Economic Analysis of Net-Zero-Energy for Wastewater Treatment Plants in Australia

Abstract

In Australia and globally around the world, water sector is one of the major energy consuming sectors and it is influenced by the need to pump water, sewage and sewage treatment processes. In the dealing with the increasing threat of climate change and exploding population, many water utilities are adopting renewable energy and experimenting Net-Zero-Energy technologies to address their increasing energy demands and reducing carbon footprint. The investments, however, are not necessarily viable due to high capital costs and highly volatile electricity prices. This study is an attempt to determine the correlation between size of the wastewater treatment plants, energy demands and the costs for implementing Net-Zero-Energy through cogeneration in conventional and large wastewater treatment plants around Australia with particular emphasis on large treatment plants in Sydney.

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Engineering Economics

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Key Abbreviations

ABS	*Australian Bureau of Statistics*
AEMC	*Australian Energy Market Commission*
AEMO	*Australian Energy Market Operator*
APE	*Absolute Percentage Error*
BCR	*Benefit to Cost Ratio*
CAS	*Conventional Activated Sludge*
CPI	*Consumer Price Index*
CSIRO	*Commonwealth Scientific and Industrial Research Organisation*
FV	*Future Value*
GWh	*Gigawatt hour* (10^6 *x kWh)*
HWC	*Hunter Water Corporation*
kWh	*Kilowatt hour (3.6 MJ or 3.6 x* 10^6*J)*
LCC	*Life Cycle Cost*
MWe	*Megawatts electric*
NPV	*Net Present Value*
NZE	*Net-Zero-Energy*
PB	*Payback Period*
PV	*Present Value*
IRR	*Internal Rate of Return*
SBR	*Sequencing Batch Reactor*
SEQ	*South East Queensland*
WSAA	*Water Services Association of Australia*
WWTP	*Wastewater Treatment Plant*

1 INTRODUCTION

Water sector, influenced by the need to pump water, sewage and sewage treatment processes, is one of the major energy consuming sectors. In Australia, Sydney Water is known to be the largest water utility consuming over 426,000,000 kWh of energy a year (Sydney Water, 2018). The Household Energy Consumption Survey, conducted by the Australian Bureau of Statistics (ABS) in 2012, indicated a mean weekly electricity consumption of 123.6 kWh per household (ABS, 2013) which is equivalent to approximately 6,427 kWh/year per household. These figures suggest that electricity consumed by Sydney Water alone could provide electricity supply for more than 66,000 households annually.

In recent decades, climate change has been globally recognised as an influencing factor affecting governments, businesses, industries, communities, households and individuals. As an effort to help tackling climate change and to avoid challenges of carbon constrained environment, many water utilities are adopting renewable energy technologies to address their increasing energy demands.

Despite a diverse range of renewable energy technologies such as cogeneration, hydroelectricity and solar, Sydney Water generated just over 18% of their total electricity demands in 2017-18 (Sydney Water, 2018). In comparison, Melbourne Water's water supply network generates electricity exceeding its demands and biogas from wastewater treatment processes provides up to 40% of electricity for some of their wastewater treatment plants while other treatment plants are energy self-sufficient. Two large wastewater treatment plants at Oxley Creek and Luggage Point, operated by Queensland Urban Utilities, produce up to 50% of their electricity demands. In South Australia, the Bolivar wastewater treatment plant is 87% energy self-sufficient. A waste to energy facility, built by Yarra Valley Water, links to a wastewater treatment plant not just generating enough biogas to meet the energy demands of both sites but also provide surplus energy to local electricity grid (WSAA, 2017).

The main objective of this research is to conduct an economic feasibility study on net-zero-energy applications for wastewater treatment plants in Australia and, in particular, the wastewater treatment plants in Sydney and the Hunter Region. The research is an attempt to determine if it is economically viable to upgrade all of wastewater treatment plants in Australia to be energy self-sufficient using state-of-the-art resource recovery technologies.

2 SITUATIONAL ANALYSIS

2.1 Energy Demands of Wastewater Treatment in Australia

In wastewater services, energy demands depend on the size of the treatment plant and level of treatment. A 2012 study on energy use from 15 water utilities across Australia conducted by CSIRO for the Water Services Association Australia (CSIRO-WSAA Report) shows Sydney Water, Melbourne Water, Water Corporation and SA Water are the four main utilities that require highest energy demands for wastewater services compared to all other water service providers in the study, refer to Figure 1, (Cook, S. et al., 2012).

The 2012 Household Energy Consumption Survey conducted by the ABS indicates a mean weekly electricity consumption of 123.6 kWh per household (ABS, 2013) which is equivalent to approximately 6,427 kWh/year per household. Based on this statistics, the combined $611.3\text{x}10^6$ kWh of energy demands for wastewater services by the four largest energy consuming utilities could provide enough energy to power approximately 95,000 homes if these utilities are providing net-zero-energy wastewater services.

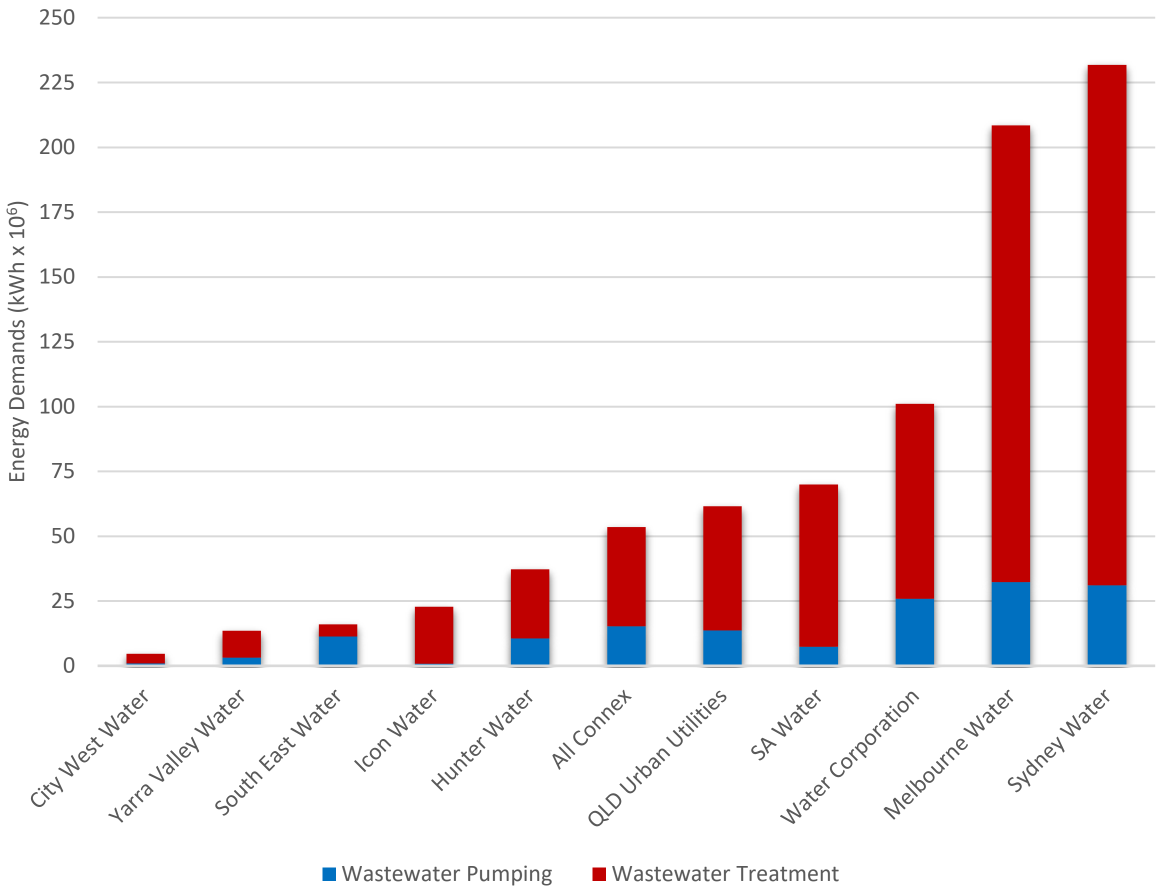


Figure 1: Comparison of Energy Used for Wastewater Treatment (Source: Cook, S. et al.)

The 2012 CSIRO-WSAA Report also outlines different trends in city-wide balance for water and wastewater services. Perth, Adelaide, Canberra and Newcastle are the four main cities with highest total energy demands per capita compared to Sydney and Melbourne which have much larger population, Figure 2.

Perth has the highest total energy per capita due to significant decline in inflows to the city's surface water catchments. The city had to rely on groundwater pumping and desalination to boost the water supply. Desalination plant accounted for about 82% of the total energy required for water treatment but provided only 12% of Perth's water demands (Cook, S. et al., 2012).

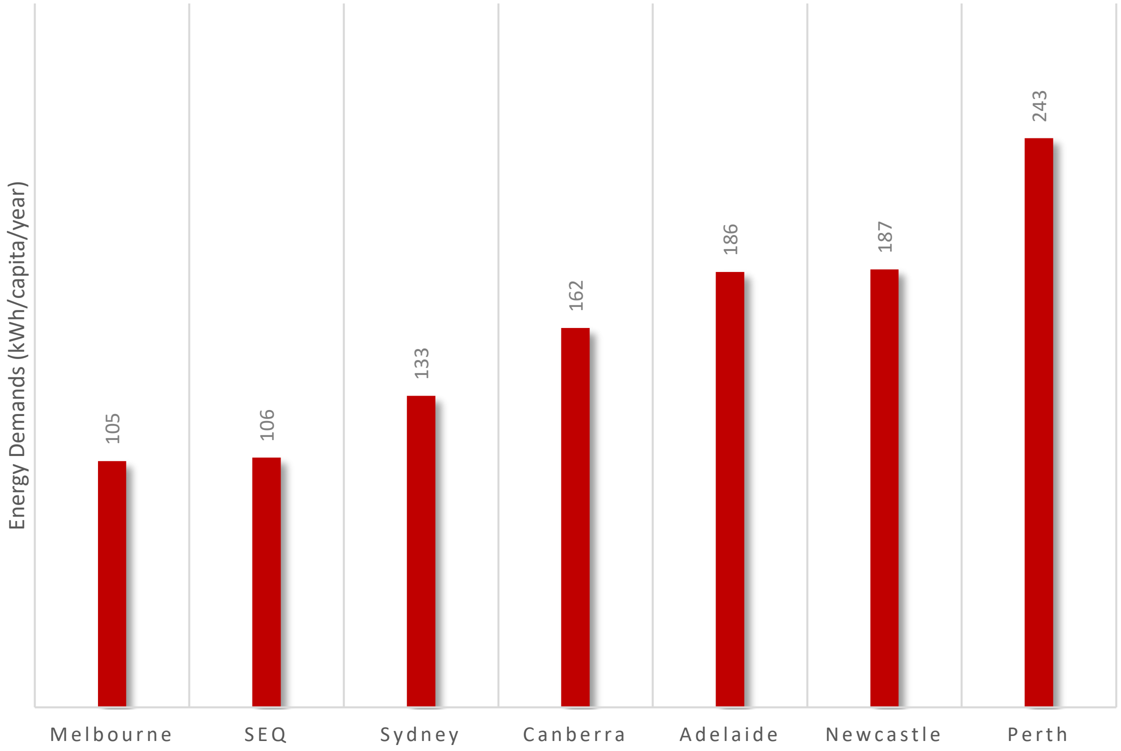


Figure 2: Comparison of Energy Used per Capita (Source: Cook, S. et al.)

Past studies indicated that population growth has direct contribution to increasing energy demands for water and wastewater services. By 2030, the median population growth of major cities in Australia is 39% from 2011 projections by each State, Figure 3. The mean 39% population growth will significantly increase energy demands for water and wastewater services.

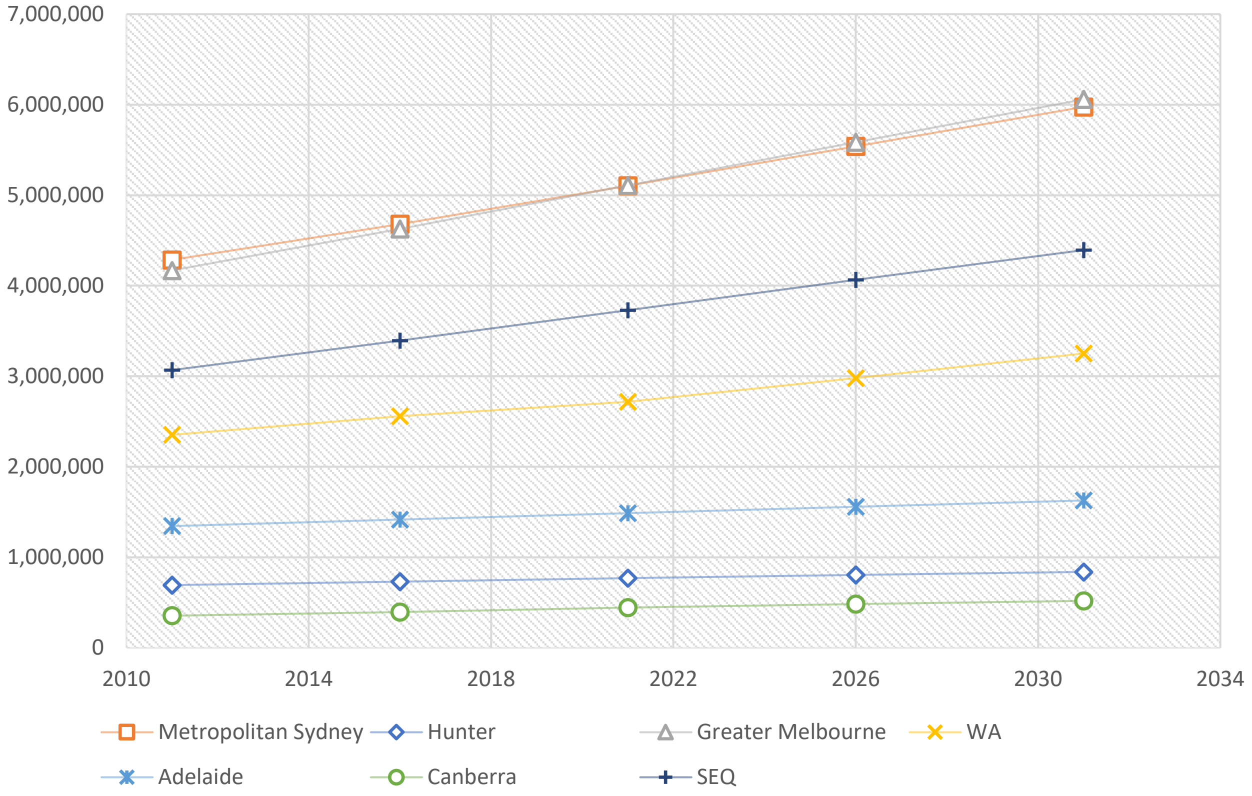


Figure 3: Population Projections in Major Cities

Considering climate change and increasing expectations of environmental sustainability from the communities, population growth will be one of the main drivers for innovation and efficiency of energy usage in water and wastewater treatment in Australia.

2.2 Renewable energy Technologies

Over the past decade, research and development of renewable energy for wastewater treatment have expanded substantially. Some of the emerging technologies such as cogeneration, trigeneration, hydroelectricity, wind turbines and solar are being tested and rolled out across the country by the major water utilities.

Interest in biogas in cogeneration systems has been growing steadily compared to other renewable technologies. At WWTPs, biogas produced as a by-product of the solids stabilisation process which contains up to 70% methane, 30% carbon dioxide and other contaminants (Wason, 2006).

Utilising biogas from wastewater treatment process through cogeneration can provide significant financial benefits from avoided electricity costs. In NSW, Sydney Water has been using biogas to operate some of their cogeneration facilities for the past 15 years. However, biogas was only accounted for approximately 15% of the facilities' energy demands. For facilities with smaller engines, less than 200kW, financial benefits from biogas cannot be achieved due to limitations in construction and operating costs, targeted production rates and high market value of energy (Sanbrook, A. et al., 2014).

Further investments in biofuel production through algae, advanced biogas recovery, solar and small-scale hydro would be required in ensuring the WWTPs becoming energy self-sufficient and potentially reaching net-zero-energy target.

2.3 Risks and Uncertainties

According to the Australian Energy Market Commission (AEMC), current power system is failing to keep up with changes and constantly unstable forcing the Australian Energy Market Operator (AEMO) to carry out rolling blackouts to stabilise the grid. Consequently, more than 200,000 households in Victoria was left without electricity while a Portland-based aluminium smelter, being operated by Alcoa, was forced to power down. The grid instability is believed to be caused by unpredictable renewable energy flowing into the network in combination with less reliable, aging coal-fired power stations (Latimer, 2019).

With less reliable energy system, lack of investment in renewable technologies, incentives and climate change policy, our WWTPs may not be able to cope with increasing demands and unreliable energy supply.

Difference in the rate of population growth and infrastructure delivery can also be considered as one of the main risks where energy and wastewater treatment demands are greater than the systems can supply causing chaos and total catastrophic failures.

