility. It has a design capacity (ADWF) of 26 Ml/d and consists of a 15 Ml/d conventional biofilter unit followed by a polishing module and 11 Ml/d activated sludge module. Both the activated sludge plant as well as the polishing plant is equipped with surface aerators. The main AS reactor is equipped with an automated DO control system to control aerator speed via VSD.

The plant receives flow via gravitational feed to the head of works located on a lower elevation. After screening and degritting wastewater is lifted by approximately 40 meters and discharged into a newly constructed balancing dam (not yet commissioned at the time of the case study). The raw inflow consists of 60% domestic- and 40% industrial effluent. The main industrial contributors are the abattoir, Coca-Cola Fortune, Manganese Metal Company, Mondi and Delta EMD.

Figure 8: Case study 2 site with HOW in the south eastern corner on the bank of the river

The average annual daily flow into the 26 Ml/d plant is 19.4 Ml/d with an average COD of 1 005 mg/l during the 2020 calendar year. The average daily electrical energy consumption over the same twelve month study period was 8312 kWh/d, resulting in an average power absorbed of 346 kW, of which 200 kW was absorbed by the pumping of screened degritted sewage from the lower level head of works.

Operational Culture - Demonstrated management EE commitment:	VERY HIGH	(Score = 0.87/1.0)	Comments
Regular estimation of SPC (specific power consumption)	5/5 (of 0.17)	0.17	Not SPC specifically, but energy consumption and flow regularly monitored
Benchmarking of plant has been done	1/5 (of 0.13)	0.03	No plant benchmarking done, aware that plant stats close to industry standard.
Process Controllers aware of SPC value and actively manage	5/5 (of 0.13)	0.13	Effluent quality has higher priority than energy saving
Energy audit or balance has been done	5/5 (of 0.20)	0.20	Case study for "Guideline for EE audits at WWTW's"
EE training has been done	4/5 (of 0.13)	0.11	No on site training, but EE training indirectly via DoE project
PC's adequately sensitive to energy cost and implications	5/5 (of 0.10)	0.10	No energy saving at the cost of effluent quality
Low profile EE projects have been implemented (from plant budget)	5/5 (of 0.13)	0.13	i.e. do control, VSD's, high efficiency motors

Single score assessment -	EE saving potential based on SPC:	LOW	(Score = 0.7)	Comments
Aerated process: AS, SBR, MBR, etc.	Typical 412 kWh/Ml	Capacity:	11 Ml/d	
Unaerated process, TF, RBC, etc.	Typical 177 kWh/Ml	Capacity:	15 Ml/d	
Capacity weighted WWTW SPC	**Typical 276 kWh/Ml**	Tot.capacity	26 Ml/d	
Estimated SPC allocated to non process, i.e. Head of works lift pumps			247 kWh/Ml	Estimated raw lift pumpstation SPC
Actual recorded/estimated WWTW SPC over past 12 months			181 kWh/Ml	Effective (estimated) treatment process SPC

Multiple score assessment - EE saving potential:	LOW	(Score = 0.37/1.0)	Comments
Operationally flexible modules for load optimising possible?	2/5 (of 0.15)	0.06	Some level of load optimisation could be possible between AS and TF
Regional load optimisation among plants viable?	0/5 (of 0.15)	0.00	
Current aeration system upgradable to fine bubble aeration?	2/5 (of 0.13)	0.05	Study required to demonstrate cost efficiencies. Constrained by shallow AS tank
Aeration system upgradable to variable aeration control (VSD)?	2/5 (of 0.09)	0.04	Only polishing unit does not have VSD aeration control
Manual aeration control upgradable to automated DO control?	2/5 (of 0.09)	0.04	AS has DO control, possible polishing plant upgrade to automated control?
Manual control upgradable to automated ammonium control?	3/5 (of 0.13)	0.08	
Can anaer/aerobic sludge digestion, mixing, aeration, etc be optimised?	0/5 (of 0.06)	0.00	Little potential because AD mixers operating at minimum levels
Can low eff. electric motors be replaced with high efficiency motors?	3/5 (of 0.04)	0.02	Replace oversized motors?
Pump motors upgradable to VSD control to enable load matching?	3/5 (of 0.04)	0.03	
Can pump systems be optimised: duty point, throttling, efficiency, etc?	2/5 (of 0.08)	0.03	Higher head due to new balancing tank. Constant evaluation of impeller wear.
Can RAS/recyle/process flows and/or head be reduced/optimised?	3/5 (of 0.04)	0.02	Possible room for optimisation

CHP RE qualifier CHP readiness:	HIGH	(Score = 1.4)	Comments
WWTW has PST's and anaerobic digesters		YES	
Is both primary sludge and WAS fed to the AD's?		YES	
Actual COD loading of WWTW to exceed 5000 kg/d		19 516 kg/d	COD mass estimated from data: flow 19.4Ml/d at COD 1005 mg/l

PV RE qualifier Solar PV readiness:	VIABLE	(Score = 1.2)	Comments
Estimate WWTW ave. power absorbed in kW		346 kW	Concluded from energy consumprtion over past 12 month period
Area available for erection of solar PV panels		2996 sq.m	
Site location solar intensity in kWh/kWp (refer Solar Map)		1753 kWh/kWp	Select from solar map
Solar kWp installation required		415 kWp	
Estimated area required for PV panel erection to match ave plant power draw		2 989 sq.m	

Hydropower RE qualifier Hydropower readines:	HIGH	(Score = 1.3)	Comments
Minimum hydropower generating capacity deemed feasible in kW		20 kW	Feasibility justified taking into account all civil, mechanical and electrical costs
WWTW average outflow		13 Ml/d	Actual effluent flowrate used.
Actual effluent stream head loss available/utilisable at WWTW		30 m	Available head 33 to 34 m possible depending on system losses
Est.min required head loss for stated generating capacity and flow as above		23 m	

Thermal power RE qualifier	NIL	(Score = 0.0)	Comments
Is there a matched thermal power client adjacent or vey close to site?		NO	None identified
WWTW average outflow		13 Ml/d	Actual effluent flowrate used.
Envisaged temperature drop in degree C		1 C	
Thermal power potential		619 kW	

Table 12: Case study 2 framework assessment

5.2.2 Discussion of case study 2 assessment

Operational Culture – Demonstrated management EE commitment: VERY HIGH (Score = 0.87/1.0)
The high score of 0.87/1.0 confirms a high awareness by management and operating personnel with regard to EE and RE. High scores in this section is essential for the implementation of any EE or RE project and increases the probability of a successful project implementation.

Single score assessment – EE saving potential based on SPC: LOW (Score = 0.7)
The plant SPC is exceptionally low at 181 kWh/Ml, indicating a low potential for EE savings. If the head of works lift pump station energy is included, the total plant SPC increases to 428 kWh/Ml. Because the pumping energy is not typically part of the process, the latter SPC is not used for assessment. It is however clear that, for this plant, the selection of efficient pumps and the efficient design of the

delivery system is of prime importance. Although this low score may suggest poor EE saving potential, minor EE savings may still be possible as indicated by the multiple score assessment below.

Multiple score assessment – EE saving potential: LOW (Score = 0.37/1.0)
The potential EE savings is estimated to be low, but some operational aspects could be investigated for improved EE. It can be concluded from the higher contribution of some of the item scores listed below that these aspects are key to the potential savings at the plant. The focus of EE projects on the plant should therefore be on the following process aspects:

- The possibility of load optimisation between the trickling filter and activated sludge modules is feasible and should be positively pursued. EE improvement is possible due to the fact that the trickling filter SPC is lower than the activated sludge module SPC and the plant is not operating at full design loading.
- The current surface aeration system could be upgraded to fine bubble diffused aeration although basin configuration and depth may limit potential savings.
- The activated sludge module DO control is currently automated (with VSD). The polishing unit DO control has not been automated, nor are VSDs fitted on the surface aerators. The installation of VSDs on the polishing module surface aerator motors together with an automated control system could contribute to more stable operating DO levels and related energy savings.
- The current DO control system is upgradable to automated ammonium control. Ammonium control systems save energy by maintaining DO levels to ensure nitrification and has the potential to operate at lower DO levels while still maintaining adequate nitrification.

