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Taylor, Jamie Anne

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Towards Net Zero Energy: Enhancing Wastewater Treatment Sustainability with Energy Efficiency and Biogas Integration. A case study of the Western Cape

Jamie Anne Taylor

2520792

Supervised by Dr Brian Boshoff

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand in partial fulfilment of the requirements for the degree of Masters in Urban Studies in Sustainable and Energy Efficient Cities.

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Faculty of Engineering and the Built Environment

Private Bag 3, Wits 2050, South Africa * Telephone (011) 717 – 7007 * Fax: (011) 717 7009 * Email: febe.pg@wits.ac.za

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List of Acronyms

Abbreviation	Description
AD	Anaerobic Digestion
BAU	Business As Usual
BNR	Biological Nutrient Removal
BOD	Biological Oxygen Demand
CAS	Conventional Activated Sludge
CHP	Combined Heat and Power
CoCT	City of Cape Town
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOL	Direct on Line
HRT	Hydraulic Retention Time
ICA	Instrumentation, Control, and Automation
MBR	Membrane Bio-reactor
MLE	Modified Ludzack-Ettinger
MSW	Municipal Solid Waste
NZE	Net Zero Energy
OFMSW	Organic Fraction of Municipal Solid Waste
PE	Population Equivalent
PFD	Process Flow Diagram
PLC	Programmable Logic Control
PST	Primary Settlement Tank
RAS	Return Activated Sludge
SANEDI	South African National Energy Development Institute
SCADA	Supervisory Control and Data Acquisition
SS	Soft Starter
THP	Thermal Hydrolysis Process
ToU	Time of Use
TS	Total Solids
TSS	Total Settled Solids
USEPA	United States Environmental Protection Agency
VFD	Variable Frequency Drive
VS	Volatile Solids Fraction
VSD	Variable Speed Drive
VSS	Volatile Settled Solids
WAS	Waste Activated Sludge
WRC	Water Research Commission
WWTP	Wastewater Treatment Plant
WWTW	Wastewater Treatment Works

Abstract

Urban wastewater treatment is vital for removing pollutants and preserving the water cycle by collecting and treating community-generated wastewater. Historically, wastewater treatment plants (WWTPs) prioritized meeting community demand and adhering to stringent effluent quality standards, especially concerning organic releases into water bodies. In the face of global concerns about climate change, carbon footprints, and energy efficiency, developing countries, such as South Africa, confront additional challenges like energy supply shortages and escalating electricity costs. This underscores the pressing need for implementing energy-efficient practices and exploring alternative sources in wastewater treatment.

This research aims to evaluate the feasibility of transforming a Wastewater Treatment Plant in the Western Cape, South Africa, into a Net Zero Energy (NZE) facility. The study begins by analysing the current energy consumption of the Wastewater Treatment Works (WWTW) and then applies various energy efficiency measures to estimate potential savings and project energy consumption over twelve months. Additionally, the research assesses the plant's potential biogas production and calculates the theoretical electrical energy yield, with the overarching goal of determining whether energy efficiency measures and biogas utilization can render the plant a NZE user.

The research had two main components. First, a qualitative literature review identified energy efficiency best practices and assessed potential savings for retrofitting wastewater treatment plants. The second phase involved a case study, utilizing quantitative data provided by the City of Cape Town (CoCT) over twelve months, including Eskom electricity bills, a list of mechanical equipment with power ratings, and daily sludge production and key sludge characteristics.

The study was able to conclude that an energy consumption reduction in the range of 28% could be achieved by implementing energy-efficient best practices. In addition, the theoretical average biogas production was calculated to be in excess of 505 MWh per month. Despite these promising results, the research concluded that these two interventions alone would not result in a NZE site. This does however open avenues for further study including a full energy audit of the site, based on energy monitoring equipment and real-time data. The study also invites further opportunities for improved site-based energy production through pre-treatment and co-digestion, as well as additional renewable energy sources including, but not limited to, solar energy, wind energy, heat energy recovery, hydrogen production and microbial fuel cell technology.

General limitations were faced during the study, such as time constraints, data collection challenges, limitations in analysis depth, and expertise. The study's scope had to be restricted to fit within the available time frame. Consequently, reliance on pre-existing data from a third party was necessary, as there wasn't sufficient time for a twelve-month observational data collection, crucial for the analysis. This reliance introduces a level of uncertainty. The analysis of the results was also constrained by the allocated timeframe and expertise. For the research question to be answered, the study required an in-depth understanding of both the wastewater process and plant configuration, as well as the intricacies of the mechanical equipment and subsequent electrical load. Where experience and time frame did not allow for an in-depth analysis, assumptions had to be made based on available literature.

Limitations specific to this research are acknowledged, including the exclusion of the impact of sludge variability on biogas production due to time and scope constraints. The study does not cover variables affecting methane quantity, such as sludge temperature and pH. It also does not explore the consequences of retrofitting a WWTP with additional equipment and processes, and what effect this would have on the effluent quality. Additionally, while recognising the complexity of defining a NZE facility and potential scenarios, the study does not delve into these cases. Instead, this report considers only the case to which the monthly energy consumption is offset by the theoretical energy production on site for the same month.

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1 Chapter 1

1.1 Introduction to Wastewater and its Energy Generation Potential

The treatment of wastewater is among South Africa's largest energy consumers, responsible for up to 17% of the country's municipal energy usage (Wille *et al*., 2020). However, sludge, a by-product of the treatment process, contains an energy equivalent to low-grade coal (Musvoto *et al*., 2017).

As a developing country, South Africa is prone to lagging behind first-world countries' technological advancements, deterred by financial and social factors. This refers to the current unreliable electrical energy supply and the increase in electricity tariffs that have driven South Africa to look towards a more sustainable energy solution. The question is, could NZE WWTPs, through the integration of energy efficiency measures and biogas technology, be a reality in the context of South African infrastructure?

The primary objective of this research is to assess the feasibility of a NZE Wastewater Treatment Plant in South Africa, utilizing an existing facility located in the Western Cape as a case study. The study begins with an analysis of the current energy consumption patterns of the WWTWs Subsequently, various energy efficiency measures will be applied to estimate potential energy savings and project the anticipated energy consumption over twelve months.

Additionally, the research will evaluate the potential biogas production rates of the plant during the same timeframe and calculate the resulting theoretical electrical energy yield. Ultimately, the study aims to determine whether the implementation of energy efficiency measures and the utilization of biogas are sufficient to elevate the existing plant to the status of a NZE user.

1.2 Background

Urban wastewater treatment aims to collect wastewater that is generated by communities and to remove pollutants and contaminants. The treated water may then be returned to water bodies without detriment to the existing water cycle. Until recently, WWTPs were designed to meet the demand of the community, as well as effluent quality requirements stipulated by the government or municipal bodies. The requirements of the effluent quality, typically being based on the quantity of organics that are allowed to be released into the receiving watercourse (Zvimba and Musvoto, 2020).

Worldwide concerns regarding climate change and carbon footprints, energy efficiency, reduction, and recycling have gradually become drivers in all areas of the built environment (Scheepers and Vd Merwe-Botha, 2013). Furthermore, in developing countries such as South Africa, energy supply shortages, and the increased cost of electricity provide an even stronger argument for a focus on energy efficiency, as well as alternative sources of energy to conventional fossil fuels.

WWTP technologies in South Africa currently lag behind those of developed countries. As Zvimba and Musvoto (2020) explain, this is due to financial and technological barriers such as high capital costs, and operation and maintenance requirements. Recovering energy from wastewater has piqued global interest, resulting in substantial literature on energy recovery technologies from waste. A review by Zvimba and Musvoto (2020) estimates that approximately 7% of the Eskom national supply could be provided by energy generated by municipal sludge treatment.

According to the Gandiglio et al. (2017), the most widely applied energy recovery technology is anaerobic digestion (AD). During AD, organic waste material is broken down into a combination of methane and carbon dioxide (CO_2), hereafter referred to as biogas. After the removal of CO_2, biogas can be converted into an electrical supply through a combined heat and power (CHP) plant on site, hence offsetting the energy consumption of the facility Gandiglio et al. (2017).

1.3 Problem Statement and Rationale

WWTPs in South Africa are currently consuming a large portion of the total municipal energy usage. Not only is there ample opportunity for a reduction in electricity consumption through energy efficiency measures, but the possibility also exists that energy production on WWTPs could ultimately lead to an complete offset of the energy consumption of the entire facility.

1.4 Objectives

This research focuses on exploring the potential for enhancing energy efficiency and energy recovery in current municipal wastewater treatment plants (WWTPs) in South Africa. Utilizing a case study of an existing plant, the study aims to assess the feasibility of achieving a Net Zero Energy (NZE) WWTP in South Africa by examining:

- The patterns of energy consumption in WWTPs and the impact of energy efficiency measures on reducing these levels.
- The realistic scope of energy generation via biogas production and its conversion to electrical energy should the plant be retrofitted with the appropriate digesters and CHP.
- The possibility of the WWTP offsetting its own energy consumption, thereby classifying it as an NZE entity.

1.5 Main Research Question

Could NZE WWTPs, through the integration of energy efficiency measures and the generation of electrical energy through biogas and CHP technology, be a reality in the context of South African infrastructure?

1.6 Sub-questions

1. What reduction in energy consumption could be realised on WWTPs in South Africa through the implementation of energy efficiency measures?
2. What quantifiable energy generation potential could be achieved through anaerobic digestion, biogas production and energy generation through CHP on WWTPs in South Africa?
3. Would the implementation of energy efficiency measures, and the production of electrical energy from biogas be enough to result in a NZE wastewater treatment plant?

1.7 Key Concept Definitions

Anaerobic Digestion – Natural biological process wherein microorganisms break down biodegradable materials, such as organic waste, in a confined environment without the presence of oxygen. This confined environment is typically an aerobic digester cell. The process yields two main products: biogas rich in methane and solid digestate.

Biogas – A gaseous combination of methane, carbon dioxide, and small quantities of other gases that are produced by the anaerobic digestion of organic matter in the absence of oxygen.

Biological Nutrient Removal – a treatment process that uses microorganisms to metabolise, and hence remove, specific nutrients such as nitrogen and phosphorus from wastewater.

Combined Heat and Power (CHP) - The concurrent production of electricity or mechanical power and useful thermal energy (heating and/or cooling) from a single source of energy.

Conventional Activated Sludge – a common method used to treat wastewater which involves the use of microorganisms to degrade the biodegradable and organic portion of the waste,

Direct on Line – Direct on line is a simple and cost-effective method of starting motors of smaller pumps at full load, with full line voltage applied to motor terminals.

Dissolved Oxygen – a relative measure of the quantity of oxygen that is dissolved in the wastewater.

Energy Efficiency – The use of a lesser amount of energy to perform the same or similar tasks and produce the same result.

Membrane Bio-Reactor – a process which combines microfiltration with a suspended growth bioreactor to separate the solids from the liquid portion of the wastewater.

Municipal Solid Waste – Residential, industrial, commercial, institutional and construction waste collected by the municipality and disposed of at disposal sites.

Net Zero Energy – a general term used to describe a building, site, or community which produces enough energy to meet its own energy consumption requirements.

Renewable Energy – non-depletable sources of energy which occur naturally. These are used to produce electricity, fuels, thermal energy, or a combination of these energy types.

Soft Starter – a device attached to a typical AC motor which is used to control the amount of voltage running through the motor circuits by limiting the torque in the motor. The main aim of this is to allow a smooth progression of current in the motor which limits the wear and tear on the motor.

Thermal Hydrolysis Process – Pre-treatment to the anaerobic digestion process which involves the application of elevated temperature and pressure that is used to improve the biodegradability of the solids. It is specifically introduced to plants to enhance biogas production.

Total Solids – solid matter that is suspended or dissolved in the wastewater. In simple terms, it is the solid that would theoretically be left behind if the water in the wastewater was evaporated.

Variable Speed Drive/ Variable Frequency Drive– Drives that control the frequency of electrical power supply to adjust the flow or pressure to the actual demand. These are used to achieve significant power savings.

Volatile Solids – undissolved organic content of a wastewater sample.

Waste Activated Sludge – a by-product of wastewater treatment process plants. The excess microorganisms that are removed from the process to keep the biological system in balance is called the waste activated sludge.

Wastewater Treatment Plant – a facility designed to treat a mix of domestic and/or industrial effluent to a level that is environmentally acceptable is often known as a sewage works in South Africa. This facility ensures that the effluent quality meets the standards required for environmental safety.

2 Literature Review

2.1 Introduction

Due to rapid global urbanisation, the generation of municipal solid waste (MSW) is on an unavoidable upward trajectory (Musvoto *et al*., 2018). It is estimated that the average human generates 1.42kg/capita/day of MSW, and with approximately 4.3 billion urban inhabitants, this totals 2.2 billion tons/ year globally (Hannan *et al.,* 2015). This rapid growth has contributed to several management issues, predominantly the disposal of this waste (Hannan *et al.,* 2015).

Wastewater has commonly been considered a burden to society and the government, due to the energy and associated costs required to treat and dispose of the aforementioned waste (Stafford *et al*., 2013). The conventional management method for dealing with MSW has been mainly disposal by landfilling, followed by recycling and composting (Muhammad Nasir *et al*., 2012). These methods have latterly been flagged as major contributors to global warming via large-scale production of methane emissions.

Several alternatives to landfilling have been identified, the most promising of those being anaerobic digestion. Anaerobic digestion is not just a sustainable method to dispose of waste, it is also used to generate biogas which can be used as a renewable energy source (Muhammad Nasir *et al.,* 2012).

Anaerobic digestion is a process in which organic waste material is broken down into methane and carbon dioxide (CO_2), or biogas, in the absence of oxygen through a chain of biochemical reactions (Musvoto et al., 2018). According to Gandiglio *et al.*, (2017) anaerobic digestion, currently has the potential to provide approximately 50% of the total energy consumption of an entire plant. However, this can be improved by increasing the biogas of the plant through sludge pre-treatment. These pretreatments include physical, chemical, biological, and combined methods which aim to make anaerobic digestion faster and increase biogas production by up to 60% (Gandiglio *et al.,* 2017).

Although ambitious, Gandiglio et al. (2017) argue that the concept of net positive WWTP is a feasible one. As agreed by Jenicek et al, (2013), and Gandiglio et. al (2017), the preconditions to achieving an energy balance on a WWTP requires two steps, the optimization of the energy consumption of the plant, and the application of anaerobic digestion. Methods to reduce the electrical demand on a WWTP would include process optimisation through the installation of smart meters and control systems, and replacing inefficient, outdated equipment with more efficient upgrades (Wille et al., 2020).

The nationwide tariff increases and unreliability of consistent electrical energy supply in South Africa, have expedited the need for recovering energy from wastewater sludge. According to Musvoto *et al*. (2018), recent studies have shown that unprocessed sludge has an energy content comparable to low-grade coal. In addition to this, sludge characteristics across individual plants are relatively consistent and predictable, making energy recovery technologies sustainable from a planning and analysis point of view (Musvoto *et al*., 2018). Despite this, the recovery of energy from wastewater has been poorly exploited to date in South Africa (Stafford *et al*., 2013).

2.2 Wastewater Treatment Plants and Process Overview

2.2.1 Municipal Solid Waste

MSW is the term which refers to the day-to-day solid waste which is generated by households, commerce, trade, garden, and the street (Abbasi, 2018). This is inclusive of all non-hazardous, biodegradable and non-biodegradable, reusable and usable solid waste that enters any municipal system (*ibid*.). According to Abbasi (2018), MSW is generated in all areas populated by humans, but its volume and complexity are significantly greater in urban and suburban settings compared to rural areas.

2.2.2 Wastewater Treatment

The term wastewater includes liquid waste and solids transported in water from households, commercial and industrial establishments, and storm and surface runoff. Wastewater treatment aims to remove or reduce the pollutants in wastewater to an acceptable level so that it may be safely discharged to the

water environment (Qasim, 1999). WWTPs are unique in numerous ways, including design population, footprint, treatment selection, regulatory controls, and effluent limitation (Qandil *et al*., 2022).

2.2.3 The typical wastewater treatment plant

Despite the many changes in regulations and municipal standards, the theory and design principles of wastewater treatment processes have not changed for over half a century (Qasim, 1999). These include screening, sedimentation, biological waste treatment, filtration, and sludge processing systems (Gu *et al.,* 2017 and Swartz et al., 2013).

Pre-Treatment

The pre-treatment phase in a WWTP plays an important role in preparing the influent wastewater for biological treatment. During this stage, coarse screening and mechanical grit removal are used to remove large solids, non-biodegradables, and abrasive materials from causing damage to equipment downstream. Effective pre-treatment is essential for safeguarding the mechanical equipment in the facility, and for optimizing the performance of the activated sludge process. Any solids filtered out during the pre-treatment process are collected in skips and removed via tankers to the disposal site or landfill. The filtered wastewater proceeds to the primary treatment phase of the facility as shown in Figure 1. (Tchobanoglous et al., 2014)

Primary Treatment

During the primary treatment stage, influent wastewater undergoes physical separation to reduce its content of organic matter and suspended solids. This commonly involves the use of primary settlement tanks (PSTs), where mechanical clarifiers slowly rotate to aerate the wastewater, while still allowing solid organic material to settle to the base of the tank, forming primary sludge. This primary stage is crucial to the full treatment process as it serves to alleviate the organic loading on the biological treatment process, enhancing their efficiency and ensuring the overall process of the plant is effective. The sludge is conveyed to several holding tanks, that are periodically emptied via sludge tanker vehicles. The clarified water, now containing fewer suspended solids, is then directed to the secondary treatment stage, as shown in Figure 1. (Tchobanoglous et al., 2014)

Secondary Treatment

The secondary treatment phase in the process flow is aimed at further reducing the concentration of specifically organic pollutants in the effluent wastewater. The clarified wastewater from the primary treatment enters a system of aeration tanks, where it comes into contact with a mixture of microbial bacteria and protozoa, otherwise known as activated sludge (Tchobanoglous et al., 2014).

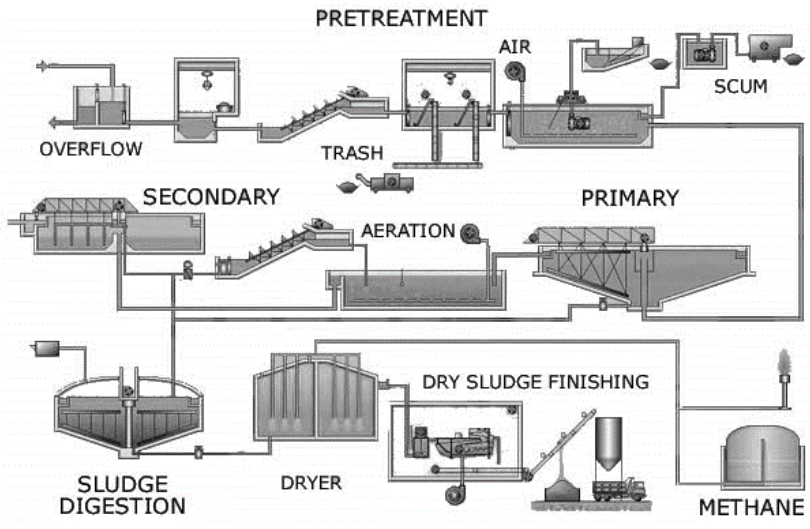


Figure 1: Wastewater Treatment Plant Process Diagram. Source: Environmental Information System (2006)

The phase involves the biological oxidation of dissolved and suspended organic matter by microorganisms that are present in the activated sludge. The microorganisms metabolize the organic compounds, converting them into biomass and other by-products. Through a secondary separation phase, the activated sludge biomass is removed from the treated water which is sent through to the next stage of the treatment process, namely the tertiary treatment. A portion of the activated sludge is returned to the aeration tanks to maintain the desired microbial population, and the remainder is sent through to the sludge holding facility to be dewatered or transported off site. (Tchobanoglous et al., 2014)

Several process treatment trains can be selected to perform the biological degradation phase. The plant designer's choice will typically consider the volume and biodegradability of the wastewater as well as the special constraints at the plant. Amongst the most widely adopted processes include the conventional activated sludge (CAS), the sequence batch reactor (SBR), the membrane bio-reactor (MBR) and the bio-film reactor (PFBR). (Phelan, 2016)

Tertiary Treatment

The tertiary treatment phase is the advanced stage in the wastewater treatment process, used to produce a final effluent which is subject to stringent quality standards (Tchobanoglous et al., 2014). The phase involves the removal of the remaining contaminants found in the water, specifically fine particles, and nutrients such as nitrogen and phosphorus. The methods used at the tertiary stage are typically filtration, chemical treatment, and advanced biological treatment. (Tchobanoglous et al., 2014)

Filtration methods such as sand, or microfiltration, are used to capture and remove suspended solids and microorganisms that are still present in the water. Advanced biological treatment techniques, such as biological reactors provide further reduction of organics and unwanted nutrients. Chemical treatment phases instead use controlled dosing methods using coagulants such as ferric sulphate to aid in precipitation and flocculation of suspended particles, which as removed via sedimentation. (Tchobanoglous et al., 2014)

2.2.4 WWTPs in South Africa

According to the South African National Energy Development Institute (SANEDI), South Africa has established a substantial wastewater management network that consists of approximately 970 treatment plants. This network treats an average of 7.6 Ml/ day and includes not only the treatment plants, but the pipe network, pumping stations, and sludge storage facilities. (SANEDI, 2021)

A general classification of WWTPs in terms of their capacity measured in megalitres per day (ML/ day), is provided by SANEDI (2021) and is tabulated in Table 2-1 below:

Table 2-1: General size classification of WWTPs according to capacity (SANEDI, 2021)

Size Classification	**Capacity Range (ML/ day)**
Micro	≤ 0.5
Small	0.5 - 2
Medium	2 - 10
Large	10 - 25
Macro	≥ 25

According to the survey performed by the Water Research Commission (WRC), the distribution of different sized WWTPs in South Africa is shown in Figure 2 below (SANEDI, 2021). The graph shows that roughly three quarters of the total the treatment plants in South Africa are classified as micro or small plants, treating less than 2 ML/ day. Furthermore, the graph illustrates that only 7% of the treatment plants are able to treat more than 25 ML/ day.

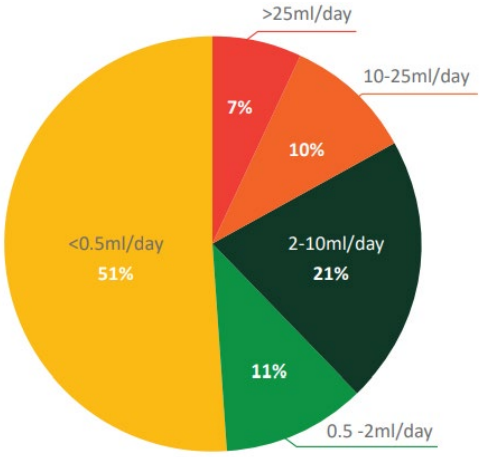


Figure 2: Size distribution of WWTPs in South Africa (DWA cited in SANEDI, 2021)

According to the publication by SANEDI (2021), the most common wastewater treatment technologies used in South Africa include activated sludge, bio/ trickling filters, biological reactors, membrane bio-reactors (MBR), and wetlands. The distribution thereof is provided in Figure 3 and shows that the most common treatment technologies in the country are the activated sludge and wastewater ponds (SANEDI, 2021)

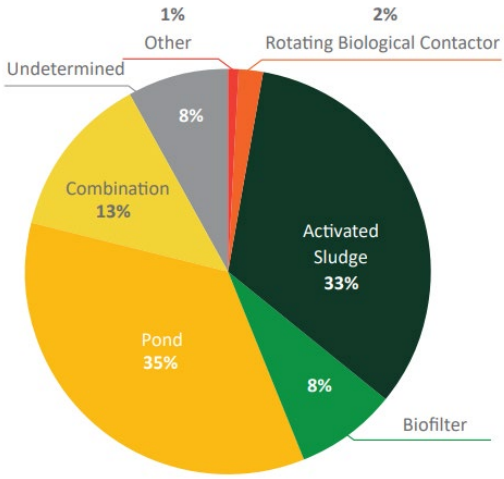


Figure 3: Distribution of treatment technologies commonly used in South Africa (DWA, cited in SANEDI, 2021)

2.3 Products of Wastewater Treatment

2.3.1 Waste effluent

The waste effluent, otherwise referred to as wastewater discharge, is the treated water that is released back into the water system after going through the full treatment purification process. Following the primary, secondary, and in some cases tertiary treatment stages, the effluent is deemed to meet the regulatory standards for release back into the environment. (Tchobanoglous et al., 2014)

2.3.2 Waste sludge

Waste sludge is a byproduct of the wastewater treatment process, which consists of solid residues such as organic and inorganic materials, pathogens, and trace elements that have been separated from the liquid wastewater. The composition of wastewater sludge varies greatly with the influent, however certain measurements can be used to characterize the sludge in order to design the treatment requirements accordingly. These include but are not limited to the total solids (TS) concentration, the settleable solids concentration, the volatile solids (VS) content, and the percentage of fatty acids (Tchobanoglous et al., 2014)

Total Solids (TS)

The TS content of waste sludge is usually expressed as a percentage and includes both solids that are suspended in the sludge and those which are dissolved. This TS content is primarily dependent on the type of processes which it has undergone. This includes processes such as thickening, conditioning, dewatering, and drying, which each function to lower the water content of the sludge and hence raise the solids content. Furthermore, the TS content of the sludge is dependent on whether any pre-treatment processes have occurred. (Tchobanoglous et al., 2014)

Typically, the sludge produced during the primary treatment of the WWTP has a solids content between 2 and 12%. Sludge produced at plants with a secondary treatment process, or a dewater plant, will typically have a solids content from 12% up to 40%. It is important to note that the efficiency of treatment processes varies over time, and therefore it is not unusual for the TS content of sludge to differ from day to day (Yan et al., 2009).

Volatile Solids Fraction (VS)

The volatile solid content of WW sludge is the percentage of the sludge which is organic and can hence be removed or destroyed when the material is subjected to high temperatures and oxidizing conditions. The VS content of sludge is expressed as the percentage of the total solids content that are volatile solids (Yan et al., 2009).

A number of authors have provided values for the typical VS content of WW sludge as shown in Table 2-1. The discrepancy between values is not unexpected due to the variability of wastewater feeds.

Table 2-2 - Typical values referenced for Volatile Solids (VS) content

Typical VS content (%)	**Comment**	**Reference**
64.7	Primary sludge only	(Arthur and Brew-Hammond, 2010)
75	Primary and secondary digester feed sludge	(Thames Water, 2014)
70	Primary and secondary digester feed sludge where chemical dosing is used.	(Thames Water, 2014)
75-85	Unstabilised sewage sludge	(Yan et al., 2009)

Volatile Solids Removal ($VS_{removal}$)

There are a number of treatment processes, such as anaerobic digestion, that are used to reduce the VS content of sludge (Yan et al., 2009). The Volatile Solids Removal ($VS_{removal}$) content of sludge is affected by many different factors according Thames Water (2014), including the ratio of primary to secondary sludge, the hydraulic retention time (HRT), the temperature in the digester and the composition of the sludge. Table 2-2 below shows the typical values identified by authors in the field.

Table 2-3 - Typical values for volatile solids removal percentage for WW sludge during AD

Typical $VS_{removed}$ content (%)	**Comment**	**Reference**
50-60	Primary sludge	(Oosterhuis et. al., 2014)
25-50	Activated sludge	(Oosterhuis et. al., 2014)
60	Primary sludge with no pre-treatment	(Thames Water, 2014)
70	Primary sludge with THP pre-treatment	(Thames Water, 2014)
20	Activated sludge with no pre-treatment	(Thames Water, 2014)
50	Activated sludge with THP pre-treatment	(Thames Water, 2014)

2.4 Energy Supply in South Africa

2.4.1 Eskom Electrical Supply

The South African electricity supply is primarily provided by Eskom Holdings SOC Ltd (Eskom). Eskom is a government-owned utility company which imports, exports, and ultimately dominates the African market for electricity. According to *The South African Energy Sector Report 2021,* compiled by the Department of Mineral Resources Energy, an integrated grid connects the electrical network of the Southern African Power Pool (SAPP), including South Africa, Botswana, Eswatini, Lesotho, Mozambique, Namibia, Zambia, and Zimbabwe (Department of Minerals Resources and Energy, 2022). Electricity generated in South Africa by Eskom, combined with imported energy from neighbouring countries, and a small portion of renewable energy, is bulk supplied to South African distributors, including large metros, and municipalities (*ibid.)*.

The South African electricity infrastructure encompasses three sub-sectors, including generation, transmission, and distribution. Eskom generates, transmits, and distributes electricity to all sectors of the country including, but not limited to the residential, commercial, agricultural, and industrial divisions. It also provides electricity to municipalities, which redistribute the electricity to businesses and households within their region (Department of Mineral Resources and Energy, 2022).

Eskom currently generates 95% of the electricity consumed in South Africa, and 45% of the electricity that is consumed by the African continent (Scheepers and Vd Merwe-Botha, 2013). Amsterdam and Thopil (2017) describe the energy generation mix in South Africa as “un-diverse”. This is supported by the reports provided by the Department of Environmental Affairs (2012) which stated that 92% of the electricity supplied to South Africa was sourced from coal-based plants. Thopil and Pouris (2015) further report that 95% of South Africa’s generation of electricity is based on non-renewable energy, as this includes nuclear energy sources. In 2018 however, this value was reported to be 65%, with crude oil and renewables contributing 18% and 11% to the total supply respectively (Scheepers and Vd Merwe-Botha, 2013).

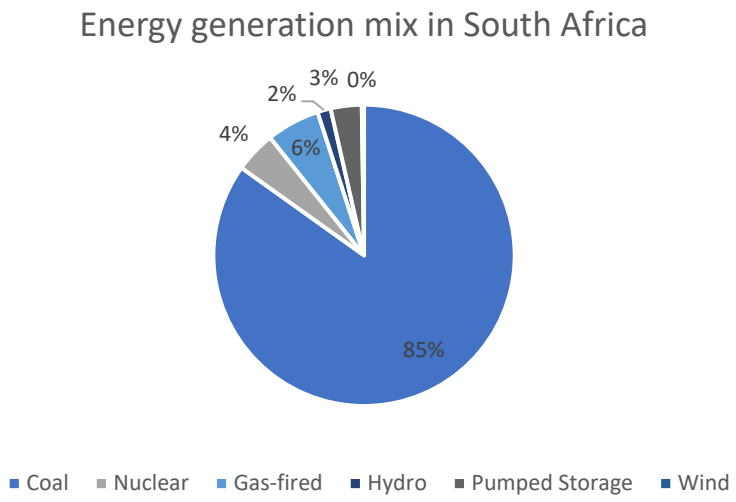


Figure 4: Distribution of energy generation mix in South Africa (DoE Energy Balances, 2018)

2.4.2 The South African Energy Crisis

Globally, the demand for electrical energy is intensifying, stimulated by a rapidly growing population, industrialisation, urbanisation, and modernisation (Amsterdam and Thopil, 2017). Electricity is essential in everyday individual and collective daily activities, and a lack of electricity is often an indication of poor quality of life and corresponds to low economic development (Amsterdam and Thopil, 2017).

For many years, South Africa had experienced an abundance of low-cost electricity. This is due to Africa having the 6th largest coal reserves in the world (Amsterdam and Thopil, 2017). However, as argued by

Scheepers and Vd Merwe-Botha (2013), January 2008 was a turning point in the history of energy supply in South Africa. Since then, Eskom has continuously failed to fulfil the demand for electricity in the country, leading to periodic electricity shortages, known as “load-shedding” (Scheepers and Vd Merwe-Botha, 2013). According to Amsterdam and Thopil (2017), these intermittent power failures are necessary to prevent the complete and catastrophic blackout of the national grid.

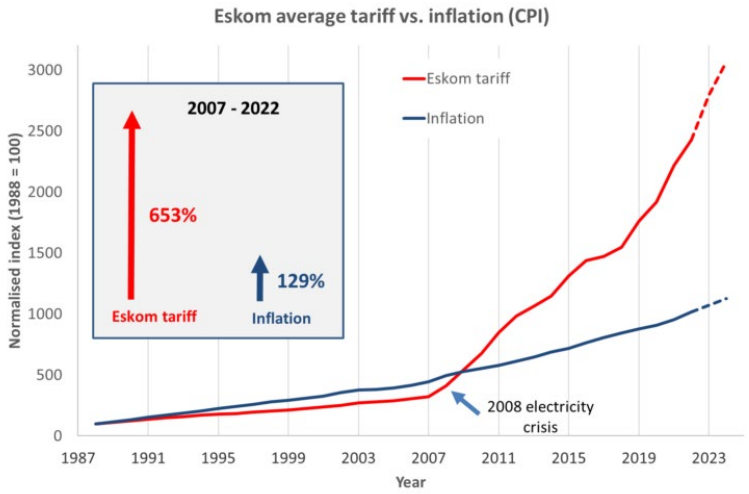


Figure 5: Graph illustrating the average Eskom tariff vs. Inflation (Power Optimal, 2022)

Not only has South Africa suffered from the lack of electricity and the livelihood effects this comes with, but the country has also experienced a disproportional increase in electricity tariffs, as illustrated in Figure 3.

Figure 3 shows that inflation has risen significantly over the past 40 years, however, the tariffs set by Eskom and the local municipalities exceed this inflation approximately five times over. The increases in the cost of electricity in South Africa are allegedly due to mismanagement within Eskom, leading to inadequate investment in the existing national grid, poor maintenance practices on ageing infrastructure, and inefficient operations (Nguyen, 2023).

These nationwide electricity shortages and the subsequent increase in electricity tariffs have caused researchers to investigate energy efficiency as well as alternative energy sources. The intention goes beyond cost-saving; other motivations encompass preventing equipment damage resulting from supply interruptions, mitigating disruptions to service delivery and end-user experiences, and the overarching goal of minimizing the overall carbon footprint of the plant. (Scheepers and Vd Merwe-Botha, 2013).

2.5 Wastewater and Electricity Demand

2.5.1 Electrical energy required to treat wastewater

All procedures associated with the treatment of wastewater require energy, predominantly as electricity, but also as fuel. This is to provide power for the treatment and sludge disposal technologies such as pumping, mixing, separating, and aerating (Gu et al., 2017)

As previously mentioned, the exact electrical energy consumption of each WWTP varies depending on several factors. These include but are not limited to, the size and age of the plant, the expected pollutant load, and the type of treatment process units at the plant (Zvimba and Musvoto, 2020). This is strongly reiterated by Panepinto et. al (2015) who’s study reports that a 50% increase in energy consumption can be observed when comparing an advanced biological nutrient retrieval (BNR) plant, in comparison with a conventional activated sludge (CAS) plant. Gu *et al.,* 2017, further state that the energy demand of the plant is also dependant on the effluent requirements, as well as the knowledge of the operators.

According to Swartz et. al., (2013) the maximum energy consumption of the wastewater sector in developed countries averages approximately 0.7 kWh/m^3. This is consistent with the research of

Panepinto et. al (2015), which provides a range varying from 0.3 kWh/m^3 to 0.73 kWh/m^3. However, this is more than doubled in the case of South Africa, where the maximum energy consumption averages at 1.8 kWh/m^3 (Swartz et al., 2013).

2.5.2 Energy demand for different-sized plants

Although misleading, the size of the plant does not refer to the area that the facilities cover, but rather to the population equivalent (PE) or hydraulic load. Gu *et al.,* (2017) illustrate another unexpected trend, being that the energy consumption per cubic metre of wastewater, decreases with an increasing PE. In Japan and China, a study showed that conventional activated sludge treatment facilities with an inflow ranging from 600m^3/d to 283000m^3/d, held indirectly proportional energy demands of 1.89 kWh/m^3 and 0.3 kWh/m^3 respectively (Gu et. al., 2017).

What these figures indicate, is that the equipment and devices used to treat WWTPs, can work with high efficiency as wastewater quantity and hydraulic load increase. A separate point made by Gu et. al., (2017), notes that smaller facilities may not employ as many staff, or staff with higher qualifications and experience, leading to a significant difference in management.

2.6 Energy Efficiency and WWTPs

2.6.1 Energy efficiency in the wastewater industry

Efficiency is frequently defined as the relationship between the production of a good or service and its resource demand (European Commission, 2012). In the context of energy in the wider water industry, this would traditionally be the relationship between the clean water produced, and the energy requirement thereof (Longo et al. 2023).

Longo et al. (2023) note that in the WWT industry, the service delivered is more complex as one cannot easily quantify the cleaning of wastewater or the recovery of resources. Similarly, it is noted that the role of the WWTP is not simply to clean the inflow but may be centred on outputs more specific such as eliminating nitrogen, reducing pathogens, and removing phosphorus. Furthermore, in recent years, outputs have extended past the traditional role of the WW industry into aspects such as producing energy from biogas. (Longo et al.,2023)

2.6.2 Energy efficiency benchmarking

The resource balance of WWTPs is complex and therefore its level of energy efficiency can only be measured against plants of comparable size and with similar characteristics (Zvimba and Musvuto, 2020). This process is known as benchmarking, and it particularly useful in allowing governing bodies to compare the efficiency of certain WWTPs with the rest of the industry. The main aim of this is to enable them to set realistic and achievable energy use reduction goals to bring them to standard with the best practice in the industry.

Several organisations have proposed a range of standardised tools to aid in the benchmarking of WWTPs in terms of energy efficiency. Longo et al. (2023) note that the common characteristic of each of these tools is their simplicity, observing that benchmarking is intended for a diverse audience, ranging from plant operators, to regulators, to investors and many more.