3 RESEARCH QUESTION

4 LITERATURE REVIEW

Population growth, rising cost of energy and increasing community expectations on sustainability place constant pressure on local water utilities to adopt innovative and efficient processes. In recent years, resource recovery in wastewater treatment has become a focal point of policy makers, regulators and service providers in the energy and water sectors, especially the water utilities, as a mechanism to avoid increasing operation and maintenance costs.

This study aimed to analyse what is the feasibility of net-zero-energy (NZE) in wastewater treatment plants (WWTPs) in Australia from both the financial and economic perspectives.

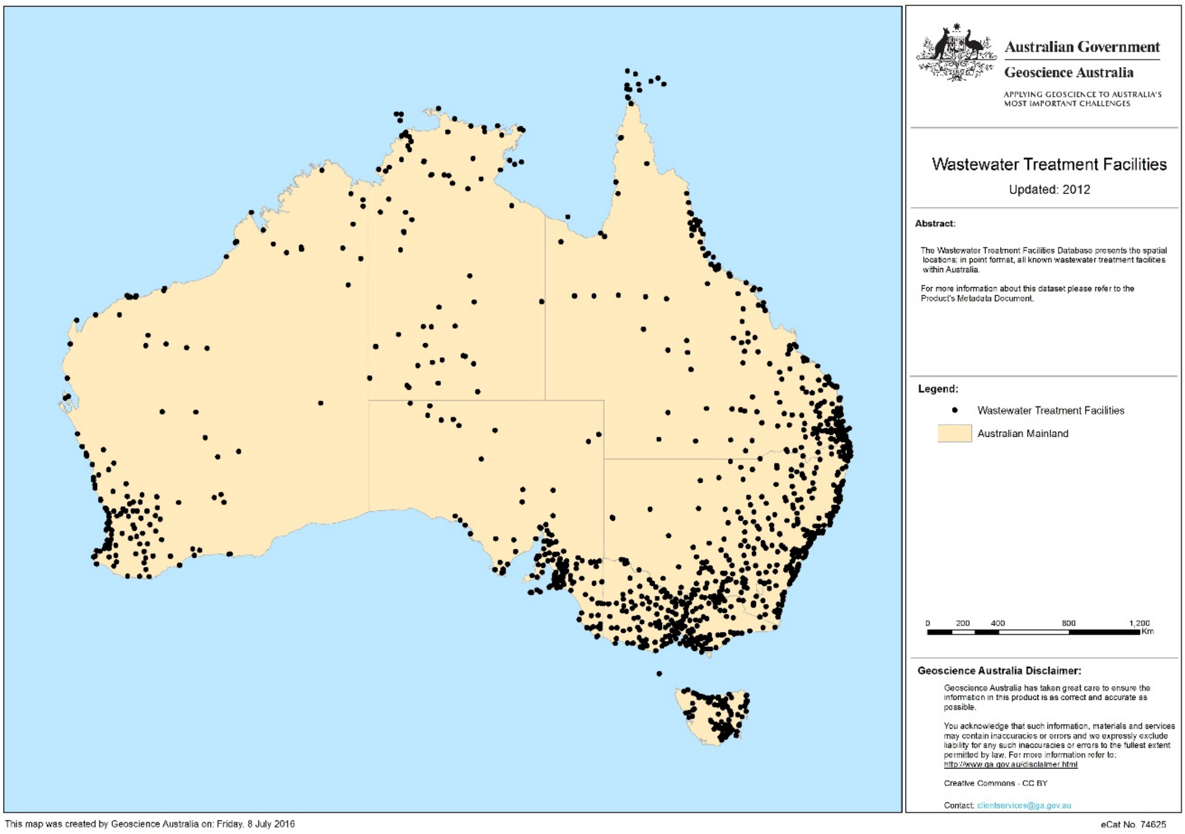
Prior to undertaking the economic and financial evaluations of NZE WWTPs in Australia, it is sensible to conduct an overview of current energy demands, financial regulation, available resource recovery technologies and future opportunities of renewable energy in Australian context.

4.1 WWTPs in Australia and Their Energy Requirements

As an effort to support decision makers from water industry, government agencies, academics and other interested parties make informed decisions using evidence-based information, a National Wastewater Treatment Facilities Database were constructed in 2011-2012 using Geoscience Australia's information such as aerial photography, orthophotos and satellite imagery (Geoscience Australia, 2016).

The database was revised in 2016 by Geoscience Australia showing more up-to-date details and locations of 1223 different operational wastewater treatment facilities across the country, Figure 4. Of those facilities, there are 505 wastewater treatment plants and 422 sewage treatment plants. The remaining facilities are water reclamation, stormwater treatment plants, waste stabilisation ponds, community wastewater management systems, water quality centres and recycled water treatment plants (Geoscience Australia, 2016).

This report mainly focuses on the energy consumption of the 927 sewage and wastewater treatment plants. Figure 5 is a comparison of operational wastewater treatment facilities in each state. New South Wales has the highest number of treatment facilities of 320 facilities, follow by Queensland and Victoria with 241 and 197 facilities respectively.



The Wastewater Treatment Facilities Database presents the spatial locations; in point format, all known wastewater treatment facilities within Australia.

For more information about this dataset please refer to the Product's Metadata Document.

Geoscience Australia has taken great care to ensure the information in this product is as correct and accurate as possible.

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Figure 4: National Wastewater Treatment Facilities ((Geoscience Australia, 2016)

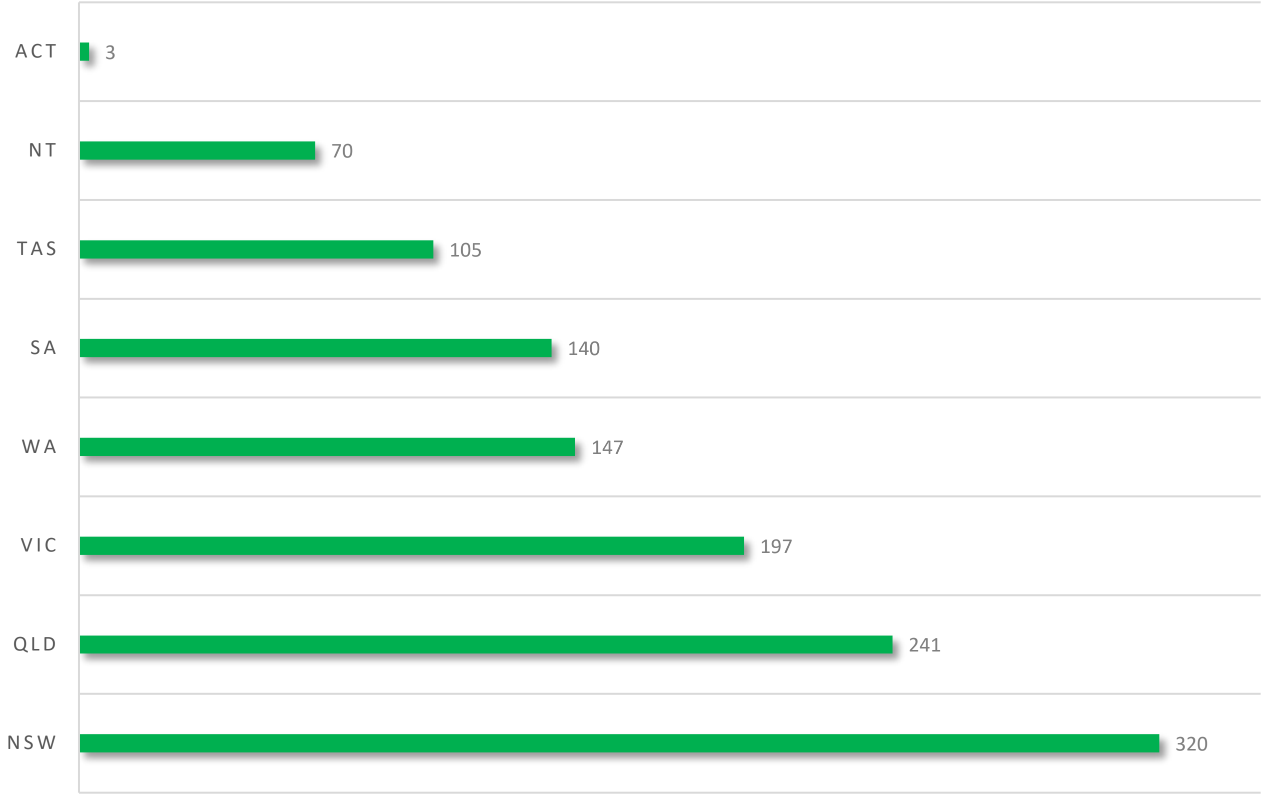


Figure 5: Wastewater Treatment Facilities by State (Source: Geoscience Australia)

In Australia, energy demands for WWTPs depends on the level of treatment and treatment process. Canberra, for example, has the highest energy intensity per capita for wastewater treatment compared to other treatment in other major cities. This was because all wastewater in Canberra undergoing tertiary level treatment. There is, however, no obvious evidence or strong relationship between the size of the treatment plant and energy intensity which indicates that factors, such as treatment process, have a greater influence on energy efficiency of the treatment plants (Cook, S. et al., 2012).

A study by Macintosh, C. et al. on Grüneck WWTP in Germany also shown a similar influencing factors for energy efficiency in treatment plants where energy usage in conventional activated sludge, aeration process was ranging between 45% to 75% of total energy demands. On this basis, the overall power consumption of the treatment plant can be significantly reduced by implementing aeration equipment upgrades and process optimisation (Macintosh, C. et al., 2019).

Despite having an average number of wastewater treatment facilities, Figure 5, Perth has the highest energy demands per capita compared to other major cities such as Sydney, Melbourne and South East Queensland, Figure 2. A comparison of energy demands per capita in major cities show that Sydney, despite having the largest number of wastewater treatment facilities in the country, has significantly lower energy demands per capita, Figure 2. Further studies of the treatment process & technologies applied in each city are required in order to have a better understanding of the key factors influencing energy efficiency.

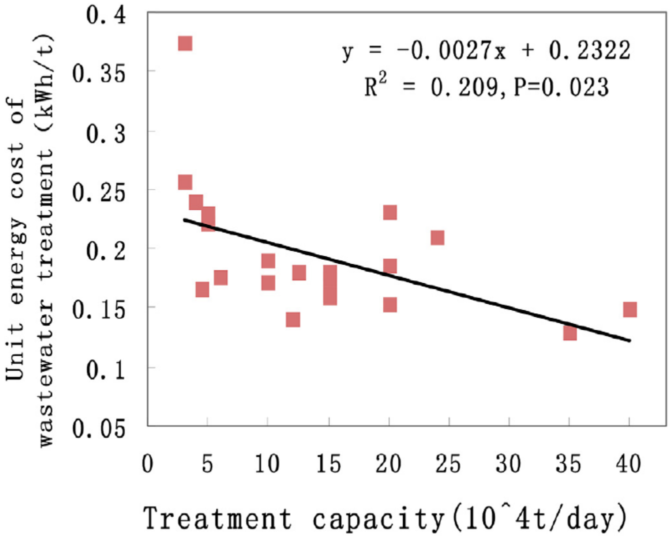
4.2 Economics of Net-Zero-Energy

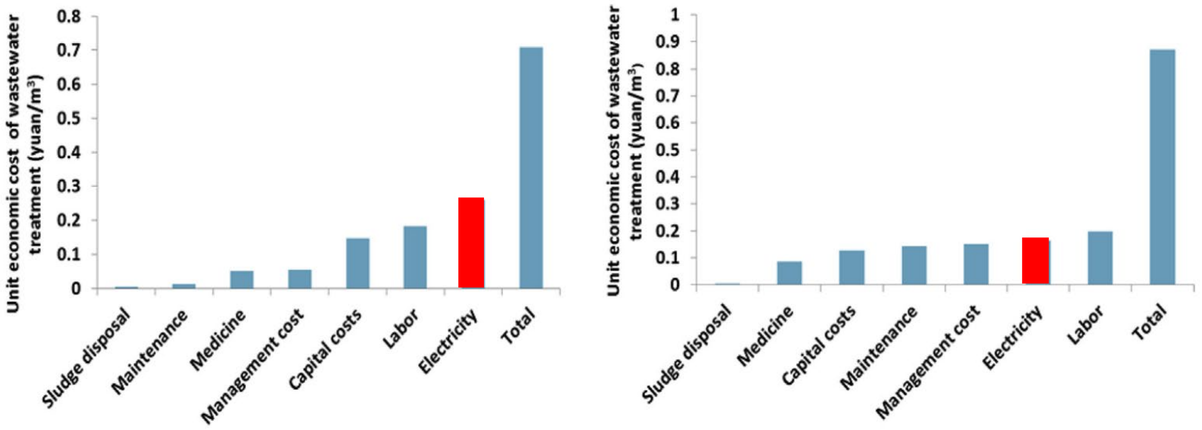
A study by Li, W. et al. (2015) on 22 WWTPs in Shenzhen, China has indicated that energy and labour are the two main economic costs despite differences in treatment technologies between the three types of treatment plant, Figure 7. In particular, energy cost accounts for approximately 26.3% of total costs in operating a WWTP in Shenzhen (Li, W. et al., 2015).

The study found that energy consumption of 449 million kWh/yr by a WWTP in Shenzhen is equivalent to annual energy consumption of about 600,000 people (Li, W. et al., 2015). These figures suggest that becoming energy self-sufficient or net-zero-energy in wastewater treatment will help to reduce not just the 26.3% operational costs of the WWTPs but also lower energy costs for many households due to energy surplus.

The same study also demonstrated a direct relationship between unit energy consumption of wastewater treatment and the treatment capacity, possibly due to the presence of scale effect. The relationship was described as negative linear regression in which the wastewater treatment capacity is opposite to the unit cost of energy, i.e. the larger wastewater treatment capacity, the lower the energy cost per unit of wastewater treatment, Figure 6.

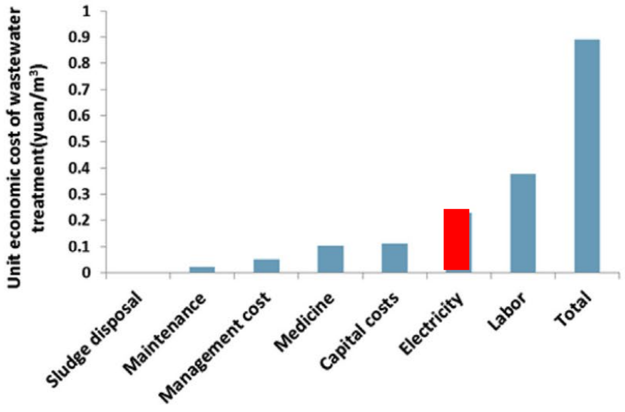
Figure 6: Wastewater treatment capacity and unit cost of energy (Li, W. et al., 2015)





(a) Plant A

(b) Plant B



(c) Plant C

Figure 7: Economic cost of WWTPs in Shenzhen, China

In addition to the influence of treatment capacity on unit cost of energy, treatment technology is also a key influencing factor effecting the economics of WWTPs. A comparison between three different types of treatment plants by Li, W. et al. (2015) shows significant differences in energy costs associated with different treatment technologies. In particular, energy costs of wastewater treatment technologies such as Refined Anaerobic-Anoxic-Oxic + FF (RA^2O+FF) and Sequencing Batch Reactor (SBR) were significantly less than technologies such as Anaerobic-Anoxic-Oxic (A^2O), Modified University of Cape Town (MUCT) and Biological Aerated Filter (BAF) which are also widely used in WWTPs in China, Figure 8.

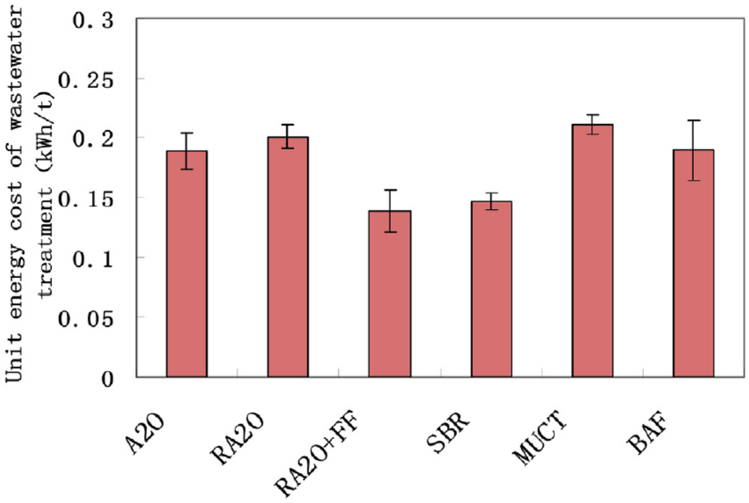


Figure 8: Wastewater treatment technologies and unit cost of energy (Li, W. et al., 2015)

4.3 Grüneck WWTP Successful Strategies

Located approximately 30km north of Munich, Germany (Figure 9), Grüneck WWTP has a design capacity of 160,000 Equivalent Population (EP) and an average operational capacity of 74,000 ± 3,000 EP (Macintosh, C. et al., 2019). The Grüneck WWTP treatment flow process is shown in Figure 6.