CHP RE qualifier – CHP readiness: HIGH (Score = 1.4)
Both modules are equipped with primary settling tanks with anaerobic digesters to treat primary and secondary sludge. With all the required basic infrastructure in place and an estimated COD loading of 19 516 kg/d, the plant is a good candidate for the implementation of a CHP system.

PV RE qualifier – Solar PV readiness: VIABLE (Score = 1.2)
There is adequate area available for the erection of solar panels to the extent that the solar panels can supply the average electrical energy consumed by the plant during peak sunlight hours of the day. The erection of a solar photovoltaic array in a grid tied system is feasible and should be investigated.

Hydropower RE qualifier – Hydropower readiness: HIGH (Score = 1.3)
There was a high hydropower readiness identified because of an elevation drop of approximately 34 meters to the treated effluent discharge point. A hydro-generator of approximately 20 kW or more is estimated. The existing effluent discharge pipe may be limiting or may require upgrading in order to realise the RE potential.

Thermal power RE qualifier – Thermal power readiness: NIL (Score = 0.0)
Although thermal energy is always available in the treated effluent, no suitable client for thermal energy in close proximity could be identified.

5.2.3 Assessment summary

The high score for demonstrated management EE commitment of 87% indicates a high probability of successful implementation of EE and RE projects for this case study, while the single score assessment indicates an exceptionally low SPC at 181 kWh/Ml, reflecting a low potential for EE savings. It is indicated that up to 37% of the current plant energy consumption can potentially be saved through various EE measures. The most promising EE measures are related to the aeration system including upgrade to fine bubble diffused aeration, installation of VSD for aeration drives with an aeration control system based on ammonium. The potential aeration energy savings is estimated at 20% of total energy consumption.

CHP is feasible for this site. Solar photo voltaic renewable energy is also feasible and would on average be capable of producing 24% of the plant power consumption. In addition, there is hydropower potential to generate approximately 4% of the total energy consumed.

5.3 Case study 3: Large capacity trickling filter and activated sludge plant

5.3.1 Background

Treatment technology at this plant is based on a combination of three 18 Ml/d trickling filter modules (total 54 Ml/d) while the balance of the original design capacity is based on a 29 Ml/d biological nutrient removal activated sludge. The total original design capacity is 83 Ml/d. The plant receives sewage from three outfall sewers, discharging effluent of significantly different organic composition to the site. Operationally there are some limitations with regard to the appropriate distribution of load among the four modules. The works is in the fortunate position to manage the quantity of flow through the plant while bypassing the excess flow, to a limited extent, to a downstream regional plant. A flow of up to 20 Ml/d is typically bypassed to the downstream plant. During a recent plant assessment, the capacities of the four modules were downgraded to 5 Ml/d, 5 Ml/d, 16 Ml/d and 29 Ml/d for modules 1 to 4 respectively, giving a total rated capacity of 55 Ml/d.

Primary sludge from all the trickling filter modules primary settling tanks, which includes humus sludge, is treated in heated and mixed primary anaerobic digesters before being transferred to open secondary digesters, and discharged on 48 drying beds for drying. Primary sludge from the BNRAS module together with DAF thickened WAS is also treated in the anaerobic digesters.

Figure 9: Case Study 3 WWTW site

The average inflow diverted through the plant during the period 1 July 2019 to 30 June 2020 was 108.6 Ml/d excluding the bypassed flow. The total average inflow was 114.2 Ml/d with an average of 5.6 Ml/d bypassed to the downstream regional plant. The average COD concentration was 623 mg/l, resulting in an average daily COD mass load of 71 111 kg/d. The average daily electrical energy consumption over the same twelve month study period was 12 703 kWh/d, resulting in an average power absorbed of 529 kW.

Operational Culture - Demonstrated management EE commitment:	AVERAGE	(Score = 0.43/1.0)	Comments
Regular estimation of SPC (specific power consumption)	5/5 (of 0.17)	0.17	Weekly reporting on SPC
Benchmarking of plant has been done	0/5 (of 0.13)	0.00	Not compared to similar plants
Process Controllers aware of SPC value and actively manage	4/5 (of 0.13)	0.11	BNR aerators started and stopped as required
Energy audit or balance has been done	1/5 (of 0.20)	0.04	High level awareness regarding large power consumers, no audit or balance
EE training has been done	0/5 (of 0.13)	0.00	No formal EE training done
PC's adequately sensitive to energy cost and implications	2/5 (of 0.10)	0.04	Partially aware, sensitivity could improve
Low profile EE projects have been implemented (from plant budget)	3/5 (of 0.13)	0.08	EE project for example sensors for site lighting, energy efficient globes

Single score assessment -	EE saving potential based on SPC:	LOW	(Score = 0.5)	Comments
Aerated process: AS, SBR, MBR, etc.	Typical 412 kWh/Ml	Capacity:	29 Ml/d	Based on original design capacity
Unaerated process, TF, RBC, etc.	Typical 177 kWh/Ml	Capacity:	54 Ml/d	Based on original design capacities
Capacity weighted WWTW SPC	**Typical 259 kWh/Ml**	Tot.capacity	83 Ml/d	Average weighted COD 623 mg/l for 2019/20
Estimated SPC allocated to non process, i.e. Head of works lift pumps			0 kWh/Ml	Estimated raw lift pumpstation SPC
Actual recorded/estimated WWTW SPC over past 12 months			117 kWh/Ml	Effective treatment process SPC estimated from 12 month record

Multiple score assessment - EE saving potential:	VIABLE	(Score = 0.51/1.0)	Comments
Operationally flexible modules for load optimising possible?	3/5 (of 0.15)	0.09	Load cannot be fully distributed according to capacity
Regional load optimisation among plants viable?	2/5 (of 0.15)	0.06	Limited load can be bypassed to downstream plant as capacity allows
Current aeration system upgradable to fine bubble aeration?	2/5 (of 0.13)	0.05	Could be possible, needs to be confirmed.
Aeration system upgradable to variable aeration control (VSD)?	2/5 (of 0.09)	0.04	Can be done for BNR module
Manual aeration control upgradable to automated DO control?	2/5 (of 0.09)	0.04	Can be done for BNR module
Manual control upgradable to automated ammonium control?	2/5 (of 0.13)	0.05	Can be done for BNR module
Can anaer/aerobic sludge digestion, mixing, aeration, etc be optimised?	2/5 (of 0.06)	0.02	AD mixing can possibly be optimised
Can low eff. electric motors be replaced with high efficiency motors?	5/5 (of 0.04)	0.04	Yes, all motors still standard efficiency
Pump motors upgradable to VSD control to enable load matching?	5/5 (of 0.04)	0.04	No present VSD's
Can pump systems be optimised: duty point, throttling, efficiency, etc?	4/5 (of 0.08)	0.06	Possible scope
Can RAS/recyle/process flows and/or head be reduced/optimised?	3/5 (of 0.04)	0.02	Possible scope

CHP RE qualifier CHP readiness:	VERY HIGH	(Score = 2.6)	Comments
WWTW has PST's and anaerobic digesters		YES	
Is both primary sludge and WAS fed to the AD's?		YES	
Actual COD loading of WWTW to exceed 5000 kg/d		71 111 kg/d	COD mass estimated from data

PV RE qualifier Solar PV readiness:	VIABLE	(Score = 1.2)	Comments
Estimate WWTW ave. power absorbed in kW		529 kW	Concluded from energy consumption over 2019/20 year
Area available for erection of solar PV panels		16500 sq.m	
Site location solar intensity in kWh/kWp (refer Solar Map)		1753 kWh/kWp	Select from solar map
Solar kWp installation required		635 kWp	
Estimated area required for PV panel erection to match ave plant power draw		4 573 sq.m	Adequate area available for estimated panel area

Hydropower RE qualifier Hydropower readines:	NIL	(Score = 0.5)	Comments
Minimum hydropower generating capacity deemed feasible in kW		20 kW	Feasibility justified taking into account all civil, mechanical and electrical costs
Actual effluent stream head loss available/utilisable at WWTW		2 m	No ideal location identified for hydropower
WWTW average outflow		106 Ml/d	Actual effluent flowrate used.
Est.min required head loss for stated generating capacity and flow as above		3 m	

Thermal power RE qualifier	NIL	(Score = 0.0)	Comments
WWTW average outflow		106 Ml/d	Actual effluent flowrate used.
Is there a matched thermal power client adjacent or vey close to site?		NO	None identified
Envisaged temperature drop in degree C		1 C	
Thermal power potential		5 133 kW	

Table 13: Case study 3 framework assessment

5.3.2 Discussion of case study 3 assessment

Operational Culture – Demonstrated management EE commitment: AVERAGE (Score = 0.43/1.0)

The score of 0.43/1.0 confirms some awareness by management and operating personnel with regard to EE and RE. Higher scores in this section will enhance the success rate for the implementation of any EE or RE project.