Longo et al. (2023) note that the specific energy consumption has been reported by several large global datasets to roughly characterize the energy efficiency of a WWTP. The specific energy consumption of the plant is defined as the energy used per unit volume or wastewater and is typically reported in kWh/ m^3 (Longo et al., 2023).

2.6.3 Energy efficiency auditing

An organisation named ENERGY STAR was established in 1992 by the United States Environmental Protection Agency (USEPA) (Phelan, 2016). The organisation was formed with the overall aim of providing energy guidelines, trends in energy usage, and the analysis of energy efficiency across specific sectors of industry. The sectors identified by ENERGY STAR include, but are not limited to breweries, dairy processing plants, cement manufacturing plants, food processing facilities, and

pharmaceutical manufacturing plants. The guidance of ENERGY STAR is aimed towards analysing energy use patterns, identifying energy efficiency potentials, administrating energy saving plans and educational resources (Phelan, 2016).

Noticeably, ENERGY STAR does not provide similar guidance on WWTPs (Phelan, 2016). Although ENERGY STAR has performed significant research in the area of wastewater treatment, a sector-specific guide for the wastewater industry has not yet been produced (Phelan, 2016).

Similarly, the American Society for Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has produced detailed guidance on performing energy audits (Phelan, 2016). ASHRAE provides three levels of audit, each increasing in level of intensity as shown in Table 2-3 below.

Table 2-4 - ASHRAE Energy Audit Level Summary (Adapted from Phelan, 2016)

ASHRAE Energy Audit Levels		
Level	Description of Work	Inclusions
1	Walk-through assessment	• Interviews with operations staff • Analysis of utility bills • Analysis of available plant or building data
2	Energy survey and analysis	• Level 1 survey findings • Detailed energy survey • Analysis of seasonal variations
3	Detailed analysis and modelling	• Level 1 and 2 findings • Long-term energy monitoring • Plant-wide digital simulation • Energy saving opportunities

Although ENERGY STAR and ASHRAE both provide detailed guidance and tools for the performance of energy audits, Phelan (2014) rightfully notes that both of these organisations have not targeted WWTPs on an industry-specific basis. These tools can be used as a starting point or as general guidance; however, they are not capable of providing stand-alone guidance for the energy audit of WWT.

The publication '*A Practical Guideline for Energy Efficiency Audits at Wastewater Treatment Works*' authored by Wille et al. (2020) provides guidance on energy auditing that is specific to WWTPs. According to this guideline, there are several focus areas of an energy efficiency audit at a WWTP. These include reviewing current and historical energy consumption data, benchmarking the consumption of the plant against industry norms, identifying opportunities to improve the energy efficiency of the plant through best practice, and to quantify the energy savings that could be realised. (Wille et al. 2020)

Similarly to that of the ASHRAE audit, Wille et al. (2020) provide different levels of audit, ranging from simple energy audits or intermediate energy audits, to detailed or investment-grade energy audits. Table 2-4 below summarises the key differences between the two key levels of audit proposed.Table 2-5 – Comparative summary of the levels of energy efficiency audits at WWTPs (Adapted from Wille et al, 2020)

Category	Simple/ Intermediate Audit	Detailed/ Investment-grade Audit
Outcome	Basic understanding of WWTW's energy use	In-depth evaluation of individual pieces of equipment and processes
Procedure	Desktop analysis of available energy use and cost data.	Detailed analysis of historical energy use and billing data as well as actual site investigations, tests, measurements, monitoring and simulations.
Cost	Inexpensive or low cost	High cost
Aim	Benchmark the plant to industry norms, identify major issues and focal areas to provide potential high-level solutions and energy management strategies.	Provide detailed quantified energy and cost savings, capital requirements, and return on investments for all identified energy improvements.

Due to the high cost and time associated with the detailed audit, the guideline advises that this should not be carried out unless energy usage of the plant is already under serious consideration and potential financing has been assured (Wille et al. 2020).

Energy efficiency results from previous studiesGandiglio et al. (2017) highlight that WWTPs are among the major energy consumers for municipalities. However, the Water Environment and Reuse Foundation (WERF) indicates that adopting best practices can lead to a 40% reduction in energy consumption, based on their models and analyses of various plants. This is evident in international efforts, with countries like Switzerland and Germany achieving energy savings of 38% and over 50%, respectively (WERF, cited in Gandiglio et al., 2017).

As discussed in Section 2.1.1, aeration is typically the most energy-demanding process in wastewater treatment, accounting for 50 to 65% of a plant's total energy use (Zvimba and Musvoto, 2020). Enhancing energy efficiency in WWTPs often involves process optimization, such as the installation of smart meters and the deployment of advanced control systems for aeration and water pumps (Gandiglio et al., 2017). Similarly, Qandil et al. (2021) suggest a focus on the overall operation of the facility, including a thorough analysis of energy flow through each treatment component.

The report by Qandil et al. (2021) also notes that the electrical energy consumption at each plant fluctuates throughout the year, responding to changes in inflow rates and the increased need for heat energy during colder months.

2.6.4 Limitations of energy auditing on WWTPs

The WWT industry varies from others in that energy auditing and recommendations cannot be performed in isolation of the plant process (Phelan, 2016). Any changes made to the plant could result in direct changes to the effluent water quality, meaning a simultaneous process analysis would need to run in parallel to the energy audit (Earhart and Harrington, 2014).

2.7 Best practice methods and energy optimisation strategies for WWTPs

2.7.1 Process control optimisation

According to Longo et al., (2023), plant operators often face a daunting amount of data that is challenging to analyse. Implementing methods and tools for systematic information extraction from datasets can optimize plant performance, improve effluent quality, reduce energy consumption, and enhance operator knowledge of plant processes.

Instrumentation, control, and automation (ICA) was introduced to the wastewater treatment industry over 40 years ago and has since made significant strides. ICA can be used to facilitate system reliability, improve plant efficiency, and achieve energy savings across WWTPs (Phelan, 2016). Process control measures vary according to the different stages of treatment, as well as the type of treatment that is employed on WWTPs.

In wastewater treatment plants, Supervisory Control and Data Acquisition (SCADA) systems, alongside Programmable Logic Controller (PLC) systems, are essential. SCADA offers easy-to-use graphical interfaces to observe and manage different processes, while PLCs handle the control logic and automate certain equipment or subsystems. Integrating these systems smoothly improves efficiency in operations, data gathering, and system dependability.

2.7.2 Instrumentation, monitoring, and control systems

Plant instrumentation feeds data to the overarching control system, which can be programmed in such a way that both process precision and energy optimisation are considered. Examples of this include controlling airflow rates to biological reactors, adjusting pumping rates, and controlling rotating plant machinery to reduce overuse of the equipment. Each of these controls are significantly more efficient than manual operations as they ensure that equipment is operated as closely to the process requirements as possible, eliminating human error and inefficiencies. (Phelan, 2016)

In wastewater treatment plants, SCADA systems, alongside PLC systems, are essential. SCADA offers easy-to-use graphical interfaces to observe and manage different processes, while PLCs handle the control logic and automate certain equipment or subsystems. Integrating these systems smoothly improves efficiency in operations, data gathering, and system dependability. (Phelan, 2016)

Automation in these plants leads to enhanced energy management. It allows for precise monitoring of energy usage, fine-tuning of pump functions, and the application of methods to conserve energy, thus substantially lowering energy expenses. Through the use of smart control algorithms and Variable Frequency Drives (VFDs), the speed of motors is adjusted according to real-time demand, promoting an energy-saving mode of operation. Each of these controls are significantly more efficient than manual operations as they ensure that equipment is operated as closely to the process requirements as possible, eliminating human error and inefficiencies. (Phelan, 2016)

2.7.3 Aeration

As discussed in Section 2.2.3, the aeration process occurs in the secondary treatment phase at a WWTP. According to Swartz et al., (2013) aeration is a required to oxidise pollutants, especially organic particles. Aeration takes place in large tanks, which are fitted with blowers, pipes, or diffusers that supply air (Swartz et al., 2013).

The aeration process typically accounts for 40 – 60% of the entire facilities energy demand, making it a key process to be run as efficiently as possible (SEA, 2017) . Swartz et al., (2013) provide key factors which influence the energy efficiency of existing aeration systems and well as possible interventions which could improve the energy efficiency of the process. These have been adapted and summarised below in Table 2-5.

Table 2-6 - Energy efficiency influences on Aerators (Swartz et al., 2013).

Factor category	Description
Energy consumption influences	
Maintenance	Blower inlet conditions
Maintenance	Blower condition, wear and tear, seals and leaks, lubrications system.
Maintenance	Diffuser condition, type, cleanliness inside the tank and size of the bubbles
Operation	Control system accuracy, response time, cleaning, and calibration of instrumentation
Design	Air distribution system size, control valves and flow measurement.
Design	Depth of tank and floor area
Process	Strength of mixed liquors, upstream treatment, and homogeneity.
Potential Interventions	
Maintenance	Check blower flow and head against metered electrical input
Operation	Assess system pipework, valves, and control set-points for optimum settings
Design	Implement Real Time Control using the flows entering and exiting the tank through. This would require the installation of PLC controls
Design	Installation of dissolved oxygen (DO) control
Design	Installation of variable speed drivers (VSDs) to surface aerators

There are many different aerator technologies used at WWTPs. According to Drewnowski et al., (2019) the two most common methods are mechanical surface aerators, and subsurface aerators.

Mechanical aeration typically employs motor-driven impellers or rotors that rotate at the surface of the water. This agitates the water, creating turbulence and introducing oxygen. Mechanical aerators were used preferentially until the 1990's, when the high energy demand of the equipment became a concern to the overall electricity consumption of the plant. (Drewnowski et al., 2019)

In a subsurface aeration system, oxygen is introduced into the aeration tanks by diffusers that are submerged in the wastewater. The air is introduced as very small bubbles, allowing for greater surface contact with the water, and hence a high oxygen transfer efficiency (Drewnowski et al., 2019). According to Musvuto and Ikumi (2016), FBDA is not only three or four more times more efficient in terms of oxygen transfer, the new blower and membrane diffuser technology is also the preferred option when

energy efficiency is being considered. Swartz et al. (2013), further states that the implementation of FBDA can result in an energy demand reduction of 10 to 20% in comparison to the conventional mechanical surface aerators.

In combination with FBDA, Musvuto and Ikumi (2016), and Zvimba and Musvoto (2020) performed two case studies on WWTPs in South Africa, namely the Zeekoegat and JP Marais WWTPs located in Gauteng. The case studies were used, in conjunction with process and energy simulations in the attempt to provide municipalities with aeration energy conservation programs for WWTPs under different low to high capital investments. The findings of the study showed that for older treatment, such as JP Marais WWTP, the replacement of less efficient mechanical aerators with ammonia-controlled, FBDA in combination with PLCs could reduce the energy consumption of the overall aeration system by 37%. (Muvuto and Ikumi, 2016)

2.7.4 Dissolved Oxygen

According to Phelan (2016), DO is the most widely used control variable in the WWTP industry. Typically, sensors are installed to quantify and monitor the oxygen dissolved in the raw water and hence use real-time data to facilitate the precise control of aeration systems. According to Swartz et al. (2013), a 30 to 60% savings in the aeration system can be achieved through the installation of DO monitoring systems.

Recently, WWTPs have started implementing ammonium-based cascade control using a DO set-point. This controller adjusts the air flow to the tanks based on the DO sensor readings, and the set-point becomes variable according to whether the ammonium levels are low or high at the effluent as shown in Figure 4 below. It has been shown that switching to ammonium-based control can decrease the airflow requirements by up to 20%. (Phelan, 2016)

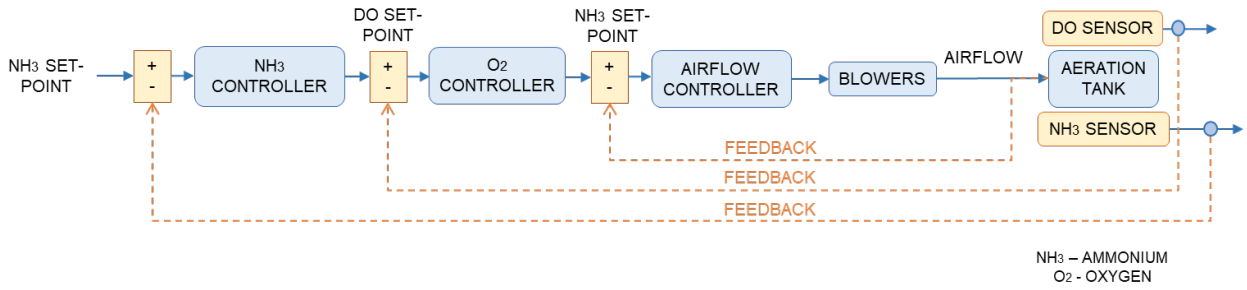


Figure 6 : DO and NH3 based control and monitoring system (adapted from Phelan, 2016)

In a case-specific study carried out by Phelan (2016), an 80% energy reduction to the aeration system of a site was achieved by integrating a new pumping method, ammonia-based monitoring, and in integrated PLC.

2.7.5 Pumping Control Methods and Variable Frequency Drives

According to Thames Water (2008), pumping is the single greatest operational cost on wastewater treatment plants. Therefore, optimising the facilities pumping systems is crucial to developing an energy-efficient plant (Thames Water, 2008).

To enhance energy efficiency in WWTPs an additional consideration involves optimizing pumping systems. This optimization includes the installation of more energy-efficient pumps, incorporating VFDs and implementing control systems for their operation (Thames Water, 2008). VFDs are ultimately used to alter the frequency of the input signal to an AC motor.

These measures ensure that pumping operations align with optimal energy conservation conditions. The introduction of an advanced control system for pumping headers could potentially result in an energy saving ranging from 10% to 15% of the pumping system's consumption. Furthermore, the replacement of pumps and motors, along with the integration of frequency variators in pumping systems, could yield energy savings ranging from 10% to 20% of the full plants energy consumption

(Lozano Avilés et al., 2019). Gandiglio et al., (2018) and Phelan (2014) suggest that VFDs can reduce a pumps energy by as much as 50%.

On a more significant scale, Phelan (2014) identified a case where a set of blowers were running at 100% speed all day and all night. By simply adding a VFD to each blower, an energy saving of 80% per blower was achieved, contributing a reduction to the site's total energy consumption of 16.7% whilst still maintaining the required oxygen levels for the site (Phelan, 2016).

2.7.6 Other energy efficient best practices

Maintenance Programmes

Regular and improved maintenance plans are pivotal in enhancing the energy efficiency of a wastewater treatment plant. By ensuring that critical equipment such as pumps, blowers, and motors are well-maintained and in optimal working condition, these plans enable the machinery to operate more efficiently while consuming less energy (Swartz et. al., 2013). Routine maintenance plays a key role in the early detection and resolution of potential issues, preventing equipment failures that can otherwise lead to inefficient, energy-intensive emergency operations and replacements (Daw et. al., 2012).

Furthermore, maintenance activities such as the calibration of instrumentation and adjustment of process controls like aeration systems, ensure that these systems are running optimally. This improves the performance of the equipment and leads to significant improvements in the overall energy efficiency of the plant (Swartz et. al., 2013).

Leak Reduction

Proper leak management and reduction in wastewater treatment plants are crucial for energy efficiency, as leaks in the system can lead to unnecessary energy consumption by pumps and treatment processes. By identifying and repairing leaks promptly, plants can reduce wastage of both water and energy, thereby operating more efficiently and sustainably (Swartz et. al., 2013).

Co-digestion

Implementing co-digestion of waste sludge with additional organic substrates in wastewater treatment plants effectively increases the biogas yield, as it creates a more favourable environment for methane-producing bacteria (Swartz et. al., 2013). Various feedstocks can be used alongside the primary sewage sludge to enhance biogas production, including food and agricultural waste (Gandiglio et al., 2017).

As discussed by Ram et al., 2021, the process of co-digestion enhances the overall efficiency of biogas production by improving the feedstock's nutrient balance and accelerating the digestion process. Additionally, co-digestion offers an environmentally friendly solution for managing various organic wastes, turning them into valuable energy resources (Mukawa et. al., 2022).

Building and Plant Services Management

As outlined in the 'Energy and Carbon Management Requirements for Capital Projects Asset Standard' by Thames Water (2014), several best practices are recommended for implementing energy efficiency improvements in facility buildings. Wille et al. (2020) provide guidelines on these measures that can be implemented.

These measures include replacing incandescent bulbs with energy-efficient or LED lighting and transitioning from mercury vapor lights to more efficient high-pressure sodium lights or LEDs in plant lighting, as these alternatives consume roughly a third of the power. Additionally, it's important to prioritize the selection of energy-efficient appliances, especially for HVAC systems. Lastly, opting for solar water heaters or heat pumps instead of traditional electric geysers can significantly reduce energy consumption and enhance the overall energy efficiency of the building. (Wille et al., 2020)

2.8 Energy Generation from Wastewater Sludge in South Africa

2.8.1 Waste to Energy

Recently, significant research has been conducted on MSW treatment processes which generate energy in the form of heat, electricity, or transport fuels (Ram et al., 2021). Waste to energy (WtE) technologies can be characterised by their conversion process, being either thermo-chemical or biochemical. According to Khan et al, (2022), the thermo-chemical conversions include technologies such as incineration, gasification, and pyrolysis. Bio-chemical conversions include technologies such as fermentation and anaerobic digestion (Khan et al., 2022). Both authors provide a similar summary which has been adapted into Figure 5 below.

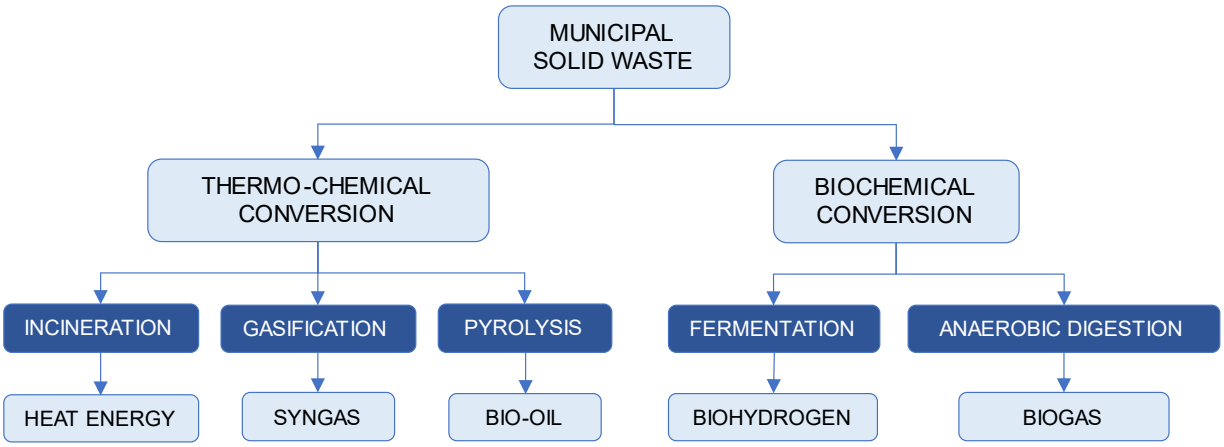


Figure 7: Waste to Energy (WtE) technologies (adapted from Ram et al., 2021)

The South African wastewater treatment sector currently comprises 955 municipal wastewater treatment plants (WWTPs), accounting for approximately 35% of municipalities' energy consumption. The engineering design of conventional WWTPs is largely focused on meeting growing capacity needs, environmental protection, and public health requirements, with little consideration for energy use. (Zvimba and Musvoto, 2020).

The waste generated in South Africa holds a high inherent energy, which could be recovered through methods such as anaerobic digestion, landfill gas recovery, and incineration (Adeleke *et al*., 2021). Several studies have presented theoretical calculations, indicating a significant energy potential recoverable from waste generated in African countries. The same studies have, however, reported the lack of investment in the infrastructure required for the countries to realise the full potential of this energy generation capacity (Adeleke *et al*., 2021).

Zvimba and Musvoto (2020) have found that energy generated from sludge can offset up to 15% of a WWTP's energy demand. Additionally, they suggest that implementing best practices and focusing on energy efficiency could reduce the energy consumption of WWTPs by as much as 25%. This 15% energy offset reported by Zvimba and Musvoto (2020) contrasts with Gandiglio et al.'s (2017) estimate, which suggests up to 50% energy offset is possible. This is attributed to the variability across WWTPs in terms the treatment processes, size, loading, location, topography and many more aspects.

Currently, very few South African WWTPs recover energy or other valuable resources from wastewater sludge (Musvoto *et al*., 2018), largely due to technological and financial barriers. Although energy recovery technologies have been accepted in many countries, there is still debate as to whether they are suitable for developing countries, such as South Africa, from both an operation and maintenance perspective. Some lessons could be learned from successful waste-to-energy schemes in developed countries, particularly in the EU (Adeleke et al., 2021).

2.8.2 Waste-to-Energy Barriers for Developing Countries

The Waste to Energy industry is far more established in developed countries, with those in Europe boasting over 300 operational waste-to-energy facilities (Amsterdam and Thopil, 2017). Similarly, the United States reports the combustion of 7% of their total MSW in waste-to-energy facilities.

While these success stories could aid in the development of a roadmap for developing countries, Adeleke *et al*., (2021) caution that the developed models cannot simply be transferred in the South African context without considering local factors which may impede them. Musvoto *et al*., (2018) further argue that energy from waste technologies is expensive in terms of initial capital, which often deters local municipalities that may not have sufficient knowledge of its outputs, or the budget allocated. This is particularly apparent when the economic benefits may only be realised over only over a period of time.

In addition to the capital requirements of WTE schemes, Stafford *et al*., (2013) note further barriers that exist, preventing the implementation of the technology in South Africa. There exists a general lack of collaborative research and research sharing between studies, research groups, and government practitioners. Moreover, the recognition of wastewater as a renewable energy source has not yet been established, with a lack of understanding and information causing a lack of social buy-in. Of the 200 biodigesters that have been installed in South Africa, 90% of them are for small-scale use. These are typically at household or community level (Tshemese et al, 2023).

The technological ancillaries to biogas generation, including gas conditioning, engines, and micro-turbines, are also not abundantly available in South Africa. This means that while the technology can be imported and installed, there are few providers that could provide local maintenance and repair to the required equipment (Burton *et al.,* 2009).

In addition to this, there is little government buy-in, with no formal incentives such as feed-in tariffs or peak tariffs for the generation of clean, renewable energy. Stafford *et al.* (2013) argue that certain financial benefits could tip the balance of economic feasibility when considering WTE technology.

2.8.3 Government Policy and Incentives

The Renewable Energy White Paper and the 2011 National Climate Change Response Policy outline the South African government's objectives and dedication to making renewable energy a major component of the nation's energy mix. Additionally, the Western Cape's Green Economy Strategy Framework emphasizes that investment in renewable energy technologies is a key method for reducing carbon emissions in South Africa. (Fouché and Brent, 2019)

Although in general there is a commitment from the South African government, both Burton et al., (2009) and Musvuto et al., (2018) comment on the need for the government to develop more specific policies, incentives, and market support to optimise the use of biogas technology. The role of organisations like the South African Biogas Industry Association (SABIA) and the South African National Energy Development Institute (SANEDI) are vital in creating a deeper understanding of the subject and advancing the development and application of biogas technology. (Burton et al., 2009 and Musvuto et al., 2018)

2.9 Anaerobic Digestion and Biogas Production

2.9.1 Anaerobic digestion

The most widely applied and established WTE technology is anaerobic digestion (Musvoto *et al*., 2018). As previously introduced, anaerobic digestion is a process in which organic waste material is broken down into a gaseous combination of methane and carbon dioxide (CO_2), henceforth referred to as biogas. This process occurs anaerobically, or in the absence of oxygen through a chain of biochemical reactions (Musvoto *et al*., 2018). Further to producing biogas, another by-product of anaerobic digestion is a nutrient-rich digestate, commonly used as fertiliser or soil conditioner (Muhammad Nasir *et al.,* 2012).

According to the Asset Standards produced by Thames Water, *AM-DES-WWT-WWT 8.6 Primary Sludge Digestion,* the main objectives of AD are to render the sludge produced during the treatment process less offensive with regards to odour and the handling process. Further to this, it is also introduced to reduce the numbers of pathogenic bacteria present, and to decrease the solid content of the sludge. According to the asset standards though, the key driver to introducing AD into a WWTP is to produce the methane-rich biogas which can in turn be used for heating and power generation (Thames Water, 2014).

The advantages and disadvantages of AD extend beyond energy production and are clearly outlined by Phelan (2014). These have been summarised in Table 2-5 below.

Table 2-7 - Advantages and disadvantages of Anaerobic Digestion at WWTPs (adapted from Phelan, 2016)

Advantages of AD	**Disadvantages of AD**
Methane gas produced in the digester can be used to produce energy through a CHP, gas turbines and engines, microturbines, boilers or fuel cells.	Operational, control, and maintenance expertise is essential for managing the plant, and this requirement can pose a challenge for developing countries.
Reduction in sludge mass, reducing the need to transport additional sludge offsite for disposal.	High initial capital cost.
Reduction in the requirement of chemicals.	Large space requirements for the reactors.
Improvement to sludge odour on site.	
Market is created for excess sludge in the form of biosolids or fertilisers.	

2.9.2 Anaerobic Digesters for WWTPs

An anaerobic digester in a wastewater treatment plant (WWTP) is a specialized tank or vessel designed to facilitate the biological breakdown of organic matter in the absence of oxygen (Tchobanoglous et al., 2014). The process flow of the anaerobic digester is shown in Figure 6.

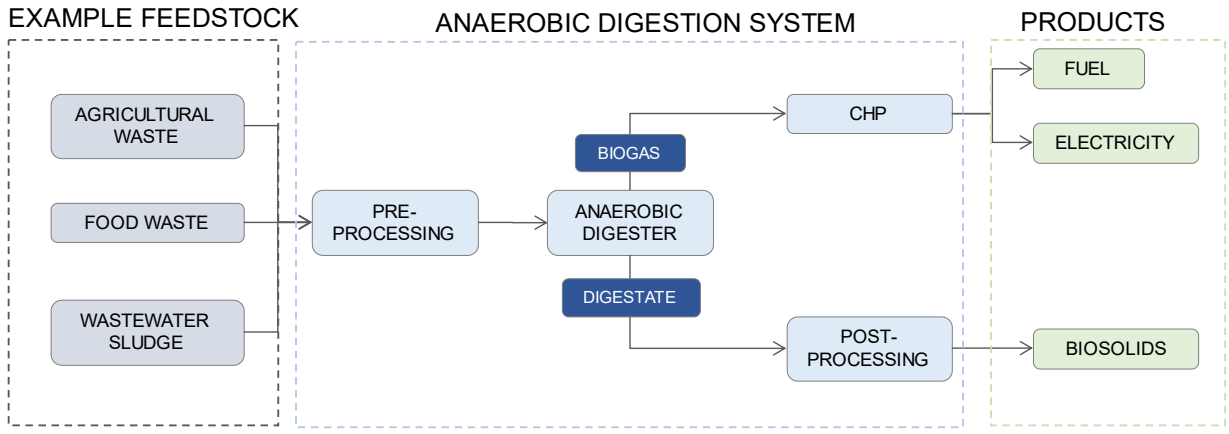


Figure 8: Process flow for AD at WWTPs (Adapted from Cambi, 2022)

2.9.3 *The Biological Anaerobic Digestion Process*

AD is a process which is extensively employed to stabilise sludge in the absence of oxygen. AD reduces the number of volatile solids, also referred to as organic solids, in the sludge by converting it to biogas (Judd, 2020). The AD process can either be carried out at mesophilic (30-39°C) or thermophilic temperature conditions (49-57°C) (Judd, 2020).

Biogas production involves numerous stages carried out by various microorganisms (Musvoto *et al*., 2018). This biological decomposition of organic substrates involves four key steps as shown in Figure 7, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Tshemese et al, 2023).

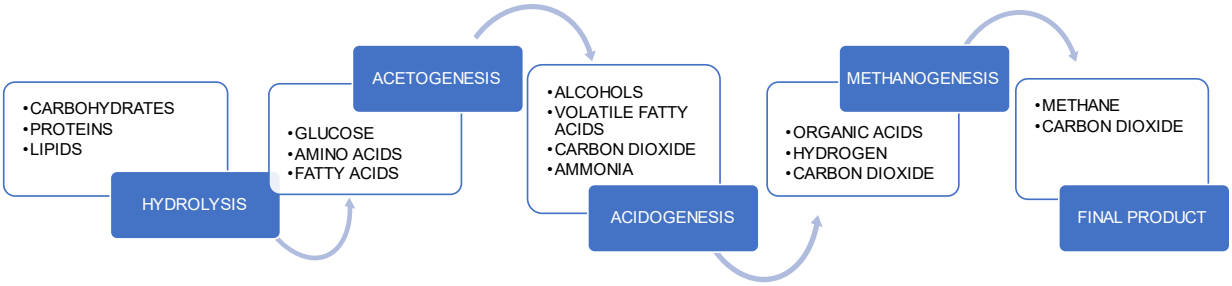


Figure 9: Summary of Anaerobic Digestion Process (adapted from Tshemese et al, 2023).

2.9.4 *OFMSW, anaerobic digestion, and methane generation*

The organic fraction of municipal solid waste (OFMSW) is the portion of the MSW which is used to produce biogas. The principal factor in determining the methane generation potential of wastewater is the quantity of degradable organic material in the wastewater source (Rajaratne and Kumara, 2014). Typical parameters used to measure this, are the Biochemical Oxygen Demand (BOD), and the Chemical Oxygen Demand (COD) of the waste. A high BOD and COD in wastewater is an indication of a high methane-yielding potential (Rajaratne and Kumara, 2014).

Biogas can be used with little modification in many applications, including stoves and boilers (Stafford *et al*., 2013). For other applications, such as generators or motor car engines, significant processes are required to upgrade the gas to remove the non-methane components (Stafford *et al*., 2013). Furthermore, when stripped of the CO_2, the biogas, now pure methane, can be injected straight into the gas network (Bachman, 2015).

Methane, a compound denoted by the chemical formula CH_4, is the most abundant organic compound on earth. It is also the main component of natural gas. Several factors will determine the methane generation rate of biogas, the most prominent of these being the composition of the waste source (Rajaratne and Kumara, 2014). Additionally, various pre-treatment methods, such as thermal hydrolysis, can augment the production rate of biogas during anaerobic digestion (Oosterhuis et al., 2014).

2.9.5 *Combined Heat and Power*

As shown in Figure 6, before being utilized in the co-generation process, the biogas undergoes purification to eliminate unwanted elements like moisture and sulphur compounds, which can cause corrosion. Once ignited, the energy from the biogas is harnessed to power either a gas engine or a gas turbine, producing electricity. This electricity is then used on-site, reducing the need for externally sourced power and thereby enhancing the overall energy efficiency of the site. (Wille et al., 2020)

CHP systems at wastewater treatment plants (WWTPs) exhibit varying efficiency levels in biogas conversion, largely dependent on their size and technology. Traditional internal combustion engines and micro gas turbines used in CHP systems typically achieve conversion efficiencies ranging from 25 to 45%. This percentage can be further increased by supplementing the AD system with primary sludge,

waste-activated sludge, and other organic wastes, thereby generating more electricity. (Wille et al., 2020)

2.9.6 The relationship between biogas generation and sludge characteristics

Biogas production depends on the composition of the substrate, its biodegradability, and its composition of proteins, carbohydrates, and lipids. According to Laffratta et al, (2020), the sludge that is fed to an anaerobic digester is characterised by its Dry Solids (DS) percentage, and its Volatile Solids (VS) content. More specifically, as highlighted by Thames Water (2014), biogas production is reliant on the Volatile Solid Removal percentage which occurs during anaerobic digestion.

The typical value accepted by Thames Water (2014) in terms of the biogas production rate is that 1 cubic metre of biogas if typically generation for every kilogram of VS removed during AD.

Furthermore, the pH of the sludge is also used in its characterisation (Laffratta et al., 2020). As shown by Table 2-6, the range of pH values referenced by various authors is highly variable, ranging from as low as 5.5 (Admasu et al., 2022) to as high as 8.5 (Admasu et al., 2022 and Tshemese et al., 2023).

pH

Table 2-8 - Typical values for pH of wastewater sludge

Typical pH value	Reference
5.5 – 8.5	(Admasu et. al., 2022)
6.1 ± 0.3	(Laffratta et al., 2020)
7.5	(Oosterhuis et. al., 2014)
6.8	(Arthur and Brew-Hammond, 2010)
6.0 – 8.5	(Tshemese et al, 2023)

2.9.7 Advantages and Disadvantages of Anaerobic Digestion

Aside from the key advantage outlined by this research report being the production of biogas and its conversion to electrical energy, there are several other advantages which Phelan (2016) briefly discusses. This includes the removal of sludge odours, the digestate by-product which can be used as fertiliser, the reduction of sludge mass and hence the reduced disposal requirements, and finally, the removal of the need for lime stabilisation (Phelan, 2016).

Phelan (2016) further provides the disadvantages of anaerobic digestion implementation. One key disadvantage is the space requirement for the reactors to stabilise the sludge effectively. Arguably, this is more of a disadvantage for brownfield or retrofit projects as this may be a limitation of implementation, rather than a disadvantage. Phelan (2016) also discusses the high initial cost of the equipment required for anaerobic digestion. This could also be argued to be a limitation, rather than a disadvantage, as it may limit the entire implementation, but ultimately any efficient feasibility study should determine whether the initial costs would be offset by the energy-saving returns of the plant (Phelan, 2016).

2.9.8 Thermal Hydrolysis Process

In terms of pre-treatment options for anaerobic digestion, the Thames Water Asset Standards for Primary Sludge Digestion provides four options that are widely accepted in the United Kingdom (UK). The first of these options is conventional digestion, a process which includes primary digestion as well as a secondary digestion stage. The second and third options are pasteurisation and acid hydrolysis which accommodate the primary digestion. The final, and preferred option in the UK, is the thermal hydrolysis process (THP) (Thames Water, 2014).

The THP of sewerage sludge is a commercial technology which was established in 1995 (Barber, 2016). The process involves the application of heat, typically by live stream injection at a specified design temperature and pressure (Barber, 2016).

One of the key benefits of thermal hydrolysis is that it improves the biodegradability of both primary and activated sludge. It also allows significantly higher loading rates, which can in turn decrease the size of the plant. Furthermore, the rate of biogas production is increased (Barber, 2016). Chang (2020) explains

that this is because the conversion of the sludge organic content to methane gas is enhanced, and hence the anaerobic digestion process is significantly improved.

Oosterhuis et al. (2014) performed an experimental study on the effect of pre-treatment thermal hydrolysis on the biogas production of sewage sludge. The results, as shown in Figure 8 below, indicate that by introducing THP, the biogas yield potential of sludge through anaerobic digestion can theoretically be improved by up to 30% (Oosterhuis et al., 2014). Surampalli et al., (2014) also reported a 30% increase in biogas production, whereas Nielsen et al., (2010) provided a range in biogas production enhancement of 13 to 30%.

According to Oosterhuis et. al (2014), Surampalli et. al (2014), and Nielsen et. al (2010), there is a large discrepancy in many of the figures reported due to the variability of wastewater feeds tested, the temperature at which the pre-treatment THP occurs, and the HRT of the study.

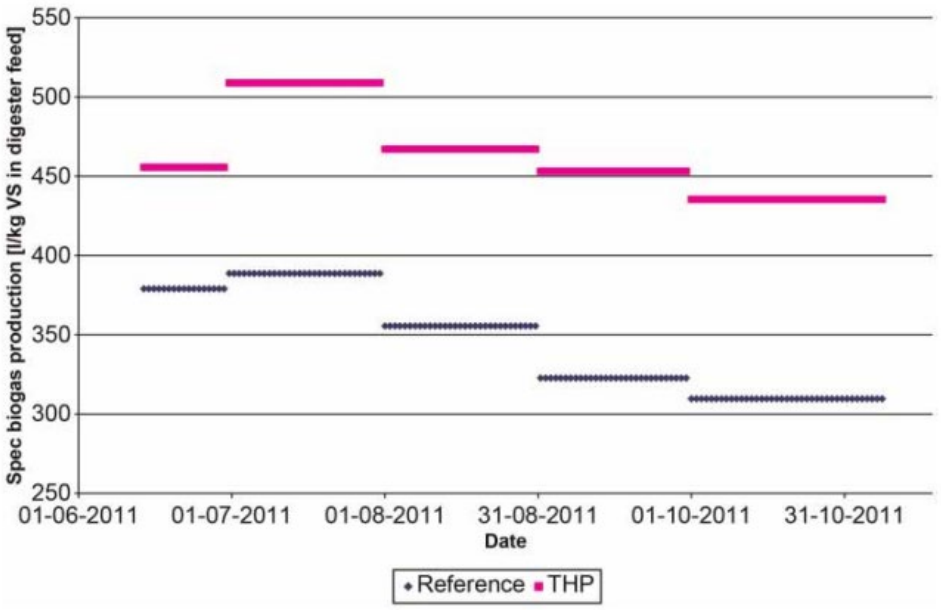


Figure 10: Experimental results of the study to show the effect of THP as a pre-treatment to anaerobic digestion on biogas production (Oosterhuis et. al., 2014)

2.9.9 Quantifying the Energy Generation from Biogas

According to operating data collected in the United States, approximately 600 kWh of electricity is generated from the combustion of 1 tonne of MSW (Psomopoulos *et al.,* 2009).

Aside from energy generation, Burton *et al.,* (2009) provide several additional benefits of the production of biogas from wastewater. These include cleaner effluents, health and sanitation benefits, financial savings on waste disposal and transportation, and the storage of energy for peak demands or load-shedding events (Burton *et. al.,* 2009).