Like many other wastewater treatment facilities around the world, Grüneck WWTP faced enormous pressures to improve energy efficiency to mitigate the increasing energy costs, meet tightening effluent discharge requirements and increasing demands from population growth. Through a combination of reducing power consumption by upgrading aeration system and increasing energy production through food waste co-digestion, Grüneck WWTP improved its energy self-sufficiency from 64 to 88%. The main improvement was increasing energy production with food waste co-digestion with helped improving energy efficiency by 16% (Macintosh, C. et al., 2019).

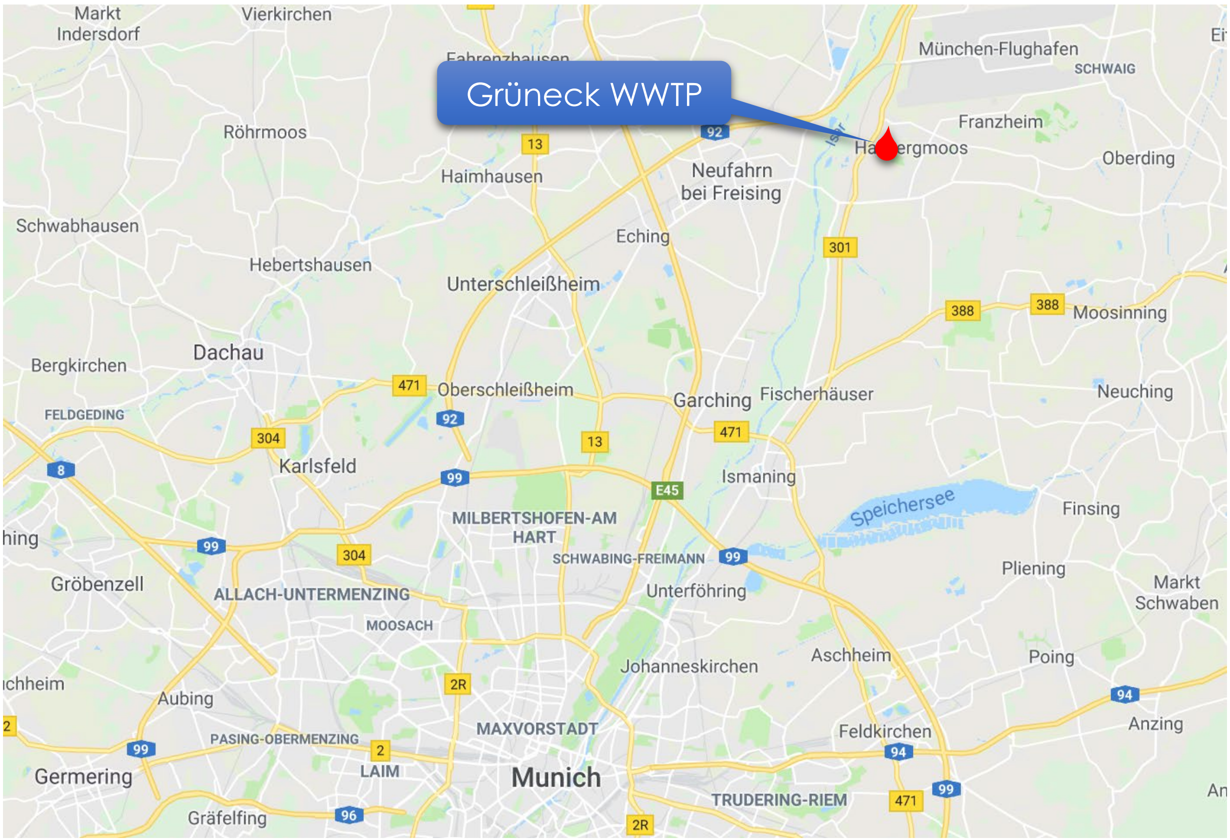
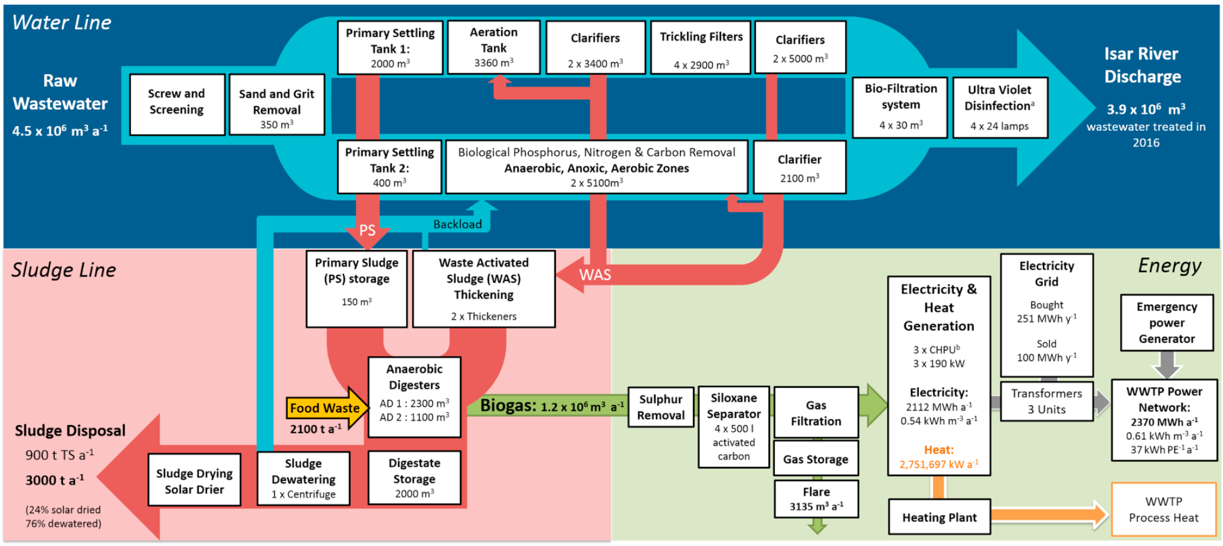


Figure 9: Grüneck WWTP Location (Source: Google Map)

In addition to aeration equipment upgrades and food waste co-digestion, a solar dryer was also installed to manage the increased biosolids production from co-digestion process and reducing biosolids transportation costs by up to 30%. The dryer, however, marginally increases total plant energy consumption by less than 2% which is insignificant compared to the overall increased energy production and efficiency (Macintosh, C. et al., 2019).



[a] UV Disinfection unit operated only during Isar river swimming season
[b:] CHPU : Combined Heat and Power Unit

Figure 10: Grüneck WWTP Process Flow Diagram (Macintosh, C. et al., 2019)

In conventional WWTPs, the plant energy use through aeration process can vary between 45% to 75%. Upgrading aeration equipment and optimising the process can significantly reduce the overall plant power consumption. Example of aeration equipment upgrade includes replacing traditional ceramic and elastomeric membrane diffusers with ultra-fine bubble diffusers. Direct-drive turbo blowers and rotary lobe blower replacements can also boost aeration energy efficiency by more than 35% (Macintosh, C. et al., 2019).

In wastewater treatment, biogas produced from the anaerobic digestion can be combusted and converted to energy to supply 50 to 60% of the on-site electricity demands. In reality, many existing anaerobic digesters in WWTPs are operating at low organic loading rates (OLRs). To increase OLRs, anaerobic co-digestion (AcoD) is often introduced to simultaneously digest two or more substrates such as food waste which contains high methane yield, fast digestion kinetics and readily available from local areas (Macintosh, C. et al., 2019).

Aeration upgrades and AcoD are the two common strategies that are widely applied to improve WWTP energy self-sufficiency. Other strategies include upgrading combined heat and power units (CHPUs) and installing on-site renewable energy technologies such as hydroelectricity, solar generation and wind turbines. The payback periods for aeration upgrades and AcoD were 10 and 17 months, respectively. With the increased energy efficiency, these relatively short payback periods demonstrate that there is significant incentive for similar WWTPs to improve energy self-sufficiency through aeration upgrades and AcoD (Macintosh, C. et al., 2019).

4.4 Bolivar Wastewater Treatment Plant Cogeneration Facility

Located approximately 16km north of Adelaide, the Bolivar WWTP, which is the largest WWTP in the Adelaide region, processes more than 60% of Adelaide's metropolitan wastewater. The plant was originally commissioned in 1966 as a trickling filter plant. It wasn't until February 2001, the plant was upgraded to an activated sludge treatment plant. The plant has a design capacity of 165 MLD servicing an equivalent population (EP) of 695,630 (SA Water, 2013).

In late 2012, the South Australian Government approved a $25.8 million project aiming to optimise the energy utilisation on the Bolivar WWTP site. The project was delivered by SA Water involving major upgrade to the WWTP power supply by three high electrical efficient dual-fuel gas engines from Clarke Energy Australia. Each GE Jenbacher gas engine is producing 2.4MWe and they integrate the electricity (generated from the digester gas produced during the wastewater treatment process) into the existing electrical infrastructure (Energy Source & Distribution, 2012).

The project was completed and commissioned in July 2013. The upgraded Bolivar WWTP generates up to 85% of the plant's annual electricity demand. The estimated annual electricity savings was $1.3 million with an estimated 8 years capital payback period (Energy Source & Distribution, 2012).

The gas engines also generate low carbon emission electricity which reduces greenhouse gas emissions by more than 11,000 tonnes annually. Additionally, the new WWTP also earn $0.7 million per annum from electricity market revenue and creating Renewable Energy Certificates worth approximately $0.9 million each year (Energy Source & Distribution, 2012).

Figure 12: Bolivar wastewater treatment plant (Source: SA Water, 2013)

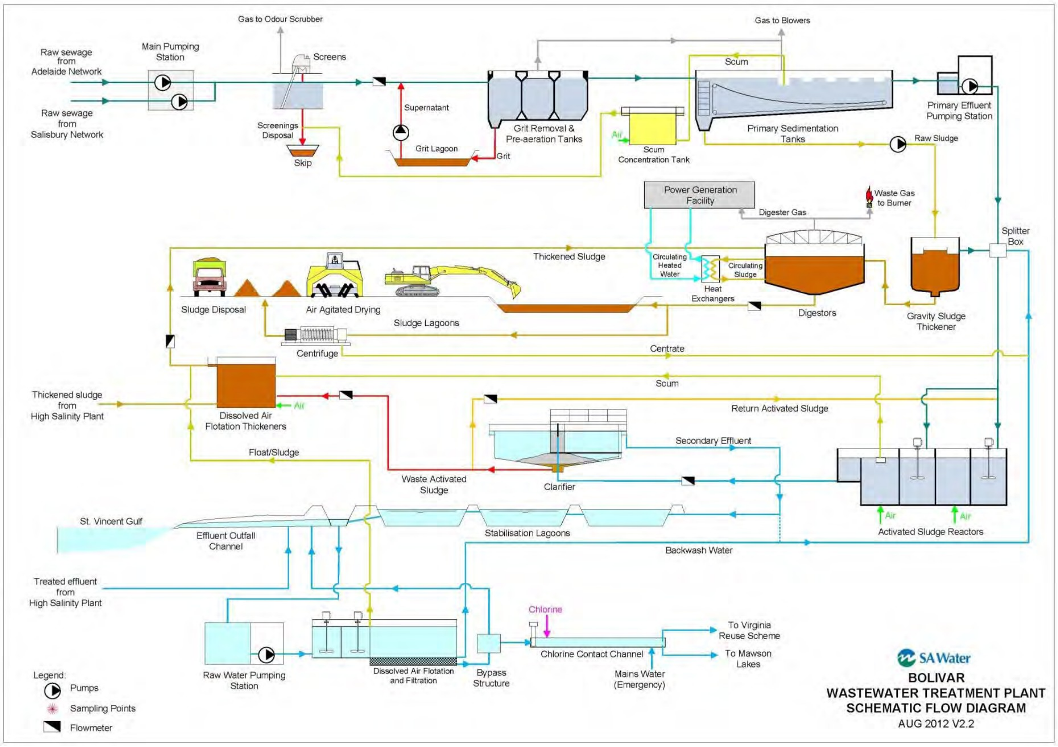


Figure 11: Bolivar WWTP Process Diagram (Source: SA Water, 2013)

5 RESEARCH METHODOLOGY

5.1 Alternative Net-Zero-Energy WWTPs

Wastewater treatment require energy intensive components and processes to remove solids and microorganisms. The wastewater, however, contains significantly high amount of potential energy that is approximately 9−10 times greater than that used for the treatment. The potential energy sources in wastewater could be utilised to improve energy sufficiency in WWTPS. One of the approaches is to recover internal energy in the WWTPs using CH_4 biogas, which is produced during sludge anaerobic digestion process, as biofuel to generate power and heat through cogeneration process. The main idea is to capture more organic energy than the required energy for wastewater treatment so that external energy input from the main electrical grid is not required to create an independent and self-sufficient energy recycling system (Yan, P. et al., 2016). A theoretical model with the characteristic of the model shown in Figure 13 will be developed to evaluate the feasibility of achieving NZE in WWTPs in Australia.

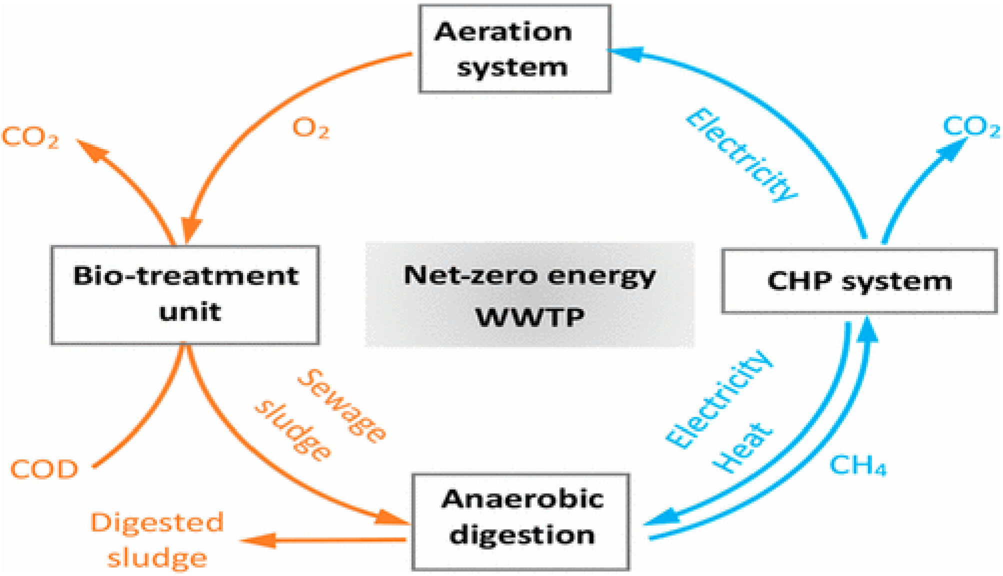


Figure 13: Example of NZE WWTP Model (Yan, P. et al., 2016)

5.2 Data Collection and Analysis

Energy demands of large WWTPs from major water utilities will be obtained and analysed using quantitative data analysis methods which consist of both descriptive analysis and inferential analysis.

Descriptive analysis will help to summarise the data and identify patterns of energy demands in WWTPs while the inferential analysis will help to find the relationship between several different variables, processes and components within the WWTPs affecting the energy demands.