Single score assessment – EE saving potential based on SPC: LOW (Score = 0.5)

The plant SPC is exceptionally low at 117 kWh/Ml, indicating a low potential for EE savings. It is however clear that, for this plant, load optimisation and the design of efficient pumping systems is of prime importance. Although this low score may suggest poor EE saving potential, minor EE savings may still be possible as indicated by the multiple score assessment below.

Multiple score assessment – EE saving potential: VIABLE (Score = 0.51/1.0)

The potential EE savings is estimated to be viable, but specific operational aspects could be investigated for improved EE. It can be concluded from the higher contribution of some of the item scores listed below that these aspects are key to the potential savings at the plant. The focus of EE projects on the plant should therefore be on the following process aspects:

- The possibility of load optimisation among the various trickling filter and activated sludge modules is feasible and should be positively pursued. There are practical challenges with regard to module load management that need to be addressed.
- Regional load optimisation among plants is possible but limited due actual loads exceeding design loads.
- The current surface aeration system could be upgraded to fine bubble diffused aeration although basin configuration and depth may limit potential savings. Limited to AS module.
- The activated sludge module DO control can be automated and upgraded to VSD. The installation of VSDs on the polishing module surface aerator motors together with an automated control system could contribute to more stable operating DO levels and related energy savings.
- The current DO control system is upgradable to automated ammonium control. Ammonium control systems save energy by maintaining DO levels to ensure nitrification and has the potential to operate at lower DO levels while still maintaining adequate nitrification.
- Pumping systems should be optimised with regard to system losses and pump efficiencies.

CHP RE qualifier – CHP readiness: VERY HIGH (Score = 2.6)

Both modules are equipped with primary settling tanks with anaerobic digesters to treat primary and secondary sludge. With all the required basic infrastructure in place and an estimated COD loading of 71 111 kg/d, the plant is an extremely good candidate for the implementation of a CHP system.

PV RE qualifier – Solar PV readiness: VIABLE (Score = 1.2)

There is adequate area available for the erection of solar panels to the extent that the solar panels can supply the average electrical energy consumed by the plant during peak sunlight hours of the day. The erection of a solar photovoltaic array in a grid tied system is feasible and should be investigated.

Hydropower RE qualifier – Hydropower readiness: NIL (Score = 0.5)

The plant terrain is relatively flat and there is no potential to harvest hydropower.

Thermal power RE qualifier – Thermal power readiness: NIL (Score = 0.0)

Although thermal energy is always available in the treated effluent, no suitable client for thermal energy in close proximity could be identified.

5.3.3 Assessment summary

The average score for demonstrated management EE commitment of 43% indicates an average probability of successful implementation of EE and RE projects for this case study, while the single score assessment indicates an exceptionally low SPC at 117 kWh/Ml, reflecting a low potential for EE savings. It is indicated that up to 51% of the current plant energy consumption can potentially be saved through various EE measures. The most promising EE measures are related to regional/module load optimisation with a potential 15% saving and the aeration system including upgrade to fine bubble diffused aeration, installation of VSD for aeration drives with an aeration control system based on ammonium. The potential aeration energy saving is estimated at 18% of total energy consumption.

CHP is feasible for this site. Solar photo voltaic renewable energy is also feasible and would on average be capable of producing 24% of the plant power consumption.

Chapter 6 – Benefits and potential of EE and RE in South Africa

The principles of the framework, case study results, industry estimates and EE/RE benchmarks are considered in building a picture of the municipal wastewater sector and map the benefits of energy efficiency and co-generation in South Africa.

The capacities of the case study plants assessed ranged from 20 Ml/d to 85 Ml/d and could possibly be biased towards better managed WWTWs in South Africa, following on the requirement that representative information for the assessment should be readily available. This approach may have resulted in the selection of WWTWs with above average management for case study assessment and results should be viewed in this context.

6.1 Plant management

The summary assessment outcome for the operational culture reflected below have been arranged with aspects requiring more attention (lower scores) at the top of the list, to aspects that generally appear to be in place (higher scores) toward the bottom of the list, i.e. items at the top of the list demand priority attention to improve the EE and RE environment.

Operational Culture - Demonstrated management EE commitment	LOW	HIGH	AVE
Benchmarking of plant has been done and reported	0.0	5.0	2.0
EE training has been done	0.0	4.0	2.7
Energy audit or balance has been done	1.0	5.0	3.7
PC's adequately sensitive to energy cost and implications	2.0	5.0	4.0
Low profile EE projects have been implemented (from plant budget)	3.0	5.0	4.3
Process Controllers aware of SPC value and actively manage	4.0	5.0	4.7
Regular estimation & recording of SPC (specific power consumption)	5.0	5.0	5.0

Table 14: Summary results for Operational Culture (scores out of 5)

Benchmarking of plant has been done and reported: Responses ranged from “no benchmarking done”, to “internal (own plants) benchmarking done” and “awareness of industry standard”. The assessment indicates that benchmarking is the management aspect that receives least attention. The value of benchmarking is apparently underestimated with regard to the potential positive impact it could have on the management approach. An accessible national benchmarking database could be helpful to assist plant management in this regard.

EE training has been done: Responses ranged from “informal discussion, instructions and Green Drop requirements” to “no formal training done”. Indirect training via a recent Department of Energy project was also reported. This item addresses specific training related to energy efficiency and renewable energy. EE and RE training is generally done on an informal basis. Formal courses and material directed at the Process Controller could make a useful contribution to the promotion of EE and RE.

Energy audit or balance has been done: Although formal energy audits are the ultimate objective, informal assessment of how energy is consumed on each plant could be the point of departure to facilitate a ground level understanding of the energy consumption patterns on each plant. Understanding which equipment are major energy consumers and which are of lesser importance forms the foundation of efficient energy management. No formal audits conducted on own initiative were reported. One formal audit was conducted among the case studies, a project commissioned by GIZ/SAGEN (2019).

PCs adequately sensitive to energy cost and implications: Responses ranged from “Partially aware” to “exposed to EE information on a daily basis”. EE was reported to have a lower priority than effluent quality. All the management aspects that were assessed, EE training in particular, will contribute positively towards an EE sensitivity at Process Controller level as well as an understanding of how to integrate and optimise energy consumption versus plant performance and effluent quality.

Low profile EE projects have been implemented (from plant budget): Projects included EE lighting, daylight switches, VSD installation and solar geysers. The implementation of EE projects demonstrate management’s commitment to EE initiatives.

Process Controllers aware of SPC value and actively manage: At the two plants that were scored full marks, Process Controllers record energy consumption, get SPC feedback, optimise energy consumption and monitor SPC, while effluent quality is never compromised. Active management included manual starting and stopping of aerators as required.