Table 2-9 - Typical values referenced for the energy value of biogas

Energy value of biogas (kWh/m^3)	**Reference**
6 – 6.5	(Mukawa et. al., 2022)
9.26 – 11.05	(Berktay and Nas, 2007)
4.7 – 6.4	(Masłoń, 2019)

According to Admasu et al., (2022), the simplest way to generate energy from waste is through CHP with an internal combustion engine. The calculation used to determine the electricity generation potential (E_{elec}) from a certain quantity of biogas (Q_{biogas}) is provided as:

$$E_{elec} = Q_{biogas} \times F_{CH4} \times CP_{CH4} \times \eta_{elec}$$

As explained by Admasu et al., (2022), this electrical energy is dependent on the percentage methane (F_{CH4}) contained in the biogas, as well as the specific heat of methane measured (CP_{CH4}) in kWh/m^3. The percentage methane contained in the biogas is variable according to feedstock as illustrated by Table 2-8 below.

Table 2-10 - Typical values of percentage methane contained in biogas

Percentage Methane (%)	Reference
~60	(Admasu et. al., 2022)
68-72	(Arthur & Brew-Hammond, 2010)
55-80	(Berktay & Nas, 2007)
64.29	(Mukawa et. al., 2022)
60-70	(Musvuto et al., 2018).
43-70	(Severn Trent Water, 2017)
50-75	(Thames Water, 2014)

The calculation also takes into consideration the efficiency of the combustion engine, which may be as low as 25%, or in cases where certain technologies are employed, as high as 43% (Admasu et al., 2022).

Table 2-11 - Typical values for the efficiency of the CHP engine

Engine Efficiency (η_{eff}) (%)	Reference
25-43	(Admasu et. al., 2022)
29	(Arthur & Brew-Hammond, 2010)
38	(Berktay & Nas, 2007)
38	(Laffratta et al., 2020)

The calculation also takes into consideration the efficiency of the combustion engine, which may be as low as 25%, or in cases where certain technologies are employed, as high as 43% (Admasu et al., 2022). The typical values reviewed by literature are provided in Table 2-9.

2.10 Conceptual Framework

The conceptual framework as provided in Figure 9 aims to summarise the key aspects of the literature review. This ultimately looks at the process flow of a typical WWTP, however, instead of the inputs and

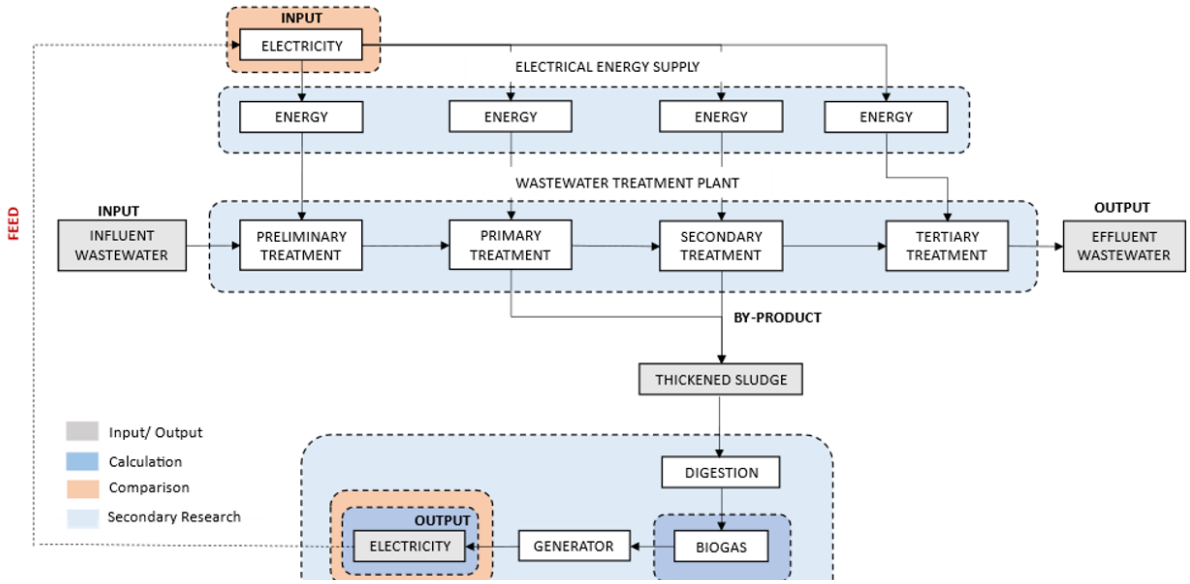


Figure 11 - Conceptual Framework

outputs, being influent and effluent wastewater respectively, it includes the input and output of energy required and generated. The main aim, as mentioned in Chapter 1, is to determine if the potential 'feed' energy produced at a single facility, can offset the energy supply required for the operation of the plant.

3 Research Method of Study

3.1 Introduction

This chapter presents and motivates for the methods of the study undertaken during both the quantitative and qualitative responses to the sub-questions provided in Section 1.6. This chapter is divided into five components including the research design, data collection requirements, data management, process and presentation plan, ethical considerations, and finally, the assumptions and limitations of the study.

3.2 Research Design

This study employs mixed method research, based exclusively on secondary data, in both a quantitative and qualitative capacity. Data which is not actively collected by the researcher is considered to be secondary data, regardless of whether it is numerical or of literary characteristics. Both methods are undertaken in parallel to provide a response to the main research question, however each sub-question would be addressed on either a quantitative or qualitative basis.

The nature of both the systematic literature review, and the qualitative data collection is further described in section 3.3 and section 3.4. Figure 10 below shows the full research design and process.

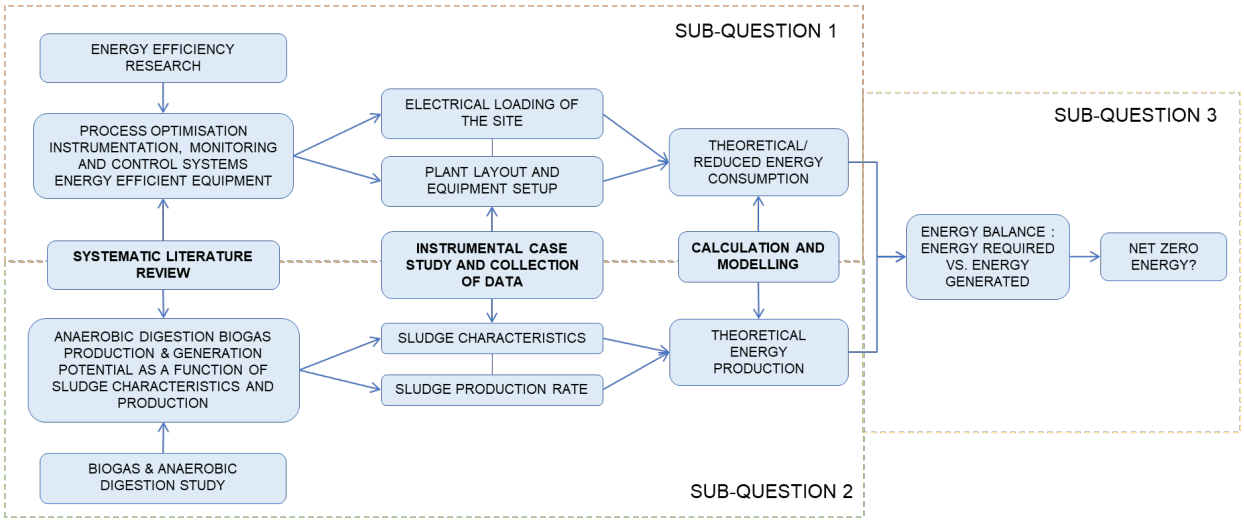


Figure 12: Research Design

3.2.1 The Case Study

The use of an instrumental case study was selected to allow a broad topic to be explored, while still maintaining the boundaries of a masters-level degree. The aim of the case study to allow a clear and decisive response to the research questions, by demonstrating a scenario where a NZE WWTP in South Africa is either definitively viable, or not viable. Being an instrumental case study, acknowledgement must be made regarding the limitations of the research conclusions, as provided in Section 3.6.

3.3 Qualitative systematic literature review

A systematic literature review aims to provide an answer to a clearly formulated question or set of questions by identifying, selecting, and critically appraising research compiled by others (Dewey and Dahota, 2016).

3.3.1 Sub-question 1

The aim of this section of the research, as provided by sub-question 1, is to quantify a realistic value to which the energy consumption of a WWTP can be reduced through energy efficiency measures. To provide context to this, background into the general energy efficiency design and practice in WWTPs has been provided in Section 2. This provides insight into how energy efficiency measures have been implemented in other countries, as well as lessons learnt from case studies. From Section 2.6 and Section 0, it is observed that to be able to quantify the theoretical energy reduction that could be achieved, three main categories should be investigated, and an approximation of the theoretical energy savings be deducted. These are categorised as follows:

- Process control optimisation
- Instrumentation, monitoring, and control systems
- Energy efficient equipment

3.3.2 Sub-question 2

Sub-question 2, as introduced in Section 1.6, investigates the biogas production, and subsequent energy generation potential of the WWTP. Similar to sub-question 1, the answer to sub-question 2 is informed by both systematic literature review and quantitative data analysis.

The initial literature review, as detailed in 2, aims to provide context to and motivation for the implementation of anaerobic digesters on WWTPs to produce biogas. This chapter further aims to provide a condensed scientific background regarding the relationship between WWT sludge characteristics and its biogas production potential. This is important as it provides the baseline for the systematic literature review, which aims to determine the calculations and modelling methods required to predict the biogas production of a WWTP. This is based on the general sludge characteristics and the sludge production rate of the plant.

3.4 Quantitative data collection and analysis

Quantitative research is the process of collecting and analysing numerical data. In this case, the data will include the energy demand data of the WWTP over time, as well as the sludge production rates over the same period. Due to the timeframe limitations of the study, and the nature of the data, the information requested from the CoCT will extend backwards for a twelve-month period, up until the date that the data is retrieved.

3.4.1 Sub-question 1 and 3

The answer to sub-question 1, is two-fold. Firstly, the study must determine a quantity or percentage in which the energy consumption is reduced through specific and available energy efficiency measures. Secondly, the study should provide theoretical energy consumption of the site in kW, one which would consider the applied energy efficiency measures.

Both of these should relate specifically to the site, in that the energy efficiency measures included in the reduction quantity, should be based on the process and equipment that is found on the existing site. For example, an energy consumption reduction assumption should not be included for process control optimisation if the existing site is already making use of such technology. This means, that details of the process, instrumentation, and plant equipment of the existing site must be collected.

To provide an outcome for sub-question 3, which is linked to sub-question 1, the energy demand of the existing site must also be collected or retrieved as shown in step 1 in Figure 11. This is to feed into the final energy balance as the energy required for the site to operate. It is important to note that this energy

demand data should extend through a minimum of twelve months. This is to take into consideration the variation in energy demand due to seasonal fluctuations, rainfall patterns, social sanitation trends, and influences such as interrupted municipal power supply.

In an ideal world, a NZE user should be consistently net-zero. To elaborate on this, the plant needs to be able to generate enough energy, that it does not require any electrical input, even in its peak demand periods. This is a debatable statement, as a plant may claim to be net-zero if its overall energy demand throughout the year is offset by the energy generation over the same period. This means, that during periods when the energy generation exceeds energy demand, this excess energy is stored either thermally, in batteries or for specific cases, in hydrogen fuel cells to offset future energy demand. Therefore, in periods of excess demand, the energy saved during periods prior to this may be used to offset the excess.

In order to simplify this study, the analysis will focus purely on the peak periods of energy consumption, being the output or outcome of sub-question 3. The flow of this quantitative data collection process is represented in Figure 11 below.

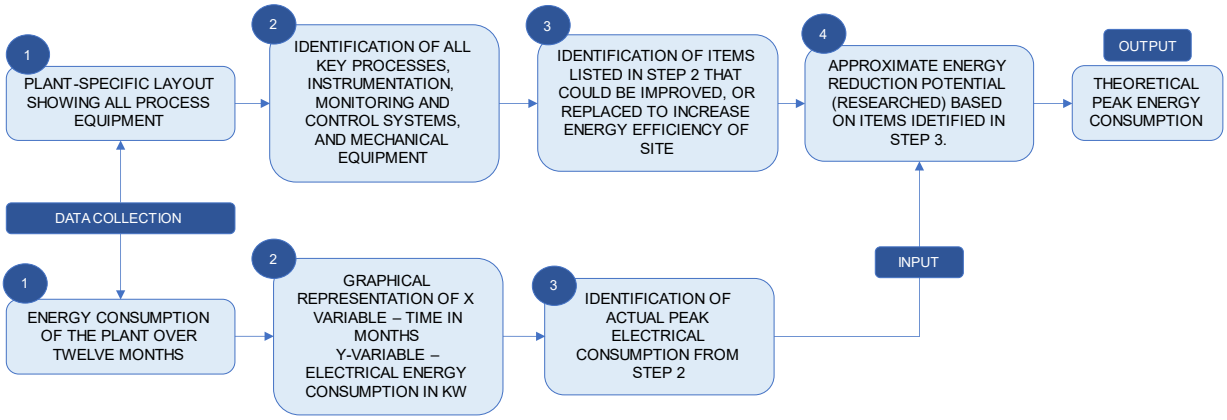


Figure 13: Quantitative Data Collection for Sub-question 1 and 3

3.4.2 Sub-question 2 and 3

Sub-questions 2, involves a second, yet equally important data collection stage. As discussed in the literature review, there are multiple variables which influence the production of biogas. Due to the constraints outlined in Section 3.6, only two key variables will be included in the calculation of theoretical biogas production. The first is the sludge characteristics of the site, provided as the Total Solid (TS) percentage of the sludge produced at the site, as well as the Volatile Solid (VS) percentage. These values determine the ratio of methane (CH_4) to the total biogas produced during anaerobic digestion. The second variable to be investigated, is the sludge production rate. Both the sludge characteristics and the rate of sludge production are essential in quantifying the potential volume of the biogas which could be realised.

Both of these variables form the inputs for the theoretical volume of methane generated through the anaerobic digestion process as shown in Figure 12. The final output of the data collection process, is the theoretical energy generated from biogas, reported in kWh. This is directly proportional to the volume of methane generated.

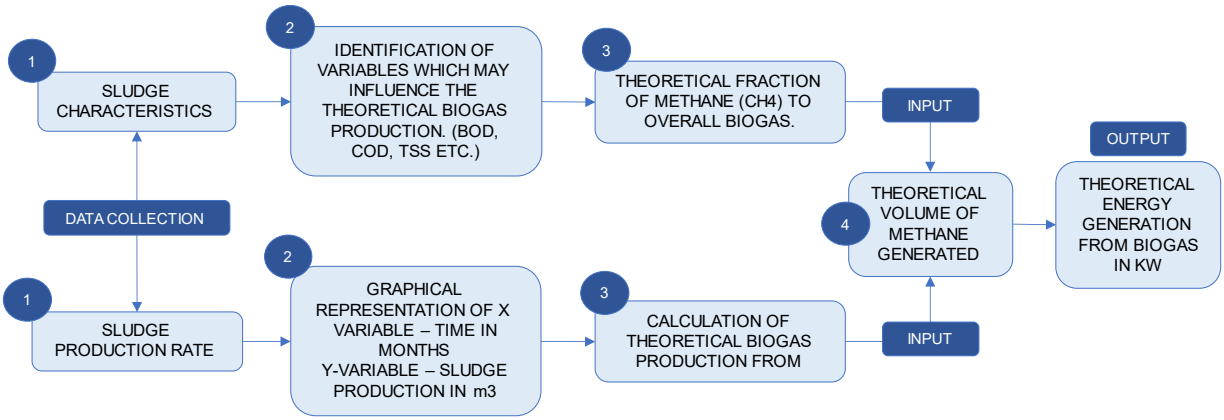


Figure 14: Quantitative Data Collection for Sub-question 2 and 3

The theoretical energy generation forms the input for Sub-question 3, and ultimate the 'energy required' variable of the overall site energy balance. To provide a positive outcome for sub-question 3, being that the plant has the potential to be categorised as a NZE user, the theoretical energy generation should exceed the theoretical energy consumption determined through the methodology provided in Section 3.4.1.

3.4.3 Summary of data collection requirements

Table 3-1 provides a summary of the research design, linking the data collection methods and the analysis of the data to the research objectives of each sub-question provided in Section 1.6.

Table 3-1 - Summary of research objectives and data collection

Research objectives	**Data required**	**Data Sources**	**Data analysis method**	**Output requirement**
Research sub-question 1: What reduction in energy consumption could be realised on WWTPs in South Africa through the implementation of energy efficiency measures?				
Opportunities to retrofit an existing WWTP with the necessary equipment for energy recovery, more specifically anaerobic digestion, and biogas technologies.	a) Existing site layout and process information. b) Equipment and implementation requirements.	a) City of Cape Town. b) Previous studies/ literature.	1. Systematic literature review. 2. Secondary research data	Insight into the practical methods and feasibility of reducing energy demand of the site using energy efficiency and process optimisation methods.
Research sub-question 2: What quantifiable energy generation potential could be achieved through anaerobic digestion and biogas production on WWTPs in South Africa?				
Energy consumption patterns within WWTPs and what quantitative effect energy efficiency measures could have on reducing this.	a) Energy consumption of the WWTP. b) Energy demand reduction trends in WWTP through energy efficiency.	a) City of Cape Town. b) Previous studies/ literature.	1. Systematic literature review. 2. Secondary research data	Deduction and approximation of the energy generation potential of a WWTP based on the sludge production of the existing site.
Research sub-question 3: Would the implementation of energy efficiency measures, and the production of electrical energy from biogas be enough to result in a NZE wastewater treatment plant?				

The extent of energy production that could realistically be achieved through the production of biogas and its conversion to electrical energy.	a) Total daily sludge production rates on site. b) Sludge characteristics (TSS, TS and VS)	a) City of Cape Town. b) Previous studies/ literature	Secondary research (data collected by others).	Calculation and theoretical prediction of biogas production from sludge. Furthermore, the calculation and theoretical prediction of electrical energy which could be generated from the biogas.
Main research question: Could NZE WWTPs, through the integration of biogas technology, be a reality in the context of South African infrastructure?				
The potential to offset the energy consumption of the site, characterising it as a NZE user.	a) Combination of data collected in sub-question 1, 2, and 3.	Combination of sources in sub-question 1, 2, and 3.	Theoretical calculations based on data collected.	Comparison of actual energy demand once reduced by energy efficiency quantity and theoretical energy generated.

This design of research is particularly advantageous as it based primarily on secondary research, in that the data has already been collected by others for a separate purpose. In this case, the data would already be recorded by the municipality who owns the WWTP as part of mandatory site monitoring.

Furthermore, a large sample size will be analysed, with outliers being accounted for and variable bias being avoided. As deduced from the initial literature review, energy demand and sludge production are both variables whose quantities will vary throughout the year, and therefore it is imperative that a full twelve-month period is included in the study.

3.5 Ethical considerations

According to Beauchamp and Childress (1983), there are four principles of ethical concerns that should be respected in any research. They are respect for individual rights, beneficence, not doing harm and being just. These align with the ethics framework of Wits University to which this study will require clearance for.

Many ethical considerations need to be met during data collection as well as reporting in a research study. This is oftentimes most important when studies involve qualitative assessments such as human studies and/or interviews. As much of the data to be collected and analysed is quantitative, the ethical issues considered would simply include the privacy and confidentiality of the source at the City of Cape Town unless permission is granted.

3.6 Assumptions and limitations of the study

The scope of this study is limited to a case study of one particular site located in the Western Cape of South Africa. The report is also limited to the level of a master's degree, constrained to one year of research. Several assumptions and limitations to the study have been noted, with many more to be identified over the course of the reporting period.

3.6.1 Assumptions

It is assumed that energy efficiency measures implored on similar facilities would yield the same, or similar energy reduction on the site under investigation. This would need to be reported with a relevant amount of uncertainty to account for the differences in physical layout and topography of the site, as well as the treatment process and requirements. The topography and layout of the site plays a significant role in the pumping requirements due to the differences in elevation and pipe lengths that can arise. The treatment process is equally as influential on the energy consumption of the site as it dictates the type and size of equipment that is found at the plant.

Secondly, it is assumed that energy efficiency measures are scalable to a degree, based on the energy demand and PE of the plant. Additionally, it is assumed that the data collected over a period of twelve months is a true reflection of the site, despite the changes in demand that occur annually and seasonal changes that may occur between differing years of study. This assumption is particularly relevant given the varied weather patterns in the Western Cape of South Africa in the last five years, characterized by distinct drought periods and extended heavy rainfall. These weather conditions directly affect the plant's operational load, as it is heavily dependent on the inflow rates, including those received from storm systems.

3.6.2 Limitations

This master's dissertation encounters general limitations, including time constraints, challenges in data collection, and limitations in analysing depth and expertise. To align with the available time frame, the study's scope had to be narrowed. Consequently, reliance on existing third-party data became necessary, as there wasn't enough time for a twelve-month observational data collection—a vital component for analysis. This reliance introduces uncertainty, recognising the study's dependence on third-party data.

Analysing results was also restricted by the allocated timeframe and expertise. The investigation demanded a thorough literature review and understanding of wastewater processes, plant configurations, and mechanical equipment intricacies, including electrical load. In instances where experience and time didn't permit an in-depth analysis, assumptions were made based on available literature.

Aside from the general limitations above, there are limitations and corresponding assumptions that are specific to each variable within the study that must be highlighted. These limitations and the assumptions based thereon are provided in Table 3-2.

Table 3-2 - Table identifying the limitations and associated assumptions of the study

Limitation	**Assumption**
Energy Efficiency Measurements	
There are multiple factors, other than those recommended in Section 3.3.1, that would influence or potentially reduce the energy consumption of WWTPs. This includes aspects such as training of personnel and facility management, replacement of faulty equipment etc.	It is assumed that no other energy efficiency measures other than those identified in Section 6 are implemented.
The Current State of Electrical Supply in South Africa	
As mentioned in 2.4, South Africa is currently experiencing disruptions in the supply of electricity, otherwise known as loadshedding. The impact of loadshedding will show as a reduction in energy demand, as no municipal electricity would be used during periods when loadshedding occurs. These disruptions and an overall decrease in energy demand shown by the energy consumption records are acknowledged but the effect will not be included in the study.	It is assumed that the energy consumption is Business as usual (BAU) with no consideration for loadshedding, and therefore the recorded electricity consumption is used, unadjusted.
Wastewater Sludge Characteristics and Biogas Production	
The overall production of biogas is influenced by the characteristics of sludge that is collected during the primary and secondary settlement stages. This has been accounted for, however, the variability of this will not likely be considered. The sludge characteristics will vary over time, depending on the influent wastewater received by the plant. Due to the time and scope limitations, this will not be considered.	The sludge characteristics of the plant are assumed to be consistent throughout the period under investigation.
There are multiple variables which would determine the quantity of methane present in the biogas including the temperature and pH of the sludge. This is however beyond the scope of the study.	It is assumed that the temperature and pH levels of the sludge are consistent throughout the treatment process throughout the investigation.

Type of WWTP Secondary Treatment Process	
There are numerous secondary treatment processes found on WWTP including CAS, MBR, SBR and PBFRs. Each type of treatment train is a determinant of what equipment will be found on site and where the energy will likely be consumed.	The site chosen has two secondary treatment processes, the CAS and MBR. Therefore, the other treatment processes will not be considered for this study.
Site Considerations	
In projects associated with retrofitting an existing WWTP, significant consideration would be given towards the implications that changes to the plant may have on the overall process and effluent quality. Prior to any retrofitting of the site, the effluent quality should also be monitored to ensure that standards are still being met.	For this report, an idealisation is created, and it is assumed that the process requirements of the plant are not impacted by the changes included.
The Definition of NZE	
As mentioned in Section 3.4.1, a definition for a NZE facility should typically look at various loading cases. There are a relatively large number of cases which could be argued for different scenarios regarding the label Net Zero. The site's average energy production should entirely offset the average energy consumption. However, there should be a case where the minimum energy production can still offset the maximum.	This study will only make a comparison between data within the same month. Eg. the calculated biogas production based on the sludge data received for that month will be compared to the energy consumption of that specific month.

4 Data Collection

Due to ethical considerations, the WWTP studied for this investigation shall remain anonymous and shall be referred to as “the site”. Only information that is pertinent to the research shall be disclosed.

4.1 Process Information

4.1.1 Process Parameters

The key process parameters of the site are provided in Table 4-1 below.

Table 4-1 – Site characteristics of WWTP

Parameter	**Description**
Site Location	Western Cape
Design Capacity	72 Ml/day
Process	2 No. CAS (MLE) and 2 No. MBR (full BNR)
Primary Sedimentation Included	Yes
Aeration	CAS Module: Mechanical Surface MBR Module: Fine Bubble
Disinfection	Chlorine Gas
Anaerobic Digester	None
Dewatering	Mechanical Primary Sedimentation and Waste Activated Sludge.
Catchment	Residential (middle and lower income), Commercial, and Industrial

4.1.2 Process Flow

The process flow of the site is illustrated in Figure 13 below, indicating the summarised flow through the treatment plant from the distribution network to the discharge points.

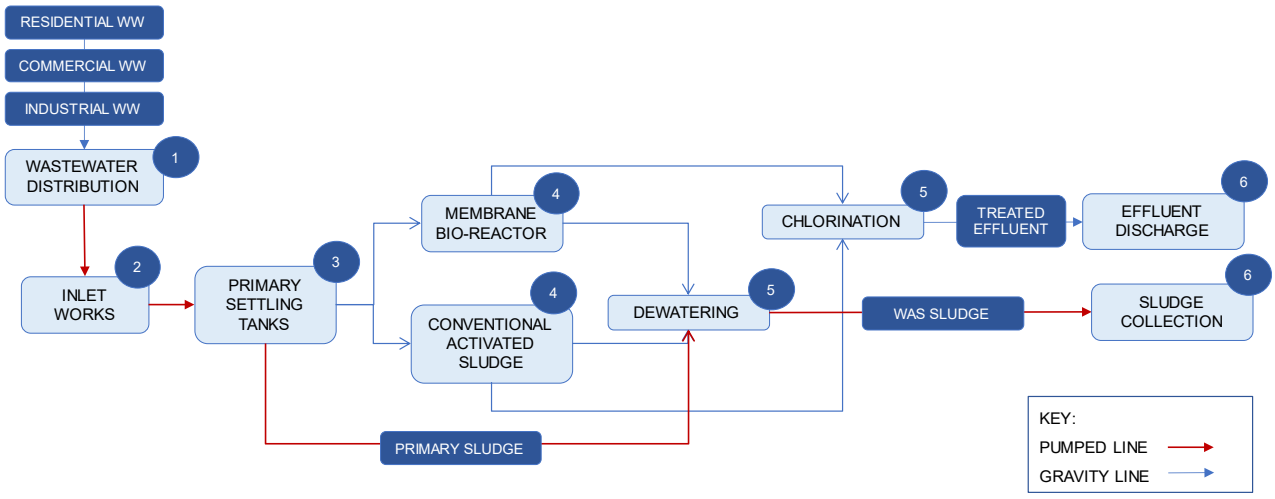


Figure 15: Process Flow Diagram for WWTP

As shown in the process flow diagram (PFD) above, the wastewater leaves the distribution network, entering the site at the inlet works. After screening at the inlet works, the wastewater, is pumped to a total of four PSTs. The wastewater is separated here into the primary effluent, sent to the CAS and MBR process plants, and the primary sludge which is pumped to the sludge holding and collection area. The primary effluent undergoes further filtration and settling at the MBR and CAS plants, with the filtered effluent flowing to the chlorination site to be chemically treated.

The sludge produced at the MBR and CAS plants is sent the dewatering facilities to be further separated into solids and suspended liquids. The waste activated sludge (WAS) join the primary sludge at the

sludge holding facilities, whereas the liquids removed are sent through to the chlorination plant. From the chlorination plant, the now treated effluent is at a quality deemed suitable to be returned to the existing water course. The solids are stored on site and periodically removed via sludge transportation vehicles.

4.2 Site Process Equipment

A comprehensive list of the key mechanical equipment found on site, as well as each subsequent power rating was provided by the CoCT for the study and is summarised in Table 4-2.

4.2.1 Full Site Mechanical Equipment List and Power Ratings

Table 4-2 - Full Site Mechanical Equipment List and Power Ratings

Location	Equipment	Power Rating (kW)	Motor Type	Total Installed
Inlet Works	Trash Rack Screen Hoist	0.4	VSD	1
Inlet Works	Belt Conveyor	3	DOL	1
Inlet Works	Grit Classifier (Degritters)	0.75	DOL	4
Inlet Works	Course Screens	1.5	VSD	4
Inlet Works	Fine Screens	1.5	VSD	4
Inlet Works	Bull Gear (Degritters)	1.5	DOL	4
Inlet Works	Trash Max	2.2	VSD	3
Inlet Works	Odour Control Units	4.22	DOL	2
Inlet Works	Brush Drive Fine Screens	2.2	VSD	4
Inlet Works	Course Screens Compactor	5.5	DOL	2
Inlet Works	Fine Screens Compactor	5.5	DOL	2
Inlet Works	Course Screens Washer	6	DOL	2
Inlet Works	Fine Screens Washer	6	DOL	2
Inlet Works	Pump (Degritters)	11.2	DOL	4
Inlet Works	Screw Pumps	185	SS	4
Upper Screw PS	Screw Pumps	185	SS	4
Upper Screw PS	Odour Control Units	4.22	DOL	1
PSTs	Bridge Motors	0.18	DOL	8
PSTs	Primary Sludge Pumps	18.5	VSD	2
PSTs	Primary Macerator	2.2	DOL	1
MBR Pumpstation	Pumps	55	VSD	4
MBR Fine Screen	Fine Screen Motor	0.55	DOL	6
MBR Fine Screen	Fine Screen Screw Conveyor	1.5	DOL	6
MBR Fine Screen	Common Screw Conveyor	3	DOL	2
MBR Fine Screen	Common Screw Compactor	4	DOL	2
CAS Plants - A and B	Aerators (90 kw)	90	VSD	6
CAS Plants - A and B	Aerators (75 kw)	75	VSD	10
CAS Plants - A and B	Aerators (55 kw)	55	VSD	4
CAS Plants - A and B	Submersible Mixers	7.7	DOL	16
CAS Plants - A and B	AE-AX Recycle Pumps	21.7	VSD	6
CAS Plants - A and B	RAS Pumps	40	VSD	4
CAS Plants - A and B	WAS Pumps	3	DOL	4
CAS Plants - A and B	SST Bridges	0.18	DOL	24
MBR-B	Anaerobic Mixers	3	DOL	12
MBR-B	Anoxic Mixers	7.5	DOL	12
MBR-B	AX-AN Recycle Pumps	2.5	VSD	9
MBR-B	AE-AX Recycle Pumps	10	VSD	9
MBR-B	Swing Recycle Pumps	20	VSD	4
MBR-B	FBDA Blowers	160	VSD	5

Location	Equipment	Power Rating (kW)	Motor Type	Total Installed
MBR-B	Air Scour Blowers	132	VSD	6
MBR-B	Membrane Feed Pumps	20	VSD	6
MBR-B	Membrane Tank Drain Pumps	18.5	VSD	3
MBR-B	WAS Pumps	18.5	VSD	2
MBR-B	Permeate pumps	75	VSD	9
MBR-B	Ventilation Fans	5.5	DOL	8
MBR-B	Air compressors	18.5	DOL	2
MBR-B	Citric Acid mixer	1.1	DOL	1
MBR-B	Service water	11	VSD	4
Dewatering	Hydraulic Power Packs	1.1	DOL	10
Dewatering	Belt Drives	5.5	VSD	10
Dewatering	Linear Screen Drives	2.2	VSD	6
Dewatering	WAS Feed Pumps	22	VSD	6
Dewatering	WAS Poly Pumps	1.5	VSD	6
Dewatering	Primary Feed Pumps	15	VSD	4
Dewatering	Primary Poly Feed Pumps	1.5	VSD	4
Dewatering	Poly Lube Pumps	0.75	VSD	3
Dewatering	Compressors	5.5	DOL	2
Dewatering	Odour Control	15	DOL	1
Dewatering	WAS Screw Conveyors	7.5	DOL	2
Dewatering	Primary Screw Conveyors	7.5	DOL	2
Dewatering	WAS Cake Pumps	55	VSD	3
Dewatering	Primary Cake Pumps	55	VSD	3
Dewatering	WAS Silo Discharge screws	5.5	DOL	4
Dewatering	Primary Silo Discharge Screws	7.5	DOL	4
Dewatering	WAS Holding Aerators	37	SS	6
Dewatering	Primary Degritted Pumps	7.5	DOL	2
Dewatering	Grit stirrer	0.55	DOL	1
Dewatering	Grit Classifier	1.5	DOL	1
Dewatering	Primary Recirculation Pumps	37	DOL	2
Dewatering	WAS Central Collection	30	DOL	2
Dewatering	WAS Macerator	4	DOL	1
Dewatering	Primary Filtrate Pumps	15	DOL	2
Dewatering	WAS Filtrate Pumps	55	DOL	3
Dewatering	Service Water Pumps	75	VSD	4

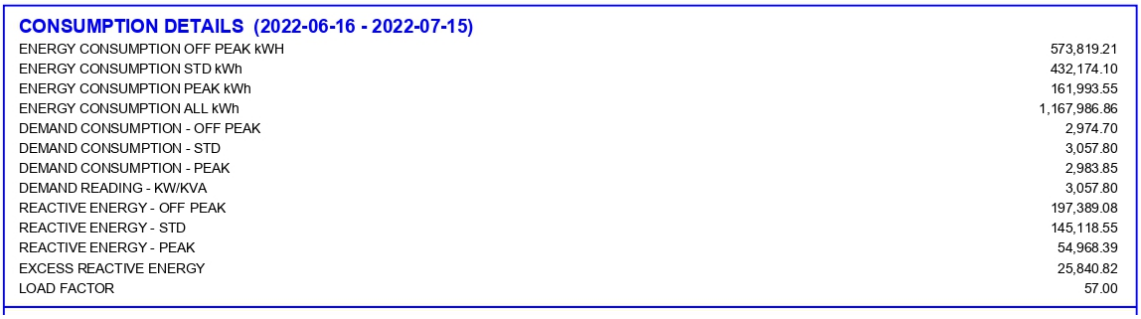
4.2.2 Equipment Electrical Demand

Table 4-3 - Electrical demand (kW) of mechanical equipment per process on site

Equipment Category	Inlet Works	Upper Screw PS	PSTs	MBR PS	MBR Fine Screens	CAS Plants - A & B	MBR-B	De-watering	**Category Total (kW)**
Screening	76.8	/			26.3		/	247	**350**
Grit Removal	9	/	/	/	/	/	/	2.05	**11**
Mixing	/	/	/	/	/	123.2	127.1	/	**250**
Aeration	/	/	/	/	/	1510	1592	222	**3324**
Pumping	784.8	740	37	220	/	302.2	1080	1018.25	**4182**
Misc.	8.44	4.22	3.64	/	/	4.32	125	109.2	**255**
Plant Sub-Process Total	**879**	**744**	**41**	**220**	**26**	**1940**	**2924**	**1599**	**8373**

4.3 Electricity Consumption Readings

The energy consumption data was provided in the form of Eskom electricity bills. Figure 14 below shows an example of the key information extracted from the individual utility bills. The remainder of the records can be found in Appendix C.



CONSUMPTION DETAILS (2022-06-16 - 2022-07-15)	
ENERGY CONSUMPTION OFF PEAK kWH	573,819.21
ENERGY CONSUMPTION STD kWh	432,174.10
ENERGY CONSUMPTION PEAK kWh	161,993.55
ENERGY CONSUMPTION ALL kWh	1,167,986.86
DEMAND CONSUMPTION - OFF PEAK	2,974.70
DEMAND CONSUMPTION - STD	3,057.80
DEMAND CONSUMPTION - PEAK	2,983.85
DEMAND READING - KW/KVA	3,057.80
REACTIVE ENERGY - OFF PEAK	197,389.08
REACTIVE ENERGY - STD	145,118.55
REACTIVE ENERGY - PEAK	54,968.39
EXCESS REACTIVE ENERGY	25,840.82
LOAD FACTOR	57.00

Figure 16: Energy consumption details extracted from individual Eskom Utility bills

This gave insight into not only the energy consumption of the site, but also provided a demand consumption of the site to which the mechanical equipment demand discussed in Section 4.2 could be compared.

4.4 Process Control Implementations

A number of process controls are implemented on site to control the equipment based on level, flow, oxygen content, and pressure. The main aim of these implementations is to ensure that the equipment is not overused, and that the discharge effluent is of the correct quality. A full list of the control interventions is provided in the Appendix E and further discussions thereon are provided in Section 6.2.

4.5 Sludge Characteristics

The CoCT provided three sets of records which outlined the mandatory sludge testing results which are required to be carried out every three months. For quality control purposes, each test requires a minimum of three samples. The results of the full testing procedure are found in Appendix A, however the characteristics key to this study are recorded in Table 4-4 below.

Table 4-4 - Key sludge characteristics as per site sample testing

Sample Date	25/08/2022			29/11/2023			09/03/2023		
Sample No	1	2	3	1	2	3	1	2	3
pH	5.64	5.48	5.38	6.71	6.66	6.54	6.08	6.01	5.99
Total Solids (%)	11.6	11.8	11.7	19	15.7	16	12.9	12.9	12.8
Volatile Solids (%)	8.8	8.7	8,8	12.9	12.6	12.9	9	9.2	8.9
Volatile Fraction (%)	75.9	73.7	75.2	80.8	80.3	80.6	69.8	71.3	69.5
Volatile Fatty Acids	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

4.6 Sludge production rates

4.6.1 Primary Sludge

As shown in the process diagram found in Section 4.1.2, sludge from the primary settlement tanks is conveyed to the dewatering building. A complete record of the primary sludge generated each day for the period of 16/06/2022 through to 15/06/2023 can be located in Appendix B.