5.3 Identification of Outliers

Outliers are the observations that are numerically distant from the rest of the data and when included in the analysis, the results derived will be misleading. In statistics, therefore, it is important that outliers are being identified and removed from the data. The outliers' removal method can be described as below.

a. *First Quartile (Q_1)* = *25th percentile*
b. *Second Quartile (Q_2)* = *50th percentile*
c. *Third Quartile (Q_3)* = *75th percentile*
d. *Inter-quartile Range (IQR)* = $Q_3 - Q_1$
e. *Mid Outliers (MO)* = $x_i < Q_1 - 1.5IQR$ *OR* $x_i > Q_3 + 1.5IQR$
f. *Extreme Outliers (EO)* = $x_i < Q_1 - 3IQR$ *OR* $x_i > Q_3 + 3IQR$

5.4 Sample Mean, Variance, Correlation and Absolute Percentage Error

The sample Mean, Variance and Correlation can be calculated using the below formulae (Montgomery, D., Runger, G. & Hubele, N., 2011).

a. *Sample Mean ($\bar{x}$)*

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (5\text{-}1)$$

b. *Sample Variance (s^2)*

$$s^2 = \frac{\sum_{i=1}^{n} (x_1 - \bar{x})^2}{n-1} \qquad (5\text{-}2)$$

c. *Correlation (r_{xy})*

$$r_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}} \qquad (5\text{-}3)$$

d. *Absolute Percentage Error (APE)*

$$APE = \frac{|Y_p - Y_a| x100}{Y_p} \qquad (5\text{-}4)$$

where Y_p = *Predicted Value*
Y_a = *Actual Value*

5.5 Economic Evaluation

Financial and cost-benefit analysis (CBA) will be systematically carried out to estimate the strengths and weaknesses of the alternative NZE WWTP model developed in Section 5.3 using some of the below basic financial evaluation concepts.

a. NPV = Net Present Value = $-I_0+\sum_{t=1}^{n}\frac{(B_n-C_n)}{(1+i)^n}+\frac{L_n}{(1+i)^n}$ *(5-5)*

b. IRR = Internal Rate of Return = $i_1-NPV_1\frac{(i_2-i_1)}{NPV_2-NPV_1}$ *(5-6)*

c. PB = Payback Period = $\frac{I_0}{B-C}$ *(5-7)*

d. BCR = Benefit to Cost Ratio = $\frac{NPV(B)}{I_0}$ *(5-8)*

e. LCC = Life Cycle Cost = $\frac{NPV(C)}{I_0}$ *(5-9)*

f. FV = Future Value = $(1+i)^n$ *(5-10)*

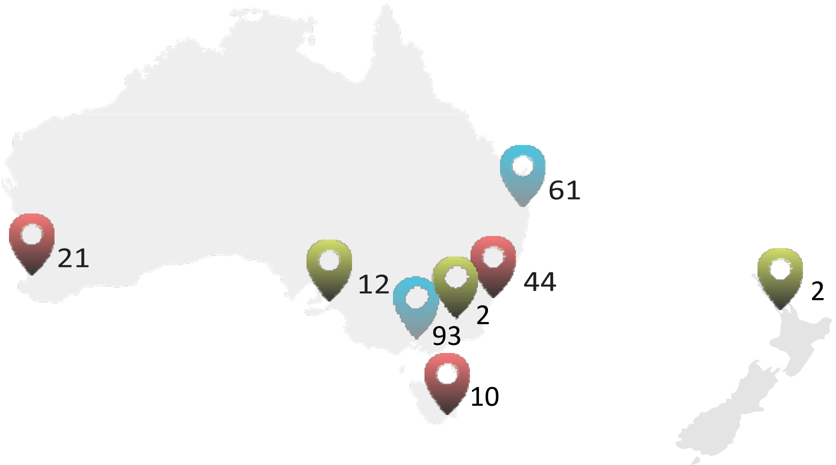
6 ENERGY BENCHMARKING STUDY

The first round of energy benchmarking for WWTPs across Australia was conducted by the Water Services Association Australia (WSAA) in 2013/14 using an approach similar to adopted by a number of European countries such as Switzerland, Germany and Austria. WSAA's 2013/14 first energy benchmarking round involved 142 WWTPs from seventeen different water utilities (WSAA, 2017).

In 2015/16, the energy benchmarking round was expended and the participated water utilities increased from 17 to a total of 31 providing data for 245 WWTPs from seven states and territories across Australia and Auckland in New Zealand (WSAA, 2017), Figure 14.

6.1 Participating Water Utilities

Victoria has the most number of WWTPs, a total of 93 plants, participated in the benchmarking study follow by Queensland and New South Wales with 61 and 44 WWTPs respectively, Figure 14.



State	WWTPs
ACT	2
NSW	44
QLD	61
SA	12
TAS	10
VIC	93
WA	21
NZ	2
Total	**245**

Figure 14: Participating Water Utilities (WSAA, 2017)

6.2 Distribution of Results

6.2.1 Sub-metering

In the 2015/16 energy benchmarking study, only one third of the participating WWTPs provided data on electrical energy use at process level. The available sub-metering data in the WSAA report were derived from physical watthour meters to provide 'snap-shots' of electrical energy use in WWTPs. In some cases, due to limited available data, the sum of the sub-meters was either over-estimated or under-estimated average total plant electrical energy use. However, for simple comparisons, the errors and discrepancies in the data were perceived as insignificant and the need for correction or adjustments were not necessary (WSAA, 2017).

The below Figure 15 and Figure 16 demonstrate that, for both Types 2 and 3 WWTPs, the aeration, pumping, disinfection and sludge treatment processes consumed required more than 70% of total energy demands. Aeration was clearly the most energy intensive process in a WWTP. These processes would be the main area of focus for addressing energy efficiency in the WWTPs.

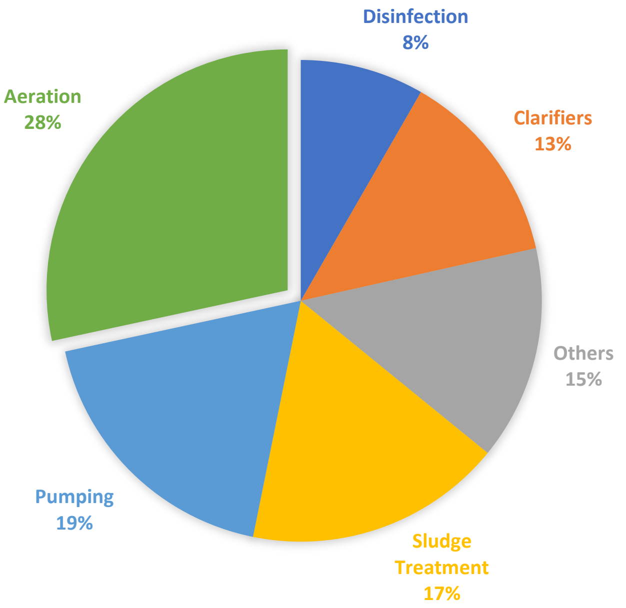


Figure 15: Type 2 Plant Sub-Metering

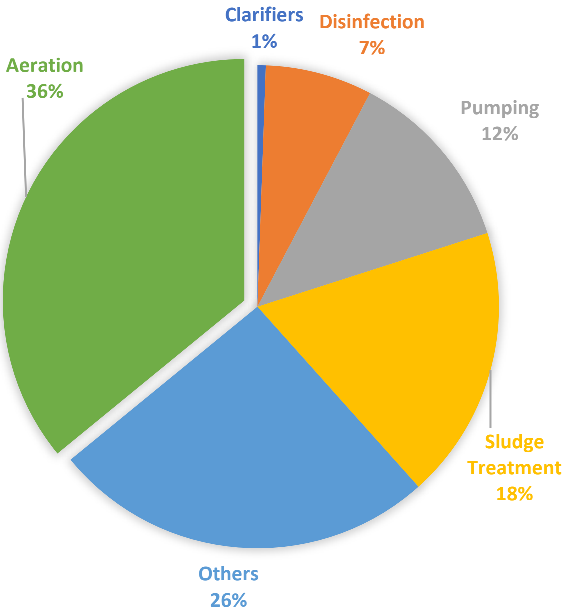


Figure 16: Type 3 Plant Sub-Metering

6.2.2 Type 2 Wastewater Treatment Plants

Type 2 plants have similar treatment processes to Type 1 plants which include activated sludge treatment, primary sedimentation and anaerobic digestion but without on-site co-generation from biogas.

A total number of 24 Type 2 plants were included in this round of energy benchmarking study. Some of the main energy usage data of Type 2 plant data are summarised in below Table 1.

Parameter	***Value***	***Unit***
Number of plants	*24*	*No.*
Average of Adopted EP	*129,095*	*EP*
Flow-specific	*886*	*kWh/ML*
Load-specific	*64*	*kWh/(EP.yr)*
Average Electrical Energy Use	*14.8*	*kWh/kgN removed*
	1.4	*kWh/kgCOD removed*
	3.0	*kWh/kgBOD removed*

Table 1: Summary of Type 2 Plants Data

Figure 17 shows overall relationships between average influent and electricity usage and average adopted EP. Figure 18 and Figure 19 show similar relationships but with and without high pumps respectively. These figures were derived using data, without the mid outliers, from the WSAA energy benchmarking study.

In summary, average electricity use and influent in Type 2 plants can be derived as below.

a. Average Total Electricity Use $= 0.116EP^{1.0302}$ (overall) *(6-1)*

$= 0.9684EP^{0.843}$ (high pump) *(6-2)*

$= 0.1184EP^{1.026}$ (w/o high pump) *(6-3)*

b. Average Influent $= 6e^{-4}EP^{0.8966}$ (overall) *(6-4)*

$= 2e^{-4}EP^{0.9969}$ (high pump) *(6-5)*

$= 9e^{-4}EP^{0.8479}$ (w/o high pump) *(6-6)*

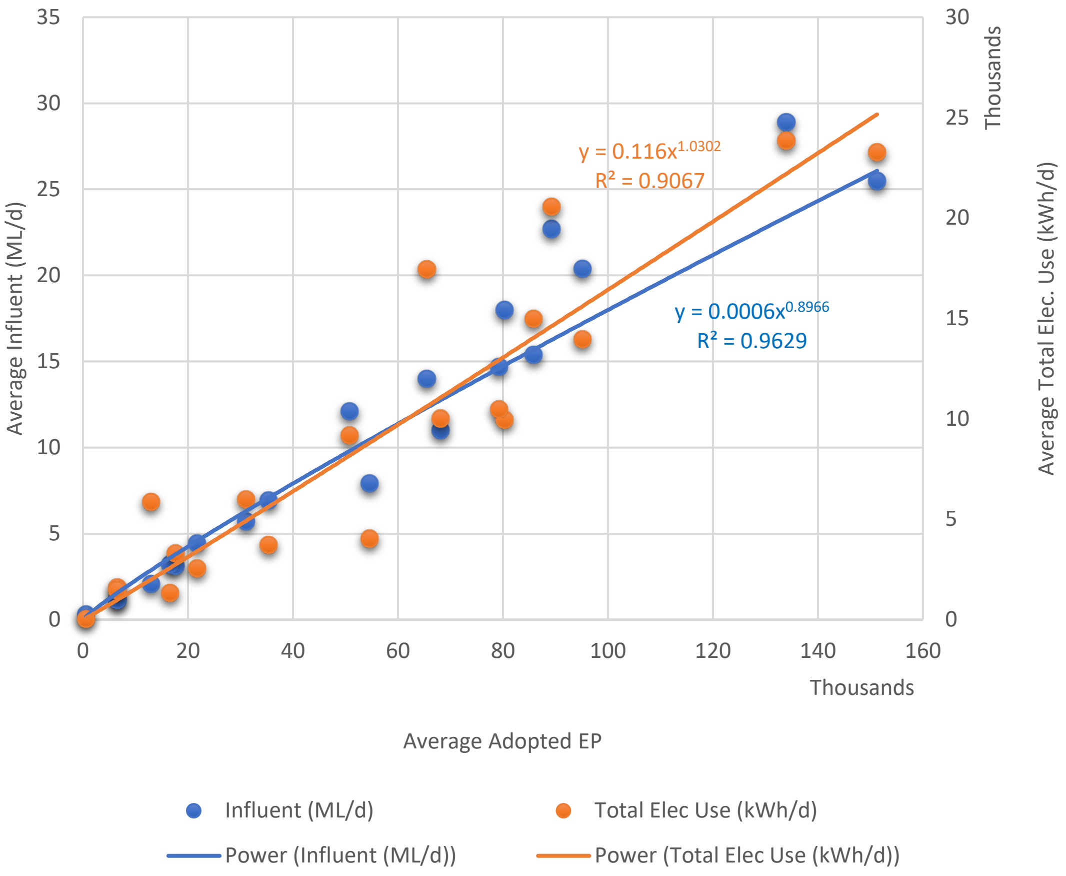


Figure 17: Type 2 Plants Influent & Electricity Usage

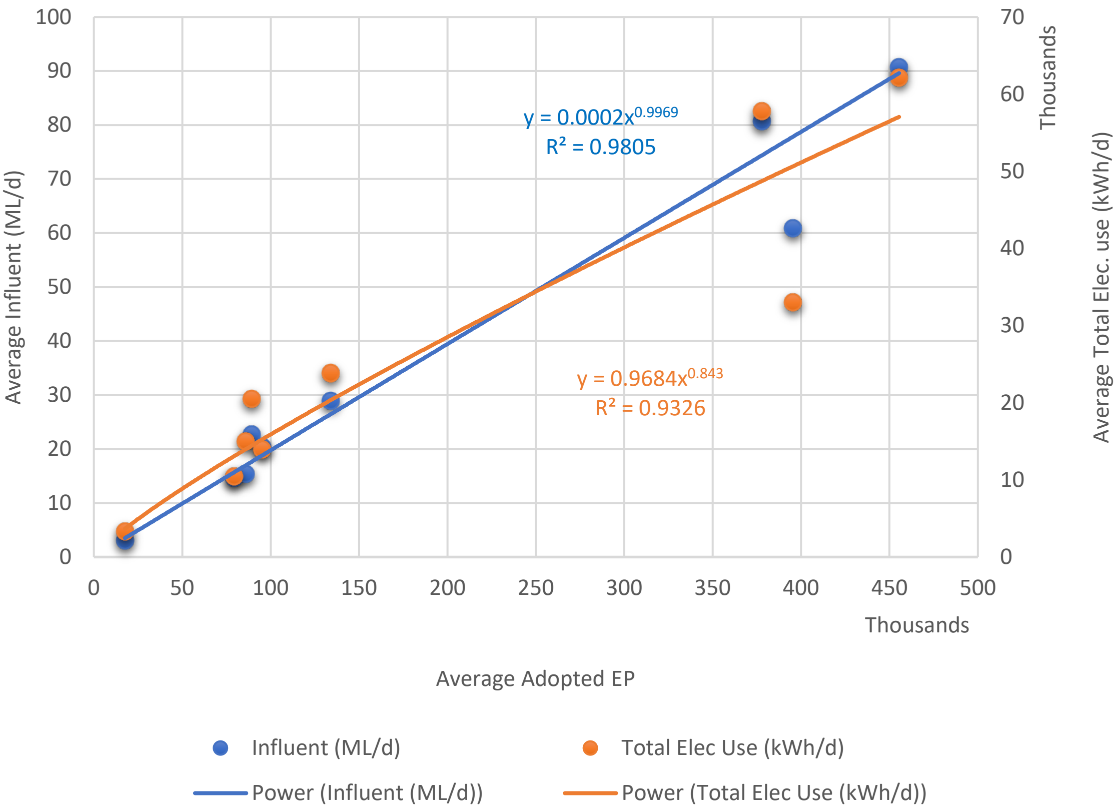


Figure 18: Type 2 Plants Influent & Electricity Usage with High Pumps

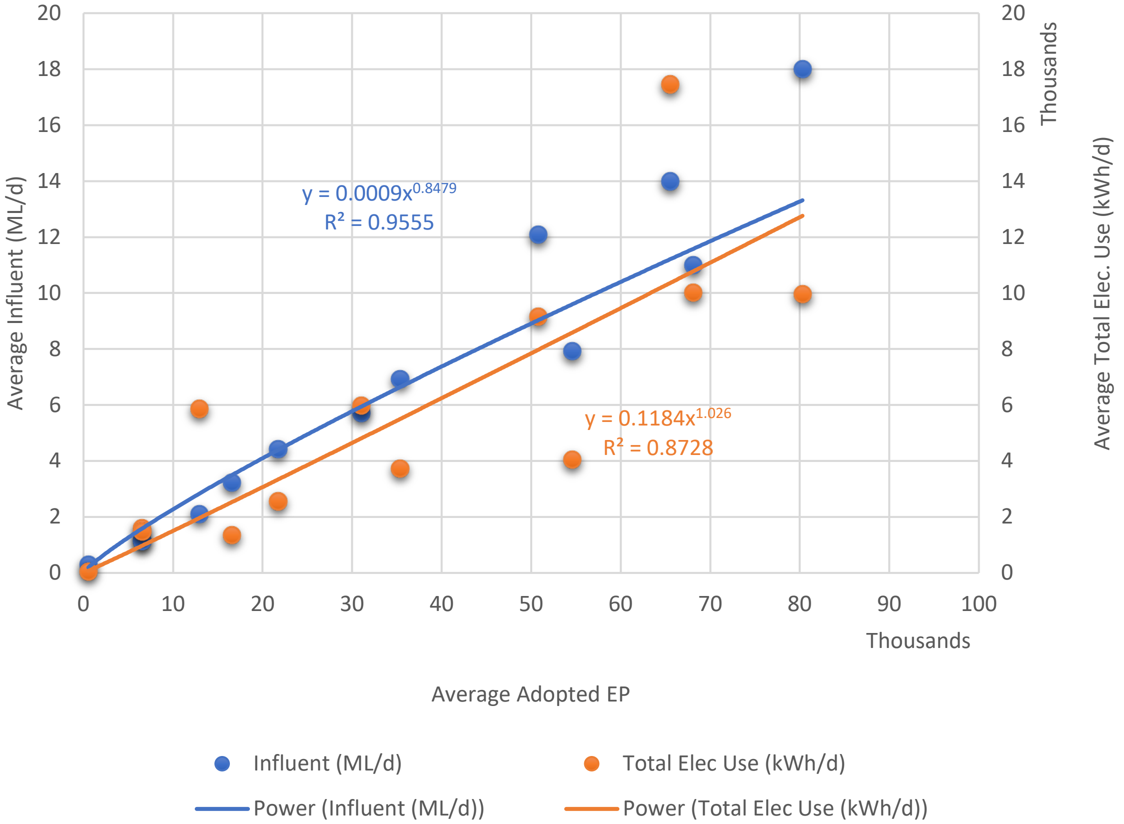


Figure 19: Type 2 Plants Influent & Electricity Usage without High Pumps

6.2.3 Type 3 Wastewater Treatment Plants

Unlike Types 1 and 2 plants, Type 3 plants have extended aeration activated sludge treatment and aerobic sludge digestion.

A total number of 133 Type 3 plants were included in this 2015/16 WSAA benchmarking study. Some of the main energy usage data of Type 2 plant data are summarised in below Table 2.