Regular estimation & recording of SPC (specific power consumption): Positive responses include that weekly or monthly reports indicating SPC are produced, regular monitoring of consumption, daily on site monitoring of SPC. One case study reported that although energy consumption was monitored, SPC was not specifically the aim.

6.2 Single score assessment - EE saving potential based on SPC

This section of the assessment attempts to estimate a SPC benchmark based on fixed media and suspended media treatment technologies in a simplified proportional manner. This SPC benchmark does not take into consideration if it is an extended aeration plant or the impact of organic loading. Extended aeration technology is considered as non-preferential in the current environment and consequently penalised by high SPCs that exceed realistic SPC targets achieved by treatment of settled effluent. High organic load is not accounted for in the estimated benchmark and SPC values should therefore be considered in this context.

The score for this section is simply the actual SPC divided by the estimated SPC. Scores of 0.5, 0.7 and 3.0 were achieved. Low scores represent plant that are more energy efficient while high scores are representative of low efficiency. This score was intended as an indicator and low scores do not necessarily imply there is no scope for energy efficiency improvements, although it may be more limited than plants with high scores. Similarly, high scores do not necessarily imply high potential for energy efficiency improvements, because high scores may be due to design time decisions that could be difficult if not impossible to mitigate, or high organic loading that is difficult to account for.

6.3 Multiple score assessment – EE saving potential

The multiple score assessment lists a number of technical drivers that is focussed on improving EE. For example, aeration efficiency is a major factor in EE. The various aspects of aeration systems (surface aeration, FBDA, VSDs, automated control, ammonia based control, etc.) evident in the assessment framework were separately identified and assessed because each of the aspects have a distinct contribution to EE. Each of the aspects that are addressed will have a quantifiable positive impact on EE, while a combined implementation including some or all of the aspects will have a cumulative positive impact on the EE of aeration.

Multiple score assessment - EE saving potential	LOW	HIGH	AVE
Manual control upgradable to automated ammonium control?	2.0	5.0	3.3
Can low eff. electric motors be replaced with high efficiency motors?	2.0	5.0	3.3
Aeration system upgradable to variable aeration control (VSD)?	2.0	5.0	3.0
Pump motors upgradable to VSD control to enable load matching?	1.0	5.0	3.0
Can RAS/recycle/process flows and/or head be reduced/optimised?	3.0	3.0	3.0
Current aeration system upgradable to fine bubble aeration?	2.0	3.0	2.3
Operationally flexible modules for load optimising possible?	1.0	3.0	2.0
Can pump systems be optimised: duty point, throttling, efficiency, etc?	0.0	4.0	2.0
Manual aeration control upgradable to automated DO control?	1.0	2.0	1.7
Regional load optimisation among plants viable?	0.0	2.0	1.3
Can anaer/aerobic sludge digestion, mixing, aeration, etc be optimised?	0.0	2.0	0.7

Table 15: Summary results for Multiple Score Assessment (scores out of 5)

Manual control upgradable to automated ammonium control: At the time of this report there were no known ammonia based automated aeration control systems in operation in South Africa. This aeration control technology promises to achieve major improvement with regard to the energy efficiency of activated sludge aeration systems. Furthermore, improvement in effluent quality with regard to biological nutrient removal is also expected because of improved control of dissolved oxygen in the a- and R-recycle streams. Beside the fact that this control approach is new in South Africa, no further obstacles were identified to implement this technology.

Can low efficiency electric motors be replaced with high efficiency motors: According to assessments electrical motors presently installed at WWTWs are mostly low efficiency units. Oversized motors were also identified as having potential negative impact on energy efficiency. Significant EE improvements can be achieved by the replacement of standard motors with high efficiency motors when motors require major repair or replacement. The replacement of operational motors can be justified, but pay-back periods (for a 24 hour duty cycle) of between to 5 to 15 years are expected depending on size. For the replacement of unserviceable standard efficiency motors with new IE3 premium efficiency motors the pay-back period based on the incremental cost will be significantly less. All new plant and equipment should be fitted with IE3 premium efficiency motors.

Aeration system upgradable to variable aeration control (VSD): Currently there still seems to be considerable scope for the upgrading of existing aeration systems to variable speed units to improve aeration control and energy efficiency. At one case study plant equipped with relatively large surface aerators controlled on an on/off basis, this option is being investigated. Variable speed drives are an important aspect of EE, although upgrading to automated ammonium control systems is reported to result in the best overall EE improvements. In addition to better aeration control, the installation of VSDs also have a positive impact on power factor correction and related energy efficiencies.

Pump motors upgradable to VSD control to enable load matching: The assessments indicate that there is considerable scope for upgrading pump motors with VSDs. Load matching achievable by the installation of VSDs has a significant positive impact on EE and depending on the specific process, load matching will probably have a positive impact on effluent quality as well.

Can RAS/recycle/process flows and/or head be reduced/optimised: The RAS recycle account for a significant portion of energy consumption, particularly if the level difference between the reactor and RAS sump is excessive. This EE initiative was acknowledged as an aspect that needs investigation. Adjustments to the delivery head where possible and process optimisation of the rate of flow will improve EE while it will have a positive impact on process performance and effluent quality as well.

Current aeration system upgradable to fine bubble diffused aeration: While upgrading of current surface aeration systems to FBDA is generally considered as viable, reactor depth was cited as a possible limitation in most cases. Reactor floor shape posed another obstacle. The option of improving EE by upgrading existing aeration system should be investigated on a case by case business. Although financial figures may not be able to motivate an upgrade to FBDA, other sustainability issues should be considered.

Operationally flexible modules for load optimising possible: Operationally flexible modules is a design time decision that should be thoroughly considered with regard to impact on EE. Aspects such as capacity of extension, module sizing, load growth rate, etc. should be considered when the design engineer commits to optimised module sizing and loading. Typically, modularisation is inversely proportional to extension capital investment and therefore modular flexibility is seldom a design priority. Once this decision is fixed, there is essentially no way around poor energy inefficiencies into the future that can be taken from an operational perspective. Typical issues that were identified during assessment were:

1) it is not physically possible to distribute load among modules due to limited hydraulic/piping options, and
2) although the flexibility is operationally available it is not utilised to its full extent from an EE perspective.

Can pump systems be optimised: duty point, throttling, efficiency, etc.: Assessments identified responses that varied from “no scope” to “possible scope”. From an engineering (design time) as well as operational perspective the Process Controllers (operational) need to be sensitive towards unnecessary system head-losses. If pumping systems are identified that consume excessive energy, these systems should be investigated from an EE perspective and mitigation measures implemented as and if required.

Manual aeration control upgradable to automated DO control: Large WWTWs are still being implemented without any form of automated dissolved oxygen control. In our current environmental situation, effective automated aeration control is not a luxury but an essential part for any plant of substantial capacity. The feasibility of automated control can be validated by performing a simple life cycle cost analysis. WWTW owners should specify automated ammonium control at project initiation as a given for larger plants.

Regional load optimisation among plants viable: This EE measure could be a very effective, but is only applicable on large sewer networks with multiple plants located along the outfall sewer. Two of the three assessed plants were capable of regional load optimisation. In both cases the existing plant capacities that formed part of the system did not allow optimisation of load distribution due to limited plant capacities, i.e. plants were overloaded.

Can anaerobic/aerobic sludge digestion, mixing, aeration, etc. be optimised: Two of two assessed plants included anaerobic digestion (AD) in the process train. One AD plant mixers were operating at minimum levels while the remaining plant acknowledged that the energy situation could be investigated with regard to energy optimisation. Limited aerobic sludge digestion is practised in South Africa and should not be encouraged as a process option for new extensions.

6.4 CHP readiness

CHP can supply up to approximately 75% of an activated sludge plant electrical energy consumption for plants treating typical municipal organic loadings. Higher than typical organic loadings will improve this percentage. Co-digestion of suitable waste material will significantly increase the renewable energy fraction. Two of the assessed plants were CHP ready.