The daily quantities were summed as shown in Table 4-5 below.

Table 4-5 - Primary sludge generated on site from 16/06/2022 to 15/06/2023

Month												
	2022							2023				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Period Start Date	16/06	16/07	16/08	16/09	16/10	16/11	16/12	16/01	16/02	16/03	16/04	16/05
Period End Date	15/07	15/08	15/09	15/10	15/11	15/12	15/01	15/02	15/03	15/04/	15/05	15/06
Total Days	29	30	30	29	30	29	30	30	27	30	29	30
tDS from Primary Sludge*(a) (tons)		775.0	762.3	712.9	723.4	586.3	717.9	842.6	704.7	776.1	673.7	653.7

*tDS = Total Dry Solids
(a) – Total dry solids is not to be confused with Total Settled Solids, being the portion of the tDS that is left behind after the liquid volume has been removed.

4.6.2 Waste Activated Sludge

As shown in the process diagram found in Section 4.1.2, sludge from the CAS and MBR process plants, which combined forms the WAS, is also sent to the dewatering building. Similarly to the primary sludge, a complete record of the WAS sludge generated each day for the period of 16/06/2022 through 15/06/2023 can be located in Appendix B.

The daily quantities were summed as shown in Table 4-6 below.

Table 4-6 - WAS generated on site from 16/06/2022 to 15/06/2023

Month												
	2022							2023				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Period Start Date	16/06	16/07	16/08	16/09	16/10	16/11	16/12	16/01	16/02	16/03	16/04	16/05
Period End Date	15/07	15/08	15/09	15/10	15/11	15/12	15/01	15/02	15/03	15/04	15/05	15/06
Total Days	29	30	30	29	30	29	30	30	27	30	29	30
tDS WAS*(a) (tons)		583.8	607.4	639.9	584.3	552.7	444.9	469.4	508.5	682.6	487.1	554.4

*tDS = Total Dry Solids
(a) – Total dry solids are not to be confused with Total Settled Solids, being the portion of the tDS that is left behind after the liquid volume has been removed.

5 Analysis and discussion of findings

5.1 Site Overview

The site is currently serving a capacity of 72 ML/ day which, as per the literature reviewed in Section 2.2.4, classifies the wastewater treatment plant as a 'macro-sized' plant. This would mean that the WWTP is larger than 93% of the treatment plants currently operating in South Africa.

In addition, the site uses a combination of treatments, being the activated sludge and MBR technologies as detailed in Table 4-1. The activated sludge technology is very common according to SANEDI's (2021) findings presented Figure 3 of 2.2.4. The same graph shows that the MBR technology is not as common, featuring in only 8% of the South African WWTPs.

5.2 Sludge Characteristics

5.2.1 Analysis of Sludge Characteristics

As reviewed in Section 2.9, the characteristics of the sludge that is collected on site is influential on the biogas production. Table 5-1 below provides a short analysis of the sludge characteristics as per the data collected in Section 4.5.

Table 5-1- Sludge characteristics on site

Sample Date	**25/08/2022**			**29/11/2023**			**09/03/2023**			**Analysis**				
Sample No	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**Min**	**Med**	**Max**	**Av**	**Range**
pH	5.64	5.48	5.38	6.71	6.66	6.54	6.08	6.01	5.99	5.38	6.01	6.71	6.05	1.33
Total Solids (%)	11.6	11.8	11.7	19	15.7	16	12.9	12.9	12.8	11.6	12.9	19	13.82	7.4
Volatile Solids (%)	8.8	8.7	8,8	12.9	12.6	12.9	9	9.2	8.9	8.7	9.1	12.9	10.38	4.2
Volatile Fraction (%)	75.9	73.7	75.2	80.8	80.3	80.6	69.8	71.3	69.5	69.5	75.2	80.8	75.23	11.3
Volatile Fatty Acids (%)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0

5.2.2 pH

As shown in Table 5-1, the average pH of the combined sludge collected at the dewatering plant is 6.05. The pH of the samples tested during each three months varied from 5.38 to 6.71. This is expected due to the variable nature of the incoming wastewater to the treatment plant. The average pH is consistent with that found in external studies as shown in Table 2-6.

Furthermore, as recommended by Admasu et. al., (2022) in Section 2.9.6, the pH of the sludge collected on this site is within the range of values considered optimal for anaerobic digestion and biogas production.

5.2.3 Total Solids (%)

The data summary shown in Table 5-1 shows that the TS of the sludge found on site ranges from 11.6% to 19%, averaging 13.82% over the entire period. This is in line with the typical TS content as presented in Section 2.3.2, which states that the TS content of wastewater sludge commonly ranges from 12 – 40% when a dewatering plant is included in the process flow.

5.2.4 Volatile Solids (%) and Volatile Fraction (%)

Similarly to the TS, the VS content of the samples ranges from 8.7% to 12.9%, averaging at 10.38% as shown in Table 5-1. The Volatile Fraction is calculated as the percentage VS of the TS, which as shown in Table 5-1 averages at 75.23% for the samples collected. This corresponds to the typical ranges provided in Table 2-1 by the authors referenced, specifically the Thames Water Asset Standards (2014)

which provide a typical value of 75% for sites which incorporate a primary and secondary treatment phase.

5.3 Sludge Production on Site

The full set of sludge production recordings is provided in Appendix B and the summary thereof in Section 4.6. The graph below shows how the PS and WAS production varies over time on the site. In particular, the relationship between PS production and WAS production can be seen. There are two main trends that would be identified, the inverse relationship, and less frequently observed, the direct relationship.

The inverse relationship can be observed between months 2 to 9, and months 11 to 12. This inverse relationship is a result of the process. When the primary settlement tanks are operating optimally, the amount of sludge collected increases. An effluent of a higher quality reaches the secondary removal process, and hence a lower quantity of the WAS is removed at the MBR and CAS plants. Similarly, during months when the primary settlement tanks were operating below optimum, an effluent with a higher solids content reaches the MBR and CAS plants. Therefore, as observed during months 4, 6, and 12, the quantity of solids removed at the secondary removal stage is increased.

A directly proportional relationship, as observed during the months 9 to 11, would suggest an external factor. This could include, for example, increased rainfall levels, increased loading on the plant, or irregular solids content entering the WWTP during that short period.

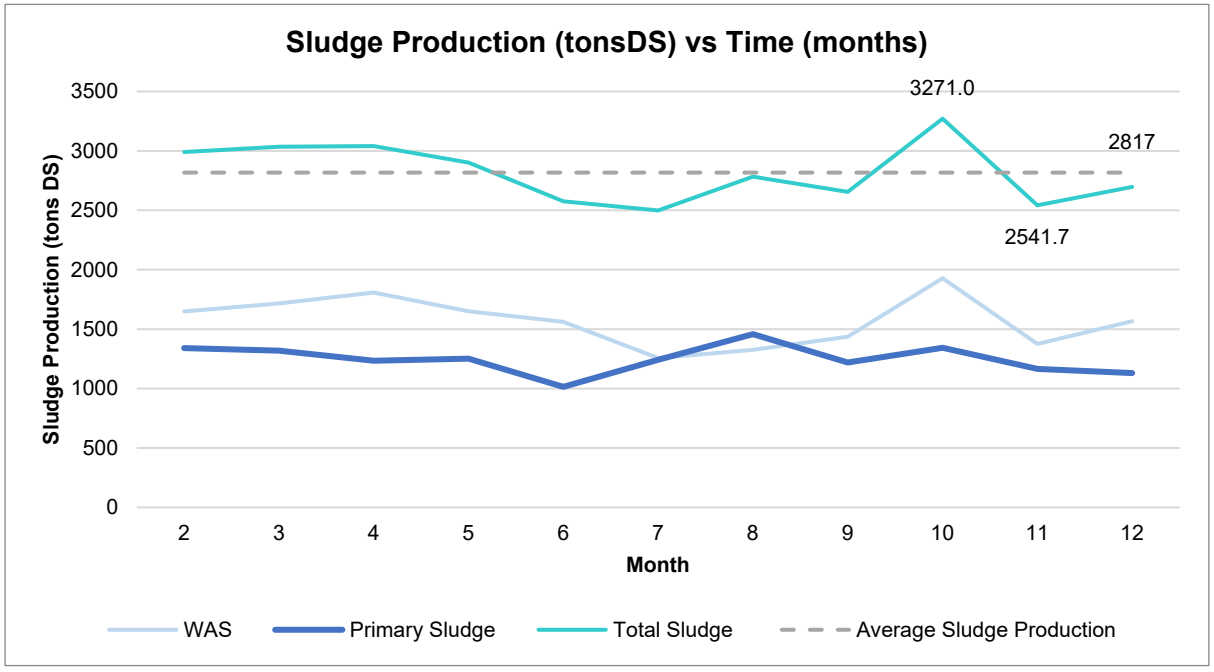


Figure 17: Graph to show the PS and WAS production over time

The total sludge was summed from the primary and waste activated sludge quantities. From Figure 17 above, the average total sludge production rate over the study period was 2817 tons/month with the minimum sludge production rate sitting at 2542 tons/month and the maximum rate at approximately 3271 tons/month.

5.4 Calculation for electricity generation from biogas production

5.4.1 Energy Production Calculation Steps

To calculate the electricity generation, the quantity of biogas produced from the site-specific sludge characteristics and sludge rate must be determined using Steps 1 – 9 below.

Step 1: From the sludge characteristics provided, determine the average Total Solids (TS%) and Volatile Fraction (VF%)

Equation 5-1: Average Total Solids

$$TS_{average} = \frac{\sum TS_i}{No.\,of\ input\ values}$$

Equation 5-2: Average Volatile Solids

$$VF_{average} = \frac{\sum VF_i}{No.\,of\ input\ values}$$

The sludge production data received from the CoCT provided the daily sludge collected from each source of both the primary settlement process as well as the waste-activated sludge (WAS) process.

Step 2: From the sludge production records provided by the CoCT, determine the monthly sludge production rate. This is shown in Section 4.6.

Equation 5-3: Monthly Sludge Production Rate for Primary Sludge

$$Primary\ Sludge\ (kg/month) = \sum Daily\ Primary\ Sludge\ Production$$

Equation 5-4: Monthly Sludge Production Rate for WAS

$$WAS\ (kg/month) = \sum Daily\ WAS\ Sludge\ Production$$

From this, the monthly Total Suspended Solids (TSS) (kgTSS/month) were calculated for both the Primary and WAS. This was based on an average Total Solids (TS%) that was determined from the sludge characteristics data.

Step 3: Determine the Total Suspended Solids (TSS) reported in kgTSS/month for both the Primary Sludge and WAS.

Equation 5-5: Monthly TSS for Primary Sludge

$$TSS_{Primary} = TS_{average} \times Primary\ Sludge\ (kgTSS/month)$$

Equation 5-6: Monthly TSS for WAS

$$TSS_{WAS} = TS_{average} \times WAS\ (kgTSS/month)$$

Step 4: Determine the Volatile Suspended Solids (VSS) reported in kgTSS/month for both the Primary Sludge and WAS.

Equation 5-7: Monthly VSS for Primary Sludge

$$VSS_{Primary} = VS_{average} \times TSS_{Primary}\ (kgVSS/month)$$

Equation 5-8: Monthly VSS for WAS

$$VSS_{WAS} = VS_{average} \times TSS_{WAS}\ (kgVSS/month)$$

Step 5: Determine the Volatile Solids Reduction using the recommended values provided by Thames Water as below.

Primary Sludge – 70% VS_{red} (Assumed from CI2.3.6 as there is chemical dosing present on the plant)

WAS – 50% VS_{red} (Assumed from CI2.3.6 as there is chemical dosing present on the plant)

Equation 5-9: Volatile Solids Reduction for Primary Sludge

$$VS_{reduction(primary)} = VSS_{primary} \times 70\% \ (kgVSS/month)$$

Equation 5-10: Volatile Solids Reduction for WAS

$$VS_{reduction(WAS)} = VSS_{WAS} \times 50\% \ (kgVSS/month)$$

Note: This is a conservative approach as it uses the minimum design values, whereas actual testing might provide a less conservative VS reduction percentage)

Step 6: Determine total plant $VS_{reduction}$ by combining the values determined in Step 5.

Equation 5-11: Total Volatile Solids Reduction

$$VS_{reduction} = \sum VS_{reduction(primary)} + VS_{reduction(WAS)} \ (kgVSS_{red})$$

Step 7: Calculate the theoretical volume of biogas produced per month for both the Primary Sludge and WAS.

Note: The VS reduced are converted into biogas, at an assumed efficiency of 60%. Again, this is conservative, and the measured biogas conversion efficiency value of the sludge samples is required to determine a more accurate result.

Equation 5-12: Biogas Conversion Calculation

$$V_{Biogas} = BP_{efficiency} \times VS_{reduction} \times {}^{1.0m^3}/_{kgVSS_{red}} \ (m^3/month)$$

Note: The biogas is quantified as 1.0m3/ $kgVSS_{reduced}$

Step 8: Determine the volume of Methane (CH_4) that would potentially be extracted from the volume of Biogas.

Equation 5-13: Volume of Methane

$$V_{CH4} = CH4_{content} \times V_{Biogas} \ (m^3/month)$$

Note: The methane content of biogas is variable according to which source is used, however, the TW asset standards provide a minimum of 50% CH4, and a maximum of 75% CH4. As this is such a wide range, a both values were used and a minimum and maximum CH4 output were calculated for comparative purposes.

Step 9: Convert the theoretical methane output to electrical energy that would be generated through a CHP generator.

Note: To convert methane to electrical energy, the volume of methane was multiplied by 10 kWh/m^3, the typical electrical conversion rate of methane to electrical energy. The efficiency of the generator motor was 35% as directed by literature.

Equation 5-14: Electrical Energy from Methane

$$E_{CHP} = V_{CH4} \times \eta_{efficiency} \times {}^{10kWh}/_{m^3} \ ({}^{kWh}/_{month})$$

The total monthly theoretical electrical energy generated for CHP was then determined.

Step 10: Repeat Step 1 – 9 for each month.

5.4.2 Electrical Energy Generation Results

The ten-step calculation process was completed for each month of the study. The full set of calculated results are as shown in Table 5-2, however a summary of the theoretical generation findings is shown in Figure 16 below.

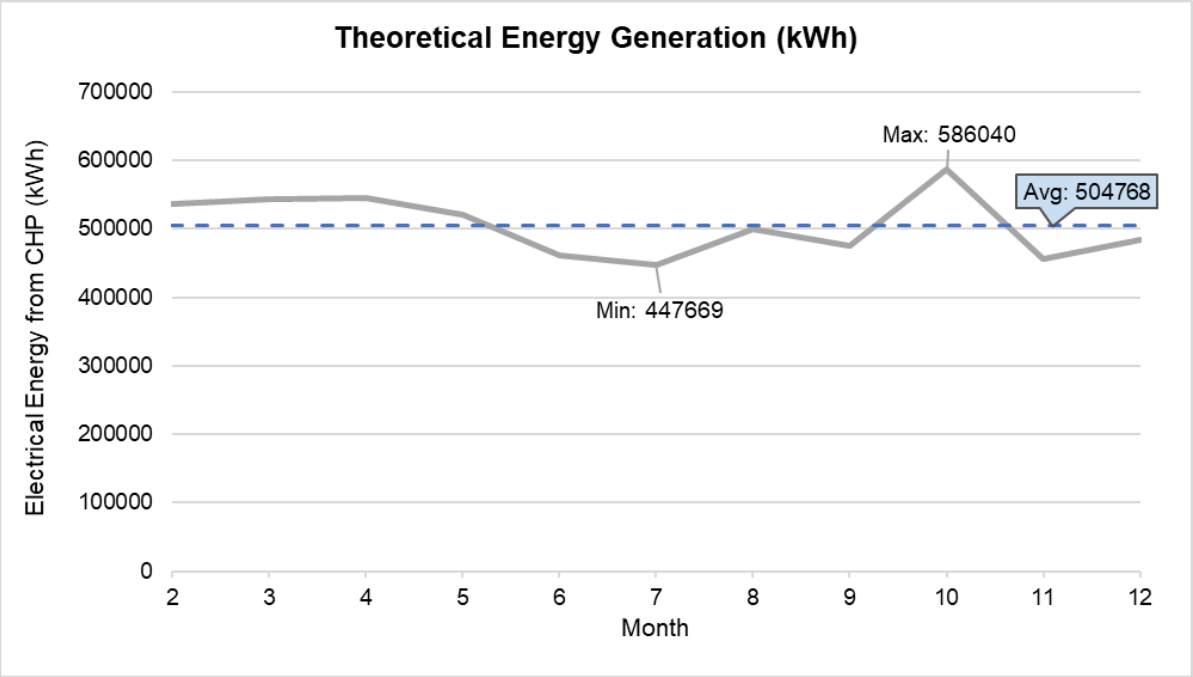


Figure 18: Theoretical Energy Generation Potential from Sludge Produced on Site

As shown in Figure 16 above, the maximum calculated potential energy generation from CHP as a function of the sludge produced on the site is 586040 kWh. During the month with the lowest sludge production, the anticipated energy generation would fall to 447669 kWh, and on average, the site would expect to generate 504768 kWh of electrical energy through an implemented CHP.

Table 5-2 - Results of Theoretical Energy Generation from Sludge Produced on Site

	Month										
Period Start Date	**16/07/2022**	**16/08/2022**	**16/09/2022**	**16/10/2022**	**16/11/2022**	**16/12/2022**	**16/01/2023**	**16/02/2023**	**16/03/2023**	**16/04/2023**	**16/05/2023**
Period End Date	**15/08/2022**	**15/09/2022**	**15/10/2022**	**15/11/2022**	**15/12/2022**	**15/01/2023**	**15/02/2023**	**15/03/2023**	**15/04/2023**	**15/05/2023**	**15/06/2023**
Total Days	30	30	29	30	29	30	30	27	30	29	30
Total Dry Sludge Production from Primary Sludge (tons/month)	1340.9	1318.9	1233.4	1251.6	1014.3	1242.0	1457.8	1219.2	1342.6	1165.6	1130.9
Total Dry Sludge Production from Primary Sludge (kg/ month)	185340.2	182297.9	170482.8	172995.5	140195.5	171678.3	201503.2	168523.3	185584.0	161106.9	156314.2
Volatile Solids Reduction (kgVS/ month)	140487.9	138181.8	129226.0	131130.6	106268.2	130132.1	152739.4	127740.7	140672.7	122119.0	118486.2
Total Dry Sludge Production from WAS (tons/month)	1649.2	1715.7	1807.6	1650.7	1561.3	1256.7	1325.9	1436.4	1928.4	1376.1	1566.2
Volatile Solids Reduction (kgVS/ month)	172795.6	179759.1	189391.3	172946.9	163582.2	131662.4	138915.9	150497.6	202040.6	144180.5	164091.4
Total Dry Sludge Production (tons/month)	2990.1	3034.6	3041.0	2902.3	2575.6	2498.7	2783.7	2655.6	3271.0	2541.7	2697.1
Total Volatile Solids Reduction (kgVS/ month)	313284	317941	318617	304077	269850	261795	291655	278238	342713	266300	282578
Biogas Production (m3)	187970	190765	191170	182446	161910	157077	174993	166943	205628	159780	169547
Methane Content (Max) (m3)	140978	143073	143378	136835	121433	117808	131245	125207	154221	119835	127160
Electrical Conversion (kWh) (Max)	1409776	1430734	1433778	1368349	1214327	1178075	1312449	1252072	1542210	1198348	1271599
Electrical Energy Generation from CHP (kWh) (Max)	535715	543679	544835	519973	461444	447669	498731	475788	586040	455372	483208

6 Energy Offset Modelling

To assess if the site's potential energy generation, as outlined in Section 5.3 could offset the plant's energy consumption, it was necessary to establish the baseline energy consumption of the site. Next, several theoretical energy reductions, provided as a percentage could be applied to the site's baseline, to determine the new reduced energy consumption.

After establishing the anticipated reduced energy consumption, a comparison can be conducted with the theoretical energy generation from sludge to determine the degree of offset.

6.1 Baseline Energy Demand and Consumption

6.1.1 Baseline Consumption Patterns

The energy consumption of the facility refers to the total amount of energy used over a specified time. In this case study, the energy consumption of the facility was provided in the form of Eskom utility bills (see section 2.4.1) as per the example provided in Section 4.3. The plant is billed in the format of the Eskom tariff with three Time of Use (ToU) periods, including off-peak, standard, and peak. This is typically measured in Kilowatt-hours (kWh) or, as in this case Megawatt-hours (MWh).

For this study, observations are based simply on the total energy consumption per month.

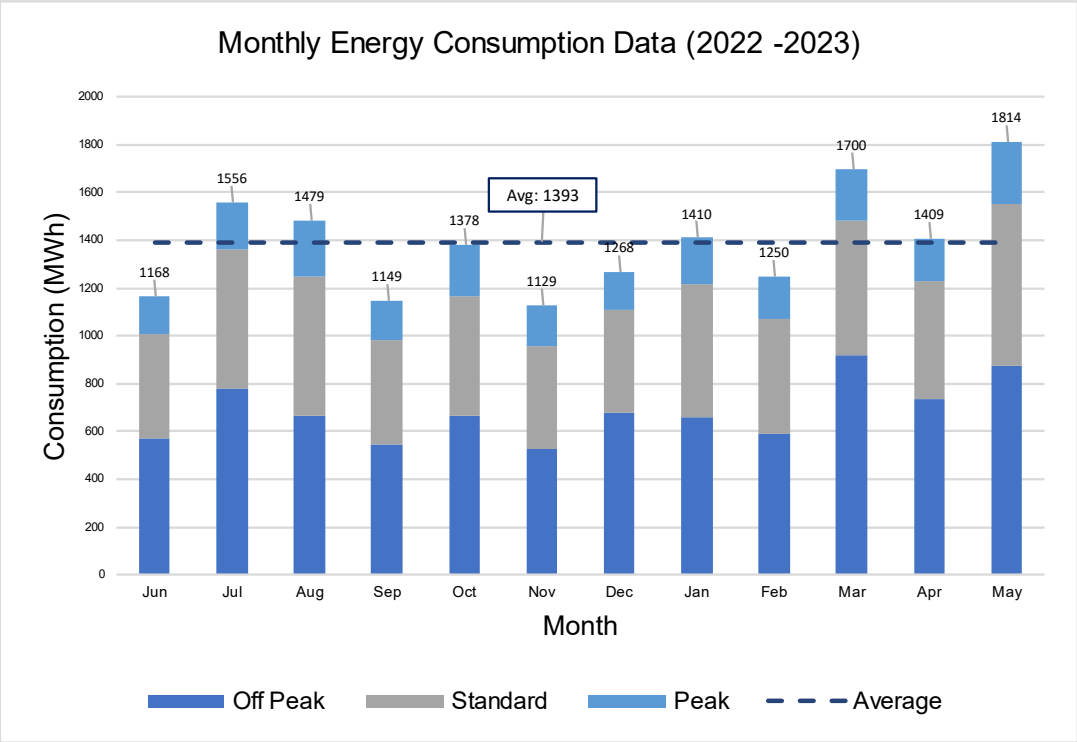


Figure 19: Monthly Energy Consumption Data (2022-2023)

Figure 17 above provides an overview of the measured consumption of the entire facility. As shown, the minimum energy consumption of the site during the study period was 1129MWh which occurred in November 2022. The maximum energy consumption of the site was 1814MWh, which occurred in May 2024. The reason for the site experiencing the maximum or minimum consumption would be reliant on aspects such as weather patterns and inflow rates as previously noted. The average energy consumption of the site was 1393MWh.

For a general indication of the energy efficiency of the plant, the specific energy consumption was calculated. At a maximum energy consumption and inflow, the plant's consumption was determined to be 0.84 kWh/m^3. This is an indication that the site is, in general, an efficient one, in comparison to many

in South Africa where the energy consumption has been reported to be as high as 1.8 kWh/m^3 as noted in Section 2.5.1. The site under investigation is however not as efficient as those in developed countries, where the maximum energy consumption ranges from 0.3 kWh/m^3 to 0.73 kWh/m^3 as reported in the study by Panepinto et. al (2015).

6.1.2 Measured Energy Demand Patterns

The energy demand measurement refers to the power that is used at a specific point in time. It represents the total instantaneous electrical energy requirement at the facility at a specific point in time. This is typically measured in a unit of power, in this case in Kilowatts (kW). As discussed in Section 6.1.1, the plant is billed in the format of the Eskom tariff, indicating the peak, standard, and off-peak periods.

Figure 18 below shows that for majority of the months recorded, the maximum demand of the site occurred during the “Standard” ToU. The maximum demand was then averaged, by taking an average of the Standards ToU readings, which is shown on the graph below. This shows that the maximum demand of the site for the twelve-month period, averaged at 3205 kW.

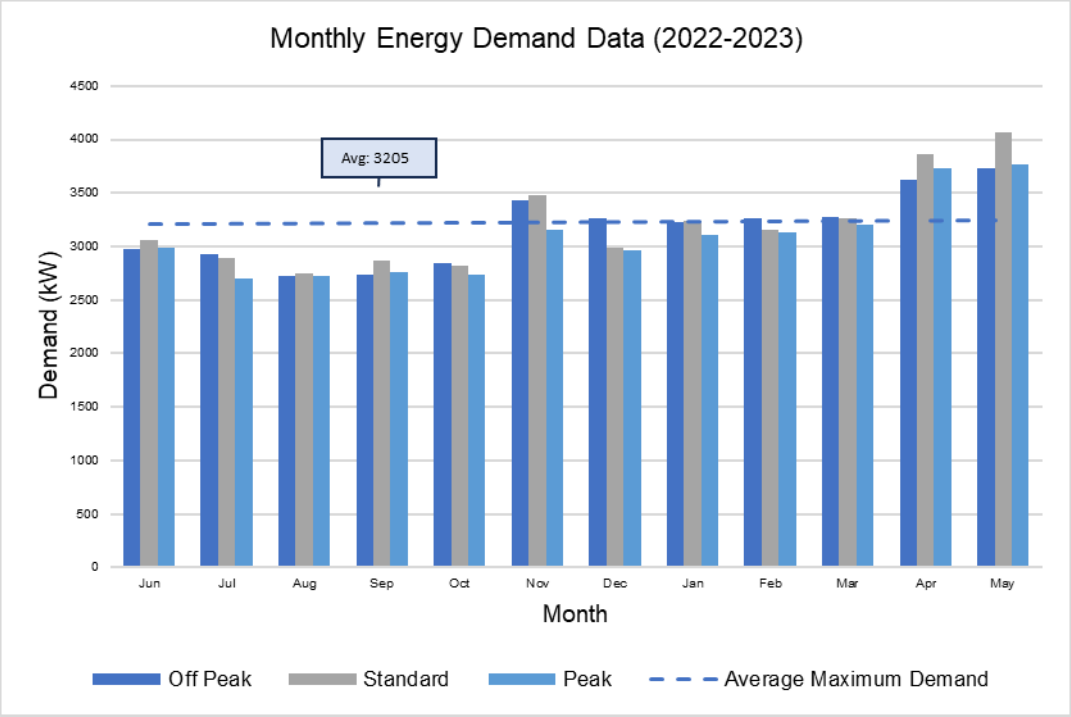


Figure 20: Month Energy Demand Data (2022-2023)

The demand measured by the electricity tariffs, can be compared to that calculated by the power ratings provided in Appendix D. The total demand of the full set of equipment is totalled at 8372.5 kW. The maximum demand measured far less than the demand of the total set of site equipment. This is as anticipated and is an indication that all the listed equipment does not, at any stage, run at maximum capacity simultaneously.

Additionally, it must be noted that while the CoCT did provide a comprehensive list of process equipment associated with the treatment plant, data for the other site infrastructure was not provided. This would include items such as lighting and HVAC systems in the buildings, dewatering systems to control groundwater, typical office equipment, security systems and street lighting.

6.1.3 Baseline Energy Distribution on Site

The full process equipment list as provided in Appendix D, was summarised to show the distribution of the energy demand both as a function of process location and of mechanical process itself. These results are shown in Figure 19 and Figure 20 respectively.

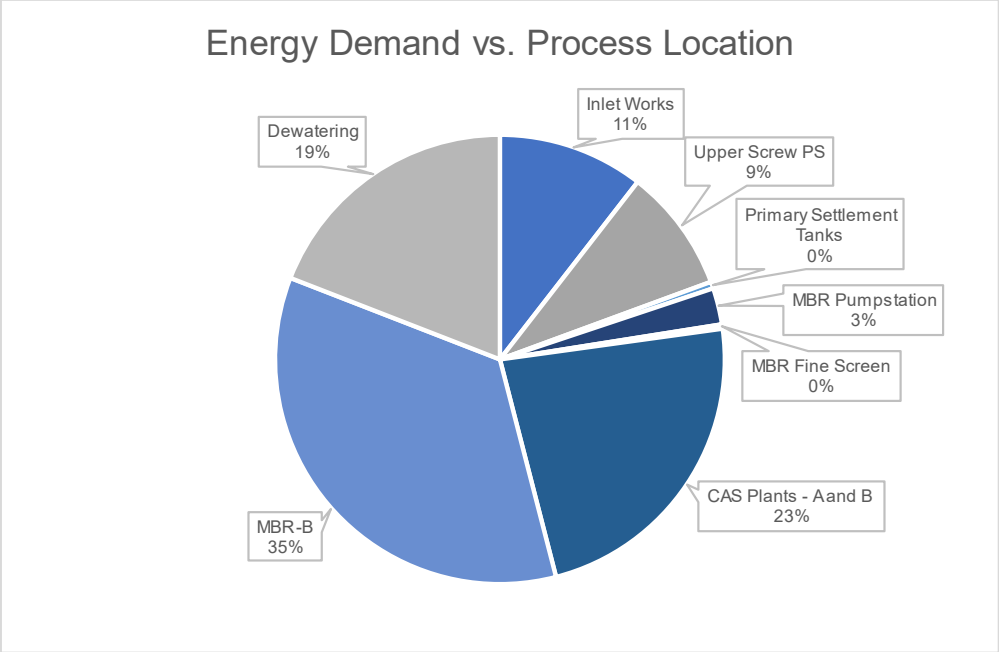


Figure 21: Energy Demand per Process Location

The energy demand of the site could be determined through the data provided in Appendix D, however, this demand is not equivalent to the consumption of the site. For a more accurate representation of the sites energy consumption distribution, an investment-level audit is required as detailed in the guideline provided by Wille et al. (2020) and reviewed in Section 2.6.3. As noted in the guideline, this would require real-time data collection using on-site monitoring equipment over a period of time. This equipment tracks real-time load and running time of each piece of equipment.

It was assumed that the energy consumption distribution was approximately proportional to the total demand of the site. Figure 20 below shows that the equipment with the highest demand, based on this assumption are the aeration and pumping processes, each accounting for 43% and 53% respectively. The percentage of energy consumed during aeration is in line with the findings of the SEAI (2017) noted in Section 2.7.3. Furthermore, the percentage of energy consumed to pump the WW to, and within the site is in line with the Thames Water guidelines reviewed in Section 2.7.5, that state that pumping is often the most energy intensive process recorded on site.

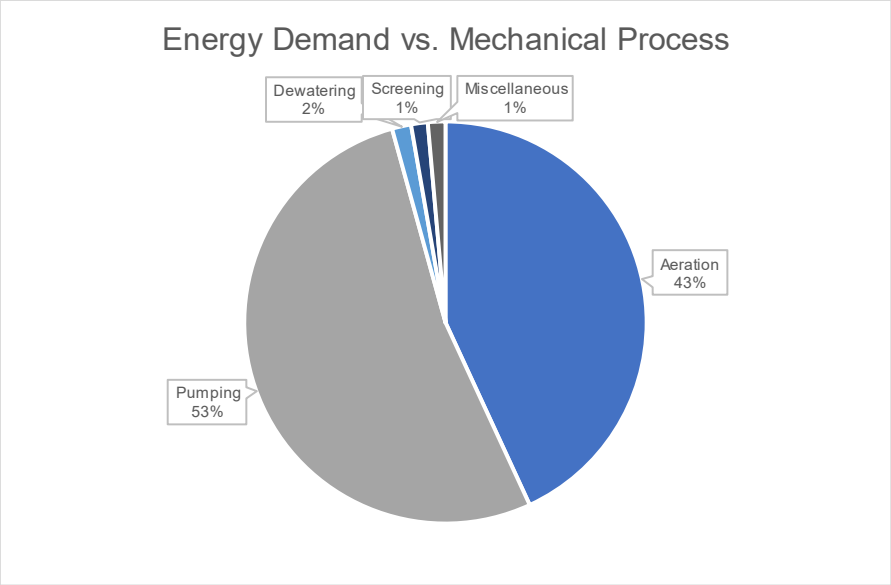


Figure 22: Energy Demand per Mechanical Process

6.2 Existing Energy Efficiency Measures Implemented

The plant in this case study has recently undergone upgrading and therefore it is already implementing a number of energy efficiency measures. As discussed in Section 6.1.1, this is evident as the recorded energy consumed per volume of influent is considerably lower than the average plant in South Africa.

6.2.1 Process Control

The following process controls are deemed energy efficiency measures as they are used to reduce the running time of the mechanical equipment, and hence the overall energy consumption of the plant. These are sub-categorised as flow control, level sensors, DO sensors and sludge density monitoring.

A full list of the control and monitoring instrumentation can be found in Appendix D, but those specific to the enhancement of energy efficiency are summarised below.

Flow Control

Table 6-1 - Existing Flow Controls on Site

Location	Subsection	Advantage
PST	Primary Sludge Pumps	VSDs control the speed of the pumps in order to maintain the operator-set flow rate for the hydro brake technology. The VSDs ensure that the pumps are only running when required.
MBRs	Raw Feed Pumps	VSDs are used to control the pumps and dictate the flow spilt between the CAS plants and the two MBR plants. As the flow to the plant increases, additionally flow is sent to the MBR. As the MBR is a complicated and energy intensive plant to operate, only the necessary flows should be sent to the MBR. This flow control ensures that the feed pumps are only running when the flow dictates them to.
MBRs	Recycle Pumps	VSDs are used to maintain the set ratio between the influent and individual reactor efficiency. This is from a pumping and a biological reaction standpoint.

Level sensors

Table 6-2 - Existing Flow Level Sensor Controls on Site

Location	Subsection	Advantage

Inlet Works	Trash Racks	The level sensor initiates the running of the screens and therefore they are not required to run continuously, only when necessary. This optimises the running time of the screens and reduces the overall energy consumption.
Inlet Works	Course and Fine Screens	The level sensor initiates the running of the screens and therefore they are not required to run continuously, only when necessary. This optimises the running time of the screens and reduces the overall energy consumption.
CAS Plants – A and B	SSTs	The quantity of sludge withdrawn from each settling tank is controlled via a flow control valve to maintain the RAS levels. If the sludge return valves were permanently opened, there would be continuous high levels at the RAS sump, and the pump would operate inefficiently, with greater energy drawn unnecessarily.
Dewatering	Belt Press Speed	Level sensors on the belts increase or decrease the speed of the belt press motors to maintain a set consistency of the dewatered sludge. By decreasing the speeds when levels are low, lower energy is required.

Dissolved Oxygen

Table 6-3 - Existing DO Controls on Site

Location	**Subsection**	**Advantage**
MBR	Aerobic Zone	The speed of the mechanical surface aerators is controlled by DO sensors, constantly measuring the DO levels in the raw water. These DO sensors are operator-set. This ensures that the aerators are not running continuously at maximum speed and are therefore conservative of energy and wear-and-tear on the machinery is reduced.

Sludge Density

Table 6-4 - Existing Sludge Density Controls on Site

Location	**Subsection**	**Advantage**
CAS plants A and B	RAS pumping	The sludge density meters will determine what volume of sludge is sent through to the dewatering plant, and what quantity is returned to feed the digester. This ensures that the sludge that is sent to the dewatering is of the correct liquid content and the dewatering process is as efficient as possible.

6.2.2 Pumping Control Methods

The methods of pumping on site are a combination of VFDs, DOLs and SSs. Each piece of mechanical equipment on site is detailed in Appendix D, including their respective pumping methods and the power rating thereof. The distribution of pumping methods on site are summarised below in Figure 21.

As shown, 49% of the pumps located at the plant are already fitted with VFDs, which is considered best practice in terms of energy efficiency as detailed in Section 2.7.

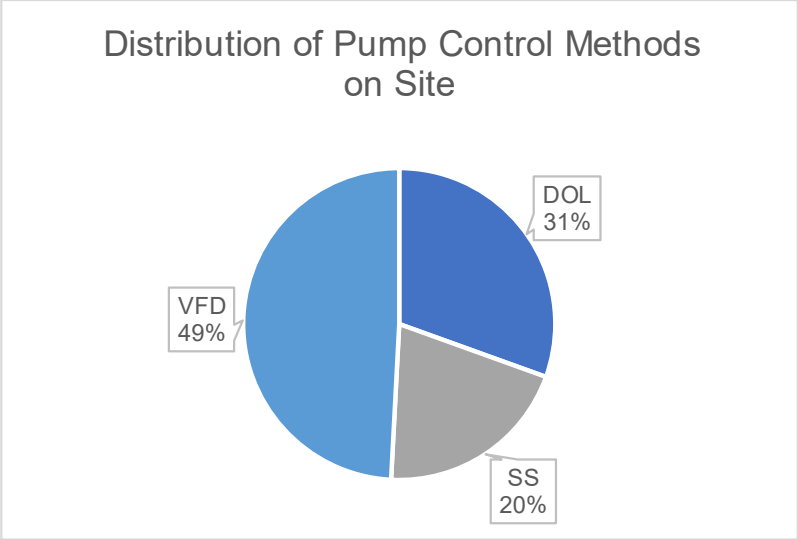


Figure 23: Pumping methods on site

6.2.3 Aeration Methods

As shown in Figure 21, the energy demand of the aeration processes on site currently accounts for 46%of the site's total energy demand. As mentioned in Section 2.7.3, the aeration process typically consumes between 40 and 60% of the entire process energy consumption, therefore this finding is in line with the literature reviewed.