Parameter	Value	Unit
Number of plants	133	No.
Average of Adopted EP	40,857	EP
Flow-specific	1,533	kWh/ML
Load-specific	107	kWh/(EP.yr)
Average Electrical Energy Use	26.3	kWh/kgN removed
	3.6	kWh/kgCOD removed
	6.2	kWh/kgBOD removed

Table 2: Summary of Type 3 Plants Data

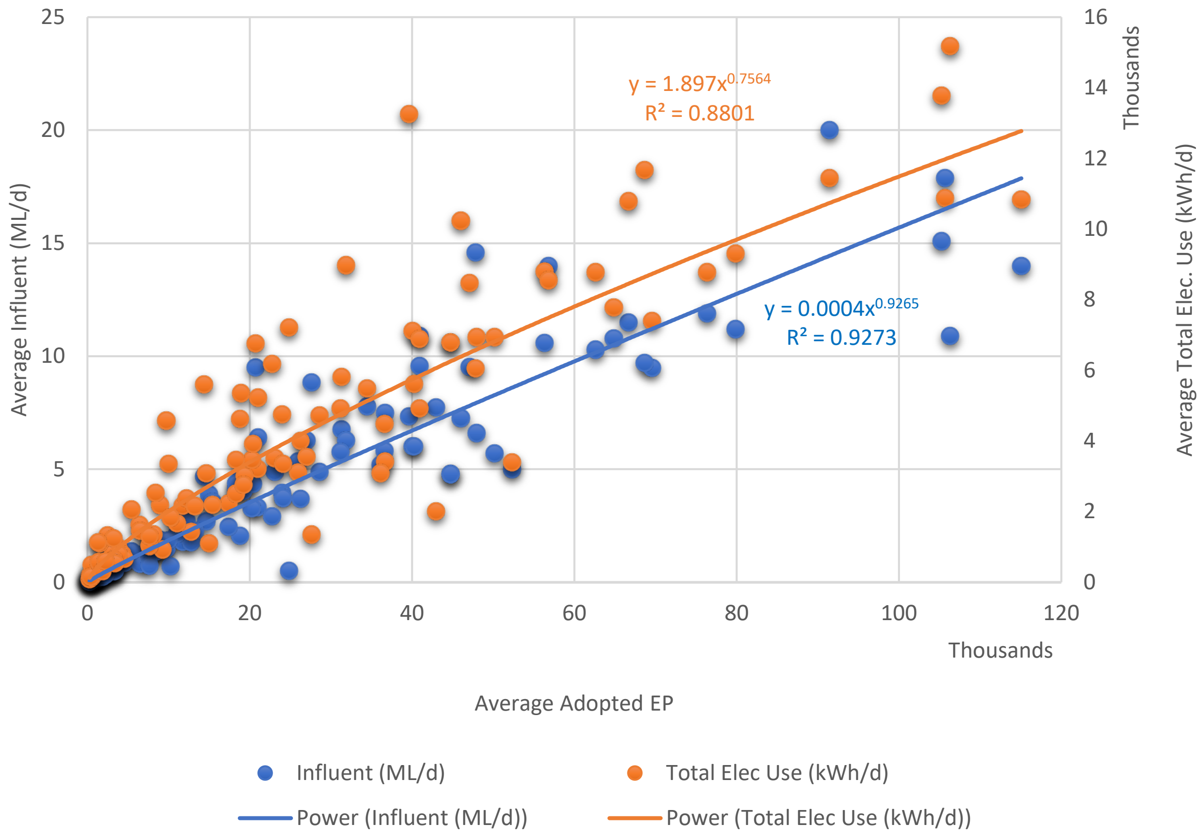


Figure 20: Type 3 Plants Influent & Electricity Usage

Figure 20 shows overall relationships between average influent and electricity usage and average adopted EP. Figure 21 and Figure 22 show similar relationships but with and without high pumps respectively. These figures were derived using data, without the mid outliers, from the WSAA energy benchmarking study.

The overall average electricity use and influent in Type 3 plants can be derived as below.

a. Average Total Electricity Use = $1.897EP^{0.7564}$ *(6-7)*

b. Average Influent = $4e^{-4}EP^{0.9265}$ *(6-8)*

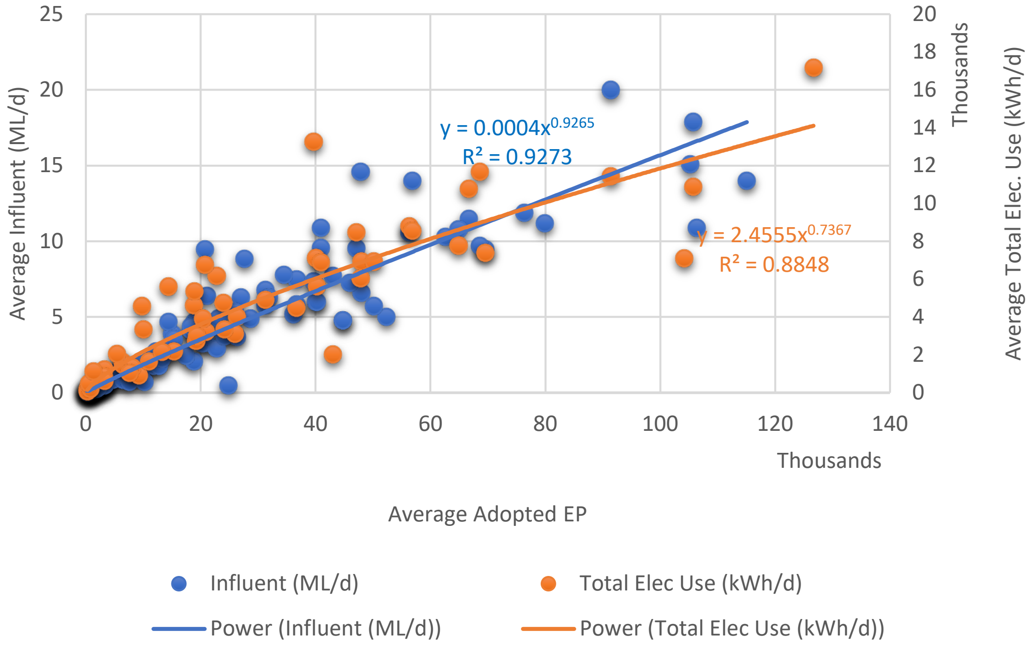


Figure 21: Type 3 Plants Influent & Electricity Usage with High Pumps

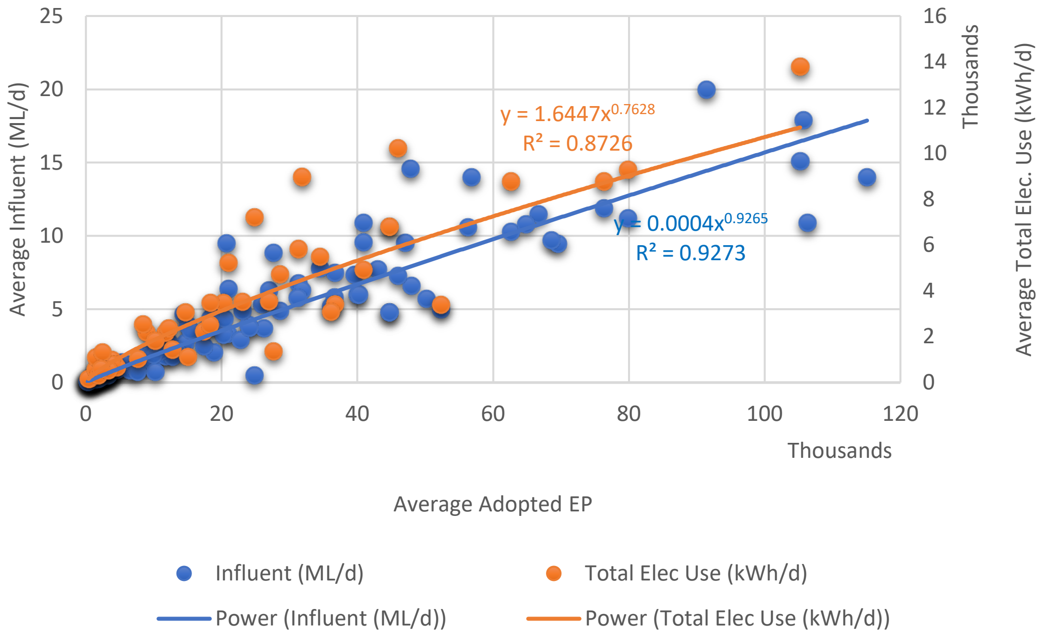


Figure 22: Type 3 Plants Influent & Electricity Usage without High Pumps

6.2.4 Hunter Water's WWTPs

Hunter Water Corporation (HWC) is a State-Owned Corporation, similar to Sydney Water, that provides potable water, recycled water, wastewater and some stormwater services to residents and businesses across the Lower Hunter *Figure 26*. Within its area of operation, HWC maintains a network of 4,995km of sewer mains, 434 wastewater pumping stations and 19 wastewater treatment plants that have the capacity of treating almost 70,000ML of wastewater annually (Hunter Water, 2019).

In relation to wastewater treatment plants, Burwood Beach and Belmont are the two largest plants receiving influent of 57.6 and 30.5 ML/d respectively, Figure 23.

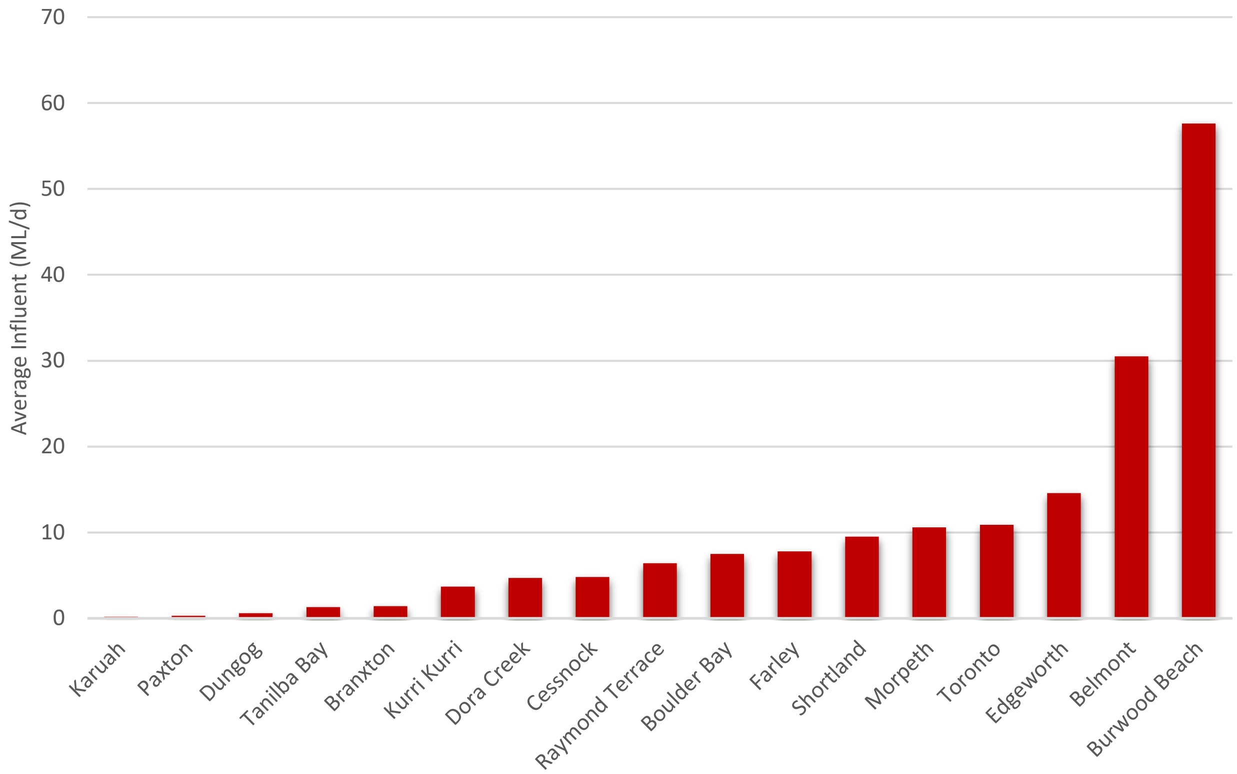


Figure 23: Average Influent of Hunter Water's Wastewater Treatment Plants

Of those 19 wastewater treatment plants within HWC's area of operation, 15 plants are Type 3 treatment plants. Electricity analysis from 2015-16 Site Reports of the 15 Type 3 treatment plants revealed a similar relationship between electricity usage and influent of other 133 Type 3 plants in the WSAA benchmarking study, Figure 24 and Figure 25.

Overall, the average electricity use and influent of HWC's Type 3 plants can be derived as below.

a. Average Total Electricity Use $= 4.2646EP^{0.6868}$ *(6-9)*

b. Average Influent $= 6e^{-5}EP^{0.1.1335}$ *(6-10)*

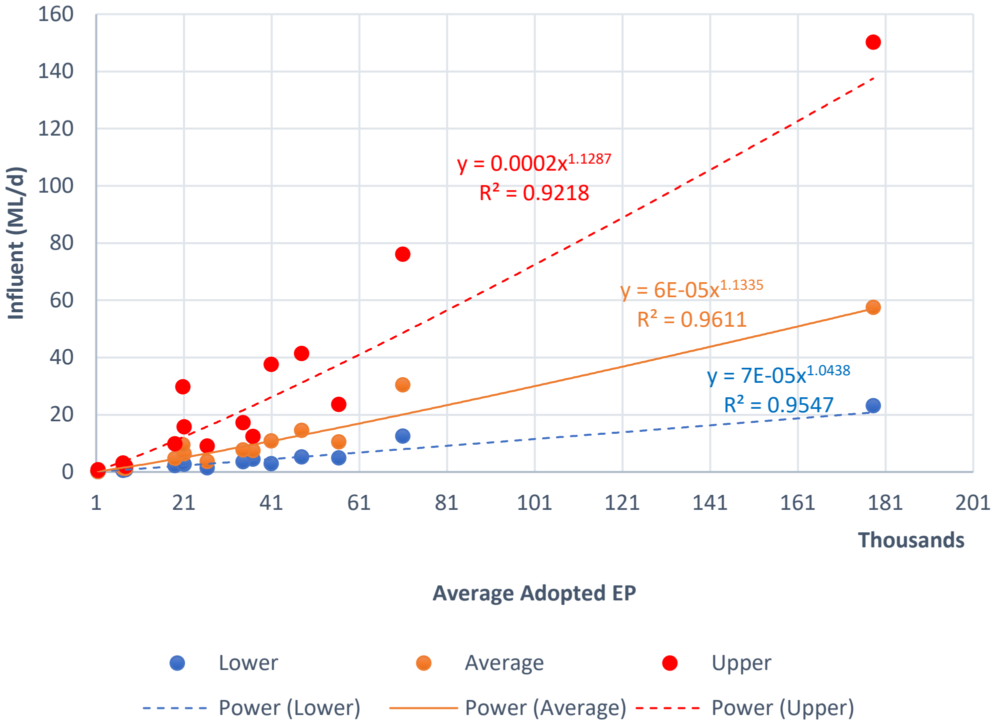


Figure 24: Influent in WWTPs in Hunter Water's Area of Operation

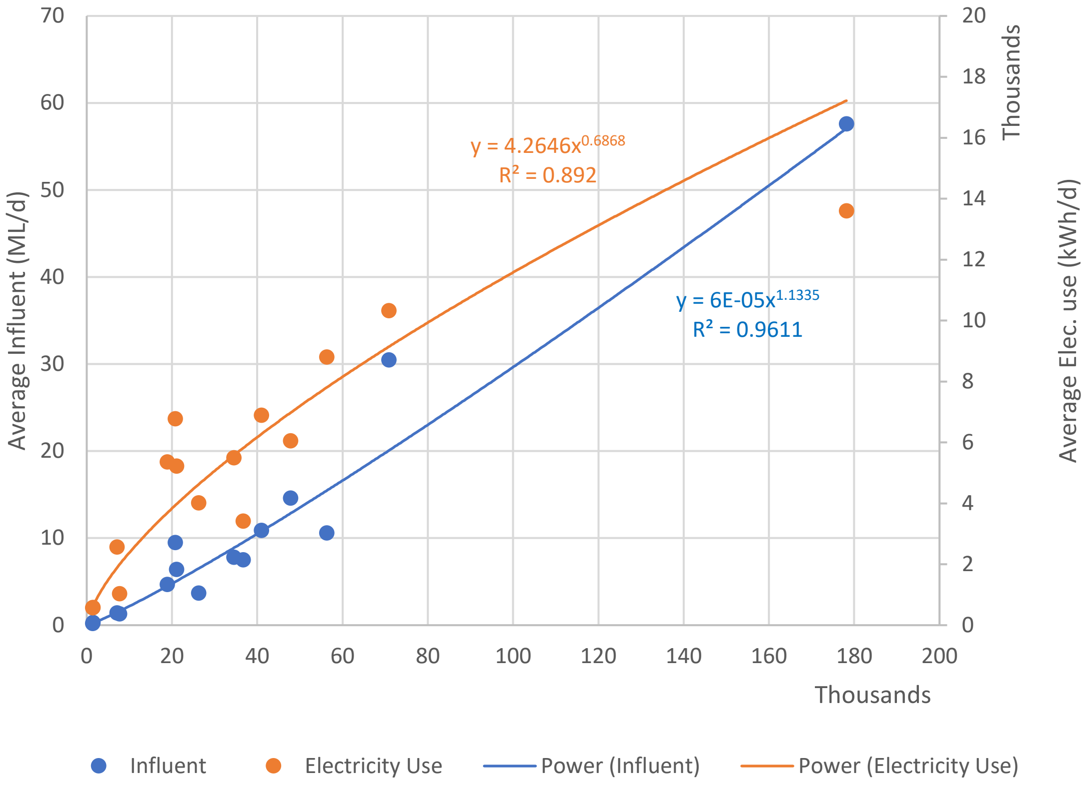


Figure 25: Average Influent and Electricity Uses of Hunter Water's WWTPs

Figure 26: Hunter Water's Area of Operation (Source: Hunter Water, 2019)

7 A CASE STUDY OF SYDNEY'S WASTEWATER NETWORK

Sydney's wastewater network is being managed by Sydney Water which is Australia's largest water utility. The network covers Sydney, the Illawarra and the Blue Mountains with the capacity to service more than 5 residents. The network also consists of nearly 26,000 km of wastewater pipes, most of which are gravity mains. There are 16 wastewater treatment plants (WWTPs) over the entire network treating more than 463,000 ML of wastewater per year (Sydney Water, 2018). The main treatment plants are Bondi, North Head and Malabar which were built in late 1800s and early 1900s as the three original major wastewater ocean systems with cliff-face outfalls to address pollution in the harbour, especially the Tank Stream (Sydney Water, 2017).