6.5 Solar photovoltaic readiness

Relatively short payback periods are expected for grid tied solar photovoltaic systems that harvest solar energy which is directly supplied into the WWTW distribution system during the sunshine hours of the day. There is a 28% reduction in solar photovoltaic energy harvesting potential from prime solar locations in the Northern Cape to the coastal areas of KwaZulu-Natal and the north-eastern coastal area of the Eastern Cape (refer Figure 5: Photovoltaic power potential in South Africa). This translates roughly into a 28% higher capital investment to establish a solar system of similar energy output capacity along the identified coastal areas as opposed to the prime solar areas. Pay-back periods of 5 to 8 years are expected in South Africa with appropriately sized solar arrays (i.e. supply matched to WWTW demand), capable of supplying approximately 25% of WWTW electrical energy consumption. Solar photo voltaic solar arrays were found provisionally feasible for all three case studies.

6.6 Hydropower readiness

The feasibility of hydropower is related to the topography of the WWTW location and the plant capacity. If a 20 kW generating capacity is assumed to be viable minimum, WWTWs with capacities of 20 Ml/d or more and utilisable topographical drops upstream, or preferably downstream, of 15 meters or more may be viable contenders for a hydropower project. Lower capacities and higher topographical or vice versa may also be viable contenders. One of the three case studies was identified for a possible viable hydropower project which is recommended for investigation regarding feasibility.

6.7 Thermal power readiness

The amount of thermal energy available in the treated effluent discharged from a typical WWTW is significant. Furthermore the technology for extraction is viable. It is however a low grade thermal energy and if there are no suitable thermal energy users (industry requiring heat energy) in close proximity to the plant, the potential cannot be viably harvested.

Chapter 7 – Findings and recommendations

In the present environment of expensive electrical energy combined with limited supply, climate change, greenhouse gas emissions, carbon footprint, etc. EE and RE interventions have become imperative. From a managerial perspective the following interventions must be highlighted:

1. Increase **EE and RE awareness** by training managers and process controllers
2. Implement monitoring and reporting programs around EE, RE, SPC and benchmarking to **sensitise management and process controllers.**
3. Conduct regular **energy balances and audits**, utilising EE and RE experts as required.
4. **Implement low cost EE projects** out of own operational/maintenance budgets to realise low cost EE savings and stimulate interest.
5. **Facilitate funding opportunities** for higher cost EE and RE interventions.

The design approach for new WWTWs and the refurbishment of existing WWTWs should pro-actively re-focus on EE and RE. This re-focusing on EE and RE should take cognisance of the following high impact aspects. A proportion of these aspects are fixed at design stage and are difficult if not impossible to adjust/modify during the operational phase:

1. We can no longer afford not to **thoroughly consider EE and RE during the design stages** of new WWTW or extensions. EE and RE design objectives have to be determined and specified from concept/feasibility stage and monitored through the design stages, moving into the commissioning stage with specific measurable targets. The establishment of a national SPC benchmark database will be of great assistance towards achieving higher efficiencies.

2. Because of the process configuration of extended aeration AS and BNRAS plants, they are simple to operate, less capital intensive, and capable of producing the required effluent and bio-solids quality. However, this simple to operate and low capital cost type plants are significantly more energy intensive and typically consume 40% more aeration energy than AS or BNRAS plants that treat settled wastewater. **Extended aeration plants should not be recommended** and should not be implemented without an appropriate life cycle cost analysis. Application should be limited to small plants with capacity less than 2 to 5 Ml/d.

3. Furthermore, extended aeration AS and BNRAS plants preclude the option of anaerobic digestion and energy generation through CHP facilities. For this reason, new WWTWs or extensions, specifically larger capacities based on extended aeration AS plants must be avoided. **Process options that include primary settling immediately unlocks the option of energy recovery** via anaerobic digestion and CHP.

4. Fully-fledged BNRAS process configurations are not always required to achieve the licensed effluent quality. **Activated sludge plants should, as a minimum, always include a denitrification step** in order to utilise oxygen released during denitrification. Apart from the significant energy saving associated with denitrification, the added advantage is the reintroduction of alkalinity for

enhanced pH stability, particularly in areas with low alkalinity water. Typically the oxygen demand, or alternatively the aeration energy, will be approximately 25% more if a denitrification step is not included in the process configuration, effectively using more energy to produce a lower quality effluent (i.e. higher effluent nitrates).

5. It is well documented that **fine bubble diffused aeration is significantly more energy efficient** than mechanical surface aeration. Although there are known challenges with regard to the maintenance of fine bubble diffused aeration systems as opposed to mechanical surface aeration, the challenges can be mitigated by appropriate design. The advantages of energy efficiency by far outweigh the operational challenges. The transfer efficiency of fine bubble diffused aeration systems are typically 40% higher than low speed mechanical surface aerators. The transfer efficiency of high speed surface aeration systems is significantly less than low speed surface aerators and therefore high speed aerators should be avoided if possible.

6. **Effective aeration control systems** have a major impact on wastewater treatment works EE. In this regard there is a recent trend towards ammonia control rather than conventional dissolved oxygen control. Ammonia control would imply lower operation dissolved oxygen levels (0.5 to 0.8 mg/l instead of the conventional ±2.0 mg/l) while achieving better effluent quality.

7. Relatively short payback periods are expected for grid tied **solar photovoltaic systems** that harvest solar energy which is directly supplied into the WWTW distribution system. Augmentation of WWTW power supply should pro-actively be investigated for implementation, particularly in prime solar radiation areas such as the Northern Cape.

8. The feasibility of **hydropower generation** is mainly related to the WWTW site topography and is typically expected to be limited to 50 kW or less. WWTWs with capacities of 20 Ml/d or more and utilisable topographical drops upstream or preferably downstream, of 15 meters or more may be a viable contender for a hydropower project. Hydropower should be investigated for these cases.

9. The amount of **thermal energy** available in the treated effluent discharged from a WWTW is significant. The feasibility of thermal energy extraction is completely driven by the availability of a suitable thermal energy user (industry requiring heat energy) in close proximity to the WWTW.

The following future research is recommended:

7. Establish a **national SPC benchmark database** for municipal WWTWs in SA
8. Share and **influence the agenda** of specific stakeholders and funding agencies in policy and financing space – e.g. SALGA interested in benchmarking, DWS in incentive regulation, DMRE in climate fund initiatives, SANEDI in reducing C, NT in reduced Opex, etc.
9. Wider application of the **Assessment Framework** to determine EE and RE feasibility at more WWTWs, using the metric tool to establish a baseline from where progress can be monitored and reported
10. Develop a **guideline of design considerations** towards energy efficient wastewater treatment technology and processes – bring in green technologies and climate change imperatives

11. Wider EE **knowledge sharing** and best practice via platforms such as Wader, WINSA, DSI, TIA, WISA
12. **EE and RE toolboxes** for practical application by WWTW superintendents and process controllers.