The site employs two methods of aeration. The CAS plants A and B use a combination of surface aerators as shown in the Table 6-5 below. These pumps are already utilising VFDs to improve their efficiency.

Table 6-5 - Mechanical Surface Aerators Installed at CAS Plants A & B

No of	Power Rating
6	90
10	75
4	55

The MBR plant is equipped with a FBDA. According to Section 2.7.5, this method of aeration is considered best practice in terms of energy efficiency in wastewater treatment plants.

6.3 Potential Energy Saving Opportunities

As previously mentioned, this site is already operating at an energy efficiency that is superior to most in South Africa. Best practices used in developing countries could be implemented on the plant to further improve this efficiency. Several opportunities were identified, including process control systems, improvements to pumping methods, and intervention to the current aerator systems.

As noted in Section 2.7.6 of the literature review, there are a number of general energy efficiency measures that could be implemented on the existing site. Although these improvements are outside of the scope of this research report, is recommended that a potential energy savings be quantified for them, and that they are incorporated in a future study.

6.3.1 Recommendations for Process Control

The process control implementations outlined in Section 6.2.1, describe those which already exist on site. These process controls however are, in general, implemented to ensure that the process runs efficiently and that the effluent discharged quality is as designed. A full set of energy monitoring equipment, integrated with a PLC and SCADA system is a suggested implementation to specifically

ensure that each piece of equipment is only running at the required load, for the required length of time, with no electrical waste.

A quantifiable savings could not be determined for the implementation of a new PLC and SCADA system alone; however, the reduction is accounted for in the section to follow. This follows the recommendation discussed in the literature review which quantifies the potential savings of implementing VFDs with integrated PLCs.

6.3.2 Recommendations for Pumping Control

Although the plant is already equipped with a number of VFDs, there is additional plant equipment that could benefit from the variable frequency. Figure 20 shows that 20% of the pumping on site is carried out by SS pumps, while an additional 31% is carried out by DOL pumps. A full mechanical assessment would be required to determine the full extent and effects of replacing existing pumping equipment, however the key areas as provided in the Table 6-6 below are suggested.

Table 6-6 - Existing equipment on site requiring VFD and PLC integration

Process Location	Process	Description	Current Motor Type	Full Daily Consumption
Inlet Works	Pumping	Screw Pumps	SS	17760
Upper Screw PS	Pumping	Screw Pumps	SS	17760
Dewatering	Pumping	WAS Filtrate Pumps	DOL	3960
Dewatering	Aeration	WAS Holding Aerators	SS	5328
Dewatering	Pumping	Primary Recirculation Pumps	DOL	1776
Dewatering	Pumping	WAS Central Collection Pumps	DOL	1440
MBR-B	Aeration	Air compressors	DOL	888
Dewatering	Pumping	Primary Filtrate Pumps	DOL	720
Dewatering	Miscellaneous	Odour Control	DOL	360
Inlet Works	Pumping	Pump (Degritters)	DOL	1075
CAS Plants - A and B	Aeration	Submersible Mixers	DOL	2960
MBR-B	Aeration	Anoxic Mixers	DOL	2160

In the model provided in Section 6.4 to follow, a 20% energy reduction was approximated as guided by a similar implementation in the study carried out by Lozano Avilés et al., (2019) reviewed in Section 2.7.5.

6.3.3 Recommendations for Aeration Methods

CAS Plant A and B

The aeration methods for the CAS plants and the MBR were considered separately. As mentioned in Section 6.2.3, the CAS plants A and B are fitted with a total of 20 mechanical aerators, rated as shown in Table 6-5. Although fitted with VFDs, this method of aeration is no longer considered preferable due to its high energy consumption as discussed in Section 2.7.3.

As discussed in the literature review, the study carried out by both Musvuto and Ikumi (2016), and Zvimba and Musvoto (2020), agree that a system such as this should be replaced with a more efficient FBDA system, ammonia control and an integrated PLC. The case study provided by Musvuto and Ikumi (2017) is based on two sites, both classified as macro WWTPs, utilising activated sludge technology to treat their incoming wastewater. Due to these similarities of the sites, it was deemed acceptable to assume that by replacing the aeration system with the ammonia-controlled, FBDA system as well as an integrated PLC, would achieve the same energy reduction percentage as that calculated through the case study.

As shown in the model provided, an anticipated energy reduction of 37% for the CAS Plants A and B aerator configuration could be achieved. This is calculated as a total saving in excess of 13400 kWh per day on site.

MBR Plant

The MBR plant, as discussed in Section 6.2.3, uses the newer technology FBDA, which according to the literature reviewed, is at present the most efficient aeration method. As demonstrated by the case study carried out by Phelan (2016), the implementation of VFDs on the existing blower, an ammonia-based monitoring system, and the integration of a PLC is recommended for the existing plant. Although the FBDA is already considered energy-efficient, the interventions mentioned are predicted to save an additional 80% of the current FBDA energy consumption. This is reported in the model provided in Section 6.4.

6.4 Theoretical Energy Demand Reduction

A complete analysis of the plant was completed with respect to the energy efficiency measures already implemented, as well as the potential for additional savings. The full list of current and potential savings is tabulated in Appendix G, but the key measures are provided below.

6.4.1 Key Energy Reduction Potential Measures

The three key potential energy reduction measures that were identified in Section 6.3, were implemented in the energy reduction model, and are summarised in Table 6-7 below.

Table 6-7 - Key Energy Reduction Measures and Corresponding Potential Energy Savings

Primary Measure	**Secondary Measure**	**Total Energy Reduction (kWh)**
Implementation of VFDs	Integrated PLC	12560
Replacement of Mechanical Surface Aerator with FBDA.	Ammonium-based monitoring and integrated PLC	13408
Implementation of VFDs	Ammonium-based monitoring and integrated PLC	30566
	Total Energy Savings	**56535**
	Percentage of Existing Total Energy Consumption	**28%**

As shown in Table 6-7, the percentage savings of the existing site's energy consumption was calculated to be 28%. This value was applied to the energy consumption measured over the full study period as shown in Figure 22. As shown, by implementing these the three key measures detailed in Table 6-7 across several processes, the average energy consumption per month is predicted to drop from 1393 MWh to 1003 MWh.

According to the findings of Section 2.6 of the literature review, the energy savings potential calculated for this site are notably less than that of the case studies reported by Gandiglio et al. (2017). These case studies showed that an energy reduction in excess of 40% was achievable based on the energy efficiency improvements suggested.

This discrepancy would be due to the fact that only a simple level audit was carried out, and a more thorough, detailed level audit could potentially show great energy reduction potentials. Further to this, additional energy savings could be identified for the remaining site infrastructure, including the building services, lighting, security and dewatering measures.

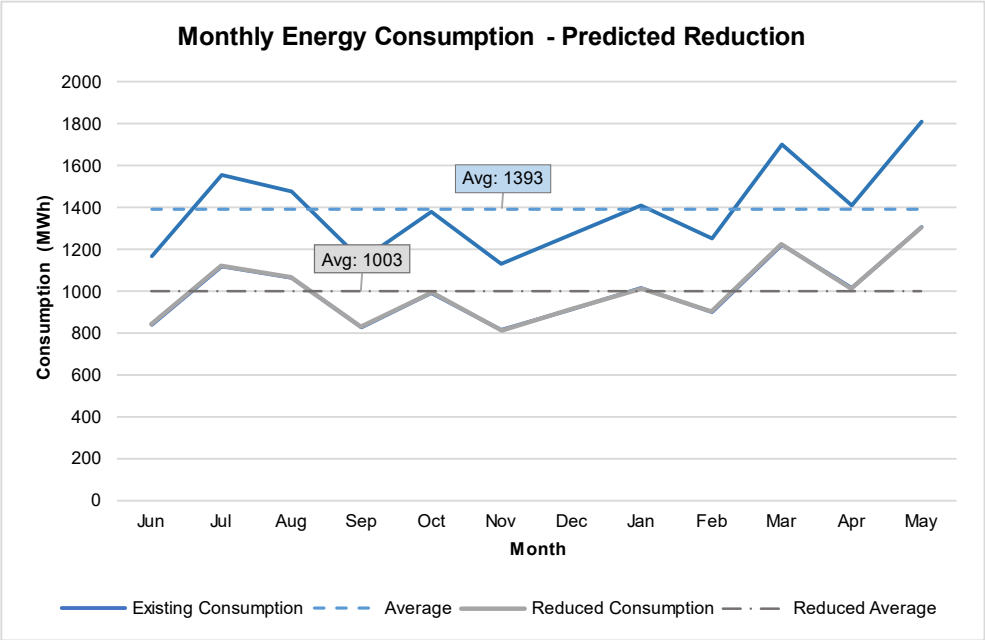


Figure 24: Baseline Energy Consumption vs. Predicted Reduced Energy Consumption

6.4.2 Energy Consumption vs Theoretical Generation

The reduced energy consumption of the site as shown in Figure 22 above was then compared to the theoretical energy production from biogas calculated in Section 5.3.2. The graph provided in Figure 23 below illustrates this.

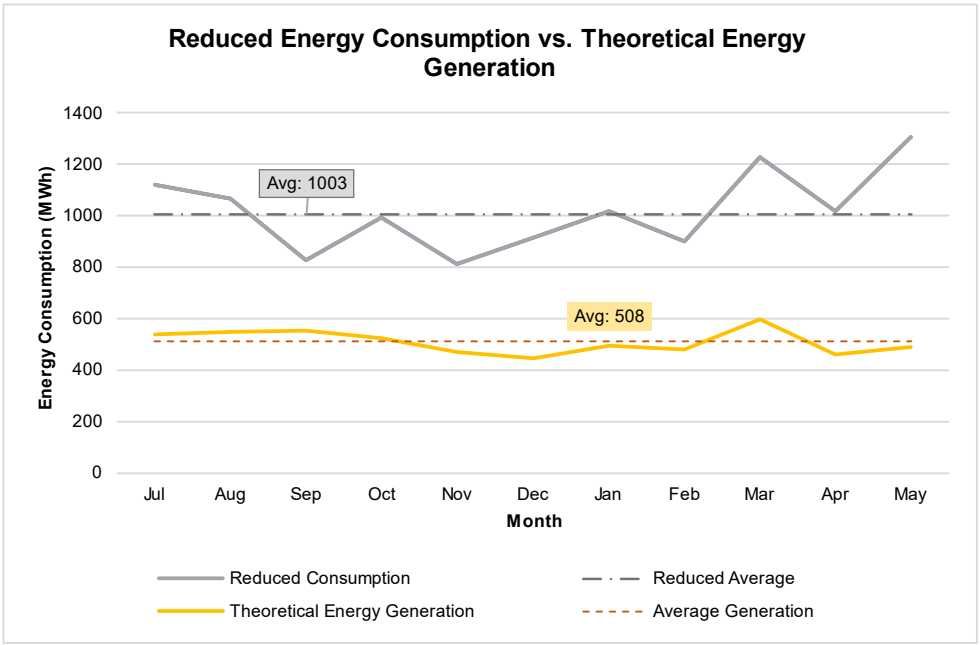


Figure 25: Reduced Energy Consumption vs. Theoretical Energy Generation from Sludge

The results illustrated by Figure 23 shown that even the reduction in energy consumption by 28% does not bring the average consumption down enough to be offset the potential energy generation from biogas. Although on average the energy generation could offset the consumption by 51%, a remaining 495 MWh would still be required from a source other than the biogas.

7 Conclusions and Recommendations

7.1 Research Approach and Design

This study employed a mixed-methods approach, combining both qualitative and quantitative research methodologies. A case study of a local WWTP was specifically chosen to contextualize the study within South Africa.

The qualitative research began with a systematic literature review, aimed at addressing the first two sub-questions of the study. For sub-question 1, an analysis of previous research and case studies, both internationally and locally, provided insights into best practices for reducing energy consumption in WWTPs. For sub-question 2, the review extended to design manuals from developed countries, helping establish a method to calculate theoretical biogas production. This review also guided the data collection requirements for the quantitative phase of the study.

The quantitative component, addressing both sub-questions 1 and 2, involved data collection and an analysis of the local WWTP. Parameters such as treatment processes, mechanical equipment, and baseline energy consumption were examined. This analysis allowed for the application of energy efficiency recommendations identified in the literature, assessing their potential impact on reducing the plant's current energy consumption patterns.

Data on sludge characteristics and monthly production rates, informed by the literature, were collected to estimate the site's biogas production and potential electrical energy generation. Despite relying on certain assumptions from design manuals, these calculations provided a measurable estimate of electrical energy generation potential.

By addressing sub-questions 1 and 2, sub-question 3 was inherently answered through an energy balance calculation, rounding out the study's comprehensive approach.

7.2 Consolidation of Findings and Reference to Research Questions

7.2.1 Research Sub-question 1

What reduction in energy consumption could be realised on WWTPs in South Africa through the implementation of energy efficiency measures?

As highlighted by Section 6.4, through several key energy efficiency interventions, the energy consumption of the plant could be reduced by 28%. Although, additional energy efficiency opportunities exist, only those quantifiable from literature could be considered for the scope of this study. It is anticipated that additional energy savings could be realised beyond the 28%, and this is recommended for further study.

7.2.2 Research Sub-question 2

What quantifiable energy generation potential could be achieved through anaerobic digestion, biogas production and energy generation through CHP on WWTPs in South Africa?

The set of calculations outlined in Section 5.3, estimates the on-site electrical energy generation which could be achieved through the implementation of AD technology, biogas production and an on-site CHP plant. From the characteristics of the sludge generated on site, and the monthly rate of sludge produced, an average electrical energy potential of 505 MWh per month was approximated.

7.2.3 Research Sub-question 3

Would the implementation of energy efficiency measures, and the production of electrical energy from biogas be enough to result in a NZE wastewater treatment plant?

The results of the energy balance are shown in Figure 23 in Section 6.4.2. The response to this sub-question is that the NZE facility is not feasible through the implementation of the energy efficiency

measures and energy generation potential alone. However, it is noted in Table 7-1, that an energy consumption offset of between 55 and 75% is still achievable.

Table 7-1 - Resultant Energy Offset over the Full Research Period

	Month										
	2	3	4	5	6	7	8	9	10	11	12
Baseline Energy Consumption (MWh)	1556	1479	1149	1378	1129	1268	1410	1250	1700	1409	1814
Reduced Energy Consumption (MWh)	1120	1065	827	992	813	913	1015	900	1224	1015	1306
Electrical Energy Generation from CHP (MWh)	539	548	553	525	469	445	494	477	594	457	489
Combined Energy Offset	63%	65%	75%	66%	70%	63%	63%	66%	63%	60%	55%

7.2.4 Main Research Question

Could NZE WWTPs, through the integration of energy efficiency measures and the generation of electrical energy through biogas and CHP technology, be a reality in the context of South African infrastructure?

The case study conducted in this research report leads to the conclusion that a NZE WWTP cannot be attained solely through the implementation of energy efficiency measures and electrical energy generation via biogas and CHP technology. However, a noteworthy reduction in energy consumption was observed, suggesting that the concept of NZE WWTPs in South Africa remains a viable and promising area for future research.

7.3 Concluding Remarks

This report investigates the feasibility of a NZE WWTP in South Africa, focusing on a local plant in the Western Cape as a case study. The study concentrates on two primary strategies: the implementation of energy efficiency opportunities and energy generation from CHP systems, utilizing AD and biogas production. These strategies were rigorously assessed to determine their impact on the NZE goal of the WWTP.

Drawing from the literature review, the report highlights several best practices for reducing energy consumption in WWTPs. The case study, based on a local WWTP, pinpointed areas for significant energy efficiency improvements. Key interventions included the integration of advanced process control with PLCs, the use of enhanced aeration methods like FBDA and ammonia-based control, and the incorporation of energy-efficient equipment such as VFDs. These measures were estimated to reduce overall energy consumption by 28%.

Furthermore, the research aimed to estimate on-site energy generation potential through biogas and a CHP system. Analysis of the plant’s primary and secondary sludge, combined with a year's sludge production data, enabled the calculation of theoretical biogas output and the associated energy generation from the CHP system. The findings suggested that an average energy generation of 505 MWh per month was achievable.

Ultimately, the research revealed that combining energy efficiency measures with on-site generation could lead to a reduction in baseline energy consumption by 55 to 75%. Although these results are encouraging, they also underscore that these measures alone, while impactful, are not sufficient on realise a completely NZE WWTP.

Aside from the energy offset, it should be noted that there are several additional benefits to the proposed site interventions. As reviewed in Section 2.9.7, the production of biogas from the sludge on site is advantageous as the overall mass of sludge is reduced significantly and therefore the sludge removal requirements are reduced, including two carbon-intensive processes, being the transportation and

incineration thereof. Further to this, the recovery of methane on site means that less of the greenhouse gas is released into the atmosphere.

Furthermore, the benefits of implementing the suggested best practices on site also present benefits outside of the energy offset and financial implications. By improving the efficiency of the pumps and aeration systems, the overall efficiency of the site is improved, and this is often seen in an increased quality of effluent. In addition, maintenance requirements as well as shutdown periods are reduced.

7.4 Recommendations for Further Study

The earlier sections of this research report highlighted several limitations, including time constraints and restricted access to resources and expertise. These constraints have inevitably narrowed the scope of the study, presenting opportunities for future research to expand upon the findings presented in this report.

7.4.1 Research Design Recommendations

This research offers valuable insights into energy efficiency in WWTPs and on-site energy generation from biogas. However, to enhance or corroborate the findings, several additional recommendations are proposed:

- Gathering real-time data on energy consumption at the site, necessitating a comprehensive energy audit and the use of energy monitoring tools.
- Measuring other sludge parameters, including BOD, COD, and the actual methane content of the sludge at the site.
- Developing a model to assess how the proposed energy efficiency measures impact both the process and effluent quality.
- Conducting a cost-benefit analysis to evaluate the financial viability of the recommendations.
- Engage in additional expertise such as mechanical systems engineers, process engineers, and sustainability experts.
- Replicating this research methodology across more WWTP case studies in South Africa to broaden the scope and applicability of the findings.

7.4.2 Increase the Scope

To definitively determine the feasibility of a NZE WWTP in the South African context, the study's scope should be expanded in future research. The following aspects are recommended for inclusion in further studies:

- Investigating pre-treatment methods like THP that can boost biogas production via AD.
- Exploring co-digestion strategies to increase biogas output without imposing additional loading on the rest of the site.
- Considering additional renewable energy sources, such as solar PV, wind energy, and hydropower, to compensate for the remaining energy consumption on site.
- Evaluating further energy efficiency strategies not covered in this report, including an analysis of building services, leak reduction efforts, and maintenance programmes.

These additional areas of study will provide a more comprehensive understanding of the potential for achieving NZE status in WWTPs within South Africa.

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Appendix A

Sludge Characteristics Data

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7915
SOUTH AFRICA
Telephone: (021) 448 6340/1
After Hours: 083-3263887
E-Mail Address: info@alabbott.co.za

sanas Testing Laboratory
(No. T0276)

Certificate of Analysis

WSSA

Sample : **Three Samples of Sludge**

Date Received : **29 November 2022** **Lab. Data Sheet No.: 22/7562**

Your Ref. : **PO-0090190**

Our Ref. : **bm/7562**
19 January 2023

		WWTW CASE STUDY **Sludge #1**
Physical Characteristics :	pH	6.71
	Total Solids (%)	16.0
	Volatile Solids (%)	12.9
	Volatile Fraction (%)	80.6
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY **Sludge #1**
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	6801
	Total Phosphate (mg/kg as P)	27.0
	Potassium (mg/kg as K)	4740

This report relates only to the samples tested and is issued subject to the company's standard terms and conditions of business.

		WWTW CASE STUDY Sludge #1	Classification
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	0.006	**a**
	Cadmium (mg/kg as Cd)	0.44	**a**
	Chromium (mg/kg as Cr)	3.4	**a**
	Copper (mg/kg as Cu)	39.4	**a**
	Lead (mg/kg as Pb)	3.5	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	7.4	**a**
	Zinc (mg/kg as Zn)	438	**a**

		WWTW CASE STUDY Sludge #1	Classification
Microbiological Quality :	Faecal Coliforms (organisms per g)	1986000	**B**
	Total Viable Helminth Ova (ova/4 g)	2	**B**

NOTES:	1.	Routine analysis of organic pollutants is not required for domestic sludge.
	2.	According to O'Shaunessy's formula, the volatile solids reduction was 20.7% = Stability Class 2

		WWTW CASE STUDY Sludge #2
Physical Characteristics :	pH	6.66
	Total Solids (%)	15.7
	Volatile Solids (%)	12.6
	Volatile Fraction (%)	80.3
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY Sludge #2
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	7426
	Total Phosphate (mg/kg as P)	34.0
	Potassium (mg/kg as K)	4761

		WWTW CASE STUDY Sludge #2	Classification
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	0.004	**a**
	Cadmium (mg/kg as Cd)	<0.10	**a**
	Chromium (mg/kg as Cr)	3.0	**a**
	Copper (mg/kg as Cu)	34.1	**a**
	Lead (mg/kg as Pb)	3.3	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	7.1	**a**
	Zinc (mg/kg as Zn)	430	**a**

		WWTW CASE STUDY Sludge #2	Classification
Microbiological Quality :	Faecal Coliforms (organisms per g)	1800000	**B**
	Total Viable Helminth Ova (ova/4 g)	1	**B**

NOTES:	1.	Routine analysis of organic pollutants is not required for domestic sludge.
	2.	According to O'Shaunessy's formula, the volatile solids reduction was 22.6% = Stability Class 2

		WWTW CASE STUDY **Sludge #3**
Physical Characteristics :	pH	6.54
	Total Solids (%)	16.0
	Volatile Solids (%)	12.9
	Volatile Fraction (%)	80.6
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY **Sludge #3**
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	6910
	Total Phosphate (mg/kg as P)	35.0
	Potassium (mg/kg as K)	4665

		WWTW CASE STUDY **Sludge #3**	**Classification**
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	<0.10	**a**
	Cadmium (mg/kg as Cd)	<0.10	**a**
	Chromium (mg/kg as Cr)	3.5	**a**
	Copper (mg/kg as Cu)	36.4	**a**
	Lead (mg/kg as Pb)	2.9	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	7.3	**a**
	Zinc (mg/kg as Zn)	408	**a**

		WWTW CASE STUDY **Sludge #3**	**Classification**
Microbiological Quality :	Faecal Coliforms (organisms per g)	1080000	**B**
	Total Viable Helminth Ova (ova/4 g)	2	**B**

NOTES:	1. Routine analysis of organic pollutants is not required for domestic sludge.
	2. According to O'Shaunessy's formula, the volatile solids reduction was 20.7% = Stability Class 2

CHARACTERISATION AND PRELIMINARY CLASSIFICATION OF SLUDGE FROM [redacted] WWTW

	WWTW CASE STUDY SLUDGE
Sludge Type	Sludge
Sampling Point	Stockpile
Microbiological Parameters	B
Vector Attraction Reduction Options Applied	2
Pollutant Class	a
Classification	B2a

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Vine Road
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WOODSTOCK, CAPE
7915
SOUTH AFRICA
Telephone: (021) 448 6340/1
After Hours: 083-3263887
E-Mail Address: info@alabbott.co.za

Certificate of Analysis

WSSA

Sample : **Three Samples of Sludge**

Date Received : **25 August 2022** **Lab. Data Sheet No.: 22/5180**

Your Ref. : **PO-0089931**

Our Ref. : **bm/5180**
18 October 2022

		WWTW CASE STUDY **Sludge #1**
Physical Characteristics :	pH	5.64
	Total Solids (%)	11.6
	Volatile Solids (%)	8.8
	Volatile Fraction (%)	75.9
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY **Sludge #1**
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	17677
	Total Phosphate (mg/kg as P)	1006
	Potassium (mg/kg as K)	5369

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		WWTW CASE STUDY Sludge #1	Classification
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	<0.10	**a**
	Cadmium (mg/kg as Cd)	<0.10	**a**
	Chromium (mg/kg as Cr)	18.7	**a**
	Copper (mg/kg as Cu)	32.1	**a**
	Lead (mg/kg as Pb)	6.9	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	6.4	**a**
	Zinc (mg/kg as Zn)	427	**a**

		WWTW CASE STUDY Sludge #1	Classification
Microbiological Quality :	Faecal Coliforms (organisms per g)	28800	**B**
	Total Viable Helminth Ova (ova/4 g)	Nil	**A**

NOTES:	1.	Routine analysis of organic pollutants is not required for domestic sludge.
	2.	According to O'Shaunessy's formula, the volatile solids reduction was 40.1% = Stability Class 1

		WWTW CASE STUDY Sludge #2
Physical Characteristics :	pH	5.48
	Total Solids (%)	11.8
	Volatile Solids (%)	8.7
	Volatile Fraction (%)	73.7
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY Sludge #2
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	13762
	Total Phosphate (mg/kg as P)	894
	Potassium (mg/kg as K)	5178

		WWTW CASE STUDY Sludge #2	Classification
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	<0.10	**a**
	Cadmium (mg/kg as Cd)	<0.10	**a**
	Chromium (mg/kg as Cr)	15.7	**a**
	Copper (mg/kg as Cu)	28.8	**a**
	Lead (mg/kg as Pb)	5.2	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	5.5	**a**
	Zinc (mg/kg as Zn)	431	**a**

		WWTW CASE STUDY Sludge #2	Classification
Microbiological Quality :	Faecal Coliforms (organisms per g)	30200	**B**
	Total Viable Helminth Ova (ova/4 g)	Nil	**A**

NOTES:	1.	Routine analysis of organic pollutants is not required for domestic sludge.
	2.	According to O'Shaunessy's formula, the volatile solids reduction was 46.5% = Stability Class 1

		WWTW CASE STUDY **Sludge #3**
Physical Characteristics :	pH	5.38
	Total Solids (%)	11.7
	Volatile Solids (%)	8.8
	Volatile Fraction (%)	75.2
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY **Sludge #3**
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	19196
	Total Phosphate (mg/kg as P)	1084
	Potassium (mg/kg as K)	5003

		WWTW CASE STUDY **Sludge #3**	**Classification**
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	<0.10	**a**
	Cadmium (mg/kg as Cd)	<0.10	**a**
	Chromium (mg/kg as Cr)	13.2	**a**
	Copper (mg/kg as Cu)	26.5	**a**
	Lead (mg/kg as Pb)	5.3	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	5.0	**a**
	Zinc (mg/kg as Zn)	397	**a**

		WWTW CASE STUDY **Sludge #3**	**Classification**
Microbiological Quality :	Faecal Coliforms (organisms per g)	26000	**B**
	Total Viable Helminth Ova (ova/4 g)	Nil	**A**

NOTES:	1. Routine analysis of organic pollutants is not required for domestic sludge.
	2. According to O'Shaunessy's formula, the volatile solids reduction was 42.2% = Stability Class 1

CHARACTERISATION AND PRELIMINARY CLASSIFICATION OF SLUDGE FROM [redacted] WWTW

	WWTW CASE STUDY **SLUDGE**
Sludge Type	**Sludge**
Sampling Point	**Stockpile**
Microbiological Parameters	**B**
Vector Attraction Reduction Options Applied	**1**
Pollutant Class	**a**
Classification	**B1a**

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7915
SOUTH AFRICA
Telephone: (021) 448 6340/1
After Hours: 083-3263887
E-Mail Address: info@alabbott.co.za

Certificate of Analysis

WSSA

Sample : **Three Samples of Sludge**

Date Received : **9 March 2023** **Lab. Data Sheet No.: 23/1675**

Your Ref. : **PO-0090569**

Our Ref. : **bm/1675**
29 May 2023

		WWTW CASE STUDY **Sludge #1**
Physical Characteristics :	pH	6.08
	Total Solids (%)	12.9
	Volatile Solids (%)	9.0
	Volatile Fraction (%)	69.8
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY **Sludge #1**
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	14950
	Total Phosphate (mg/kg as P)	1134
	Potassium (mg/kg as K)	7918

This report relates only to the samples tested and is issued subject to the company's standard terms and conditions of business.

		WWTW CASE STUDY Sludge #1	Classification
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	<0.10	**a**
	Cadmium (mg/kg as Cd)	1.2	**a**
	Chromium (mg/kg as Cr)	7.2	**a**
	Copper (mg/kg as Cu)	6.4	**a**
	Lead (mg/kg as Pb)	11.7	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	6.8	**a**
	Zinc (mg/kg as Zn)	318	**a**

		WWTW CASE STUDY Sludge #1	Classification
Microbiological Quality :	Faecal Coliforms (organisms per g)	12800	**B**
	Total Viable Helminth Ova (ova/4 g)	17	**C**

NOTES:	1.	Routine analysis of organic pollutants is not required for domestic sludge.
	2.	According to O'Shaunessy's formula, the volatile solids reduction was 56.0% = Stability Class 1

		WWTW CASE STUDY Sludge #2
Physical Characteristics :	pH	6.01
	Total Solids (%)	12.9
	Volatile Solids (%)	9.2
	Volatile Fraction (%)	71.3
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY Sludge #2
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	10109
	Total Phosphate (mg/kg as P)	680
	Potassium (mg/kg as K)	8005

		WWTW CASE STUDY Sludge #2	Classification
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	<0.10	**a**
	Cadmium (mg/kg as Cd)	<0.10	**a**
	Chromium (mg/kg as Cr)	4.0	**a**
	Copper (mg/kg as Cu)	4.0	**a**
	Lead (mg/kg as Pb)	8.0	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	4.0	**a**
	Zinc (mg/kg as Zn)	330	**a**

		ZANDVLIET WWTW Sludge #2	Classification
Microbiological Quality :	Faecal Coliforms (organisms per g)	14600	**B**
	Total Viable Helminth Ova (ova/4 g)	14	**C**

NOTES:	1.	Routine analysis of organic pollutants is not required for domestic sludge.
	2.	According to O'Shaunessy's formula, the volatile solids reduction was 52.6% = Stability Class 1

		WWTW CASE STUDY Sludge #3
Physical Characteristics :	pH	5.99
	Total Solids (%)	12.8
	Volatile Solids (%)	8.9
	Volatile Fraction (%)	69.5
	Volatile Fatty Acids (%)	0.02

		WWTW CASE STUDY Sludge #3
Nutrients :	Total Kjeldahl Nitrogen (mg/kg as N)	17066
	Total Phosphate (mg/kg as P)	910
	Potassium (mg/kg as K)	8138

		WWTW CASE STUDY Sludge #3	Classification
Metal Limits and Micro Elements :	**Metal Limits :**		
	Arsenic (mg/kg as As)	<0.10	**a**
	Cadmium (mg/kg as Cd)	<0.10	**a**
	Chromium (mg/kg as Cr)	6.1	**a**
	Copper (mg/kg as Cu)	5.7	**a**
	Lead (mg/kg as Pb)	12.1	**a**
	Mercury (mg/kg as Hg)	<0.10	**a**
	Nickel (mg/kg as Ni)	12.1	**a**
	Zinc (mg/kg as Zn)	348	**a**

		WWTW CASE STUDY Sludge #3	Classification
Microbiological Quality :	Faecal Coliforms (organisms per g)	16000	**B**
	Total Viable Helminth Ova (ova/4 g)	18	**C**

NOTES:	1.	Routine analysis of organic pollutants is not required for domestic sludge.
	2.	According to O'Shaunessy's formula, the volatile solids reduction was 56.5% = Stability Class 1

CHARACTERISATION AND PRELIMINARY CLASSIFICATION OF SLUDGE FROM [redacted] WWTW

	WWTW CASE STUDY SLUDGE
Sludge Type	Sludge
Sampling Point	Stockpile
Microbiological Parameters	C
Vector Attraction Reduction Options Applied	1
Pollutant Class	a
Classification	C1a

Appendix B

Daily Sludge Production Data

Dewatering Plant - Primary Sludge

	Sludge Pumped from Primary Pump Station	Belt Press Feed from Primary Pump Station	Primary Belt Press 1 Sludge Feed	Primary Belt Press 1 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 4 Sludge Feed	Primary Belt Press 4 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	m^3	%DS	m^3	kg	m^3	kg	m^3	kg	m^3	kg	tDS	tSolids
01/07/2022	817	3.60	0	0	268	9634	275	9911	185	6667	26.2	45.3
02/07/2022	199	3.20	0	0	451	14414	469	14996	38	1218	30.6	53.0
03/07/2022	1686	3.90	0	0	474	18466	441	17200	0	0	35.7	61.7
04/07/2022	715	4.34	0	0	412	17903	414	17977	0	0	35.9	62.1
05/07/2022	869	4.01	339	13563	279	11159	401	16079	0	0	40.8	70.6
06/07/2022	870	3.57	339	12084	280	9990	402	14331	0	0	36.4	63.0
07/07/2022	985	3.39	394	13377	0	0	386	13102	0	0	26.5	45.8
08/07/2022	842	2.71	651	17650	0	0	638	17284	0	0	34.9	60.4
09/07/2022	965	3.59	0	0	577	20707	0	0	0	0	20.7	35.8
10/07/2022	1030	2.69	157	4234	965	25953	74	1993	0	0	32.2	55.7
11/07/2022	923	2.35	223	5248	133	3133	481	11308	0	0	19.7	34.1
12/07/2022	925	2.77	225	6218	135	3738	483	13349	0	0	23.3	40.3
13/07/2022	995	3.25	427	13850	0	0	424	13759	0	0	27.6	47.8
14/07/2022	959	2.88	601	17300	0	0	699	20094	0	0	37.4	64.7
15/07/2022	912	2.96	486	14390	0	0	377	11157	0	0	25.5	44.2
16/07/2022	965	2.70	532	14356	0	0	528	14245	0	0	28.6	49.5
17/07/2022	950	2.46	83	2030	347	8539	432	10615	0	0	21.2	36.6
18/07/2022	911	2.09	369	7716	459	9585	90	1871	0	0	19.2	33.2
19/07/2022	762	2.51	0	0	275	6914	275	6907	0	0	13.8	23.9
20/07/2022	762	2.40	0	0	277	6657	275	6616	0	0	13.3	23.0
21/07/2022	815	2.58	514	13231	0	0	511	13167	0	0	26.4	45.7
22/07/2022	843	2.81	369	10355	53	1486	414	11636	0	0	23.5	40.6
23/07/2022	849	2.81	157	4417	196	5505	353	9919	0	0	19.8	34.3
24/07/2022	882	4.36	445	19419	0	0	430	18765	0	0	38.2	66.1
25/07/2022	791	3.98	512	20387	0	0	465	18515	0	0	38.9	67.3
26/07/2022	1047	3.93	465	18247	202	7940	444	17450	0	0	43.6	75.5
27/07/2022	523	2.70	232	6264	101	2727	222	5994	0	0	15.0	25.9
28/07/2022	525	2.37	233	5519	101	2400	224	5292	0	0	13.2	22.9
29/07/2022	1036	2.69	407	10946	52	1388	404	10881	0	0	23.2	40.2
30/07/2022	1039	3.49	408	14229	53	1837	404	14100	0	0	30.2	52.2
31/07/2022	1810	4.01	486	19460	27	1093	328	13120	0	0	33.7	58.3
01/08/2022	72	2.48	486	12058	28	687	328	8139	0	0	20.9	36.1
02/08/2022	921	3.83	451	17288	0	0	468	17925	0	0	35.2	60.9
03/08/2022	797	3.49	515	17944	0	0	483	16846	0	0	34.8	60.2
04/08/2022	976	2.69	297	7997	0	0	357	9615	0	0	17.6	30.5
05/08/2022	384	2.99	594	17741	0	0	61	1822	0	0	19.6	33.8
06/08/2022	386	2.55	594	15122	0	0	61	1552	0	0	16.7	28.8
07/08/2022	1146	3.78	499	18851	0	0	0	0	0	0	18.9	32.6
08/08/2022	288	2.59	567	14657	308	7972	0	0	0	0	22.6	39.2
09/08/2022	1224	3.99	583	23270	571	22779	0	0	0	0	46.0	79.7
10/08/2022	919	4.00	502	20060	445	17812	0	0	0	0	37.9	65.5
11/08/2022	957	2.46	398	9796	399	9823	0	0	0	0	19.6	33.9
12/08/2022	904	2.66	619	16491	164	4363	0	0	169	4501	25.4	43.9
13/08/2022	907	2.21	620	13667	164	3612	0	0	171	3762	21.0	36.4
14/08/2022	774	2.61	228	5947	0	0	0	0	232	6031	12.0	20.7
15/08/2022	801	2.44	512	12510	0	0	0	0	518	12652	25.2	43.5
16/08/2022	1051	2.47	515	12718	0	0	0	0	519	12822	25.5	44.2
17/08/2022	828	2.39	345	8227	0	0	0	0	364	8685	16.9	29.3
18/08/2022	926	3.78	429	16227	0	0	0	0	596	22552	38.8	67.1
19/08/2022	1010	2.64	438	11550	0	0	0	0	444	11727	23.3	40.3
20/08/2022	987	2.94	461	13548	0	0	0	0	262	7688	21.2	36.7
21/08/2022	880	2.95	843	24900	0	0	0	0	91	2696	27.6	47.7
22/08/2022	882	2.07	843	17428	0	0	0	0	92	1899	19.3	33.4
23/08/2022	819	2.21	208	4613	0	0	0	0	490	10854	15.5	26.8
24/08/2022	559	2.29	0	0	0	0	0	0	421	9615	9.6	16.6
25/08/2022	41	2.43	0	0	0	0	0	0	42	1029	1.0	1.8
26/08/2022	373	2.30	0	0	412	9455	0	0	548	12570	22.0	38.1
27/08/2022	1197	2.89	0	0	402	11592	0	0	438	12631	24.2	41.9
28/08/2022	1554	2.20	0	0	826	18176	0	0	828	18216	36.4	63.0
29/08/2022	1632	3.02	0	0	756	22865	0	0	916	27703	50.6	87.5
30/08/2022	1296	1.50	0	0	559	8410	0	0	562	8452	16.9	29.2
31/08/2022	779	1.77	0	0	446	7904	0	0	514	9113	17.0	29.4
01/09/2022	738	2.53	0	0	468	11845	0	0	512	12964	24.8	42.9
02/09/2022	1643	2.52	0	0	758	19112	0	0	495	12464	31.6	54.6
03/09/2022	1045	3.46	0	0	732	25313	0	0	0	0	25.3	43.8
04/09/2022	850	4.78	0	0	439	20977	0	0	363	17328	38.3	66.3
05/09/2022	740	3.88	0	0	386	14969	0	0	476	18484	33.5	57.9
06/09/2022	1038	2.62	0	0	121	3157	0	0	803	21028	24.2	41.8
07/09/2022	520	2.09	0	0	434	9050	0	0	317	6621	15.7	27.1
08/09/2022	800	2.50	0	0	471	11759	0	0	0	0	11.8	20.3
09/09/2022	639	3.06	0	0	635	19443	0	0	30	927	20.4	35.2
10/09/2022	1017	2.56	0	0	646	16538	0	0	387	9900	26.4	45.7
11/09/2022	1279	3.14	0	0	687	21534	0	0	644	20183	41.7	72.2
12/09/2022	1038	4.32	0	0	479	20693	0	0	427	18446	39.1	67.7
13/09/2022	799	1.89	0	0	625	11779	0	0	593	11180	23.0	39.7
14/09/2022	1272	2.28	0	0	552	12595	0	0	464	10577	23.2	40.1
15/09/2022	962	2.26	0	0	479	10825	0	0	299	6753	17.6	30.4
16/09/2022	796	2.01	0	0	486	9746	0	0	397	7952	17.7	30.6
17/09/2022	1406	3.71	0	0	667	24742	0	0	665	24672	49.4	85.5
18/09/2022	1077	3.86	0	0	0	0	0	0	1052	40566	40.6	70.2
19/09/2022	1048	1.34	0	0	769	10302	0	0	798	10699	21.0	36.3
20/09/2022	1199	1.23	0	0	1138	13995	0	0	8	95	14.1	24.4
21/09/2022	1112	2.06	0	0	609	12552	0	0	418	8611	21.2	36.6
22/09/2022	1211	2.64	459	12112	520	13723	0	0	376	9924	35.8	61.9
23/09/2022	1237	2.37	313	7406	259	6129	0	0	99	2356	15.9	27.5
24/09/2022	933	2.41	298	7182	247	5953	0	0	98	2352	15.5	26.8
25/09/2022	641	2.94	298	8764	249	7318	0	0	98	2878	19.0	32.8
26/09/2022	101	2.66	313	8328	296	7882	0	0	77	2046	18.3	31.6
27/09/2022	31	2.61	0	0	0	0	0	0	0	0	0.0	0.0
28/09/2022	1141	2.74	69	1882	434	11881	0	0	541	14834	28.6	49.5
29/09/2022	992	3.86	262	10129	216	8334	0	0	185	7122	25.6	44.3
30/09/2022	718	3.09	288	8908	233	7212	0	0	227	7014	23.1	40.0
01/10/2022	719	4.55	0	0	201	9146	0	0	137	6247	15.4	26.6
02/10/2022	383	2.91	516	15019	198	5756	0	0	138	4004	24.8	42.9
03/10/2022	368	2.41	470	11329	336	8093	0	0	0	0	19.4	33.6
04/10/2022	1203	2.94	351	10325	374	11004	0	0	57	1688	23.0	39.8
05/10/2022	1002	2.64	353	9306	376	9918	0	0	59	1552	20.8	35.9
06/10/2022	433	2.76	308	8512	344	9492	0	0	239	6599	24.6	42.6