Today these original systems collect, transfer and treat almost 80% of Sydney's sewage from Western Sydney, as far as Blacktown, and South West as far as Campbelltown prior to deep ocean disposal (Sydney Water, 2017). Out of these three systems, Malabar Wastewater Treatment Plant, originally known as Bondi Sewer Farm, is the largest system that treats almost 490 ML/d of wastewater, Figure 28.

Despite being the largest treatment plant, Malabar WWTP is only a primary treatment plant. The main aim of this report is to evaluate the current Malabar WWTP, determine an alternative treatment system and options for upgrading the existing treatment plant to produce treated wastewater for drinking water purpose.

	Wastewater
Area of operations	*12,700 km^2*
Population serviced (ppl)	*5,029,000*
Quantity produced/treated (ML)	*463,191*
Length of mains in operation (km)	*25,863*
Reservoirs/treatment plants in service	*16*
Water recycling plants in service	*-*
Pumping stations in service	*686*
Properties with service available	*1,932,569*

Table 3: Principal Statistics of Sydney Water's Wastewater Network (Sydney Water, 2018)

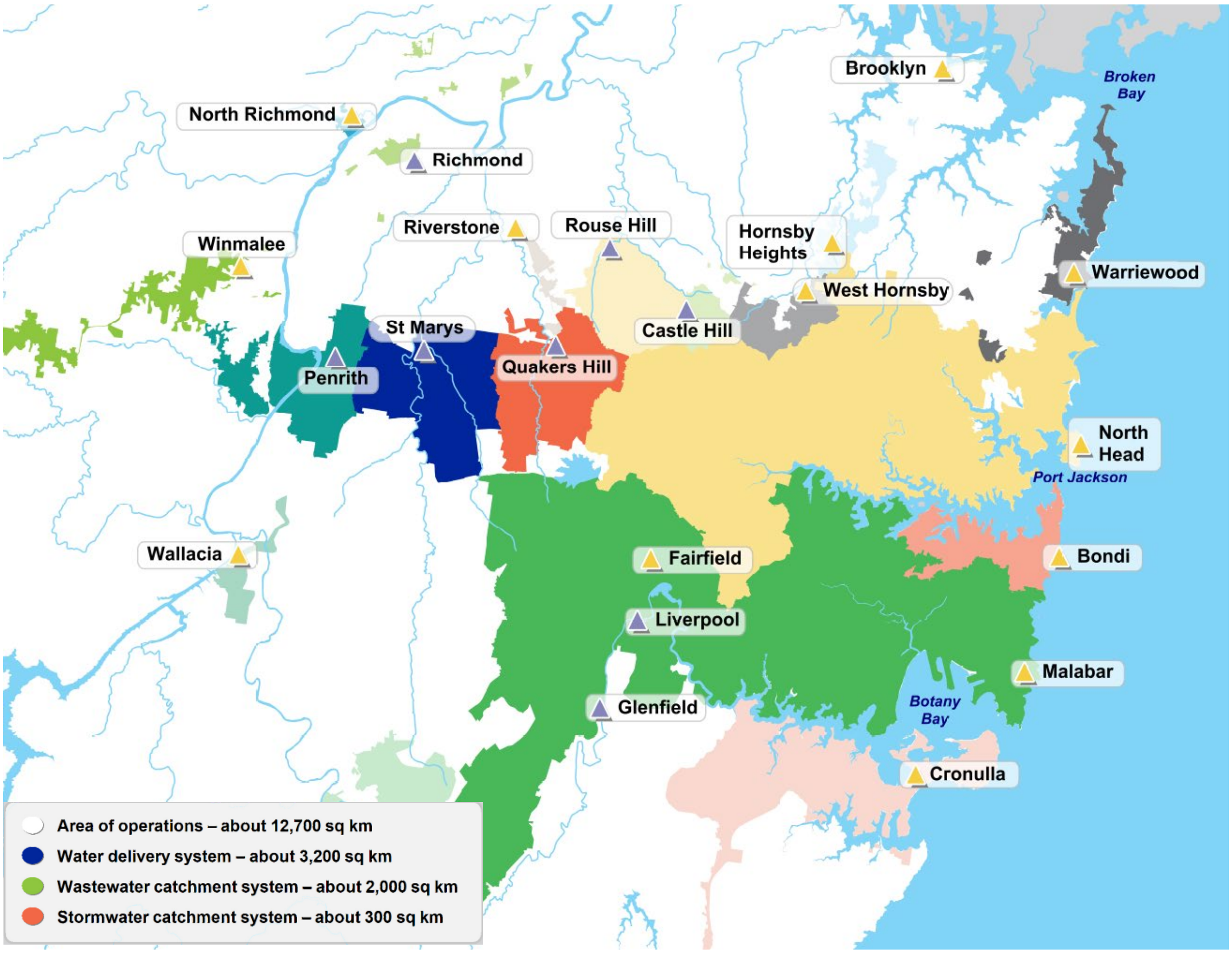


Figure 27: Sydney Wastewater Systems (Source: Sydney Water)

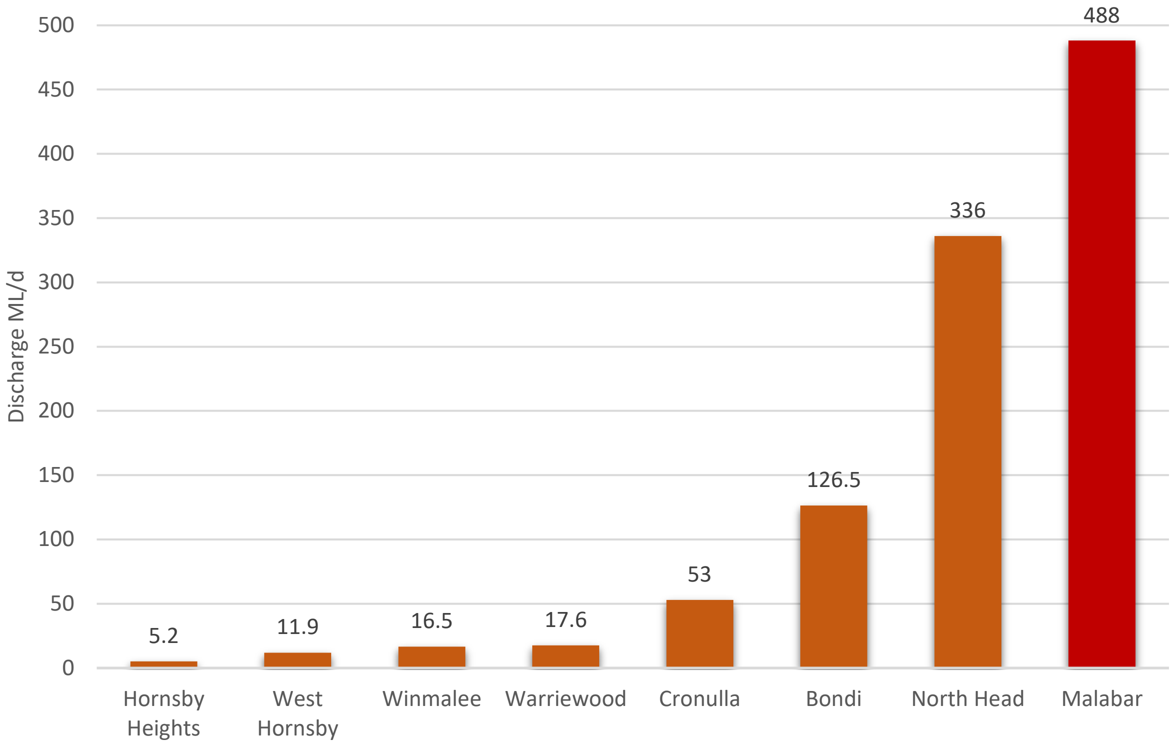


Figure 28: Comparison of Sydney WWTPs

7.1 Malabar Wastewater Treatment Plant

Located approximately 14km SE of Sydney CBD, Figure 29, Malabar WWTP was commissioned in 1975, almost 60 years after the original cliff-face outfall constructed to divert Sydney's wastewater from being discharged directly into Sydney harbour via the old Tank Stream and polluted the waterway.

In the 1960s and 1970s, as part of a long-term solution to environmental problem and water pollution associated with wastewater discharge via cliff-face outfall, several wastewater treatment and disposal options were considered. A combination of deep-water ocean outfalls and primary treatment was deemed the best overall option due to the established nature of Sydney's gravity wastewater systems and the costs for secondary treatment, advanced treatment for reuse and/or shoreline disposal were substantial and not feasible at the time (Tate, P. and Marvell, C., 2016). Subsequently, the Malabar Deep Ocean Outfall (DOO) was designed using leading edge development and commissioned in September 1990.

Prior to the commissioning of the DOO, faecal coliforms were commonly recorded in the range of 10,000 to 10,000,000 colony-forming units (cfu) per 100mL. After the decommissioning of these old outfalls, median faecal coliforms in the water fell to less than 10cfu/100mL which is much lower than the upper limit of 150cfu/100mL for swimming and recreational activities (Sydney Water, 2017).

A schematic process layout diagram of Malabar WWTP is shown in Figure 30.

Figure 29: Malabar Wastewater Treatment Plant (Source: Nearmap)

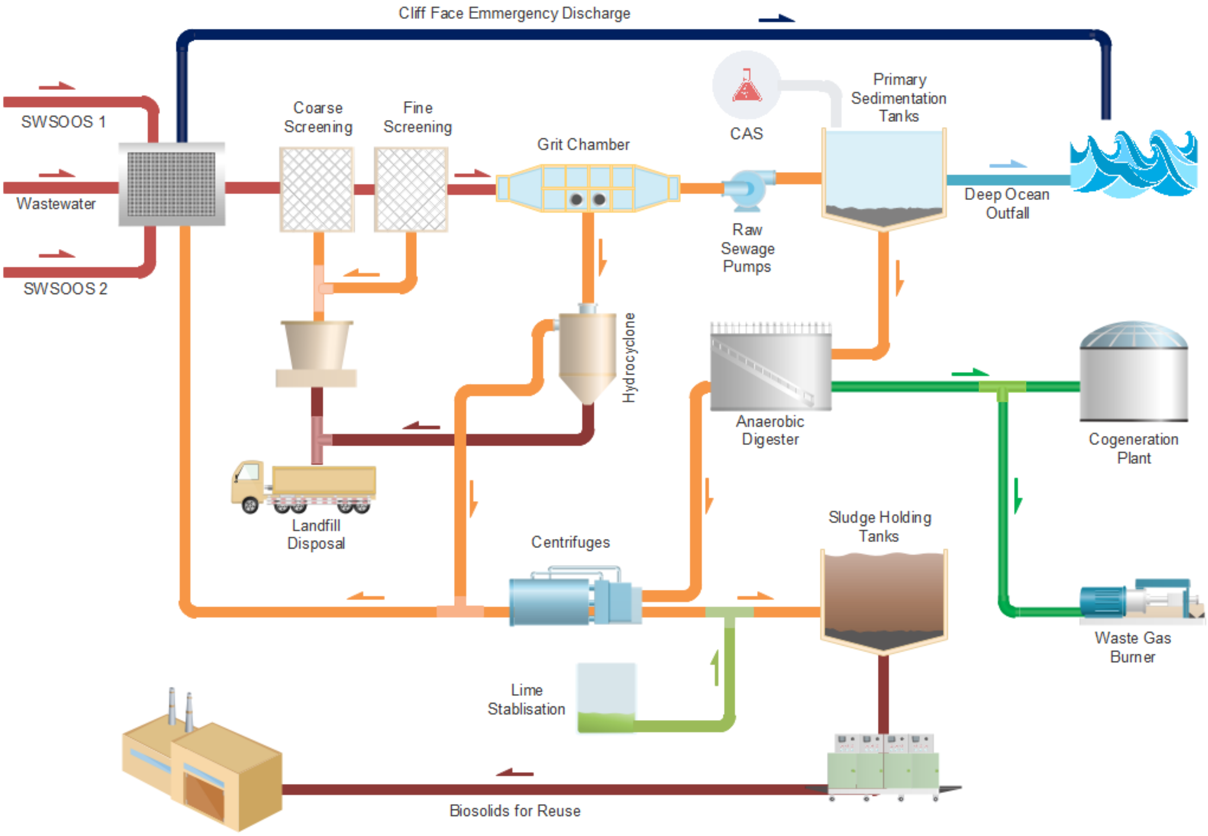


Figure 30: Malabar Wastewater Treatment Plant Process Layout Diagram (Cowgill, 201)

7.2 Alternative Malabar Wastewater Treatment System

A 2016 projection by NSW Department of Planning shows that Sydney population, with an average annual change of 1.5±0.3%, is expected to reach 6.5 million by 2036, Figure 31. With increased population projections and public awareness of the environment, current aging WWTPs, especially Malabar WWTP which the largest of all treatment plants in Sydney, would be required to be upgraded to meet increased demands and more strict environmental regulations.

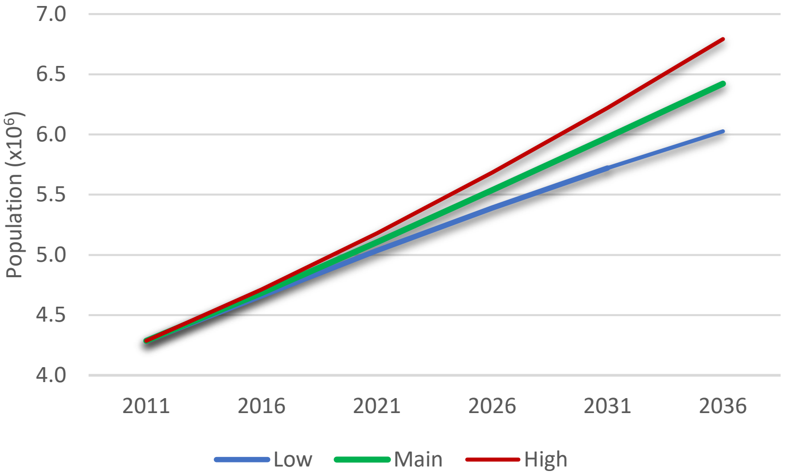


Figure 31: Sydney Population 2016 Projection (NSW DP&E, 2019)

Since its first introduction in the late 1960s, Membrane Bioreactor (MBR) is widely used today with the application of ultrafiltration (UF) and microfiltration (MF) membranes.

With better economics and reduced fouling problems compared to the first generations MBRs, it is more feasible to replace the conventional secondary treatment system by a much simpler and smaller footprint of the latest MBRs.

MBR can be configurated by either side-stream (where the membrane modules are installed externally to the bioreactor) or submerged (where the filtration elements are inside the reactor). In the case of Malabar WWTP, the current system with additional MBR, side-stream configuration as shown in Figure 32, is proposed to be the hypothetical alternative wastewater treatment system to increase effluent quality before discharging the treated wastewater into the ocean via the DOO.