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Appendix A: A summary of energy savings best practices and case studies

NERSYDA (NERSYDA, 2010) recommends a number of energy saving best practice measures with regard to wastewater treatment processes

Wastewater treatment processes EE best practice	Saving/ Payback
Operational flexibility: Evaluate facility loadings and become familiar with the treatment systems in order to identify, plan and design the most efficient and effective ways to operate the system. Modifications are mostly operational and payback typically less than 2 years. Measures may include: operating fewer aeration tanks, installing variable frequency drives so equipment operation can match system loadings, installing dissolved oxygen monitoring and control equipment, idling an aeration tank during low-flow periods, reducing air flow to the aeration tanks during low-load periods (usually nights and weekends), waiting to recycle supernatant during lower-flow periods, avoiding periods of high organic loading, operating diffusers or recycling backwash water during off-peak power demand periods.	Saving 10-25% Payback < 2yrs
Staging of capacity: When planning improvements, wastewater system personnel and designers should develop a team approach wherein they determine how modifications will effectively and efficiently meet current and projected conditions. Staging upgrades in capacity can help optimize system response to demand and also reduce energy costs.	Savings 10-30% Payback < 2 yrs
Seasonal loading: Flexible system design allows a utility to adjust and operate more efficiently during tourist related peak loadings as well as during the "off-season." This may require removing tankage that is used during peak season from service during the off-season. Savings up to 50% during off-season.	Savings Up to 50% Payback 4-6 yrs
Flexible sequencing of basin use: The selection of basin sizes can have a large impact on the energy consumed at a facility during its lifetime. The facility design team should review the existing and projected organic loadings to identify the best selection of tank sizes. Typically, the use of smaller sized basins is beneficial so that initial loadings can be near the capacity of a smaller basin. The remaining basins can then be loaded sequentially until design capacity is met. This approach allows for energy efficient operation from start-up to design flow conditions. Payback may be 2 to 5 years depending on complexity and cost to provide multiple basins.	Savings 15-40% Payback 2-5 yrs
Optimize aeration system: Determine whether the aeration system is operating as efficiently as possible for the required level of treatment. Assess present loading conditions and system performance through a comparison of kWh/Ml and other key performance indicators with those of similar facilities. Consider the potential benefits and costs of improvements such as fine-bubble aeration, dissolved oxygen control and variable air flow rate blowers. Savings of 30% to 70% of total aeration system energy consumption are typical. The payback period is generally 3 to 7 years for retrofits and about one year for new construction.	Savings 30-70% Payback 1-7 yrs
Fine bubble aeration: Assess the feasibility of implementing fine bubble diffused aeration at activated sludge treatment facilities to improve energy efficiency. It can be installed in new or existing systems. The technology usually improves operations and increases the organic treatment capability of a wastewater treatment facility. For optimum performance, combine this practice with dissolved oxygen monitoring and	Savings 20-75% Payback <1 yr

Wastewater treatment processes EE best practice	Saving/ Payback
control and a variable capacity blower. Plan for periodic diffuser cleaning (in-place gas cleaning system or scheduled drain and manual cleaning), as diffuser fouling influences system pressure and oxygen transfer efficiency. Payback may be as little as one year for new systems, but will vary depending on efficiency of system being replaced.	
Variable air flow rate: Aeration systems and blowers should have variable air supply rate capability, such as single stage centrifugal blowers with VFD, positive displacement blowers with VFD, and inlet guide-controlled multi-stage centrifugal blowers. The range of variability should respond to the specific requirements a site needs to match system demands. The blower system should be able to supply the minimum air flow required to meet existing low load conditions or mixing, as well as the high loads of design conditions. Avoid air flow discharge throttling.	Savings 15%-50% Payback < 3 yrs
DO control: Consider dissolved oxygen monitoring and control technology that will maintain the dissolved oxygen (DO) level of the aeration tanks at a preset control point by varying the air flow rate to the aeration system. Saving depends on the efficiency of the present system.	Saving 20%-50% Payback 2-3 yrs
Post aeration: Consider the installation of a cascade aeration system for post aeration applications. If the topography is favourable, this technology provides re-aeration of the effluent by increasing the water turbulence over the steps, with no need for electricity. The payback period will depend on existing infrastructure.	Saving Up to 100%
Optimise DAF: Optimise Dissolved Air Flotation (DAF) system by optimising the air-to-solids ratio in a, feeding the highest possible solids content, operating the DAF thickener continuously and adding polymers to the sludge.	
Replace centrifuge: Replace the sludge dewatering centrifuge with a screw press for energy savings.	
Replace centrifuge: Replace centrifuge with gravity belt thickener for improved sludge thickening.	
Biosolids digestion options: When planning new facilities or expansion, assess the energy and production impacts of various biosolids processing options. Standard aerobic digestion of biosolids is energy intensive compared to fine-bubble diffusers with dissolved oxygen control and a variable air-flow rate blower. It may be possible to turn off the air-flow to the digester over extended periods of time to further reduce energy costs. Anaerobic digestion requires detailed assessment. While the capital cost of an anaerobic system is considerably greater than for an aerobic system, an anaerobic system will consume less energy and can produce biogas for energy production to help offset capital costs. Both types of systems should be considered.	
Aerobic digestion options: Assess aerobic digester operation to determine if a smaller blower and/or using fine-bubble diffusers and equipment with adjustable airflow rates would provide better control of airflow. Many facilities operate aerobic digesters with surface aerators or coarse-bubble diffusers with limited ability to modify or control air flow delivered to the process. First, consider fine-bubble diffusers, which allow for variable airflow rates in digester applications. Second, choose equipment and/or controls with adjustable airflow rates. Often, air for the digestion process is bled from the secondary treatment process activated sludge blowers, allowing little or no control over the airflow delivered.	
Aerobic digestion mixing: Biosolids mixing is an energy intensive task that should be addressed in aerobic digestion. Mixing is generally provided by aeration, mechanical	Saving variable

Wastewater treatment processes EE best practice	Saving/ Payback
mixing, pumping or a combination of these methods. Aeration of the biosolids mass is required to destroy volatile solids and control odour. Still, aeration may not be the most energy-efficient way to provide complete mixing in a digester, especially if constant aeration is not required. Evaluate the energy costs of available options to identify the best technology for the site. A combination of mixing methods that will permit the system to be completely turned off periodically may be most practical. The potential energy saving will vary by application.	up to 50% Payback 1-3 yrs
Anaerobic digestion mixing: The contents of an anaerobic digester must be mixed for proper operation, the destruction of volatile suspended solids and the production of biogas. Mixing is generally accomplished by injecting biogas, pumping or mechanical mixing to achieve a higher level of volatile solids destruction and greater biogas production. Energy savings will vary substantially depending on the specific site conditions.	Saving varies
Optimise anaerobic digester: Optimize anaerobic digester performance and enhance biogas production by • optimizing process temperature (mesophilic to thermophilic) • Sludge pre-treatment to enhance hydrolysis by chemical, physical, and biological methods. Three of the most promising methods include thermal treatment, ultrasonic treatment, and enzyme dosing. • Co-digestion of other wastes to improve the nutrient and moisture content, process stability substantially enhance biogas yield.	
Reduce potable water: Reducing the consumption of potable water through the use of final effluent in process applications or wash down of tanks may save energy by limiting the supply of potable water. The final effluent system should include a pressure tank and pump control system as appropriate. Direct pumping could be implemented where consistent high pressure is required. Savings may reach 50% of the total system energy if pressure tank is used to regulate supply.	Saving Up to 50% Payback 2-3 yrs

Table 16: Wastewater treatment processes: EE best practice (NERSYDA, 2010)

NERSYDA (NERSYDA, 2010) recommends the following wastewater treatment management approach to energy saving best practice measures:

Management: EE best practice	Saving/ Payback
Energy assessment: Conducting an annual energy survey should be a common practice for all water and wastewater systems to determine any opportunities to improve energy efficiency. The survey should review all energy consuming processes.	Saving 10-50%, up to 65%
Energy monitoring: Install real-time energy monitoring system will facilitate the collection and analysis of 15-minute energy data for each treatment process and pump installation. This support tool enables utility staff and management to establish energy use reduction goals and monitor/verify demand consumption.	Saving 5-20%
Energy skills training: Al personnel should understand the relationship between energy efficiency and facility operations.	
Design planning: Clearly define utility goals and objectives and set the design criteria for system improvements. Incorporate all appropriate energy efficiency best practices	

Management: EE best practice	Saving/ Payback
into capital and operations improvement plans. This helps the utility address the critical needs of the future system and optimizes capital and operating budgets.	
Design flexibility: Operation, administration, and management personnel need to be involved with the planning and design of any improvements and/or expansions to their system. Plan and design improvements or expansions that have the flexibility to serve both current system and future system needs, taking into account any significant anticipated changes.	Payback 1-5 yrs
Peak demand management: Management of peak demand can substantially lower demand costs. The following can be done to optimize power use and reduce electric peak demand: • Assess electric bills to understand peak demand charges and examine facility operations to determine ways to avoid or reduce peak demand. • Develop an operation strategy that meets overall system demand and minimizes pumping and specific treatment processes during peak power demand periods. Consider adding storage capacity or simply delaying the time of operation. • Assess the typical and peak operation to identify areas where peak power demand can be trimmed or shifted.	Demand cost saving
Manage electricity tariff structure: Work with the utility account manager to review the facility's electric rate structure. The review process should determine if the current structure is the most appropriate pricing structure for the facility, based on peak demand and overall energy consumption.	