Dewatering Plant - Primary Sludge

	Sludge Pumped from Primary Pump Station	Belt Press Feed from Primary Pump Station	Primary Belt Press 1 Sludge Feed	Primary Belt Press 1 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 4 Sludge Feed	Primary Belt Press 4 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	m^3	%DS	m^3	kg	m^3	kg	m^3	kg	m^3	kg	tDS	tSolids
07/10/2022	1116	2.51	497	12477	318	7992	0	0	348	8737	29.2	50.5
08/10/2022	872	3.68	249	9163	159	5851	0	0	174	6403	21.4	37.1
09/10/2022	531	2.41	249	6006	161	3870	0	0	175	4220	14.1	24.4
10/10/2022	1130	1.67	817	13637	791	13208	0	0	17	276	27.1	46.9
11/10/2022	1530	1.54	476	7327	265	4081	0	0	764	11761	23.2	40.1
12/10/2022	1240	2.59	505	13087	454	11769	0	0	496	12839	37.7	65.2
13/10/2022	1381	1.49	686	10223	377	5617	0	0	247	3686	19.5	33.8
14/10/2022	1699	1.91	482	9202	483	9225	0	0	518	9898	28.3	49.0
15/10/2022	1453	2.62	624	16351	131	3440	0	0	724	18966	38.8	67.1
16/10/2022	1350	3.53	508	17932	380	13396	0	0	132	4653	36.0	62.3
17/10/2022	694	2.58	590	15214	362	9329	0	0	0	0	24.5	42.5
18/10/2022	1135	1.56	385	6012	557	8691	0	0	570	8887	23.6	40.8
19/10/2022	1324	2.95	273	8065	194	5720	0	0	386	11381	25.2	43.5
20/10/2022	1163	1.66	434	7204	430	7143	0	0	508	8436	22.8	39.4
21/10/2022	826	2.29	340	7777	443	10138	0	0	392	8968	26.9	46.5
22/10/2022	873	3.98	253	10053	459	18272	0	0	349	13874	42.2	73.0
23/10/2022	750	2.86	258	7370	226	6461	0	0	364	10419	24.2	42.0
24/10/2022	832	3.56	272	9673	113	4023	0	0	163	5813	19.5	33.8
25/10/2022	792	1.79	375	6705	356	6367	0	0	65	1167	14.2	24.6
26/10/2022	723	2.78	304	8462	306	8518	0	0	56	1548	18.5	32.1
27/10/2022	818	1.76	80	1399	449	7904	0	0	308	5412	14.7	25.5
28/10/2022	827	3.12	401	12517	0	0	0	0	356	11110	23.6	40.9
29/10/2022	801	3.39	448	15191	438	14831	0	0	0	0	30.0	51.9
30/10/2022	828	3.49	420	14665	366	12773	0	0	0	0	27.4	47.5
31/10/2022	886	2.39	393	9397	403	9629	0	0	254	6080	25.1	43.4
01/11/2022	668	2.87	191	5476	261	7494	0	0	84	2405	15.4	26.6
02/11/2022	859	1.98	491	9714	467	9237	0	0	38	758	19.7	34.1
03/11/2022	782	2.72	272	7388	260	7077	0	0	0	0	14.5	25.0
04/11/2022	942	2.34	409	9566	428	10008	0	0	0	0	19.6	33.9
05/11/2022	863	2.47	308	7615	288	7111	0	0	0	0	14.7	25.5
06/11/2022	889	2.56	442	11313	439	11238	0	0	0	0	22.6	39.0
07/11/2022	1006	1.74	651	11322	612	10656	0	0	0	0	22.0	38.0
08/11/2022	1111	2.77	725	20091	672	18620	0	0	0	0	38.7	67.0
09/11/2022	894	2.91	261	7604	209	6067	0	0	0	0	13.7	23.7
10/11/2022	950	2.19	512	11217	498	10900	0	0	0	0	22.1	38.3
11/11/2022	949	2.57	640	16443	629	16152	0	0	0	0	32.6	56.4
12/11/2022	1079	2.54	420	10671	356	9050	0	0	0	0	19.7	34.1
13/11/2022	989	2.54	499	12662	533	13541	0	0	0	0	26.2	45.3
14/11/2022	960	2.30	447	10270	319	7328	0	0	0	0	17.6	30.4
15/11/2022	1051	2.29	446	10213	443	10145	0	0	239	5475	25.8	44.7
16/11/2022	1017	1.81	356	6447	349	6322	0	0	0	0	12.8	22.1
17/11/2022	973	2.43	532	12935	540	13115	0	0	188	4561	30.6	53.0
18/11/2022	843	2.20	588	12943	588	12932	0	0	121	2651	28.5	49.4
19/11/2022	1136	2.61	109	2855	289	7553	0	0	246	6431	16.8	29.1
20/11/2022	965	2.21	512	11311	477	10531	0	0	0	0	21.8	37.8
21/11/2022	995	2.33	362	8432	449	10466	0	0	502	11692	30.6	52.9
22/11/2022	1002	2.15	336	7233	32	692	0	0	270	5799	13.7	23.7
23/11/2022	2035	1.87	1020	19072	682	12755	0	0	550	10292	42.1	72.9
24/11/2022	1045	1.95	0	0	0	0	600	11704	517	10083	21.8	37.7
25/11/2022	1087	1.72	0	0	0	0	440	7563	396	6816	14.4	24.9
26/11/2022	0	0.00	0	0	0	0	0	0	0	0	0.0	0.0
27/11/2022	906	2.19	0	0	0	0	338	7396	531	11625	19.0	32.9
28/11/2022	1032	2.30	0	0	0	0	276	6357	735	16898	23.3	40.2
29/11/2022	1040	2.24	0	0	0	0	501	11216	622	13933	25.1	43.5
30/11/2022	976	1.90	0	0	0	0	394	7484	397	7535	15.0	26.0
01/12/2022	1066	1.72	0	0	0	0	569	9783	571	9813	19.6	33.9
02/12/2022	1092	1.65	0	0	0	0	1006	16602	1023	16880	33.5	57.9
03/12/2022	1017	1.71	0	0	0	0	124	2119	122	2081	4.2	7.3
04/12/2022	960	1.96	0	0	0	0	458	8983	497	9739	18.7	32.4
05/12/2022	963	1.77	0	0	0	0	459	8124	499	8823	16.9	29.3
06/12/2022	1032	2.38	0	0	0	0	118	2818	272	6476	9.3	16.1
07/12/2022	561	2.14	0	0	0	0	542	11592	5	109	11.7	20.2
08/12/2022	973	2.08	0	0	0	0	523	10878	443	9210	20.1	34.8
09/12/2022	753	2.02	0	0	0	0	356	7191	361	7286	14.5	25.0
10/12/2022	355	2.48	0	0	0	0	475	11790	379	9407	21.2	36.7
11/12/2022	960	2.40	0	0	0	0	309	7409	431	10342	17.8	30.7
12/12/2022	1169	2.94	0	0	0	0	223	6556	664	19516	26.1	45.1
13/12/2022	821	1.77	373	6597	0	0	7	127	426	7537	14.3	24.7
14/12/2022	993	2.08	523	10872	0	0	406	8445	464	9651	29.0	50.1
15/12/2022	755	2.96	0	0	0	0	0	0	468	13865	13.9	24.0
16/12/2022	681	3.01	630	18960	0	0	0	0	648	19514	38.5	66.6
17/12/2022	773	3.67	0	0	0	0	259	9513	502	18427	27.9	48.3
18/12/2022	1080	3.17	171	5424	0	0	411	13019	601	19052	37.5	64.9
19/12/2022	316	3.05	0	0	0	0	92	2797	97	2971	5.8	10.0
20/12/2022	1030	2.69	243	6523	263	7077	0	0	516	13872	27.5	47.5
21/12/2022	864	2.70	369	9955	0	0	343	9253	385	10403	29.6	51.2
22/12/2022	1038	3.06	331	10113	263	8060	349	10686	0	0	28.9	49.9
23/12/2022	1049	2.75	389	10698	393	10810	388	10670	0	0	32.2	55.7
24/12/2022	999	3.59	473	16988	199	7141	473	16995	0	0	41.1	71.1
25/12/2022	1019	2.18	518	11284	187	4072	330	7203	0	0	22.6	39.0
26/12/2022	1006	2.64	523	13810	353	9330	169	4464	0	0	27.6	47.8
27/12/2022	1037	2.86	448	12824	169	4822	482	13779	0	0	31.4	54.4
28/12/2022	951	2.37	195	4614	197	4674	198	4700	0	0	14.0	24.2
29/12/2022	935	2.13	544	11594	193	4117	581	12365	0	0	28.1	48.6
30/12/2022	891	1.88	378	7112	117	2196	13	250	0	0	9.6	16.5
31/12/2022	881	2.44	387	9450	389	9484	0	0	0	0	18.9	32.8
01/01/2023	919	1.92	578	11098	580	11140	0	0	0	0	22.2	38.5
02/01/2023	724	1.72	364	6257	362	6233	0	0	0	0	12.5	21.6
03/01/2023	1044	1.51	265	3997	261	3943	0	0	0	0	7.9	13.7
04/01/2023	1211	1.99	443	8812	500	9952	309	6141	0	0	24.9	43.1
05/01/2023	947	1.97	598	11788	498	9809	103	2037	0	0	23.6	40.9
06/01/2023	871	1.94	388	7527	0	0	414	8032	0	0	15.6	26.9
07/01/2023	972	3.56	446	15885	0	0	166	5895	0	0	21.8	37.7
08/01/2023	889	2.87	421	12080	0	0	463	13274	0	0	25.4	43.9
09/01/2023	751	2.18	285	6213	0	0	306	6662	0	0	12.9	22.3
10/01/2023	876	2.71	377	10209	405	10986	401	10873	0	0	32.1	55.5
11/01/2023	956	2.83	329	9314	15	433	384	10873	0	0	20.6	35.7
12/01/2023	714	2.94	0	0	117	3434	303	8894	213	6274	18.6	32.2

Dewatering Plant - Primary Sludge

	Sludge Pumped from Primary Pump Station	Belt Press Feed from Primary Pump Station	Primary Belt Press 1 Sludge Feed	Primary Belt Press 1 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 4 Sludge Feed	Primary Belt Press 4 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	m^3	%DS	m^3	kg	m^3	kg	m^3	kg	m^3	kg	tDS	tSolids
13/01/2023	840	2.97	66	1966	270	8013	335	9935	164	4862	24.8	42.9
14/01/2023	281	2.90	0	0	188	5438	218	6308	114	3292	15.0	26.0
15/01/2023	557	3.86	0	0	251	9700	0	0	240	9264	19.0	32.8
16/01/2023	704	3.67	222	8129	18	675	0	0	248	9087	17.9	31.0
17/01/2023	521	3.72	197	7328	65	2418	0	0	194	7228	17.0	29.4
18/01/2023	854	3.15	269	8486	250	7862	225	7094	228	7191	30.6	53.0
19/01/2023	1179	3.29	376	12364	104	3431	381	12522	367	12081	40.4	69.9
20/01/2023	1105	3.43	251	8606	27	912	233	7978	233	7992	25.5	44.1
21/01/2023	558	3.63	193	6999	0	0	141	5111	142	5140	17.2	29.8
22/01/2023	348	3.36	349	11720	0	0	4	118	29	961	12.8	22.1
23/01/2023	781	2.99	266	7950	0	0	210	6270	236	7059	21.3	36.8
24/01/2023	610	3.33	303	10087	0	0	337	11222	54	1792	23.1	40.0
25/01/2023	955	3.20	0	0	316	10125	315	10090	271	8685	28.9	50.0
26/01/2023	1033	3.21	0	0	273	8776	348	11171	336	10770	30.7	53.1
27/01/2023	508	3.01	118	3558	0	0	145	4365	238	7167	15.1	26.1
28/01/2023	615	3.57	310	11049	0	0	0	0	324	11549	22.6	39.1
29/01/2023	579	2.13	307	6537	0	0	0	0	317	6744	13.3	23.0
30/01/2023	899	3.07	294	9010	0	0	261	8022	292	8974	26.0	45.0
31/01/2023	925	3.80	300	11389	0	0	276	10492	243	9238	31.1	53.8
01/02/2023	1047	3.00	393	11781	0	0	336	10086	359	10776	32.6	56.5
02/02/2023	749	3.54	229	8121	0	0	209	7406	211	7473	23.0	39.8
03/02/2023	1494	3.52	562	19794	0	0	550	19356	514	18103	57.3	99.1
04/02/2023	356	3.53	51	1789	0	0	49	1726	48	1687	5.2	9.0
05/02/2023	575	3.39	220	7448	0	0	205	6953	170	5756	20.2	34.9
06/02/2023	1190	3.65	453	16542	0	0	364	13301	348	12706	42.5	73.6
07/02/2023	1370	3.36	480	16115	0	0	478	16054	458	15392	47.6	82.3
08/02/2023	1080	2.70	349	9420	0	0	248	6683	379	10244	26.3	45.6
09/02/2023	2098	2.29	520	11910	0	0	268	6135	588	13467	31.5	54.5
10/02/2023	397	2.61	340	8882	0	0	360	9399	364	9506	27.8	48.1
11/02/2023	1118	2.81	367	10307	0	0	337	9456	399	11203	31.0	53.6
12/02/2023	992	3.00	311	9336	0	0	332	9960	339	10164	29.5	51.0
13/02/2023	988	3.39	234	7936	0	0	395	13374	416	14092	35.4	61.2
14/02/2023	881	3.33	313	10413	0	0	184	6121	307	10220	26.8	46.3
15/02/2023	1121	2.92	353	10308	0	0	376	10970	385	11230	32.5	56.2
16/02/2023	1116	2.63	415	10925	0	0	426	11199	451	11848	34.0	58.8
17/02/2023	1198	2.34	488	11419	0	0	529	12374	391	9152	32.9	57.0
18/02/2023	1204	2.18	419	9130	0	0	428	9333	390	8500	27.0	46.6
19/02/2023	1157	2.02	0	0	0	0	572	11550	584	11791	23.3	40.4
20/02/2023	1245	2.80	0	0	0	0	580	16237	606	16960	33.2	57.4
21/02/2023	1163	2.86	487	13928	0	0	495	14146	73	2094	30.2	52.2
22/02/2023	1139	2.62	321	8402	47	1226	279	7315	0	0	16.9	29.3
23/02/2023	1218	2.26	442	9985	383	8665	292	6601	0	0	25.3	43.7
24/02/2023	1113	2.18	551	12018	210	4571	233	5069	238	5188	26.8	46.4
25/02/2023	1135	2.10	854	17942	14	290	670	14074	0	0	32.3	55.9
26/02/2023	1123	2.16	556	12010	253	5458	185	4000	120	2592	24.1	41.6
27/02/2023	1125	2.22	557	12359	254	5628	185	4116	120	2671	24.8	42.9
28/02/2023	1045	2.48	448	11098	307	7614	309	7656	0	0	26.4	45.6
01/03/2023	958	2.35	427	10023	260	6117	209	4909	0	0	21.0	36.4
02/03/2023	1063	2.05	597	12243	252	5166	38	769	0	0	18.2	31.4
03/03/2023	1656	2.59	331	8573	807	20906	453	11720	0	0	41.2	71.3
04/03/2023	828	2.22	165	3665	404	8969	226	5017	0	0	17.7	30.5
05/03/2023	829	2.59	158	4092	405	10487	227	5872	0	0	20.5	35.4
06/03/2023	1107	2.29	1	25	577	13220	457	10470	0	0	23.7	41.0
07/03/2023	1093	1.99	346	6893	764	15196	332	6609	0	0	28.7	49.7
08/03/2023	1025	1.87	40	741	552	10319	395	7381	0	0	18.4	31.9
09/03/2023	1032	1.86	170	3164	109	2026	239	4440	0	0	9.6	16.7
10/03/2023	932	2.16	540	11673	0	0	419	9053	0	0	20.7	35.9
11/03/2023	1002	2.46	481	11833	0	0	374	9198	0	0	21.0	36.4
12/03/2023	1023	2.76	693	19116	0	0	423	11661	0	0	30.8	53.2
13/03/2023	971	2.75	599	16481	0	0	470	12928	0	0	29.4	50.9
14/03/2023	961	2.49	519	12911	0	0	466	11611	0	0	24.5	42.4
15/03/2023	1043	2.32	459	10649	0	0	494	11456	0	0	22.1	38.2
16/03/2023	879	2.90	354	10269	128	3712	414	12000	0	0	26.0	44.9
17/03/2023	1065	3.42	223	7616	548	18738	309	10561	0	0	36.9	63.9
18/03/2023	1059	2.89	363	10476	305	8823	287	8289	0	0	27.6	47.7
19/03/2023	771	2.98	166	4932	320	9548	83	2476	0	0	17.0	29.3
20/03/2023	287	2.90	0	0	192	5574	28	821	0	0	6.4	11.1
21/03/2023	850	2.65	438	11604	16	419	425	11263	0	0	23.3	40.3
22/03/2023	869	2.44	430	10494	137	3338	223	5441	0	0	19.3	33.3
23/03/2023	990	2.30	458	10529	320	7349	437	10042	0	0	27.9	48.3
24/03/2023	734	2.15	69	1481	258	5553	196	4214	0	0	11.2	19.5
25/03/2023	851	2.52	1	13	668	16826	260	6547	0	0	23.4	40.5
26/03/2023	913	2.67	0	0	631	16845	407	10867	0	0	27.7	47.9
27/03/2023	691	2.53	0	0	440	11122	434	10968	0	0	22.1	38.2
28/03/2023	817	2.61	0	0	489	12760	335	8754	0	0	21.5	37.2
29/03/2023	845	2.55	0	0	413	10534	360	9190	0	0	19.7	34.1
30/03/2023	1008	2.31	0	0	430	9935	456	10529	0	0	20.5	35.4
31/03/2023	1355	2.43	0	0	691	16799	290	7047	0	0	23.8	41.3
01/04/2023	981	2.47	0	0	454	11211	246	6084	0	0	17.3	29.9
02/04/2023	1198	2.49	359	8932	636	15836	537	13379	0	0	38.1	66.0
03/04/2023	1203	2.50	429	10723	453	11320	224	5597	0	0	27.6	47.8
04/04/2023	1210	2.51	351	8813	387	9711	386	9696	0	0	28.2	48.8
05/04/2023	972	2.51	245	6157	0	0	251	6298	0	0	12.5	21.5
06/04/2023	987	2.66	644	17117	0	0	477	12688	0	0	29.8	51.6
07/04/2023	962	2.86	490	14003	0	0	529	15127	0	0	29.1	50.4
08/04/2023	1003	2.96	506	14984	0	0	491	14537	0	0	29.5	51.1
09/04/2023	960	3.06	540	16536	0	0	552	16897	0	0	33.4	57.8
10/04/2023	967	3.02	480	14496	0	0	519	15665	0	0	30.2	52.2
11/04/2023	941	2.98	633	18872	0	0	464	13824	0	0	32.7	56.6
12/04/2023	929	2.62	513	13443	0	0	392	10273	0	0	23.7	41.0
13/04/2023	901	2.52	544	13706	0	0	313	7883	0	0	21.6	37.4
14/04/2023	1070	2.59	586	15172	0	0	532	13766	0	0	28.9	50.1
15/04/2023	1169	2.64	731	19285	260	6867	487	12857	0	0	39.0	67.5
16/04/2023	1282	2.67	424	11326	65	1722	632	16882	0	0	29.9	51.8
17/04/2023	961	2.69	435	11702	145	3903	424	11406	0	0	27.0	46.7
18/04/2023	979	2.74	436	11941	192	5264	207	5677	0	0	22.9	39.6
19/04/2023	1034	1.90	905	17199	50	944	0	0	22	414	18.6	32.1
20/04/2023	538	1.77	587	10390	29	508	0	0	1	19	10.9	18.9

Dewatering Plant - Primary Sludge

	Sludge Pumped from Primary Pump Station	Belt Press Feed from Primary Pump Station	Primary Belt Press 1 Sludge Feed	Primary Belt Press 1 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 2 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 3 Sludge Feed	Primary Belt Press 4 Sludge Feed	Primary Belt Press 4 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	**m^3**	**%DS**	**m^3**	**kg**	**m^3**	**kg**	**m^3**	**kg**	**m^3**	**kg**	**tDS**	**tSolids**
21/04/2023	877	2.71	541	14656	0	0	0	0	0	0	14.7	25.4
22/04/2023	1014	2.52	573	14442	2	38	0	0	369	9299	23.8	41.1
23/04/2023	1334	2.42	318	7698	467	11311	0	0	516	12492	31.5	54.5
24/04/2023	1220	2.32	0	0	591	13700	0	0	635	14723	28.4	49.2
25/04/2023	1032	2.43	0	0	435	10580	0	0	563	13686	24.3	42.0
26/04/2023	913	2.19	0	0	527	11543	0	0	592	12956	24.5	42.4
27/04/2023	823	2.23	487	10856	0	0	0	0	498	11110	22.0	38.0
28/04/2023	877	2.27	570	12946	0	0	0	0	458	10406	23.4	40.4
29/04/2023	974	2.39	328	7832	0	0	0	0	625	14945	22.8	39.4
30/04/2023	926	2.00	763	15256	0	0	0	0	131	2614	17.9	30.9
01/05/2023	996	1.97	170	3353	598	11779	0	0	0	0	15.1	26.2
02/05/2023	1022	2.08	0	0	745	15486	0	0	0	0	15.5	26.8
03/05/2023	647	2.19	0	0	569	12457	0	0	11	234	12.7	22.0
04/05/2023	1206	2.74	0	0	618	16933	0	0	627	17177	34.1	59.0
05/05/2023	1008	2.52	0	0	473	11915	0	0	789	19878	31.8	55.0
06/05/2023	742	2.45	0	0	286	7007	0	0	279	6833	13.8	23.9
07/05/2023	733	2.37	0	0	0	0	0	0	567	13440	13.4	23.3
08/05/2023	393	1.92	0	0	0	0	0	0	422	8106	8.1	14.0
09/05/2023	744	2.62	0	0	283	7409	0	0	440	11533	18.9	32.8
10/05/2023	1096	2.82	0	0	557	15693	0	0	523	14760	30.5	52.7
11/05/2023	1254	2.41	0	0	710	17113	0	0	647	15581	32.7	56.6
12/05/2023	1056	2.98	0	0	592	17645	0	0	499	14861	32.5	56.2
13/05/2023	1179	2.38	0	0	612	14566	0	0	672	16001	30.6	52.9
14/05/2023	1180	1.78	0	0	612	10894	0	0	673	11987	22.9	39.6
15/05/2023	1050	1.84	0	0	505	9288	0	0	510	9384	18.7	32.3
16/05/2023	1055	1.89	0	0	488	9225	0	0	158	2986	12.2	21.1
17/05/2023	313	1.93	0	0	62	1197	0	0	154	2963	4.2	7.2
18/05/2023	1164	1.96	628	12311	0	0	0	0	536	10504	22.8	39.5
19/05/2023	1706	2.31	1049	24234	0	0	69	1589	763	17616	43.4	75.2
20/05/2023	1372	1.91	1283	24501	0	0	0	0	194	3703	28.2	48.8
21/05/2023	1216	1.83	1079	19737	0	0	0	0	0	0	19.7	34.1
22/05/2023	1063	1.99	707	14065	0	0	0	0	272	5405	19.5	33.7
23/05/2023	1188	2.35	1220	28675	0	0	0	0	83	1943	30.6	53.0
24/05/2023	609	2.13	408	8690	0	0	0	0	0	0	8.7	15.0
25/05/2023	1096	1.93	675	13031	218	4205	0	0	563	10858	28.1	48.6
26/05/2023	830	2.01	318	6386	54	1087	0	0	200	4026	11.5	19.9
27/05/2023	2025	2.43	1186	28813	669	16252	0	0	570	13858	58.9	101.9
28/05/2023	834	2.64	410	10813	158	4158	0	0	249	6571	21.5	37.3
29/05/2023	549	2.75	270	7436	0	0	0	0	213	5866	13.3	23.0
30/05/2023	909	2.80	312	8730	0	0	0	0	309	8646	17.4	30.1
31/05/2023	411	2.85	589	16772	0	0	0	0	64	1810	18.6	32.1
01/06/2023	1382	2.11	518	10926	0	0	0	0	321	6767	17.7	30.6
02/06/2023	874	1.85	672	12430	0	0	0	0	625	11553	24.0	41.5
03/06/2023	1902	1.83	847	15506	0	0	0	0	798	14609	30.1	52.1
04/06/2023	1006	1.82	530	9642	95	1720	0	0	853	15516	26.9	46.5
05/06/2023	923	1.81	439	7939	16	290	0	0	192	3477	11.7	20.3
06/06/2023	230	2.36	342	8066	0	0	0	0	0	0	8.1	14.0
07/06/2023	1538	2.18	829	18074	0	0	0	0	404	8798	26.9	46.5
08/06/2023	1539	2.27	831	18852	0	0	0	0	404	9178	28.0	48.5
09/06/2023	1534	2.32	880	20425	0	0	0	0	592	13730	34.2	59.1
10/06/2023	1241	1.18	636	7508	0	0	0	0	608	7170	14.7	25.4
11/06/2023	1212	1.56	741	11558	0	0	0	0	620	9677	21.2	36.7
12/06/2023	775	0.95	734	6977	216	2052	0	0	0	0	9.0	15.6
13/06/2023	847	1.78	489	8717	267	4761	0	0	0	0	13.5	23.3
14/06/2023	936	1.84	778	14312	236	4346	0	0	0	0	18.7	32.3
15/06/2023	1465	0.84	646	5422	595	4994	0	0	0	0	10.4	18.0
16/06/2023	1267	0.97	825	8006	853	8276	0	0	0	0	16.3	28.2
17/06/2023	1252	1.04	394	4094	147	1530	0	0	0	0	5.6	9.7
18/06/2023	898	1.07	274	2932	644	6885	0	0	0	0	9.8	17.0
19/06/2023	982	1.10	527	5797	523	5753	0	0	0	0	11.6	20.0
20/06/2023	815	1.09	448	4878	447	4876	0	0	0	0	9.8	16.9
21/06/2023	702	1.83	486	8885	482	8821	0	0	0	0	17.7	30.6
22/06/2023	630	1.99	227	4515	335	6670	0	0	0	0	11.2	19.4
23/06/2023	588	2.35	356	8371	324	7621	0	0	0	0	16.0	27.7
24/06/2023	553	2.13	276	5883	271	5781	0	0	0	0	11.7	20.2
25/06/2023	628	1.93	317	6124	316	6101	0	0	0	0	12.2	21.1
26/06/2023	520	2.01	0	0	323	6492	0	0	0	0	6.5	11.2
27/06/2023	1104	2.43	527	12796	507	12325	0	0	0	0	25.1	43.5
28/06/2023	1104	2.64	528	13926	508	13411	0	0	0	0	27.3	47.3
29/06/2023	1843	2.75	1074	29538	966	26554	0	0	0	0	56.1	97.0
30/06/2023	2000	2.80	1021	28591	736	20600	0	0	0	0	49.2	85.1
D/Ave.	**950.9**	**2.57**	**329.3**	**8232.6**	**238.4**	**5874.1**	**163.8**	**4448.2**	**207.2**	**5193.0**	**23.7**	**41.1**
Total	**347079**	**937**	**120199**	**3004912**	**87012**	**2144045**	**59775**	**1623610**	**75641**	**1895441**	**8668**	**14997**