MBR with side-stream configuration is proposed due to several advantages over the submerged MBRs. These advantages include (The MBR Site, 2019):

- Higher flux operation reduces required membrane area
- Complete operational flexibility for both operation and the cleaning cycle without any chemical risk to the biomass
- Lower maintenance costs due to easy accessibility and shorter downtime are required for membrane module replacement
- Operation of the membrane modules can easily be controlled in respond to hydraulic loading
- The membrane modules can operate at higher solids concentrations

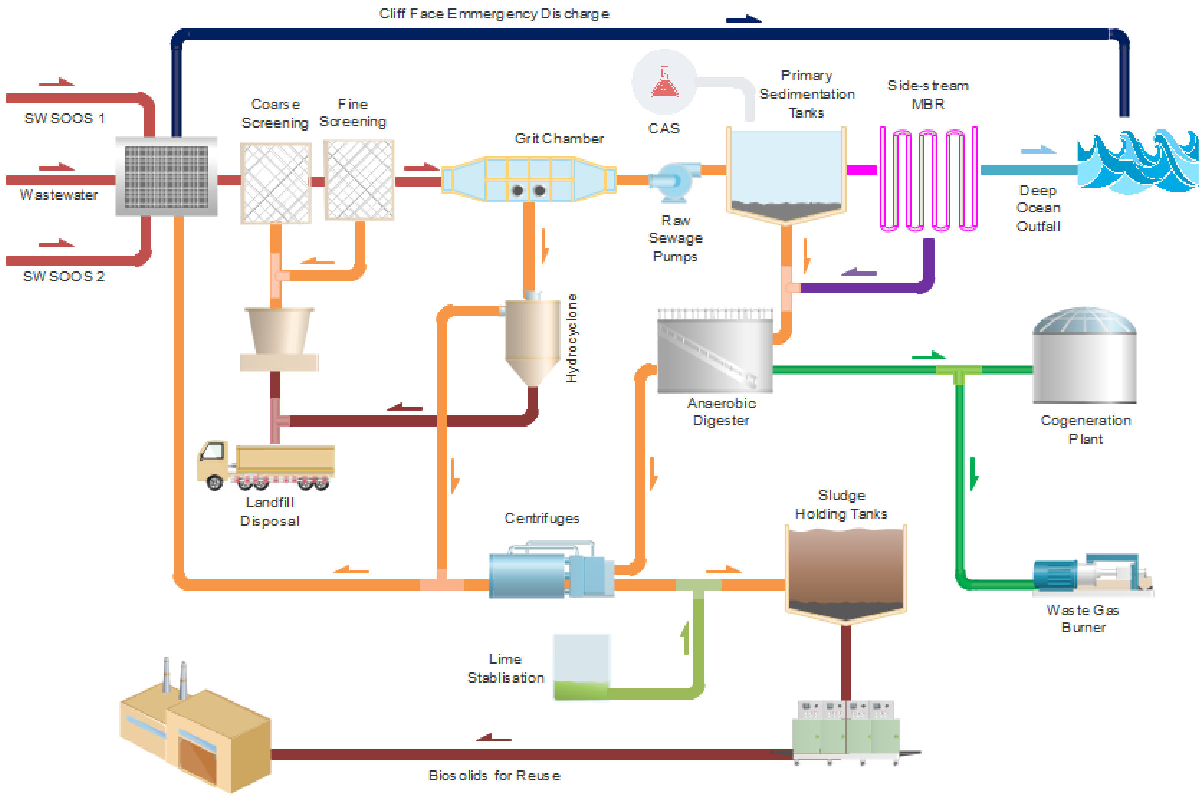


Figure 32: Alternative Malabar MBR Wastewater Treatment System

Although side-stream MBRs are more energy intensive compared to submerged MBRs due to higher flux operation, the system energy efficiency could be improved through cogeneration process where biogas is being utilised to offset energy costs. Sydney

Water has been using biogas to operate some of their cogeneration facilities for the past 15 years. However, biogas was only accounted for approximately 15% of the facilities' energy demands. Further investments in biofuel production through advanced biogas recovery using GE Jenbacher dual-fuel gas engines, similar to those at the Bolivar WWTP, and solar would be required to ensure Malabar WWTP is energy self-sufficient with the application of side-stream MBR.

For comparative design analysis purposes, the detailed calculations were carried out to compare the spaces and power required by the MBR and current wastewater treatment plant in Sydney Water using given design parameters and assumed from additional references.

Formula	***Unit***
Main	
$Vol_{bio} = \frac{BOD_{load} \times Sludge\ Yield \times SRT}{MLSS}$	m^3
$Vol_{aer} = Vol_{total} \times \frac{Aerobic\ Zone\ SRT}{SRT}$	m^3
$Solids\ Load = Flow_{max} \text{ x } MLSS$	kg/d
$PWWF = 3 \text{ x } ADWF$	m^3/d
$RAS = 1 \text{ x } ADWF$	m^3/d
$Flow_{max} = PWWF + RAS$	m^3/h
$Surface\ Area_{clarifier} = \frac{Solids\ Load}{Max\ Loading\ Rate \times No.\ Clarifiers}$	m^2
$Surface\ Area_{MBR} = \frac{PWWF}{Peak\ Flux}$	m^2
$SOR = \frac{AOR \times DO_{sat}}{(\beta \times DO_{sat} - DO_{zone})\alpha} = 0.5AOR \text{ (coarse bubbles)}$	kg/d
$Sludge\ Yield = \frac{VSS}{BOD_{raw}}$	-
$Power_{bio} = 3.5\ kgO_2(SOR)/kWh$	
$Power_{aer} = 0.3\ kWh/m^3 \text{ of MBR Permeate Produced}$	
Other Equations	
$S_x = \frac{(1-\alpha_r)MLSS.Q}{A_s} = \text{Loading Rate (Flux)}$	$kg/m^2.d$
$Peak\ Flux = 2 \text{ x } S_x$	$kg/m^2.d$
$\alpha_r = \frac{Q_r}{Q} = \frac{X}{X_r - X} = \text{Recycle Ratio}$	

Given / Assumed Data

ADWF	488×10^6	L/d	(Sydney Water)
BOD_{raw}	0.275×10^{-3}	kg/L	
$NH_3\text{-}N_{(raw)}$	39	mg/L	
$MLSS_{MBR}$	10	kg/m^3	*(assumed)*
$MLSS_{ASP}$	2	kg/m^3	
$MLVSS_{MBR}$	8	kg/m^3	*(assumed 80% of MLSS)*
$MLVSS_{ASP}$	10	kg/m^3	*(assumed)*
VSS	0.24×10^{-3}	kg/L	
SRT	20	d	
SRT_{az}	14	d	*(assumed – typical 5.5 x safety factor 2.5)*

Power Consumption Estimation

BOD =	1.34E+05	kg/d	
Sludge Yield =	8.73E-01	-	
$Vol_{biological}$ =	**234,240**	**m^3**	
$Vol_{aerobic}$ =	**163,968**	**m^3**	
PWWF =	1.46E+06	m^3/d	
RAS =	4.88E+05	m^3/d	
$Flow_{max}$ =	8.13E+04	m^3/h	
Solids Load =	8.13E+05	kg/h	
MLVSS =	8	kg/m^3	
$MLVSS_r$ =	10	kg/m^3	
α_r =	4		
SLR = S_x =	1.02E+05	$kg/m^2.h$	
SLR_{peak} =	2.03E+05	$kg/m^2.h$	
$Area_{clarifier}$ =	**29.6**	**m^2**	*(=Solids Load / Max Loading Rate)*
$Area_{MBR}$ =	**7.2**	**m^2**	*(=PWWF/SLR_{peak})*
BOD =	2.96E+05	lbs/d	
$NH_3\text{-}N_{(raw)}$ =	4.20E+07	lbs/d	
y =	1.2		
z =	4.6		
AOR =	1.93E+08	lbs/d	
AOR=	8.77E+07	kg/d	
SOR =	4.39E+07	kg/d	
$Power_{ASP}$ =	**12,529,749**	**kWh**	*(=SOR/3.5)*
$Power_{MBR}$ =	**160,308,000**	**kWh**	*(=0.3xPWWFx365)*

Table 4: Comparison of Power Consumption in ASP & MBR Technologies

The calculations indicate that MBR would only require approximately 24% of the surface area of the conventional clarifier. The energy requirement of the MBR, however, is approximately 13 times higher than that of the ASP due to higher MLSS in the reactor which decreases the efficiency of oxygen to gas transferring process.

Compared to the conventional activated sludge (CAS) system, MBR doesn't require a secondary clarifier to allow settlement of solids and separation of liquid. Some of the advantages of MBR over the CAS system include (The Water Network, 2017):

- Higher quality effluent – The MBR filters all the biomatter, solids and microorganisms which leads to very high treated water quality
- Unlike the CAS system, solid retention time (SRT) and hydraulic retention time (HRT) are independent due to sludge solids are being retained in the bioreactor
- Smaller footprint
- Consistent performance where the water organic content can be much higher than the CAS system
- Low sludge production, and
- Less sludge dewatering

Based on above advantages, MBR is clearly a more favourable option as an alternative wastewater treatment system compared to the CAS system. The MBR system, however, should be properly designed to ensure the system is energy self-efficient.

8 ENERGY COSTS AND CONSUMER PRICE INDEX

Accordance to the Australia Energy Regulator, the 2019 median spot electricity price in Australia, Figure 33, is $90/MWh (Australian Energy Regulator, 2019). However, the spot price is the wholesale price which is approximately 40% of the actual retail price. The remaining 60% of the cost comprises of electricity transport, environmental, retailer and residual costs (AEMC, 2019).

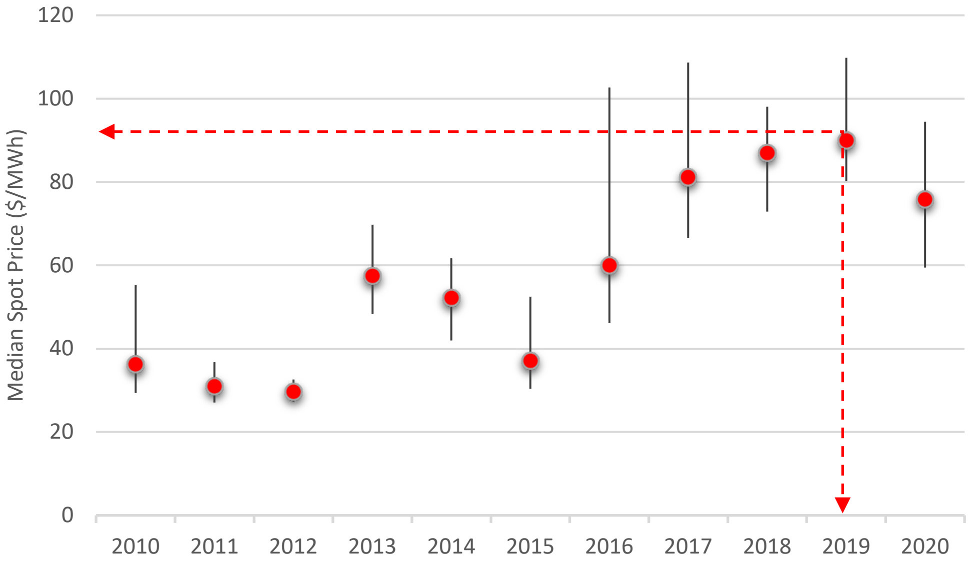


Figure 33: Median electricity spot prices (Source: Australian Energy Regulator, 2019)

Below Figure 34 outlines the electricity price projections between 2013 and 2031 published by WSAA and adopted by Hunter Water for large and small wastewater water treatment sites.

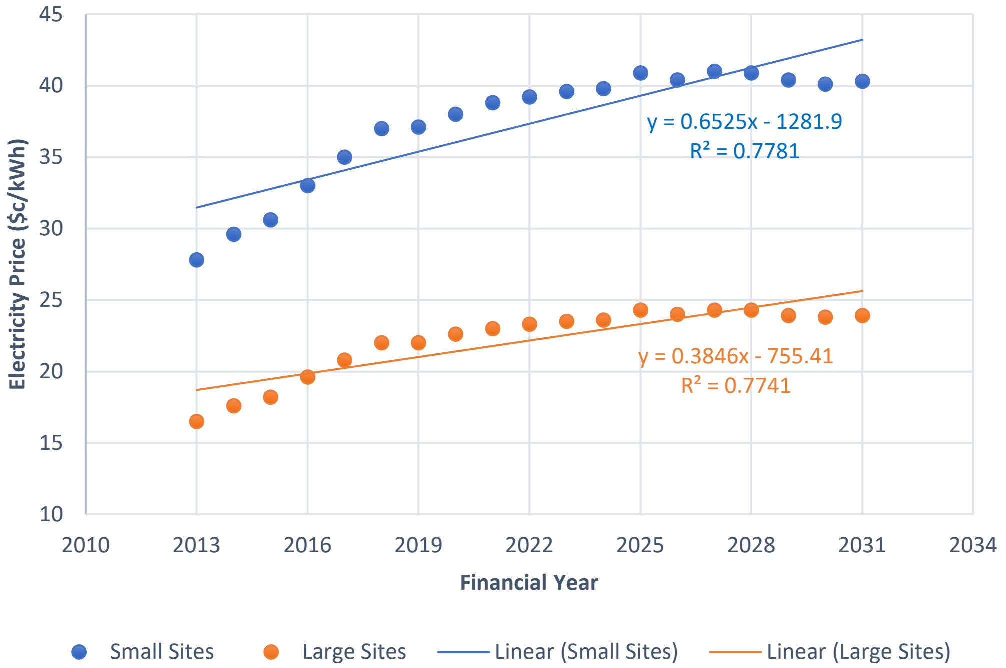


Figure 34: Electricity Price Projection (Source: HWC, 2013)

In calculation of inflation, Consumer Price Index (CPI), which is the fixed price index measuring the changes of purchase price over time, is the most commonly used statistic. In Australia, the median CPI over the past ten years is approximately 2%, Figure 35.

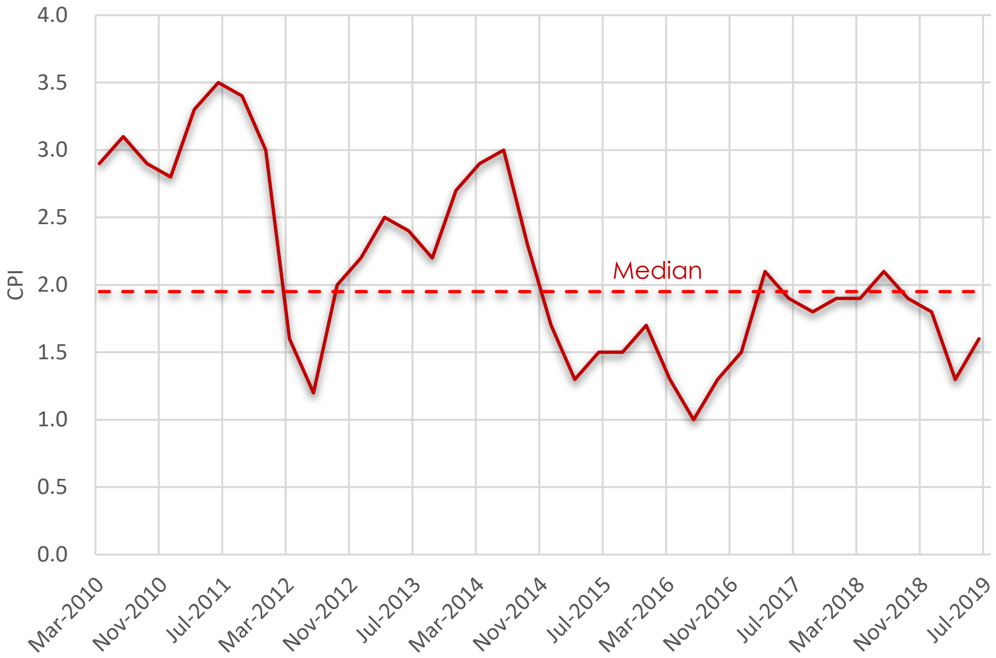


Figure 35: Consumer Price Inflation in Australia (RBA, 2019)

9 NET-ZERO-ENERGY INVESTMENT COSTS

Adopting the Bolivar WWTP case study, the following basic details of the treatment plant were established and outlined in below Table 5, (WSAA, 2012).

Adopted EP	694,630	EP
Influent	165	ML/d (design)
	144.39	ML/d (actual)
Capital Investment	$25.8	Million
GE Jenbacher Engines	3	-
Electricity Demand	30	GWh/yr (initial)
	5	GWh/yr (upgraded)
Electricity Saving	85%	p.a.
	$1.3M	p.a.
Other Revenue	$0.7M	Energy Market
	$0.9M	Renewable Certificates
Economic Value	$4.3M	Carbon Pricing
Payback Period	8	yrs

Table 5: Bolivar WWTP Energy Utilisation Optimisation Summary

For analysis and comparison purposes, the above data were assumed to be estimated and established in 2011 and the return of investment is illustrated in below Figure 36.

A close assessment of above data in Table 5 has revealed that the influent and electricity usage, prior to the cogeneration upgrade, of the Bolivar WWTP have the characteristics of a Type 2 treatment plant with high pump outlined in above Section 6.2.2 in which the energy demand and influent for the treatment plant can be estimated using the following equations derived from Figure 18:

- Electricity Demand = $0.9684EP^{0.843}$ (kWh/d)
- Influent = $0.0002EP^{0.9969}$ (ML/d)

Using data in Table 5 and applying these adopted equations, the estimated electricity demand and the adopted EP were calculated to test the validity of the equations. The results are as below.