Table 17: Wastewater treatment management: EE best practice (NERSYDA, 2010)

NERSYDA (NERSYDA, 2010) recommends the following energy saving best practice measures with regard to general wastewater treatment:

General wastewater treatment EE best practice	Saving/ Payback
Equipment to idle: Idle or turn off non-essential equipment when feasible, especially during periods of peak power demand. Review operations and schedules to determine if any equipment is not required for the proper operation of the facility.	
High efficiency motors: Survey existing motors for possible replacement with new, high efficiency motors and specify the most energy efficient motors on all new installed and inventoried equipment. Include an emergency motor replacement program that specifies energy efficient motors. Saving and payback depends on size of motor and running hours per day.	Saving 5-10% Payback <2yrs
Automated control: Use automatic controls where possible to monitor and control system functions to optimize energy consumption and production demands or treated flows.	Saving varies
SCADA: SCADA systems refer to the hardware and software systems that allow treatment plant Process Controllers to remotely monitor field instrumentation and equipment, and in some cases, make control adjustments to the treatment process. SCADA can improve energy use tracking with routine energy "benchmarking": • Monitor energy use over time, including comparisons with process variables (e.g. flow, chemical use, mass BOD, mass TSS). • Offset loads and control motor operating times to manage peak demand.	Saving and payback varies

General wastewater treatment EE best practice	Saving/ Payback
Variable frequency drives: Variable frequency drives (VFDs) match motor output speeds to the load requirement and avoid running at constant full power, thereby saving energy. Equipment must be designed to operate at peak flows. These designs often are not energy efficient at average conditions. Assess variations in facility flows and apply VFDs, particularly where peak demand is significantly higher than the average demand and where the motor can run at partial loads to save energy.	Savings 10-40% Up to 50% Payback < 5yrs
Correctly size motors: Proper sized motors for the specific application. Motors should be sized to run primarily in the 65% to 100% load range. In applications that require oversizing for peak loads, alternative strategies, such as the use of a correctly sized motor backed up with a larger motor that only operates during peak demand, should be considered.	Saving varies
Maintain motors: A regular program of preventive maintenance can increase motor efficiency and prolong service life. A typical maintenance program should include performance monitoring, winding resistance monitoring (Megger testing), lubrication, coupling/drive alignment, cooling vent cleaning and switchgear maintenance.	
Improve power factor: Improve the power factor of electric motors by minimizing the operation of idling or lightly loaded motors, avoiding operation of equipment above its rated voltage, replacing inefficient motors with energy-efficient motors that operate near their rated capacity, and installing power factor correction capacitors.	Saving 5-10%
Optimise pump system: Identify the optimum operational conditions for each pump and develop a system analysis. This analysis should include the start-up flows and progress to the design flow capacity, with a peaking factor to identify the range of flows and head conditions required to efficiently meet the design conditions. Select the pump with the peak efficiency point relative to the average operation condition. Consider operating a single pump, multiple pumps, and the use of VFDs.	Saving 15-30% up to 70% Payback <3yrs
Reduce pumped flow: Reduce flow being pumped. Energy use in a pump is directly proportional to the flow being pumped. Compare design flow with current flow and evaluate if system conditions changed. In some applications (i.e. pumping to a storage tank) it is possible to pump at a lower rate over a longer period of time. Conservation measures such as reduction of infiltration and inflow or leak detection and repairs to the water distribution system can also reduce the flow that needs to be pumped.	
Reduce pump head: Reduce the total system head losses, which include both static head and friction head losses (due to velocity, bends, fittings, valves, pipe length, diameter, and roughness). Energy use in a pump is directly proportional to the head. Plot system curve at the time of installation and compare output on the certified curve. Calculate efficiency and save for future reference. Plot system curve on a yearly basis; examine and re-plot at shorter period if problems develop. Avoid using throttling valves to control the flow rate. Run higher wet well level on suction side (if practical). Increase pipeline size and/or decrease pipe roughness.	
Avoid pump throttling: Modify operation of system to eliminate the use of throttling valves to control the flow rate from pumps. Consider energy efficient variable speed drive technologies, such as Variable Frequency Drives (VFDs).	Saving up to 50%
Filter backwash: A filtration system can have high energy costs, and the highest energy users for filtration systems are typically the backwash pumps. Consider sequencing of backwash cycles and off-peak backwash times to reduce the electric demand. In some applications, it is possible to pump at a lower rate over longer time to a water storage tank located at a higher elevation, and backwash by gravity.	Energy saving minor

General wastewater treatment EE best practice	Saving/ Payback
UV disinfection: Consider low-pressure or low-pressure high output UV systems, which are more energy efficient than medium pressure UV systems. Install lamp intensity adjustment based on flow rate or water quality, particularly UV transmittance (UVT), for low-pressure high output, and medium-pressure systems. Regularly clean lamps, as lamp sleeve fouling affects equipment performance.	Saving 10-50%

Table 18: General wastewater treatment EE best practice (NERSYDA, 2010)

UKWIR (UKWIR, 2010) present a summary of case studies on energy interventions with outcomes in terms of savings achieved from the British Compendium.

Management: EE best practice	Saving
Pump duty point measures: Control of pumps is by variable speed drive with normal operation close to maximum frequency. Operational change to reduce operational frequency on VSD. Pumping rate reduced with increased pump operating times but reducing friction head on system.	5-20%
Pump efficiency by VSD: Before VSD installation, the pump was not energy efficient with a throttled valve.	Up to 12%
RAS pumping: Fixed RAS flow reduced.	Up to 55%
AS aeration: Installation of ammonium control which regulates DO input according to ammonium measured in last pocket of each lane.	Up to 40%
BNR aeration: Fit ammonium control system to reduce aeration when ammonium levels in the AS lanes is low.	Up to 60%
UV disinfection: A two channel UV layout did not need to operate all of the time but did not have the facility for upstream isolation. Estimated that 40% power saving available 50-75% of the time if flow could be controlled. New software to control UV operation with flow set points.	Up to 40%
AD sludge feed: Fitting a macerator and increasing the pump bore has enabled digester feed to be run without blockages, enabling up to two extra tanker loads of sludge to be accepted each day.	Reliable increased biogas flow

Table 19: Summary of Case Studies from the British Compendium (UKWIR, 2010)

Appendix B: The South African legislative environment for EE and RE

According to SEA (SEA. 2015) National policies that could impact EE and RE at the level of municipal wastewater treatment facilities include, but are not limited to:

- **The White Paper on Renewable Energy (2003)**, ensures that renewable energy is a significant part of the country's energy mix and sets a target of 10 000 GWh of RE by 2013 (target date under revision).

- **The Integrated Resource Plan (IRP)** 2010 and 2012 update – This national electricity plan emanates from the Electricity Regulation Act of 2006, and is established by the national government to give effect to national policy. It refers to the coordinated schedule of generation expansion and demand-side intervention programmes, taking into account multiple criteria to meet the electricity demand. This national electricity plan makes provision for efficiency and renewable energy development and yet also calls for new coal-fired power stations and nuclear. It has given priority to the deployment of RE technologies and calls for RE to make up 42% of new power generation and is considering small scale embedded generation at the municipal level.

- **Biofuels Industrial Strategy** (adopted in 2006 and revised in 2007) stipulates a 2% (400 million litres per year) penetration into the national liquid fuels mix. While this is considerably small, when finally implemented, this would contribute to a shift in the country's energy and emissions profile considering that liquid fuels (petrol and diesel) account on average for half the total energy consumed in the major urban centres. The biofuels strategy offers an opportunity for municipalities to participate. The rapidly increasing liquid fuel prices, for instance, enhances the viability of conversion of landfill gas into biofuels at the municipal level.