Dewatering Plant - WAS Sludge

	Sludge Pumped from Central WAS / Buffer Tank	Belt Press Feed from Central WAS / Buffer Tank	WAS Belt Press 1 Sludge Feed	WAS Belt Press 1 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 6 Sludge Feed	WAS Belt Press 6 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	m^3	%DS	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	tDS	tSolids
16/07/2022	938	1.14	556	6356	665	7605	0	0	0	0	0	0	0	0	14.0	39.4
17/07/2022	3060	1.00	1207	12034	1251	12465	9	92	0	0	0	0	0	0	24.6	69.5
18/07/2022	1530	0.92	604	5557	625	5750	4	37	0	0	0	0	0	0	11.3	32.0
19/07/2022	765	0.84	302	2547	313	2640	2	17	0	0	0	0	0	0	5.2	14.7
20/07/2022	765	0.87	303	2629	314	2717	4	33	0	0	0	0	0	0	5.4	15.2
21/07/2022	1092	1.14	556	6320	551	6268	0	0	0	0	0	0	0	0	12.6	35.6
22/07/2022	1662	1.09	651	7121	658	7196	0	0	435	4758	0	0	0	0	19.1	53.9
23/07/2022	1525	0.82	568	4656	574	4703	0	0	429	3519	0	0	0	0	12.9	36.4
24/07/2022	845	1.32	454	5994	435	5745	0	0	0	0	0	0	0	0	11.7	33.2
25/07/2022	1273	1.09	536	5826	544	5915	0	0	0	0	0	0	0	0	11.7	33.2
26/07/2022	4322	1.20	1509	18107	1620	19436	0	0	1649	19792	0	0	0	0	57.3	162.0
27/07/2022	1747	1.47	359	5282	581	8563	0	0	582	8578	0	0	0	0	22.4	63.3
28/07/2022	873	1.28	180	2310	290	3722	0	0	292	3747	0	0	0	0	9.8	27.6
29/07/2022	437	1.12	90	1005	145	1619	0	0	146	1630	0	0	0	0	4.3	12.0
30/07/2022	438	1.05	90	945	146	1535	0	0	146	1533	0	0	0	0	4.0	11.3
31/07/2022	1514	1.14	531	6053	571	6507	0	0	567	6464	0	0	0	0	19.0	53.7
01/08/2022	1515	1.18	532	6272	571	6735	0	0	567	6693	0	0	0	0	19.7	55.7
02/08/2022	1727	1.13	505	5708	537	6070	0	0	536	6060	0	0	0	0	17.8	50.4
03/08/2022	3957	1.14	161	1828	573	6504	0	0	1227	13921	1113	12636	824	9351	44.2	125.0
04/08/2022	1978	1.28	0	0	286	3670	0	0	613	7867	557	7148	412	5287	24.0	67.7
05/08/2022	989	1.54	0	0	143	2207	0	0	307	4738	278	4290	206	3179	14.4	40.7
06/08/2022	991	0.91	0	0	144	1310	0	0	307	2794	280	2546	208	1891	8.5	24.1
07/08/2022	725	1.79	0	0	133	2365	0	0	449	8011	322	5746	624	11140	27.3	77.0
08/08/2022	1908	1.17	0	0	502	5842	0	0	468	5451	0	0	501	5833	17.1	48.4
09/08/2022	2016	1.17	0	0	629	7383	0	0	625	7337	0	0	626	7347	22.1	62.3
10/08/2022	2176	0.97	0	0	626	6074	0	0	566	5485	0	0	630	6106	17.7	49.9
11/08/2022	4548	1.01	824	8353	1350	13676	0	0	659	6673	485	4918	1267	12836	46.5	131.2
12/08/2022	2274	1.71	412	7031	675	11520	0	0	330	5632	243	4147	633	10803	39.1	110.5
13/08/2022	1137	1.58	206	3255	337	5325	0	0	165	2607	121	1912	316	4993	18.1	51.1
14/08/2022	1138	0.90	207	1852	339	3035	0	0	165	1478	122	1093	318	2844	10.3	29.1
15/08/2022	879	0.78	231	1791	443	3443	0	0	389	3024	0	0	443	3440	11.7	33.0
															583.8	1649.2
16/08/2022	1982	0.80	234	1868	606	4845	0	0	400	3197	36	287	610	4882	15.1	42.6
17/08/2022	1984	0.82	234	1922	607	4973	0	0	401	3288	37	307	611	5012	15.5	43.8
18/08/2022	2418	1.15	0	0	577	6655	0	0	569	6566	0	0	654	7538	20.8	58.6
19/08/2022	2386	1.76	418	7338	611	10728	0	0	583	10245	0	0	695	12205	40.5	114.5
20/08/2022	1892	1.32	391	5180	494	6532	0	0	365	4824	0	0	555	7346	23.9	67.5
21/08/2022	1846	1.25	522	6536	530	6645	0	0	426	5339	0	0	303	3798	22.3	63.0
22/08/2022	1846	1.11	522	5771	265	2933	0	0	213	2357	0	0	303	3355	14.4	40.7
23/08/2022	2573	1.30	543	7063	265	3449	0	0	214	2781	0	0	612	7952	21.2	60.0
24/08/2022	1544	1.15	578	6620	551	6310	0	0	542	6208	0	0	500	5726	24.9	70.2
25/08/2022	2027	1.12	147	1642	579	6483	0	0	476	5336	0	0	515	5771	19.2	54.3
26/08/2022	2161	1.13	0	0	556	6281	13	141	505	5707	0	0	829	9368	21.5	60.7
27/08/2022	0	1.18	0	0	567	6674	0	0	516	6073	0	0	829	9755	22.5	63.6
28/08/2022	1204	1.09	0	0	573	6244	0	0	573	6247	0	0	829	9036	21.5	60.8
29/08/2022	3367	1.08	0	0	463	5013	0	0	441	4776	0	0	324	3510	13.3	37.6
30/08/2022	0	1.15	0	0	507	5828	0	0	471	5418	0	0	162	1863	13.1	37.0
31/08/2022	0	1.24	0	0	153	1886	367	4536	542	6703	0	0	163	2013	15.1	42.8
01/09/2022	2713	1.27	151	1915	0	0	512	6476	520	6578	289	3660	549	6947	25.6	72.2
02/09/2022	2143	1.12	195	2183	0	0	628	7030	421	4712	302	3382	228	2558	19.9	56.1
03/09/2022	1467	1.04	0	0	0	0	282	2937	224	2328	0	0	0	0	5.3	14.9
04/09/2022	1216	1.00	46	458	0	0	59	588	602	6018	0	0	564	5636	12.7	35.9
05/09/2022	1933	0.96	515	4915	0	0	779	7439	527	5033	584	5574	0	0	23.0	64.9
06/09/2022	2042	0.94	209	1951	0	0	337	3151	357	3338	467	4370	0	0	12.8	36.2
07/09/2022	1572	1.16	204	2371	0	0	432	5009	355	4118	384	4457	0	0	16.0	45.1
08/09/2022	1566	1.36	1	19	0	0	737	10016	715	9717	691	9398	0	0	29.2	82.3
09/09/2022	1236	1.08	15	158	0	0	557	6011	515	5562	459	4960	0	0	16.7	47.2
10/09/2022	2040	1.13	0	0	0	0	594	6710	515	5820	629	7111	0	0	19.6	55.5
11/09/2022	1032	1.11	0	0	0	0	527	5818	530	5853	488	5397	0	0	17.1	48.2
12/09/2022	1971	0.86	443	3806	0	0	480	4124	422	3630	439	3775	0	0	15.3	43.3
13/09/2022	2226	1.00	444	4438	0	0	426	4263	447	4471	446	4457	320	3204	20.8	58.9
14/09/2022	2642	1.00	407	4049	0	0	535	5327	519	5159	517	5148	472	4699	24.4	68.9
15/09/2022	2470	1.17	289	3370	0	0	525	6121	593	6907	565	6582	109	1265	24.2	68.5
															607.4	1715.7
16/09/2022	2316	1.47	441	6461	0	0	660	9665	605	8862	649	9508	0	0	34.5	97.4
17/09/2022	2035	1.08	69	742	0	0	411	4440	642	6935	862	9304	0	0	21.4	60.5
18/09/2022	1755	1.37	0	0	0	0	597	8153	519	7083	626	8539	0	0	23.8	67.2
19/09/2022	2333	1.17	560	6568	0	0	734	8612	543	6375	680	7980	0	0	29.5	83.4
20/09/2022	2638	1.06	417	4402	0	0	859	9076	654	6905	673	7112	0	0	27.5	77.7
21/09/2022	2243	1.29	405	5227	0	0	753	9710	304	3915	783	10096	0	0	28.9	81.8
22/09/2022	2164	1.20	242	2903	0	0	758	9091	254	3044	725	8700	0	0	23.7	67.1
23/09/2022	2046	1.22	101	1235	0	0	680	8292	583	7108	663	8093	0	0	24.7	69.9
24/09/2022	1996	1.32	5	61	0	0	602	7950	600	7925	701	9248	0	0	25.2	71.1
25/09/2022	1996	0.84	6	46	0	0	603	5067	602	5053	703	5901	0	0	16.1	45.4
26/09/2022	2476	0.82	413	3388	0	0	819	6714	718	5885	530	4349	0	0	20.3	57.4
27/09/2022	2115	1.04	291	3023	0	0	755	7852	589	6127	751	7809	0	0	24.8	70.1
28/09/2022	2320	1.14	0	0	0	0	804	9169	671	7645	864	9852	0	0	26.7	75.3
29/09/2022	1018	1.17	179	2092	0	0	446	5217	59	684	685	8010	0	0	16.0	45.2
30/09/2022	1649	1.03	392	4041	0	0	414	4260	0	0	634	6529	0	0	14.8	41.9
01/10/2022	1915	1.14	429	4886	0	0	179	2037	0	0	646	7364	0	0	14.3	40.4
02/10/2022	921	0.94	272	2555	0	0	0	0	0	0	583	5480	0	0	8.0	22.7
03/10/2022	922	1.09	344	3750	0	0	104	1128	0	0	832	9071	0	0	13.9	39.4
04/10/2022	1509	0.89	455	4051	0	0	426	3790	0	0	525	4676	0	0	12.5	35.4
05/10/2022	1642	1.19	685	8156	0	0	667	7941	0	0	682	8115	0	0	24.2	68.4
06/10/2022	2774	0.94	841	7905	0	0	582	5472	0	0	828	7783	0	0	21.2	59.8
07/10/2022	2278	1.19	979	11644	0	0	19	224	0	0	1237	14720	0	0	26.6	75.1
08/10/2022	1139	0.99	489	4841	0	0	9	89	0	0	619	6128	0	0	11.1	31.2
09/10/2022	1140	1.23	491	6038	0	0	11	134	0	0	620	7621	0	0	13.8	39.0
10/10/2022	1974	1.02	657	6700	0	0	592	6041	0	0	690	7040	0	0	19.8	55.9
11/10/2022	1784	1.36	559	7597	0	0	577	7846	0	0	649	8830	0	0	24.3	68.6
12/10/2022	2100	1.14	371	4228	0	0	460	5241	0	0	651	7419	289	3295	20.2	57.0
13/10/2022	2188	1.19	620	7378	0	0	593	7061	0	0	617	7341	473	5629	27.4	77.4
14/10/2022	1787	1.08	541	5842	0	0	461	4973	0	0	502	5416	407	4400	20.6	58.3
15/10/2022	2288	1.12	511	5725	0	0	614	6875	0	0	520	5825	497	5568	24.0	67.8
															639.9	1807.6
16/10/2022	1370	0.83	460	3820	0	0	512	4250	0	0	425	3528	453	3762	15.4	43.4
17/10/2022	1478	1.38	367	5063	0	0	215	2964	0	0	438	6039	78	1076	15.1	42.8
18/10/2022	329	1.13	490	5540	0	0	379	4286	0	0	82	929	0	0	10.8	30.4
19/10/2022	1932	1.17	611	7152	0	0	431	5046	0	0	551	6444	0	0	18.6	52.7
20/10/2022	2350	1.04	628	6531	0	0	350	3639	0	0	798	8301	0	0	18.5	52.2
21/10/2022	1427	1.31	690	9035	0	0	331	4339	0	0	395	5178	0	0	18.6	52.4
22/10/2022	1460	1.36	697	9482	0	0	0	0	0	0	586	7964	0	0	17.4	49.3

Dewatering Plant - WAS Sludge

	Sludge Pumped from Central WAS / Buffer Tank	Belt Press Feed from Central WAS / Buffer Tank	WAS Belt Press 1 Sludge Feed	WAS Belt Press 1 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 6 Sludge Feed	WAS Belt Press 6 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	m^3	%DS	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	tDS	tSolids
23/10/2022	1243	0.96	583	5601	0	0	568	5448	0	0	537	5153	0	0	16.2	45.8
24/10/2022	1794	1.12	641	7180	0	0	594	6648	0	0	522	5842	0	0	19.7	55.6
25/10/2022	1573	1.11	553	6133	0	0	505	5608	0	0	552	6129	0	0	17.9	50.5
26/10/2022	1547	1.27	621	7882	0	0	622	7903	0	0	11	140	0	0	15.9	45.0
27/10/2022	1949	1.23	521	6411	379	4657	499	6132	0	0	487	5991	0	0	23.2	65.5
28/10/2022	1719	0.96	485	4658	519	4981	381	3657	0	0	552	5300	0	0	18.6	52.5
29/10/2022	1805	1.19	500	5950	537	6388	0	0	0	0	333	3963	0	0	16.3	46.0
30/10/2022	1787	1.74	631	10986	667	11606	9	157	0	0	590	10269	0	0	33.0	93.3
31/10/2022	2284	1.03	600	6183	625	6440	409	4208	0	0	609	6275	0	0	23.1	65.3
01/11/2022	1539	1.08	538	5814	367	3958	184	1987	0	0	516	5574	0	0	17.3	49.0
02/11/2022	2337	1.07	648	6929	263	2809	643	6882	0	0	598	6394	0	0	23.0	65.0
03/11/2022	1503	1.10	582	6403	0	0	582	6400	0	0	563	6191	425	4672	23.7	66.9
04/11/2022	2120	1.02	474	4839	0	0	414	4221	0	0	480	4896	562	5732	19.7	55.6
05/11/2022	1928	0.93	598	5561	0	0	415	3856	0	0	415	3860	570	5301	18.6	52.5
06/11/2022	1612	1.37	589	8067	0	0	579	7932	0	0	300	4103	492	6735	26.8	75.8
07/11/2022	1847	0.71	632	4489	0	0	453	3213	0	0	0	0	452	3208	10.9	30.8
08/11/2022	2209	1.13	557	6299	0	0	522	5902	0	0	86	976	686	7750	20.9	59.1
09/11/2022	2069	0.64	536	3432	0	0	536	3428	0	0	0	0	572	3663	10.5	29.7
10/11/2022	1955	1.15	599	6890	0	0	599	6889	0	0	0	0	634	7296	21.1	59.5
11/11/2022	1475	1.11	597	6631	0	0	597	6623	0	0	0	0	613	6807	20.1	56.7
12/11/2022	2133	0.72	559	4023	0	0	562	4047	0	0	0	0	626	4504	12.6	35.5
13/11/2022	1689	1.09	610	6645	0	0	607	6611	0	0	0	0	646	7041	20.3	57.3
14/11/2022	2248	1.13	629	7107	0	0	628	7098	0	0	0	0	616	6964	21.2	59.8
15/11/2022	1614	1.13	722	8156	0	0	739	8351	0	0	0	0	260	2940	19.4	54.9
															584.3	1650.7
16/11/2022	2107	0.95	213	2024	0	0	708	6725	0	0	532	5049	112	1064	14.9	42.0
17/11/2022	1474	0.98	1061	10394	0	0	305	2991	0	0	213	2083	550	5392	20.9	58.9
18/11/2022	1398	1.09	620	6762	0	0	391	4260	0	0	213	2320	482	5256	18.6	52.5
19/11/2022	1783	1.21	506	6120	0	0	487	5889	0	0	27	328	136	1641	14.0	39.5
20/11/2022	1700	0.92	551	5069	0	0	586	5391	0	0	503	4625	0	0	15.1	42.6
21/11/2022	2273	1.09	595	6508	0	0	609	6664	0	0	439	4802	552	6040	24.0	67.8
22/11/2022	2522	1.08	663	7186	0	0	663	7190	0	0	601	6515	614	6650	27.5	77.8
23/11/2022	2515	1.01	706	7133	0	0	698	7052	0	0	641	6471	640	6462	27.1	76.6
24/11/2022	2411	1.09	605	6598	0	0	575	6264	0	0	497	5415	1192	12987	31.3	88.3
25/11/2022	2001	0.98	657	6434	0	0	654	6411	0	0	0	0	596	5842	18.7	52.8
26/11/2022	2001	0.97	658	6386	0	0	655	6353	0	0	0	0	0	0	12.7	36.0
27/11/2022	1437	0.97	544	5274	0	0	489	4740	0	0	320	3102	0	0	13.1	37.1
28/11/2022	1943	0.96	680	6525	0	0	552	5303	0	0	682	6551	0	0	18.4	51.9
29/11/2022	1952	1.03	732	7539	0	0	544	5607	0	0	729	7505	0	0	20.7	58.3
30/11/2022	1990	1.05	434	4557	0	0	629	6601	0	0	675	7084	0	0	18.2	51.5
01/12/2022	2349	1.09	1069	11652	0	0	664	7235	0	0	611	6656	0	0	25.5	72.2
02/12/2022	2009	0.95	739	7023	0	0	630	5986	0	0	717	6814	0	0	19.8	56.0
03/12/2022	2023	1.02	635	6473	0	0	630	6421	0	0	627	6392	0	0	19.3	54.5
04/12/2022	1693	1.06	590	6254	0	0	548	5812	0	0	528	5594	0	0	17.7	49.9
05/12/2022	1943	1.09	605	6595	0	0	592	6454	0	0	592	6448	0	0	19.5	55.1
06/12/2022	1918	0.90	621	5587	0	0	621	5586	0	0	619	5571	0	0	16.7	47.3
07/12/2022	1461	0.79	615	4858	0	0	611	4823	0	0	305	2406	0	0	12.1	34.1
08/12/2022	1798	0.82	620	5086	0	0	600	4921	0	0	539	4416	0	0	14.4	40.7
09/12/2022	1857	0.97	603	5847	0	0	602	5836	0	0	580	5625	0	0	17.3	48.9
10/12/2022	1590	1.00	602	6019	0	0	572	5724	0	0	373	3726	0	0	15.5	43.7
11/12/2022	1211	1.09	539	5870	0	0	550	5999	0	0	139	1514	0	0	13.4	37.8
12/12/2022	1423	1.02	607	6188	0	0	605	6174	0	0	189	1929	0	0	14.3	40.4
13/12/2022	1713	0.91	581	5283	0	0	579	5268	0	0	532	4845	0	0	15.4	43.5
14/12/2022	1914	1.00	639	6390	0	0	603	6030	0	0	520	5200	0	0	17.6	49.8
15/12/2022	1894	1.05	607	6374	0	0	605	6350	0	0	0	0	602	6316	19.0	53.8
															552.7	1561.3
16/12/2022	1460	1.11	533	5919	0	0	560	6212	0	0	244	2704	263	2914	17.7	50.1
17/12/2022	1528	1.11	584	6484	0	0	539	5986	0	0	0	0	201	2230	14.7	41.5
18/12/2022	1539	1.34	618	8276	0	0	583	7807	0	0	188	2517	97	1293	19.9	56.2
19/12/2022	1402	0.88	543	4781	0	0	526	4624	0	0	506	4453	0	0	13.9	39.1
20/12/2022	1694	0.97	606	5881	0	0	608	5901	0	0	596	5782	0	0	17.6	49.6
21/12/2022	2092	1.43	530	7572	0	0	532	7612	0	0	526	7522	0	0	22.7	64.1
22/12/2022	1955	1.02	575	5867	0	0	665	6785	0	0	657	6703	0	0	19.4	54.7
23/12/2022	1836	1.06	625	6621	0	0	575	6099	0	0	574	6087	0	0	18.8	53.1
24/12/2022	1755	1.00	622	6221	0	0	603	6032	0	0	594	5937	0	0	18.2	51.4
25/12/2022	1904	1.03	585	6028	0	0	594	6121	0	0	582	5997	0	0	18.1	51.3
26/12/2022	1711	0.96	571	5483	0	0	560	5380	0	0	554	5318	0	0	16.2	45.7
27/12/2022	2005	0.88	644	5670	0	0	644	5671	0	0	643	5661	0	0	17.0	48.0
28/12/2022	1492	0.94	620	5831	0	0	639	6003	0	0	616	5794	0	0	17.6	49.8
29/12/2022	1973	1.05	670	7033	0	0	668	7016	0	0	642	6743	0	0	20.8	58.7
30/12/2022	2645	1.16	717	8311	0	0	702	8148	0	0	683	7923	0	0	24.4	68.9
31/12/2022	2152	0.85	705	5995	0	0	714	6071	0	0	675	5741	0	0	17.8	50.3
01/01/2023	1747	0.99	776	7680	0	0	744	7367	0	0	154	1528	0	0	16.6	46.8
02/01/2023	1421	1.02	691	7048	0	0	625	6374	0	0	81	830	0	0	14.3	40.3
03/01/2023	1581	1.00	646	6464	0	0	519	5187	0	0	0	0	500	4999	16.7	47.0
04/01/2023	1458	0.75	662	4965	0	0	715	5366	0	0	440	3296	20	146	13.8	38.9
05/01/2023	1184	0.76	454	3451	0	0	442	3362	0	0	564	4289	0	0	11.1	31.4
06/01/2023	1351	0.85	268	2281	0	0	267	2265	0	0	260	2213	0	0	6.8	19.1
07/01/2023	924	1.04	534	5552	0	0	531	5518	0	0	525	5459	0	0	16.5	46.7
08/01/2023	575	0.86	315	2705	0	0	200	1717	0	0	84	721	0	0	5.1	14.5
09/01/2023	1681	0.78	659	5143	0	0	644	5024	0	0	329	2565	0	0	12.7	36.0
10/01/2023	756	0.72	359	2588	0	0	367	2642	0	0	5	35	0	0	5.3	14.9
11/01/2023	756	0.78	389	3036	0	0	354	2761	0	0	84	658	0	0	6.5	18.2
12/01/2023	1077	0.73	0	0	0	0	450	3287	0	0	435	3176	0	0	6.5	18.3
13/01/2023	397	0.82	0	0	0	0	321	2631	0	0	307	2514	0	0	5.1	14.5
14/01/2023	910	0.76	0	0	0	0	506	3847	0	0	339	2579	0	0	6.4	18.2
15/01/2023	870	0.82	0	0	0	0	490	4021	0	0	342	2808	0	0	6.8	19.3
															444.9	1256.7
16/01/2023	1229	0.82	444	3641	0	0	385	3155	0	0	515	4221	0	0	11.0	31.1
17/01/2023	1847	1.08	700	7562	0	0	0	0	0	0	698	7537	0	0	15.1	42.7
18/01/2023	1206	0.82	740	6065	0	0	0	0	0	0	731	5994	0	0	12.1	34.1
19/01/2023	1501	0.83	688	5708	0	0	0	0	0	0	676	5607	0	0	11.3	32.0
20/01/2023	1888	0.84	641	5387	0	0	641	5386	0	0	684	5741	0	0	16.5	46.7
21/01/2023	1816	0.85	608	5165	0	0	526	4468	0	0	592	5035	0	0	14.7	41.4
22/01/2023	1637	0.81	489	3960	0	0	718	5819	0	0	377	3051	0	0	12.8	36.2
23/01/2023	1655	0.85	653	5546	0	0	575	4888	0	0	71	602	0	0	11.0	31.2
24/01/2023	2077	0.91	647	5890	0	0	615	5600	0	0	536	4878	0	0	16.4	46.2
25/01/2023	1782	1.01	719	7260	0	0	715	7224	0	0	702	7089	0	0	21.6	60.9
26/01/2023	2322	0.78	793	6186	0	0	778	6066	0	0	736	5738	0	0	18.0	50.8
27/01/2023	1575	0.88	546	4805	0	0	631	5551	0	0	324	2850	0	0	13.2	37.3
28/01/2023	1913	0.79	865	6837	0	0	593	4682	0	0	230	1817	0	0	13.3	37.7
29/01/2023	1520	0.96	761	7302	0	0	666	6396	0	0	0	0	0	0	13.7	38.7

Dewatering Plant - WAS Sludge

	Sludge Pumped from Central WAS / Buffer Tank	Belt Press Feed from Central WAS / Buffer Tank	WAS Belt Press 1 Sludge Feed	WAS Belt Press 1 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 6 Sludge Feed	WAS Belt Press 6 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	m^3	%DS	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	tDS	tSolids
30/01/2023	1641	0.99	731	7235	0	0	729	7216	0	0	0	0	0	0	14.5	40.8
31/01/2023	2096	0.87	806	7016	0	0	801	6970	0	0	340	2961	0	0	16.9	47.9
01/02/2023	1690	1.05	621	6517	0	0	637	6687	0	0	272	2853	0	0	16.1	45.4
02/02/2023	1539	1.30	643	8364	0	0	641	8337	0	0	258	3359	0	0	20.1	56.7
03/02/2023	2432	0.92	959	8822	0	0	958	8815	0	0	538	4950	0	0	22.6	63.8
04/02/2023	1039	0.87	486	4232	0	0	484	4208	0	0	300	2610	0	0	11.0	31.2
05/02/2023	1628	0.90	678	6099	0	0	676	6081	0	0	268	2412	0	0	14.6	41.2
06/02/2023	1828	0.97	545	5286	0	0	613	5946	0	0	527	5107	0	0	16.3	46.2
07/02/2023	1502	1.16	667	7741	0	0	566	6570	0	0	418	4849	0	0	19.2	54.1
08/02/2023	1833	0.89	750	6675	0	0	754	6714	0	0	8	71	0	0	13.5	38.0
09/02/2023	1996	0.79	735	5808	0	0	773	6105	0	0	342	2700	0	0	14.6	41.3
10/02/2023	1945	1.08	702	7584	0	0	701	7568	0	0	693	7488	0	0	22.6	64.0
11/02/2023	1862	0.00	679	0	0	0	456	0	0	0	673	0	0	0	0.0	0.0
12/02/2023	1833	0.73	554	4046	0	0	548	4003	0	0	517	3773	0	0	11.8	33.4
13/02/2023	1609	0.85	543	4615	0	0	534	4536	0	0	372	3159	0	0	12.3	34.8
14/02/2023	1882	1.09	499	5434	0	0	666	7255	0	0	725	7906	0	0	20.6	58.2
15/02/2023	1808	0.98	697	6833	0	0	731	7164	0	0	814	7976	0	0	22.0	62.1
															469.4	1325.9
16/02/2023	1947	0.98	710	6962	0	0	604	5918	0	0	673	6591	0	0	19.5	55.0
17/02/2023	1899	0.78	656	5114	0	0	515	4020	114	885	665	5190	0	0	15.2	43.0
18/02/2023	2579	0.00	784	0	0	0	799	0	232	0	758	0	0	0	0.0	0.0
19/02/2023	1719	0.89	115	1026	0	0	732	6514	533	4745	488	4341	0	0	16.6	47.0
20/02/2023	1882	0.74	3000	22197	0	0	730	5401	584	4319	401	2970	0	0	34.9	98.5
21/02/2023	1882	0.92	496	4560	0	0	0	0	589	5422	644	5928	0	0	15.9	44.9
22/02/2023	1927	0.76	618	4695	0	0	0	0	555	4221	561	4266	0	0	13.2	37.2
23/02/2023	1693	0.97	656	6363	0	0	0	0	561	5446	603	5849	0	0	17.7	49.9
24/02/2023	2075	1.11	685	7604	0	0	0	0	622	6904	679	7535	0	0	22.0	62.3
25/02/2023	1875	0.92	692	6366	0	0	268	2465	351	3232	595	5476	0	0	17.5	49.5
26/02/2023	1875	0.93	692	6436	0	0	268	2491	351	3267	595	5536	0	0	17.7	50.1
27/02/2023	1977	0.93	731	6800	0	0	527	4902	0	0	703	6534	0	0	18.2	51.5
28/02/2023	1958	0.98	805	7885	0	0	0	0	506	4958	748	7326	0	0	20.2	57.0
01/03/2023	1933	0.90	710	6394	0	0	0	0	482	4342	675	6076	0	0	16.8	47.5
02/03/2023	1885	1.00	645	6452	505	5054	0	0	145	1450	676	6764	0	0	19.7	55.7
03/03/2023	3187	0.99	1008	9977	885	8762	0	0	797	7891	182	1800	0	0	28.4	80.3
04/03/2023	1593	0.97	503	4879	442	4287	0	0	398	3857	90	873	0	0	13.9	39.3
05/03/2023	1594	0.79	505	3988	443	3503	0	0	400	3156	92	725	0	0	11.4	32.1
06/03/2023	2143	0.82	657	5388	0	0	592	4851	680	5579	720	5903	0	0	21.7	61.4
07/03/2023	2398	0.85	796	6765	0	0	805	6846	0	0	678	5759	0	0	19.4	54.7
08/03/2023	1964	0.96	612	5875	0	0	728	6987	0	0	720	6913	0	0	19.8	55.9
09/03/2023	119	0.87	592	5146	165	1435	753	6553	0	0	572	4977	0	0	18.1	51.2
10/03/2023	4041	0.75	781	5859	97	729	588	4412	0	0	416	3123	0	0	14.1	39.9
11/03/2023	2111	0.85	382	3246	0	0	842	7160	0	0	817	6944	0	0	17.4	49.0
12/03/2023	2297	0.94	817	7683	0	0	816	7670	0	0	685	6440	0	0	21.8	61.6
13/03/2023	2011	0.80	786	6285	0	0	561	4484	0	0	666	5328	0	0	16.1	45.5
14/03/2023	2070	0.90	877	7889	0	0	842	7576	0	0	603	5425	0	0	20.9	59.0
15/03/2023	2146	1.03	462	4754	0	0	722	7432	0	0	795	8190	0	0	20.4	57.6
															508.5	1436.4
16/03/2023	1979	0.88	500	4396	516	4544	670	5892	39	342	159	1402	0	0	16.6	46.8
17/03/2023	2087	0.83	0	0	557	4625	794	6589	759	6302	0	0	0	0	17.5	49.5
18/03/2023	2300	0.73	0	0	0	0	820	5985	776	5666	495	3614	0	0	15.3	43.1
19/03/2023	1951	0.99	0	0	0	0	715	7081	585	5792	639	6322	0	0	19.2	54.2
20/03/2023	2153	0.79	0	0	0	0	829	6547	754	5956	825	6517	0	0	19.0	53.7
21/03/2023	2188	0.67	0	0	0	0	812	5442	529	3546	715	4791	0	0	13.8	38.9
22/03/2023	2132	0.66	0	0	703	4637	820	5411	0	0	811	5352	0	0	15.4	43.5
23/03/2023	3966	0.94	0	0	1031	9691	864	8119	694	6527	1034	9723	0	0	34.1	96.2
24/03/2023	2214	0.72	0	0	200	1441	725	5217	672	4837	682	4911	0	0	16.4	46.3
25/03/2023	2960	0.83	0	0	558	4629	276	2287	794	6586	782	6489	0	0	20.0	56.5
26/03/2023	1992	0.89	0	0	322	2869	445	3961	465	4142	620	5521	0	0	16.5	46.6
27/03/2023	1763	1.15	0	0	559	6430	728	8369	385	4426	647	7441	0	0	26.7	75.3
28/03/2023	2899	0.98	0	0	688	6739	631	6180	576	5649	592	5801	197	1928	26.3	74.3
29/03/2023	3942	0.71	457	3246	799	5671	440	3124	791	5618	791	5614	592	4200	27.5	77.6
30/03/2023	2657	0.95	850	8078	855	8123	0	0	575	5464	458	4352	406	3853	29.9	84.4
31/03/2023	2625	0.84	931	7817	998	8379	0	0	788	6618	584	4902	246	2065	29.8	84.1
01/04/2023	2626	1.43	582	8320	576	8238	0	0	220	3146	83	1183	43	616	21.5	60.7
02/04/2023	2685	1.13	706	7979	887	10026	0	0	628	7094	437	4937	4	43	30.1	85.0
03/04/2023	2441	0.98	708	6942	369	3611	0	0	679	6655	363	3553	263	2575	23.3	65.9
04/04/2023	2227	0.83	522	4335	660	5480	0	0	652	5415	514	4267	198	1643	21.1	59.7
05/04/2023	3267	1.22	819	9993	593	7238	0	0	807	9844	809	9865	102	1241	38.2	107.9
06/04/2023	3005	0.87	894	7780	217	1890	0	0	867	7545	842	7323	0	0	24.5	69.3
07/04/2023	2880	0.81	847	6862	223	1805	0	0	846	6853	828	6710	181	1468	23.7	66.9
08/04/2023	2858	0.78	882	6880	1	4	0	0	842	6571	873	6812	0	0	20.3	57.2
09/04/2023	2926	0.75	993	7445	0	0	0	0	983	7370	962	7217	0	0	22.0	62.2
10/04/2023	2802	0.63	929	5852	4	25	0	0	931	5868	903	5686	0	0	17.4	49.2
11/04/2023	2600	0.51	731	3726	222	1133	0	0	787	4014	791	4036	425	2166	15.1	42.6
12/04/2023	2695	0.72	439	3159	0	0	0	0	955	6874	949	6834	126	908	17.8	50.2
13/04/2023	2569	0.80	409	3269	365	2918	0	0	848	6786	825	6598	645	5158	24.7	69.9
14/04/2023	2853	0.70	698	4888	0	0	0	0	543	3799	802	5613	626	4380	18.7	52.8
15/04/2023	2192	0.69	25	172	763	5263	0	0	642	4428	869	5997	658	4538	20.4	57.6
															682.6	1928.4
16/04/2023	4009	0.69	0	0	425	2933	0	0	891	6147	916	6319	698	4813	20.2	57.1
17/04/2023	2809	0.68	796	5409	297	2018	0	0	808	5494	813	5527	405	2756	21.2	59.9
18/04/2023	3088	0.74	825	6102	182	1345	0	0	578	4276	880	6513	611	4521	22.8	64.3
19/04/2023	2020	1.10	760	8355	0	0	0	0	620	6823	828	9103	0	0	24.3	68.6
20/04/2023	3198	0.81	704	5703	0	0	0	0	328	2656	536	4338	670	5424	18.1	51.2
21/04/2023	1599	0.87	0	0	714	6208	0	0	587	5104	0	0	779	6776	18.1	51.1
22/04/2023	1599	0.91	499	4545	191	1741	0	0	539	4901	0	0	742	6750	17.9	50.7
23/04/2023	2630	0.93	1	7	872	8108	0	0	655	6092	0	0	872	8113	22.3	63.1
24/04/2023	3351	0.94	0	0	943	8864	0	0	640	6015	0	0	971	9125	24.0	67.8
25/04/2023	1676	0.78	0	0	556	4336	0	0	549	4282	482	3756	466	3638	16.0	45.2
26/04/2023	1677	0.78	689	5371	0	0	0	0	622	4851	164	1279	828	6457	18.0	50.7
27/04/2023	1893	0.98	709	6950	0	0	0	0	536	5250	0	0	713	6983	19.2	54.2
28/04/2023	1851	1.18	587	6931	321	3793	0	0	443	5224	0	0	595	7025	23.0	64.9
29/04/2023	1795	0.67	629	4216	0	0	0	0	485	3251	0	0	942	6308	13.8	38.9
30/04/2023	1476	0.77	490	3769	34	260	0	0	416	3201	0	0	277	2135	9.4	26.5
01/05/2023	2552	0.84	680	5713	14	118	0	0	599	5035	0	0	125	1050	11.9	33.7
02/05/2023	1354	0.90	1	5	606	5452	0	0	525	4723	241	2165	1138	10238	22.6	63.8
03/05/2023	858	0.81	0	0	476	3852	0	0	335	2717	0	0	0	0	6.6	18.6
04/05/2023	586	0.67	0	0	269	1804	0	0	244	1637	0	0	0	0	3.4	9.7
05/05/2023	743	0.73	0	0	289	2107	0	0	370	2698	0	0	0	0	4.8	13.6
06/05/2023	826	0.76	0	0	457	3470	0	0	355	2698	0	0	0	0	6.2	17.4
07/05/2023	1470	0.78	0	0	757	5903	0	0	564	4396	0	0	0	0	10.3	29.1
08/05/2023	1941	1.88	0	0	639	12019	0	0	510	9596	453	8507	0	0	30.1	85.1

Dewatering Plant - WAS Sludge

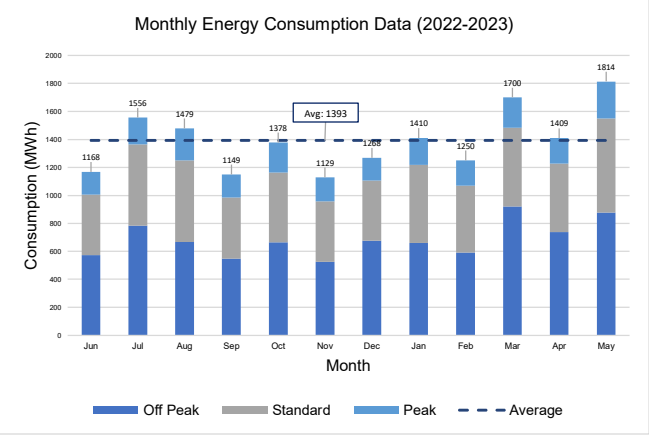
	Sludge Pumped from Central WAS / Buffer Tank	Belt Press Feed from Central WAS / Buffer Tank	WAS Belt Press 1 Sludge Feed	WAS Belt Press 1 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 2 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 3 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 4 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 5 Sludge Feed	WAS Belt Press 6 Sludge Feed	WAS Belt Press 6 Sludge Feed	Tons Dry Solids To BP	Tons Solids Removed (Weigh Bridge)
Date	**m^3**	**%DS**	**m^3**	**kg**	**m^3**	**kg**	**m^3**	**kg**	**m^3**	**kg**	**m^3**	**kg**	**m^3**	**kg**	**tDS**	**tSolids**
09/05/2023	2013	1.52	0	0	886	13472	0	0	771	11712	785	11924	0	0	37.1	104.8
10/05/2023	1999	0.87	0	0	750	6547	0	0	663	5791	668	5827	0	0	18.2	51.3
11/05/2023	1267	0.89	2	19	238	2120	0	0	385	3429	317	2824	317	2818	11.2	31.7
12/05/2023	1105	0.70	0	0	587	4109	0	0	473	3312	0	0	0	0	7.4	21.0
13/05/2023	1244	0.66	0	0	944	6233	0	0	129	849	0	0	514	3390	10.5	29.6
14/05/2023	1245	0.66	0	0	371	2446	0	0	130	859	0	0	514	3392	6.7	18.9
15/05/2023	2353	0.66	0	0	612	4037	0	0	344	2270	207	1363	653	4312	12.0	33.8
															487.1	1376.1
16/05/2023	781	0.65	0	0	415	2697	0	0	146	949	0	0	428	2779	6.4	18.1
17/05/2023	1683	0.75	0	0	797	5978	0	0	642	4816	0	0	413	3100	13.9	39.3
18/05/2023	3780	0.85	0	0	906	7697	0	0	785	6675	560	4757	852	7245	26.4	74.5
19/05/2023	3050	0.68	0	0	881	5991	0	0	763	5191	375	2552	874	5944	19.7	55.6
20/05/2023	1747	0.74	0	0	636	4707	0	0	651	4814	256	1896	759	5617	17.0	48.1
21/05/2023	1440	0.88	0	0	297	2612	0	0	417	3671	0	0	253	2227	8.5	24.0
22/05/2023	2072	0.83	845	7010	682	5661	0	0	870	7224	0	0	76	633	20.5	58.0
23/05/2023	2969	0.83	930	7716	929	7709	0	0	884	7336	0	0	126	1049	23.8	67.3
24/05/2023	2725	0.85	635	5400	782	6647	0	0	667	5671	118	1004	0	0	18.7	52.9
25/05/2023	2445	0.85	735	6249	730	6206	7	61	632	5375	419	3558	549	4670	26.1	73.8
26/05/2023	2999	0.75	820	6152	805	6040	62	462	657	4930	290	2173	687	5153	24.9	70.4
27/05/2023	2572	0.84	761	6392	759	6375	0	0	543	4560	0	0	635	5335	22.7	64.0
28/05/2023	1177	0.88	198	1742	412	3626	0	0	292	2566	0	0	197	1734	9.7	27.3
29/05/2023	1725	0.90	340	3062	610	5489	0	0	431	3875	0	0	532	4784	17.2	48.6
30/05/2023	3201	0.92	698	6424	753	6931	0	0	333	3059	0	0	672	6184	22.6	63.8
31/05/2023	1048	0.54	505	2729	425	2296	0	0	47	255	0	0	614	3318	8.6	24.3
01/06/2023	2085	0.79	257	2030	641	5061	0	0	641	5066	0	0	634	5010	17.2	48.5
02/06/2023	1741	0.92	490	4509	666	6123	0	0	642	5905	0	0	0	0	16.5	46.7
03/06/2023	301	1.12	129	1440	129	1443	0	0	48	536	0	0	0	0	3.4	9.7
04/06/2023	1724	1.22	522	6368	508	6198	0	0	460	5607	0	0	238	2908	21.1	59.6
05/06/2023	1766	1.32	495	6535	509	6724	0	0	460	6075	0	0	240	3168	22.5	63.6
06/06/2023	2302	1.14	561	6394	716	8158	0	0	382	4358	0	0	650	7415	26.3	74.4
07/06/2023	3056	0.83	728	6043	709	5886	0	0	0	0	0	0	571	4740	16.7	47.1
08/06/2023	1155	0.68	575	3910	574	3900	0	0	0	0	0	0	390	2651	10.5	29.6
09/06/2023	1979	0.52	688	3576	685	3564	0	0	560	2910	0	0	684	3556	13.6	38.4
10/06/2023	2205	0.83	546	4536	542	4502	0	0	359	2979	0	0	543	4507	16.5	46.7
11/06/2023	2964	0.88	214	1881	577	5077	0	0	593	5216	0	0	589	5182	17.4	49.0
12/06/2023	553	1.05	349	3665	344	3609	0	0	376	3952	0	0	376	3952	15.2	42.9
13/06/2023	2157	1.08	722	7794	689	7441	0	0	393	4244	0	0	703	7591	27.1	76.5
14/06/2023	1861	1.10	668	7347	686	7541	0	0	0	0	0	0	683	7512	22.4	63.3
15/06/2023	3267	0.79	0	0	929	7340	0	0	858	6780	0	0	920	7269	21.4	60.4
															554.4	1566.2
16/06/2023	2896	0.85	750	6373	896	7613	0	0	796	6762	0	0	837	7116	27.9	78.7
17/06/2023	2529	0.88	254	2232	874	7689	0	0	747	6572	0	0	738	6495	23.0	64.9
18/06/2023	1825	0.90	0	0	325	2929	0	0	324	2917	0	0	324	2912	8.8	24.7
19/06/2023	810	0.91	0	0	181	1644	0	0	123	1122	0	0	180	1639	4.4	12.4
20/06/2023	1285	0.98	0	0	856	8389	0	0	495	4854	0	0	753	7375	20.6	58.2
21/06/2023	2148	0.95	0	0	767	7284	0	0	562	5337	0	0	384	3646	16.3	46.0
22/06/2023	837	0.94	0	0	639	6008	0	0	364	3418	0	0	592	5566	15.0	42.3
23/06/2023	1160	0.93	0	0	541	5032	0	0	54	504	0	0	400	3720	9.3	26.1
24/06/2023	2383	0.93	0	0	942	8764	0	0	56	521	0	0	803	7468	16.8	47.3
25/06/2023	2603	0.92	0	0	1042	9586	0	0	495	4549	0	0	926	8523	22.7	64.0
26/06/2023	2200	0.88	0	0	897	7893	0	0	467	4110	0	0	657	5779	17.8	50.2
27/06/2023	2024	0.86	0	0	774	6656	0	0	805	6926	0	0	654	5623	19.2	54.3
28/06/2023	2025	0.84	0	0	772	6487	0	0	572	4802	0	0	773	6492	17.8	50.2
29/06/2023	2304	0.90	0	0	987	8884	0	0	749	6743	0	0	1003	9031	24.7	69.7
30/06/2023	2744	0.92	319	2938	672	6181	0	0	537	4942	0	0	823	7571	21.6	61.1
D/Ave.	**1891.5**	**0.98**	**453.1**	**4401.6**	**246.7**	**2407.4**	**316.4**	**3098.4**	**281.5**	**2711.5**	**361.7**	**3522.9**	**216.9**	**2088.7**	**34.6**	**97.8**
Total	**662023**	**343**	**158575**	**1540560**	**86345**	**842599**	**110740**	**1084439**	**98542**	**949013**	**126601**	**1233020**	**75924**	**731062**	**12496**	**35299**

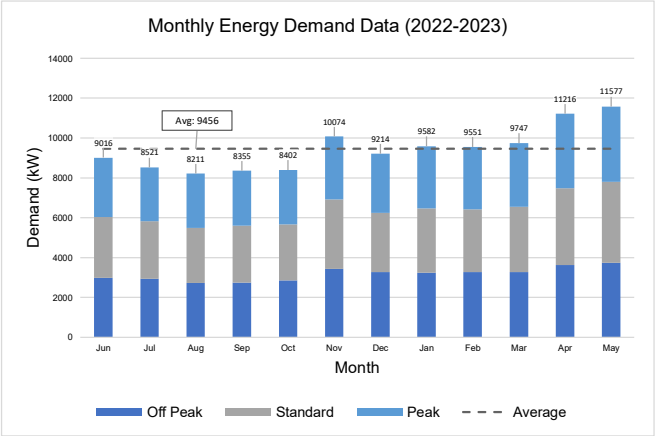
Appendix C

Electrical Energy Consumption Data

			Month														
			1	2	3	4	5	6	7	8	9	10	11	12			
			June	July	August	September	October	November	December	January	February	March	April	May			
	Invoice Date		20/07/2022	20/08/2022	20/09/2022	20/10/2022	20/11/2022	20/12/2022	20/01/2023	20/02/2023	20/03/2023	20/04/2023	20/05/2023	20/06/2023			
	Period Start Date		16/06/2022	16/07/2022	16/08/2022	16/09/2022	16/10/2022	16/11/2022	16/12/2022	16/01/2023	16/02/2023	16/03/2023	16/04/2023	16/05/2023			
	Period End Date		15/07/2022	15/08/2022	15/09/2022	15/10/2022	15/11/2022	15/12/2022	15/01/2023	15/02/2023	15/03/2023	15/04/2023	15/05/2023	15/06/2023	MAX	MIN	AV
	Total Days		29	30	30	29	30	29	30	30	27	30	29	30	30	27	29.4
Energy Consumption	Off-Peak	kWh	573819.2	782910.1	666474.3	547148.8	666429.1	525012.5	676693.2	661731.4	590547.1	919872.7	737425.5	877038.1	919872.7	525012.5	685425.2
Energy Consumption	Standard	kWh	432174.1	581545.4	583408.9	436956.7	497282.1	433614.6	429113.4	556637.4	478188.0	561611.2	490006.6	672697.1	672697.1	429113.4	512769.6
Energy Consumption	Peak	kWh	161993.6	191226.0	229598.7	165109.6	214598.5	170363.2	161953.1	191243.8	181496.5	218277.8	182017.9	263906.9	263906.9	161953.1	194315.5
Energy Consumption	Total	kWh	1167986.9	1555681.6	1479482.0	1149215.1	1378309.6	1128990.2	1267759.6	1409612.7	1250231.5	1699761.7	1409450.0	1813642.1	1813642.1	1128990.2	1392510.2
Demand Consumption	Off-Peak	kW	2974.7	2931.7	2730.5	2733.3	2840.8	3431.9	3260.5	3233.5	3267.6	3281.3	3619.6	3736.0	3736.0	2730.5	3170.1
Demand Consumption	Standard	kW	3057.8	2892.1	2752.2	2865.9	2825.6	3482.3	2988.2	3243.4	3155.4	3263.0	3868.5	4070.2	4070.2	2752.2	3205.4
Demand Consumption	Peak	kW	2983.9	2697.6	2728.5	2755.7	2735.9	3159.5	2964.9	3105.4	3128.1	3203.0	3727.4	3771.0	3771.0	2697.6	3080.1
Demand Consumption	Total	kW	9016.4	8521.4	8211.2	8354.9	8402.3	10073.6	9213.6	9582.3	9551.1	9747.3	11215.5	11577.1	11577.1	8211.2	9455.5
Demand Reading	Total	kW/kVA	3057.8	2931.7	2752.2	2865.9	2840.8	3482.3	3260.5	3243.4	3267.6	3281.3	3868.5	4070.2	4070.2	2752.2	3243.5

Energy Consumption	The kWh charge (consumption) is the measurement of the amount of energy the site uses over the given period of time.	
Consumption	The kW charge (demand) represents the amount of energy consumed at a single point in time.	
Load Factor	The ratio of the energy generated over a specific time versus the maximum generating capability over the same period.	
Average Peak Demand	kW	8372.52





CONSUMPTION DETAILS (2022-06-16 - 2022-07-15)

ENERGY CONSUMPTION OFF PEAK kWH	573,819.21
ENERGY CONSUMPTION STD kWh	432,174.10
ENERGY CONSUMPTION PEAK kWh	161,993.55
ENERGY CONSUMPTION ALL kWh	1,167,986.86
DEMAND CONSUMPTION - OFF PEAK	2,974.70
DEMAND CONSUMPTION - STD	3,057.80
DEMAND CONSUMPTION - PEAK	2,983.85
DEMAND READING - KW/KVA	3,057.80
REACTIVE ENERGY - OFF PEAK	197,389.08
REACTIVE ENERGY - STD	145,118.55
REACTIVE ENERGY - PEAK	54,968.39
EXCESS REACTIVE ENERGY	25,840.82
LOAD FACTOR	57.00

CONSUMPTION DETAILS (2022-07-16 - 2022-08-15)

ENERGY CONSUMPTION OFF PEAK kWH	782,910.13
ENERGY CONSUMPTION STD kWh	581,545.44
ENERGY CONSUMPTION PEAK kWh	191,226.01
ENERGY CONSUMPTION ALL kWh	1,555,681.58
DEMAND CONSUMPTION - OFF PEAK	2,931.73
DEMAND CONSUMPTION - STD	2,892.12
DEMAND CONSUMPTION - PEAK	2,697.56
DEMAND READING - KW/KVA	2,931.73
REACTIVE ENERGY - OFF PEAK	225,499.35
REACTIVE ENERGY - STD	169,474.59
REACTIVE ENERGY - PEAK	55,940.55
EXCESS REACTIVE ENERGY	7,627.35
LOAD FACTOR	73.00

CONSUMPTION DETAILS (2022-08-16 - 2022-09-15)

ENERGY CONSUMPTION OFF PEAK kWH	666,474.31
ENERGY CONSUMPTION STD kWh	583,408.93
ENERGY CONSUMPTION PEAK kWh	229,598.72
ENERGY CONSUMPTION ALL kWh	1,479,481.96
DEMAND CONSUMPTION - OFF PEAK	2,730.50
DEMAND CONSUMPTION - STD	2,752.20
DEMAND CONSUMPTION - PEAK	2,728.52
DEMAND READING - KW/KVA	2,752.20
REACTIVE ENERGY - OFF PEAK	212,918.04
REACTIVE ENERGY - STD	181,280.91
REACTIVE ENERGY - PEAK	72,051.18
EXCESS REACTIVE ENERGY	8,471.44
LOAD FACTOR	75.00

CONSUMPTION DETAILS (2022-09-16 - 2022-10-15)

ENERGY CONSUMPTION OFF PEAK kWH	547,148.82
ENERGY CONSUMPTION STD kWh	436,956.69
ENERGY CONSUMPTION PEAK kWh	165,109.63
ENERGY CONSUMPTION ALL kWh	1,149,215.14
DEMAND CONSUMPTION - OFF PEAK	2,733.29
DEMAND CONSUMPTION - STD	2,865.94
DEMAND CONSUMPTION - PEAK	2,755.66
DEMAND READING - KW/KVA	2,865.94
REACTIVE ENERGY - OFF PEAK	179,467.11
REACTIVE ENERGY - STD	140,018.88
REACTIVE ENERGY - PEAK	54,246.27
LOAD FACTOR	58.00

CONSUMPTION DETAILS (2022-10-16 - 2022-11-15)

ENERGY CONSUMPTION OFF PEAK kWH	666,429.05
ENERGY CONSUMPTION STD kWh	497,282.06
ENERGY CONSUMPTION PEAK kWh	214,598.52
ENERGY CONSUMPTION ALL kWh	1,378,309.63
DEMAND CONSUMPTION - OFF PEAK	2,840.75
DEMAND CONSUMPTION - STD	2,825.62
DEMAND CONSUMPTION - PEAK	2,753.90
DEMAND READING - KW/KVA	2,840.75
REACTIVE ENERGY - OFF PEAK	213,305.55
REACTIVE ENERGY - STD	156,472.26
REACTIVE ENERGY - PEAK	69,360.90
LOAD FACTOR	68.00

CONSUMPTION DETAILS (2022-11-16 - 2022-12-15)

ENERGY CONSUMPTION OFF PEAK kWH	525,012.49
ENERGY CONSUMPTION STD kWh	433,614.56
ENERGY CONSUMPTION PEAK kWh	170,363.18
ENERGY CONSUMPTION ALL kWh	1,128,990.23
DEMAND CONSUMPTION - OFF PEAK	3,431.87
DEMAND CONSUMPTION - STD	3,482.25
DEMAND CONSUMPTION - PEAK	3,159.47
DEMAND READING - KW/KVA	3,482.25
REACTIVE ENERGY - OFF PEAK	206,005.25
REACTIVE ENERGY - STD	170,448.71
REACTIVE ENERGY - PEAK	66,117.58
LOAD FACTOR	48.00

CONSUMPTION DETAILS (2022-12-16 - 2023-01-15)

ENERGY CONSUMPTION OFF PEAK kWH	676,693.18
ENERGY CONSUMPTION STD kWh	429,113.38
ENERGY CONSUMPTION PEAK kWh	161,953.06
ENERGY CONSUMPTION ALL kWh	1,267,759.62
DEMAND CONSUMPTION - OFF PEAK	3,260.48
DEMAND CONSUMPTION - STD	2,988.20
DEMAND CONSUMPTION - PEAK	2,964.89
DEMAND READING - KW/KVA	3,260.48
REACTIVE ENERGY - OFF PEAK	259,120.76
REACTIVE ENERGY - STD	160,013.82
REACTIVE ENERGY - PEAK	56,156.69
LOAD FACTOR	56.00

CONSUMPTION DETAILS (2023-01-16 - 2023-02-15)

ENERGY CONSUMPTION OFF PEAK kWH	661,731.39
ENERGY CONSUMPTION STD kWh	556,637.44
ENERGY CONSUMPTION PEAK kWh	191,243.82
ENERGY CONSUMPTION ALL kWh	1,409,612.65
DEMAND CONSUMPTION - OFF PEAK	3,233.51
DEMAND CONSUMPTION - STD	3,243.40
DEMAND CONSUMPTION - PEAK	3,105.35
DEMAND READING - KW/KVA	3,243.40
REACTIVE ENERGY - OFF PEAK	152,883.42
REACTIVE ENERGY - STD	133,655.61
REACTIVE ENERGY - PEAK	45,338.37
LOAD FACTOR	59.00

CONSUMPTION DETAILS (2023-02-16 - 2023-03-15)

ENERGY CONSUMPTION OFF PEAK kWH	590,547.05
ENERGY CONSUMPTION STD kWh	478,188.01
ENERGY CONSUMPTION PEAK kWh	181,496.48
ENERGY CONSUMPTION ALL kWh	1,250,231.54
DEMAND CONSUMPTION - OFF PEAK	3,267.62
DEMAND CONSUMPTION - STD	3,155.38
DEMAND CONSUMPTION - PEAK	3,128.12
DEMAND READING - KW/KVA	3,267.62
REACTIVE ENERGY - OFF PEAK	121,551.81
REACTIVE ENERGY - STD	100,440.69
REACTIVE ENERGY - PEAK	37,798.71
LOAD FACTOR	58.00

CONSUMPTION DETAILS (2023-03-16 - 2023-04-15)

ENERGY CONSUMPTION OFF PEAK kWH	919,872.71
ENERGY CONSUMPTION STD kWh	561,611.20
ENERGY CONSUMPTION PEAK kWh	218,277.76
ENERGY CONSUMPTION ALL kWh	1,699,761.67
DEMAND CONSUMPTION - OFF PEAK	3,281.27
DEMAND CONSUMPTION - STD	3,262.98
DEMAND CONSUMPTION - PEAK	3,203.01
DEMAND READING - KW/KVA	3,281.27
REACTIVE ENERGY - OFF PEAK	176,028.66
REACTIVE ENERGY - STD	109,322.28
REACTIVE ENERGY - PEAK	42,559.56
LOAD FACTOR	71.00

CONSUMPTION DETAILS (2023-04-16 - 2023-05-15)

ENERGY CONSUMPTION OFF PEAK kWH	737,425.50
ENERGY CONSUMPTION STD kWh	490,006.55
ENERGY CONSUMPTION PEAK kWh	182,017.91
ENERGY CONSUMPTION ALL kWh	1,409,449.96
DEMAND CONSUMPTION - OFF PEAK	3,619.63
DEMAND CONSUMPTION - STD	3,868.53
DEMAND CONSUMPTION - PEAK	3,727.37
DEMAND READING - KW/KVA	3,868.53
REACTIVE ENERGY - OFF PEAK	156,279.06
REACTIVE ENERGY - STD	109,431.64
REACTIVE ENERGY - PEAK	38,566.93
LOAD FACTOR	52.00

CONSUMPTION DETAILS (2023-05-16 - 2023-06-15)

ENERGY CONSUMPTION OFF PEAK kWH	877,038.11
ENERGY CONSUMPTION STD kWh	672,697.08
ENERGY CONSUMPTION PEAK kWh	263,906.94
ENERGY CONSUMPTION ALL kWh	1,813,642.13
DEMAND CONSUMPTION - OFF PEAK	3,735.96
DEMAND CONSUMPTION - STD	4,070.19
DEMAND CONSUMPTION - PEAK	3,770.97
DEMAND READING - KW/KVA	4,070.19
REACTIVE ENERGY - OFF PEAK	191,587.83
REACTIVE ENERGY - STD	156,630.73
REACTIVE ENERGY - PEAK	59,444.37
EXCESS REACTIVE ENERGY	10.39
LOAD FACTOR	61.00

Appendix D

Energy Rating

Process Equipment List and Power Ratings							
Process Location	**Category**	**Equipment**	**Power Rating**	**Motor Type**	**Total Installed**	**Full Demand**	**Full Dailty consumption**
Inlet Works	Pumping	Screw Pumps	185	SS	4	740	17760
Upper Screw PS	Pumping	Screw Pumps	185	SS	4	740	17760
CAS Plants - A and B	Aeration	Aerators (75 kw)	75	VSD	10	750	18000
MBR-B	Aeration	FBDA Blowers	160	DOL	5	800	19200
MBR-B	Aeration	Air Scour Blowers	132	DOL	6	792	19008
MBR-B	Pumping	Permeate pumps	75	VSD	9	675	16200
CAS Plants - A and B	Aeration	Aerators (90 kw)	90	VSD	6	540	12960
Dewatering	Pumping	Service Water Pumps	75	VSD	4	300	7200
Dewatering	Pumping	WAS Filtrate Pumps	55	DOL	3	165	3960
MBR Pumpstation	Pumping	Pumps	55	VSD	4	220	5280
CAS Plants - A and B	Aeration	Aerators (55 kw)	55	VSD	4	220	5280
Dewatering	Aeration	WAS Holding Aerators	37	SS	6	222	5328
Dewatering	Pumping	WAS Cake Pumps	55	VSD	3	165	3960
Dewatering	Pumping	Primary Cake Pumps	55	VSD	3	165	3960
CAS Plants - A and B	Pumping	RAS Pumps	40	VSD	4	160	3840
Dewatering	Pumping	WAS Feed Pumps	22	VSD	6	132	3168
CAS Plants - A and B	Pumping	AE-AX Recycle Pumps	21.7	VSD	6	130.2	3124.8
Dewatering	Pumping	Primary Recirculation Pumps	37	DOL	2	74	1776
MBR-B	Pumping	Membrane Feed Pumps	20	VSD	6	120	2880
Dewatering	Pumping	WAS Central Collection Pumps	30	DOL	2	60	1440
MBR-B	Pumping	AE-AX Recycle Pumps	10	VSD	9	90	2160
MBR-B	Pumping	Swing Recycle Pumps	20	VSD	4	80	1920
MBR-B	Aeration	Air compressors	18.5	DOL	2	37	888
Dewatering	Pumping	Primary Filtrate Pumps	15	DOL	2	30	720
Dewatering	Pumping	Primary Feed Pumps	15	VSD	4	60	1440
MBR-B	Pumping	Membrane Tank Drain Pumps	18.5	VSD	3	55.5	1332
Dewatering	Dewatering	Belt Drives	5.5	VSD	10	55	1320
Dewatering	Miscellaneous	Odour Control	15	DOL	1	15	360
Inlet Works	Pumping	Pump (Degritters)	11.2	DOL	4	44.8	1075.2
MBR-B	Pumping	Service water	11	VSD	4	44	1056
CAS Plants - A and B	Aeration	Submersible Mixers	7.7	DOL	16	123.2	2956.8
Primary Settlement Tanks	Miscellaneous	Primary Sludge Pumps	18.5	VSD	2	37	888
MBR-B	Pumping	WAS Pumps	18.5	VSD	2	37	888
MBR-B	Aeration	Anoxic Mixers	7.5	DOL	12	90	2160
Dewatering	Pumping	Primary Silo Discharge Screws	7.5	DOL	4	30	720
Dewatering	Dewatering	WAS Screw Conveyors	7.5	DOL	2	15	360
MBR-B	Pumping	AX-AN Recycle Pumps	2.5	VSD	9	22.5	540
Dewatering	Dewatering	Primary Screw Conveyors	7.5	DOL	2	15	360
Dewatering	Pumping	Primary Degritted Pumps	7.5	DOL	2	15	360
Inlet Works	Screening	Course Screens Washer	6	DOL	2	12	288
Inlet Works	Screening	Fine Screens Washer	6	DOL	2	12	288
MBR-B	Miscellaneous	Ventalation Fans	5.5	DOL	8	44	1056
Dewatering	Dewatering	Linear Screen Drives	2.2	VSD	6	13.2	316.8
Dewatering	Pumping	WAS Silo Discharge screws	5.5	DOL	4	22	528
Inlet Works	Screening	Course Screens Compactor	5.5	DOL	2	11	264
Inlet Works	Screening	Fine Screens Compactor	5.5	DOL	2	11	264
Dewatering	Dewatering	Compressors	5.5	DOL	2	11	264
Inlet Works	Miscellaneous	Odour Control Units	4.22	DOL	2	8.44	202.56
Upper Screw PS	Miscellaneous	Odour Control Units	4.22	DOL	1	4.22	101.28
MBR Fine Screen	Screening	Common Screw Compactor	4	DOL	2	8	192
Dewatering	Dewatering	WAS Macerator	4	DOL	1	4	96
Dewatering	Pumping	WAS Poly Pumps	1.5	VSD	6	9	216
Inlet Works	Screening	Brush Drive Fine Screens	2.2	VSD	4	8.8	211.2
MBR-B	Aeration	Anaerobic Mixers	3	DOL	12	36	864
CAS Plants - A and B	Pumping	WAS Pumps	3	DOL	4	12	288
Inlet Works	Screening	Trash Max	2.2	VSD	3	6.6	158.4
Inlet Works	Screening	Course Screens	1.5	VSD	4	6	144
Inlet Works	Screening	Fine Screens	1.5	VSD	4	6	144
Dewatering	Pumping	Primary Poly Feed Pumps	1.5	VSD	4	6	144
MBR Fine Screen	Screening	Common Screw Conveyor	3	DOL	2	6	144
Inlet Works	Screening	Belt Conveyor	3	DOL	1	3	72
Primary Settlement Tanks	Miscellaneous	Primary Macerator	2.2	DOL	1	2.2	52.8
MBR Fine Screen	Screening	Fine Screen Screw Conveyor	1.5	DOL	6	9	216
Inlet Works	Screening	Bull Gear (Degritters)	1.5	DOL	4	6	144
Dewatering	Dewatering	Grit Classifier	1.5	DOL	1	1.5	36
Dewatering	Dewatering	Hydraulic Power Packs	1.1	DOL	10	11	264
MBR-B	Miscellaneous	Citric Acid mixer	1.1	DOL	1	1.1	26.4
Dewatering	Dewatering	Poly Lube Pumps	0.75	VSD	3	2.25	54
Inlet Works	Screening	Grit Classifier (Degritters)	0.75	DOL	4	3	72
MBR Fine Screen	Screening	Fine Screen Motor	0.55	DOL	6	3.3	79.2
Dewatering	Dewatering	Grit stirrer	0.55	DOL	1	0.55	13.2
CAS Plants - A and B	Miscellaneous	SST Bridges	0.18	DOL	24	4.32	103.68
Primary Settlement Tanks	Miscellaneous	Bridge Motors	0.18	DOL	8	1.44	34.56
Inlet Works	Screening	Trash Rack Screen Hoist	0.4	VSD	1	0.4	9.6

Appendix E

Existing Control Systems

WWTW CONTROL AND MONITORING SYSTEMS

Inlet Works		
Subsection	**Type of Control**	**Implementation**
Trash racks	Level sensors	There are level sensors before and after each trash rack. Common level sensor before and individual afterwards. They dictate when the trash rack's rake starts running. If the water level differential between the front and back of the screen is greater than a set input amount (operator input) then the screen will start running. Prevents the screen from running continuosly. The greater the differential, the faster the rake moves.
Screw Pumps	Flow control	The greater the flow into the plant, the more screws are running, instead of just two screws running continuosly. These are 185 kW constant speed motors. No VSD.
Course and Fine screens	Level sensors	Same concept as the Trash Racks. There are level sensors before and after each screen. They dictate when the screen's rake starts running. If the water level differential between the front and back of the screen is greater than a set input amount (operator input) then the screen will start running. Prevents the screen from running continuosly. The greater the differential, the faster the rake moves. VSD motor control.
PST	Level Control	NOT IN USE, but an option. Only once a sludge blanket reaches a certain height, then the desludging valve opens. The higher the blanket the greater the power pulled to turn the bridges.
Primary sludge Pumps	Flow Control	The pumps are on VSDs. They speed up or slow down in order to maintain a set flow rate (operator set). The set flow is for the hydrocyclone. Design ditactation of the speed / velocity of the sludge through the hydrocyclone.
MBR Raw feed pumps	Flow Control	All pumps are VSD controlled. These pumps are controlled by the flow into the plant and dictate the split of raw water flow between the two MBR plants and the Conventional Activated Sludge (CAS) plants. The more flow into the plant, the greater the amount of water sent to the MBR plants. This is to maintain individual reactor efficiency (reactor loading, energy usage and effluent compliance) and because MBR plants can be energy intensive processes & expensive to operate (electricity, mechanical components, technical expertise required for service and operation, etc).
CAS Plants (combined)		
Subsection	**Type of Control**	**Implementation**
Aerobic Zone	DO	The speed of the surface aerators are controlled by the amount of DO required in the water. DO values are operator set. The aerators speed up or slow down based on how close the DO meters are reading to the set value required.
A-Recycle, R-Recycle, S-Recycle	Flow control	All recycle pumps are on VSDs. They operate in order to maintain a set recycle ratio vs the influent into the individual reactor. Eg, 200 - 300% for A-Recycles. If the influent is 1000 m3/hr, then the A-Recycle will maintain 3000 m3/hr flow rates. This ensures both pump efficiency and biological reaction efficiency.
WAS and RAS Control	Sludge Density	Online RAS density meters will determine how much sludge is wasted (based on sludge age) and sent to dewatering belt presses . This to control reactor MLSS (lower MLSS means lower energy input to maintain DO levels) and better operation of the belt presses by not sending WAS that's too thin (bad dewaterability).
SSTs	Level control and Flow control	The amount of sludge withdrawn from each SST is controlled in order to maintain the S-recycle. If the valves are all opened up 100%, then the pumps will then be forced to speed up to prevent high levels at the RAS sump (greater energy drawn unnecessarily). So, the amount the SST sludge valves are opened is calculated based on the inflow into the reactor to allow a set RAS flow from the SSTs.
MBR Fine Screens		
Subsection	**Type of Control**	**Implementation**
Screens	Level Control	The higher the level of raw water in the inlet sump at the MBR Fine screens, the more screens will be in operation.

MBR Plants		
Subsection	**Type of Control**	**Implementation**
Aerobic Zone	DO	Fine Bubble Diffused Aeration DO control. The FBDA blower are set to maintain a set DO in the aerobic zone. The more DO required, the more blowers will be in operation. The blowers are not VSD controlled and instead maintain a set pressure (operator input). The pressure is controlled by inlet and outlet guide vanes on the individual blowers.
A-Recycle, R-Recycle, S-Recycle	Flow control	All recycle pumps are on VSDs. They operate in order to maintain a set recycle ratio vs the influent into the individual reactor. Eg, 200 - 300% for A-Recycles. If the influent is 1000 m3/hr, then the A-Recycle will maintain 3000 m3/hr flow rates. This ensures both pump efficiency and biological reaction efficiency.
Permeate trains and pumps	Flow Control	The greater the flow into the reactor, the more permeate trains in operation. Each train is linked to a permeate pump on a VSD.
WAS and RAS Control	Sludge Density	Online RAS density meters will determine how much sludge is wasted (based on sludge age) and sent to dewatering belt presses . This to control reactor MLSS (lower MLSS means lower energy input to maintain DO levels) and better operation of the belt presses by not sending WAS that's too thin (bad dewaterability).
Air Scour units	Flow Control	The greater the flow into the reactor means more permeate trains online, which in turn means more air scour units required.
Dewatering		
Subsection	**Type of Control**	**Implementation**
Belt Press speed	Level control	Level sensors on the belts speed up or slow down the belt press motors in order to maintain set thickness of dewatered sludge cake. Lower speeds, lower energy.
Sludge pumps	Flow Control	Not really for energy efficiency as it is more to maintain a set flow of solids onto the belt presses.
Service Water Pump Station		
Subsection	**Type of Control**	**Implementation**
Service Water Pump Station	Pressure Control	Amount of service water pumps running is determined by the amount of service water used. The more water, the lower the pressure, so the pumps speed up or slow down to maintain set pressure.

Appendix F

Sample Calculation: Theoretical Energy Generation

Sludge Production Sample Calculation – Month 2

Step 1:

$$TS_{average} = \frac{\sum TS_i}{No.\,of\ input\ values}$$

$$TS_{average} = 13.82\ (as\ shown\ in\ \text{Table 4-4})$$

$$VF_{average} = \frac{\sum VF_i}{No.\,of\ input\ values}$$

$$VF_{average} = 75.23\%\ (as\ shown\ in\ \text{Table 4-4})$$

Step 2:

$$Primary\ Sludge\ (kg/month) = \sum Daily\ Primary\ Sludge\ Production$$

$$Primary\ Sludge\ (kg/month) = 1340.9\ kg/month\ (as\ shown\ in\ Appendix\ B)$$

$$WAS\ (kg/month) = \sum Daily\ WAS\ Sludge\ Production$$

$$WAS\ Sludge\ (kg/month) = 1649.2\ kg/month\ (as\ shown\ in\ Appendix\ B)$$

Step 3:

$$TSS_{Primary} = TS_{average} \times Primary\ Sludge\ (kgTSS/month)$$

$$TSS_{Primary} = 13.82\% \times 1340.9 \times 1000\ kg/month$$

$$TSS_{Primary} = 185340.2\ kgTSS/month$$

$$TSS_{WAS} = TS_{average} \times WAS\ (kgTSS/month)$$

$$TSS_{WAS} = TS_{average} \times WAS\ Sludge\ (kgTSS/month)$$

$$TSS_{WAS} = 13.82\% \times 1649.2 \times 1000\ kg/month$$

$$TSS_{WAS} = 227962.5\ kgTSS/month$$

Step 4:

$$VSS_{Primary} = VS_{average} \times TSS_{Primary}\ (kgVSS/month)$$

$$VSS_{Primary} = 75.23\% \times 185340.2\ kgTSS/month$$

$$VSS_{Primary} = 140487.9\ kgVSS/month$$

$$VSS_{WAS} = VS_{average} \times TSS_{WAS}\ (kgVSS/month)$$

$$VSS_{WAS} = 75.23\% \times 227962.5\ kgTSS/month$$

$$VSS_{WAS} = 172795.6\ kgVSS/month$$

Step 6:

$$VS_{reduction} = \sum VS_{reduction(primary)} + VS_{reduction(WAS)}\ (kgVSS_{red})$$

$$VS_{reduction} = 140487.9 + 172795.6\ kgVSS_{red}$$

$$VS_{reduction} = 313284\ kgVSS_{red}$$

Step 7:

$$V_{Biogas} = BP_{efficiency} \times VS_{reduction} \times {}^{1.0m^3}/_{kgVSS_{red}}\ (m^3/month)$$

$$V_{Biogas} = 60\% \times 313284\ kgVSS_{red} \times {}^{1.0m^3}/_{kgVSS_{red}}\ (m^3/month)$$

$$V_{Biogas} = 187970\ m^3/month$$

Step 8:

$$V_{CH4} = CH4_{content} \times V_{Biogas}\ (m^3/month)$$

$$V_{CH4} = 75\% \times 187970\ m^3/month$$

$$V_{CH4} = 117481\ m^3/month$$

Step 9:

$$E_{CHP} = V_{CH4} \times \eta_{efficiency} \times {}^{10kWh}/_{m^3}\ ({}^{kWh}/_{month})$$

$$E_{CHP} = 117481\ m^3/month \times 38\% \times {}^{10kWh}/_{m^3}$$

$$E_{CHP} = 446429\ {}^{kWh}/_{month}$$

The total theoretical electricity generation potential for month 2 is 446429 kWh.

Step 10: Repeat Step 1 – 9 for each month.

Appendix G

Theoretical Energy Demand Reduction Model

Model to Show Current and Potential Energy Savings for the Case Study

Process Location	Equipment	Power Rating (kW)	Motor Type	Total Installed	Full Dailty Consumption (kW)	Other measure already implemented	Possible Intervention	New power rating	Reference	Energy Saving (kWh)
Inlet Works	Screw Pumps	185	SS	4	17760	Flow Control	Replacement with VFD and integrated PLC	20% Energy Saving	Lozano Avilés et al., 2019	3552
Upper Screw PS	Screw Pumps	185	SS	4	17760	Flow Control	Replacement with VFD and integrated PLC	20% Energy Saving	Lozano Avilés et al., 2019	3552
CAS Plants - A and B	Aerators (75 kw)	75	VSD	10	18000	VSD and DO Monitoring	Replace system with a more efficient system such as FBDA with ammonia control and PLC	37% Energy Saving	Zvimba and Musvoto, 2020 and Musvuto and Ikumi, 2016.	6660
MBR-B	FBDA Blowers	160	DOL	5	19200	DO Monitoring	Ammonia based monitoring , and VFD and PLC	80% energy savings	Phelan, 2014	15360
MBR-B	Air Scour Blowers	132	DOL	6	19008	DO Monitoring	Ammonia based monitoring , and VFD and PLC	80% energy savings	Phelan, 2014	15206
MBR-B	Permeate pumps	75	VSD	9	16200	VSD and flow control	N/A			
CAS Plants - A and B	Aerators (90 kw)	90	VSD	6	12960	VSD and DO Monitoring	Replace system with a more efficient system such as FBDA with ammonia control and PLC	37% Energy Saving	Zvimba and Musvoto, 2020 and Musvuto and Ikumi, 2016.	4795.2
Dewatering	Service Water Pumps	75	VSD	4	7200	Pressure Control	N/A			
Dewatering	WAS Filtrate Pumps	55	DOL	3	3960	Sludge Density Control	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	792
MBR Pumpstation	Pumps	55	VSD	4	5280	VSD and flow control	N/A			
CAS Plants - A and B	Aerators (55 kw)	55	VSD	4	5280	VSD and DO Monitoring	Replace system with a more efficient system such as FBDA with ammonia control and PLC	37% Energy Saving	Zvimba and Musvoto, 2020 and Musvuto and Ikumi, 2016.	1953.6
Dewatering	WAS Holding Aerators	37	SS	6	5328	N/A	Replacement with VFD and integrated PLC	37% Energy Saving	Zvimba and Musvoto, 2020 and Musvuto and Ikumi, 2016.	1971.36
Dewatering	WAS Cake Pumps	55	VSD	3	3960	VSD	N/A			
Dewatering	Primary Cake Pumps	55	VSD	3	3960	VSD	N/A			
CAS Plants - A and B	RAS Pumps	40	VSD	4	3840	VSD and Sludge Density Control	N/A			
Dewatering	WAS Feed Pumps	22	VSD	6	3168	VSD	N/A			
CAS Plants - A and B	AE-AX Recycle Pumps	21.7	VSD	6	3124.8	VSD and flow control	N/A			
Dewatering	Primary Recirculation Pumps	37	DOL	2	1776	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	355.2
MBR-B	Membrane Feed Pumps	20	VSD	6	2880	VSD	N/A			
Dewatering	WAS Central Collection Pumps	30	DOL	2	1440	Sludge Density Control	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	288
MBR-B	AE-AX Recycle Pumps	10	VSD	9	2160	VSD and Flow Control	N/A			
MBR-B	Swing Recycle Pumps	20	VSD	4	1920	VSD and Flow Control	N/A			
MBR-B	Air compressors	18.5	DOL	2	888	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	177.6
Dewatering	Primary Filtrate Pumps	15	DOL	2	720	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	144
Dewatering	Primary Feed Pumps	15	VSD	4	1440	VSD	N/A			
MBR-B	Membrane Tank Drain Pumps	18.5	VSD	3	1332	VSD	N/A			
Dewatering	Belt Drives	5.5	VSD	10	1320	VSD and Flow Control	N/A			
Dewatering	Odour Control	15	DOL	1	360	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	72
Inlet Works	Pump (Degritters)	11.2	DOL	4	1075.2	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	215.04
MBR-B	Service water	11	VSD	4	1056	VSD	N/A			
CAS Plants - A and B	Submersible Mixers	7.7	DOL	16	2956.8	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	591.36
Primary Settlement Tanks	Primary Sludge Pumps	18.5	VSD	2	888	VSD	N/A			
MBR-B	WAS Pumps	18.5	VSD	2	888	VSD and Sludge Density Control	N/A			
MBR-B	Anoxic Mixers	7.5	DOL	12	2160	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	432
Dewatering	Primary Silo Discharge Screws	7.5	DOL	4	720	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	144
Dewatering	WAS Screw Conveyors	7.5	DOL	2	360	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	72
MBR-B	AX-AN Recycle Pumps	2.5	VSD	9	540	VSD and Flow Control	N/A			
Dewatering	Primary Screw Conveyors	7.5	DOL	2	360	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	72
Dewatering	Primary Degritted Pumps	7.5	DOL	2	360	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	72
Inlet Works	Course Screens Washer	6	DOL	2	288	N/A	Replacement with VFD and integrated PLC	20% Energy Savings	Lozano Avilés et al., 2019	57.6
Dewatering	Linear Screen Drives	2.2	VSD	6	316.8	VSD	N/A			
MBR Fine Screen	Common Screw Compactor	4	DOL	2	192	Level Control	N/A			
Dewatering	WAS Poly Pumps	1.5	VSD	6	216	VSD	N/A			
Inlet Works	Brush Drive Fine Screens	2.2	VSD	4	211.2	VSD	N/A			
Inlet Works	Trash Max	2.2	VSD	3	158.4	VSD and Level Sensors	N/A			
Inlet Works	Course Screens	1.5	VSD	4	144	VSD and Level Sensors	N/A			
Inlet Works	Fine Screens	1.5	VSD	4	144	VSD and Level Sensors	N/A			
MBR Fine Screen	Common Screw Conveyor	3	DOL	2	144	Level Control	N/A			
Inlet Works	Belt Conveyor	3	DOL	1	72	VSD and Level Sensors	N/A			
MBR Fine Screen	Fine Screen Screw Conveyor	1.5	DOL	6	216	Level Control	N/A			
MBR Fine Screen	Fine Screen Motor	0.55	DOL	6	79.2	Level Control	N/A			
CAS Plants - A and B	SST Bridges	0.18	DOL	24	103.68	Level and Flow Control	N/A			
									Total Savings	**56535.36**
									Percentage of Site Savings	**28%**