- **Local Government Energy Efficiency and Renewable Energy Strategy** (SALGA, 2014): This recently developed comprehensive strategy was developed through a consultative process with municipalities throughout the country. It provides guidance to municipalities and enables them to pursue this work without the potentially costly, exercise of a consultant-developed strategy for a municipality. The strategy intends to support an ongoing level of coordination amongst external support organisations (including Provincial and National Government) and stakeholders. The Strategic Priority Areas include renewable energy, energy efficiency, energy access and mobility and urban form.

- **National Energy Efficiency Strategy** (DME, 2005, 2008, 2011), which came into effect in 2005 and was revised in 2008 and 2011, strives for affordable energy for all and to minimise the negative effects of energy usage on human health and the environment through sustainable energy development and efficient practices. The recently updated strategy prioritises energy efficiency programmes and has an overall target of 12% of energy efficiency for the country, 10% for residential and 15% for other sectors by 2015.

- **National Building Regulations – South African National Standards (SANS) 10400-XA: Energy Efficiency.** The National Buildings Regulation was recently amended and now requires all new residential and commercial buildings and renovations to existing buildings to be energy efficient. It includes efficient water heating and insulation. These requirements have also been extended to include government delivered low income housing. Local government has the responsibility for the implementation of these standards. Serious capacity shortages in this regard need to be addressed.

Burkard & van der Merwe-Botha (2017) summarised the legislative environment applicable to practitioners in the EE and RE space, from the perspective of the Department of Mineral Resources and Energy. This space 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).

Other national government departments include the Department of Environmental Affairs (DEA), Department of Water and Sanitation (DWS), Department of Agriculture and Fisheries (DAFF), Department of Energy, and the National Energy Regulator of South Africa, NERSA. Key legislature includes (but not limited to):

- 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 main activities related to renewable energy that are regulated include:

1. Environmental authorisation for establishment, construction and/or upgrading;
2. Atmospheric emission licence;
3. Registration of energy generation facility;
4. Licensing of energy generation connected to the grid;
5. Storage of biogas.

The National Environmental Management Act (NEMA No. 107 of 1998) is administered by the Department of Environmental Affairs (DEA) and provides the legal framework for environmental management. The NEMA enables the Minister to identify activities which may not commence without prior authorisation from the Minister of Member of Executive Council (MEC) and may also identify geographical areas requiring prior authorisation (DEA, 2015). Environmental Impact Assessment (EIA) Regulations (DEA, 2014) have been promulgated to regulate the procedure and criteria set out in Chapter 5 of NEMA with respect to applications for environmental authorisations for the commencement of activities subjected to environmental impact assessments. The EIA regulations were amended in 2017 (DEA, 2017). The scope of the assessment and contents of the EIA reports are clearly set out.

Government Notice Regulations GNR 983, 984 and 985 (DEA, 2014) defines listed activities and the level of authorisation processes to be followed. GNR 983 listed activities (list 1) trigger a Basic Assessment process, whilst the GNR 984 listed activities (list 2) trigger a Scoping and Environmental Impact Reporting (EIR) process and GNR 985 listed activities (list 3) trigger a basic assessment process but is determined according to geographic location. Activities that have reference to electricity generation from biogas are listed in both GNR 983 and GNR 984 based on the megawatts of electricity that will be generated (Table 5). Other potential listed activities include wastewater transportation, biogas storage facilities and electricity distribution infrastructure.

The DEA has compiled the ''EIA Guideline for Renewable Energy Projects" (DEA, 2015), to facilitate the development of first phase IPPs procurement programme in South Africa, these guidelines have been written to assist project planning, financing, permitting, and implementation for both developers and regulators.

The Air Quality Act (NEMAQA, No. 39 of 2004) is a Specific Environmental Management Act promulgated under the legislative framework of the NEMA. The Act provides for the identification of priority pollutants and setting ambient standards. Any plans that are required in terms of NEMA and Integrated Development Plans (IDP) developed by municipalities must take into account issues of air quality. Listed activities that are licensed and emission standards are set out in GNR 893. Gas combustion installations used primarily for steam raising or electricity generation are listed as subcategory 1.4. This applies to all installations with a design capacity equal to, or greater than, 50 MW heat input per unit, based on the lower calorific value of the fuel used. The pollutants of concern and emission standards measured under normal conditions of 3% oxygen, 273 Kelvin and 101.3 kPa are:

- Particulate matter: 10 mg/Nm^3;
- Sulphur dioxide: 400 mg/Nm^3; and
- Oxides of nitrogen (NO_x expressed as NO_2): 50 mg/Nm^3.

The Atmospheric Emission Licence (AEL) process is linked to the EIA process. The EIA process informs the AEL process. Applications for new AELs require a Scoping and EIR process, while changes to existing facilities that require amendment to the AEL require a Basic Assessment.

The reports are reviewed by both the EIA competent authority which will be the national DEA and the AEL licensing authority. The AEL licensing authority is the metropolitan or district municipality unless the municipality is the applicant when the provincial environmental department becomes the licensing authority. The principle route through which an AEL is issued will be via a joint process, run together with an EIA process. The AEL licensing authority is expected to play an active role in the EIA. This specifically applies to:

- Development of a new facility;
- New process within an existing facility which will result in a listed activity being carried out;

- Change to emission rates, raw materials which may increase emission levels of key pollutants;
- Any amendments to the existing AEL.

The licensing process is described in a guideline document issued by DEA (DEA, 2009). The Act also makes provision for odour control. The plant owner has a responsibility to take all reasonable steps to prevent the emission of any offensive odour caused by any activity on the premises. Offensive odour is defined as "any smell which is considered to be a malodorous or a nuisance to a reasonable person".

Burkard & van der Merwe-Botha (2017) summarised the regulation applicable to biogas energy generation and use by the following number of Acts:

National Energy Act: The key objective of the National Energy Act, (No.34 of 2008) is to ensure that diverse energy resources are available, in sustainable quantities and at affordable prices to the South African economy and increasing the generation and consumption of renewable energies. Renewable energy is defined in the Act, which includes energy generated from natural non-depleting resources including biomass energy. The Act gives effect to integrated energy planning.

The Electricity Regulation Act (No. 4 of 2006) establishes the regulatory framework for the electricity supply industry, establishment of the National Energy Regulator of South Africa (NERSA) as custodian, and the provision for licensing and registration of generation, transmission and distribution of electricity. Generation, transmission or distribution of electricity must be licensed by the Regulator. Guidelines for the licensing process have been compiled by NERSA (NERSA, 2012). Exemptions to the requirement for a licence are:

- Any generation plant constructed and operated for demonstration purposes only and not connected to an interconnected power supply;
- Any generation plant constructed and operated for own use; and
- Non-grid connected supply of electricity except for commercial use.

Registration with the Regulator may however be required if gazetted by the Minister. NERSA has issued grid connection codes for renewable power plants connected to the electricity transmission system or the distribution system (NERSA, 2014).

The National Gas Act (No. 48 of 2001) provides the national regulatory framework for the piped gas industry and to establish a National Gas Regulator (NERSA). Gas is defined to mean "all hydrocarbon gases transported by pipeline, including methane rich gas". Biogas is therefore regulated by this Act. Gas transmission, storage, distribution and liquefaction must be licensed by the Regulator. Guidelines for the licensing process have been compiled by NERSA (NERSA, 2011). Exemptions to the requirement for a licence are:

- Any person engaged in the transmission of gas for that person's exclusive use;
- Small biogas projects in rural communities not connected to the national gas pipeline grid; and
- Gas reticulation and any trading activity incidental thereto.

However, operations that are exempt from licensing and an operation involving the production of gas must register with the Regulator. Guidelines for the registration process have been compiled by NERSA (NERSA, 2011). Biogas installation for own use therefore does not require a license, but may require registration with the Registry at NERSA.