- Electricity Demand = $[365 \times 0.9684(695{,}630)^{0.843}] \times 10^{-6}$ = 29.74 GWh/yr
- Adopted EP = $(144.39 \div 0.0002)^{1/0.9969}$ = 752,879 EP

In comparison the actual data, the Absolute Percentage Error (APE) of calculated electricity demand and adopted EP were 0.87% and 7.6% respectively. From statistical analysis perspective, APE values of less than 10% are considered as highly accurate predictions. On this basis, these equations can be adopted to estimate the energy costs of Malabar WWTP current and hypothetical scenarios.

Engineering Economics

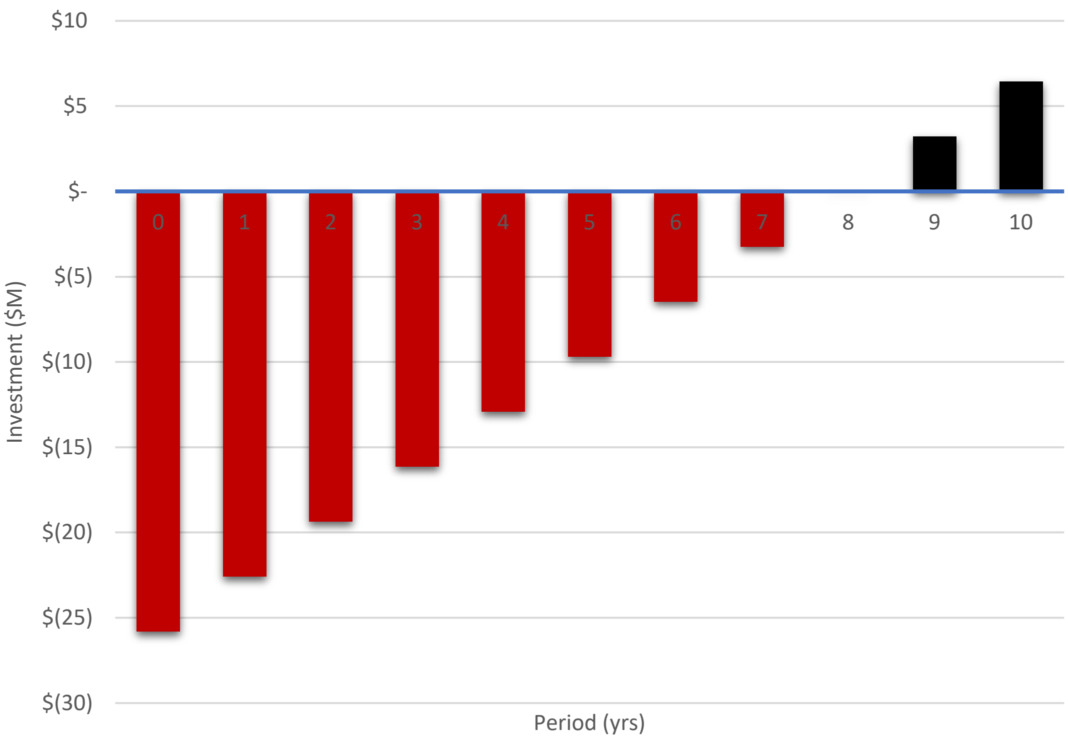


Figure 36: Return of Investment for Bolivar WWTP Energy Optimisation Project

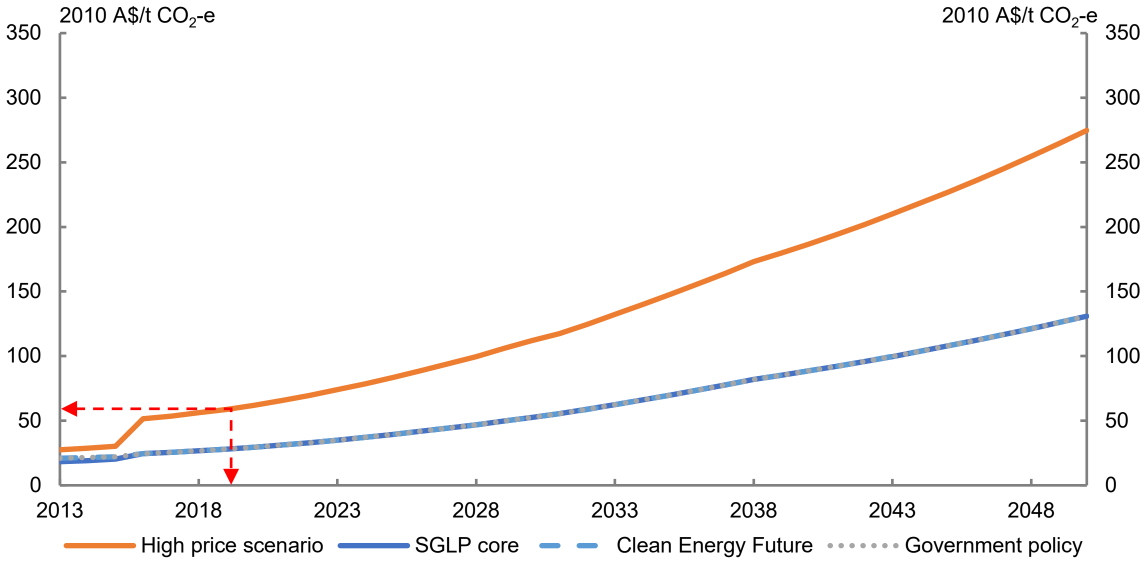


Figure 37: Australian Carbon Price Projection (Source: Commonwealth of Australia, 2011)

For the purpose of comparison and discussion, the above statistics of the Bolivar WWTP case study will be applied to consider an option for upgrading the Malabar WWTP as a hypothetical scenario.

10 COST-BENEFIT ANALYSIS AND DISCUSSIONS

10.1 Bolivar WWTP Energy Utilisation

Based on known factors and assumptions outlined in above Section 9, the carbon price, electricity price, annual costs and benefits were estimated using an assumed typical discount rate of 8%, Table 6.

With an exception of carbon price, the estimated electricity price was consistent with the 2012-2013 trends and median electricity spot price records by the Australian Energy Regulator, refer to Figure 33. However, the spot price is only representing approximately 40% of the actual retail price. The remaining 60% of the actual retail price makes up of network, environment, retail and residual costs (AEMC, 2019).

Despite the carbon price projection by the Australian Government, Figure 37, the carbon price and its $4.3M economic benefit and value added to the project may have been over estimated by SA Water. However, in absence of detailed business case, the below estimated carbon price of $48.86/t was adopted for cost-benefit analysis and economic forecast purposes.

Influent	144.39	ML/d
Adopted EP	694,630	EP
Electricity Demand	30	GWh/yr
Electricity Cost Saving	$1.30	$M
Carbon Saving	11,000	t/yr
Initial Investment (I_0)	$25.8	$M
Assumed Discount Rate (i)	8.0%	
Payback Period	8.0	yrs
Estimated Benefit (B)	$3.44	$M/yr
Estimated Cost (C)	$0.21	$M/yr
Estimated Carbon Price	$48.86	$/t
Estimated Electricity Price	$ 51.0	$/MWh

Table 6: Bolivar WWTP Energy Utilisation Cost & Benefit Estimation

10.2 Malabar WWTP Energy Utilisation – Hypothetical Scenarios

Comparing the daily inflows, the Malabar WWTP is approximately 3 times the size of the Bolivar WWTP. The estimated capital investment, annual cost and benefit of the Malabar WWTP were assumed to be proportional to the estimated values of the Bolivar WWTP. The typical discount rate is also assumed to be 8%. The adopted equivalent population (EP) and electricity demand were estimated using the below equations derived from Figure 18:

- Electricity Demand = $0.9684EP^{0.843}$ (kWh/d)
- Influent = $0.0002EP^{0.9969}$ (ML/d)

The results demonstrate that, when applying the same factors to different WWTPs, the return of investment would not necessarily be proportional to the plant sizes or capacities, Table 7 and Figure 38.

It is also noted that the calculated BCR and NPV in this scenario were 0.84 and -$18.75M respectively which indicates that the estimated net present costs of the project are higher than the net present benefits. Therefore, at the estimated electricity price of $51/MWh and carbon price of $48.68/t, the project would have no tangible net benefits and, hence, not viable.

Sensitivity analysis, Appendix 12.1, using discount rates of 3% and 10%, for low risk and high risk scenarios respectively, also resulted in negative NPV. This possibly due to the face that the estimated unit energy is too low compared to the actual market prices.

For the project to be viable with positive net benefits, it has been estimated that the electricity price should be higher than $76/MWh in which, accordance to the Australian Energy Regulator, reflecting the trend for spot median prices in the Australian energy market from 2019 onward, Figure 33.

Influent	488	ML/d
Adopted EP	2,554,185	EP
Electricity Demand	89	GWh/yr
Estimated Electricity Price	$51.0	$/MWh
Electricity Cost Saving	$3.90	$M
Carbon Saving	32969	t/yr
Estimated Carbon Price	$48.86	$/t
Discount Rate (i)	8.0%	
Initial Investment (I_0)	$87.2	$M
Estimated Benefit (B)	$10.92	$M/yr
Estimated Cost (C)	$0.72	$M/yr
Payback Period	8.5	yrs
Net Present Value	-$18.75	$M
Internal Rate of Return	1.0%	-
Benefit to Cost Ratio	0.84	-
Life Cycle Cost	1.1	-

Table 7: Malabar WWTP Hypothetical Cost & Benefit Estimation for 2012 Values

The above figures were based on 2012 values. To appreciate the magnitude of these figures in 2019 values, the 2012 rates were converted to 2019 rates by applying Future Value approach using median CPI of 2% over the 7 years period between 2012 to 2019. The results are shown in below Table 8 and Figure 39.

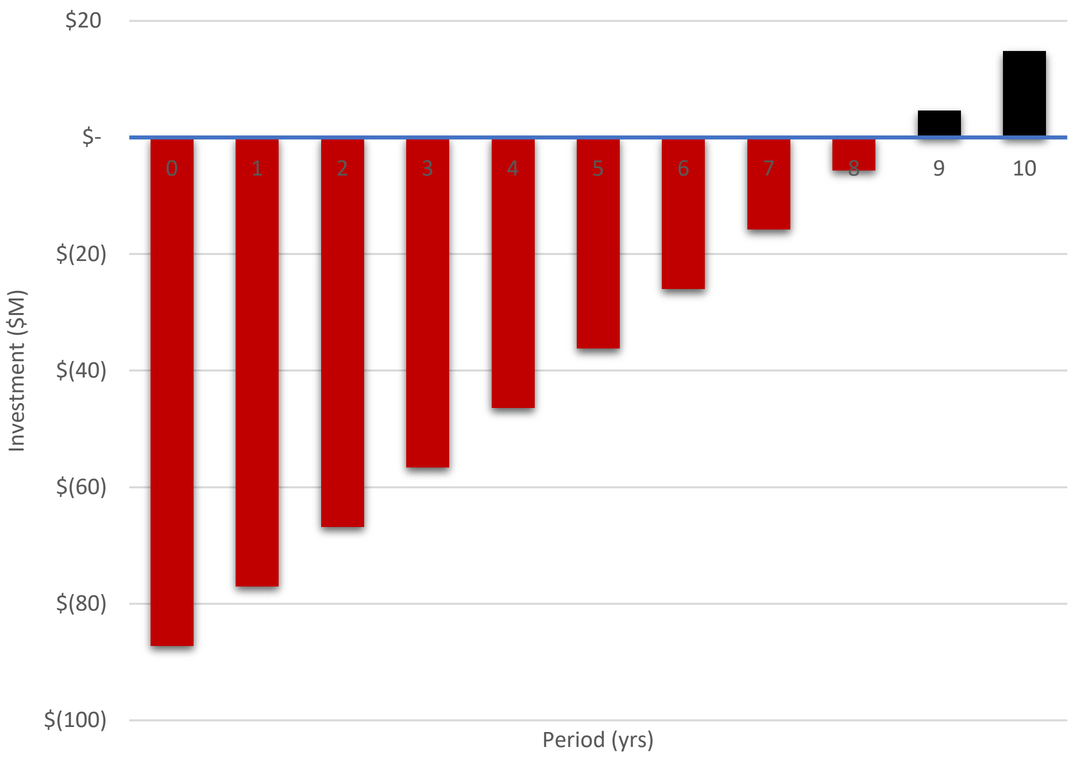


Figure 38: Malabar WWTP Hypothetical Return of Investment for 2012 Values

Influent	488	ML/d
Adopted EP	2,554,185	EP
Electricity Demand	89	GWh/yr
Estimated Electricity Price	$144.00	$/MWh
Electricity Cost Saving	$11.00	$M
Carbon Saving	32969	t/yr
Estimated Carbon Price	$48.86	$/t
Discount Rate (i)	8.0%	
Initial Investment (I_0)	$100.21	$M
Estimated Benefit (B)	$18.82	$M/yr
Estimated Cost (C)	$8.28	$M/yr
Payback Period	9.5	yrs
Net Present Value	-$27.83	$M
Internal Rate of Return	1.4%	-
Benefit to Cost Ratio	1.5	-
Life Cycle Cost	1.77	-

Table 8: Malabar WWTP Hypothetical Cost & Benefit Estimation for 2019 Values

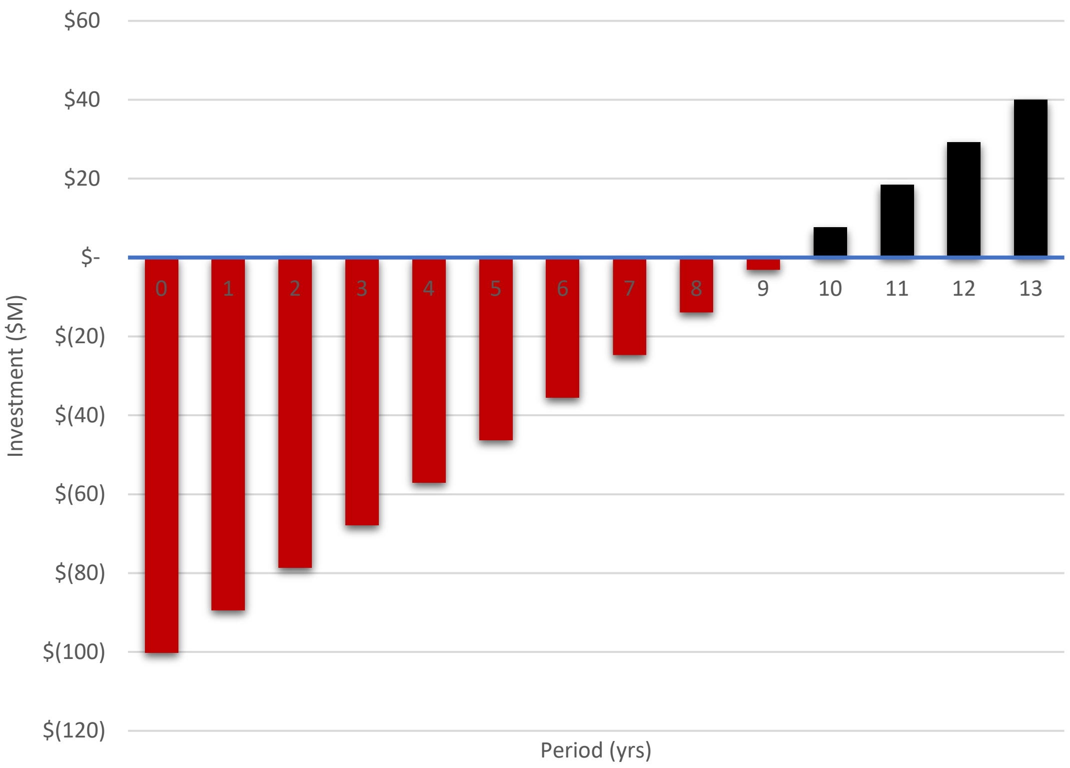


Figure 39: Malabar WWTP Hypothetical Return of Investment for 2019 Values

Both the above two scenarios clearly indicate that the energy utilisation initiative is highly influenced by the electricity price. The IRR, BCR and LCC were increased with higher electricity price. Generally, the higher a project's IRR, the more desirable and profitable it is to be undertaken. It is an indication that the project is offering stronger growth. On this basis, the hypothetical Malabar WWTP energy utilisation initiative would be more desirable investment in 2019 costs compared to that of 2012 costs. Furthermore, the energy price forecasts for large site as shown in Figure 34 indicate that the price would increase by at least 10% over the next decade. At such time, the investment would become even more desirable assuming that the technology for Net-Zero-Energy implementation would be significantly improved and the costs are gradually decreased over time.

That said, the above analysis was based on the assumption that only 85% of total energy demand in the WWTP would be generated by the GE Jenbacher gas engines. The actual cost to implement total Net-Zero-Energy solution in WWTPs in Australia is not widely published, studied or documented. However, in current economic environment, to successfully implement Net-Zero-Energy solution, it would be viable only for large Class SC5 WWTPs with adopted EP greater than 100,000 where there'll be significant influent and waste to generate biogas for powering the WWTPs.

For the hypothetical alternative MBR treatment system described in above Section 7.2, the capital investment would be at least 13 times more than the conventional treatment system making it economically unviable as an option.

11 CONCLUSION

Renewable energy technologies are well established, their economic proposition and environmental benefits are well understood. The technologies can easily be implemented in existing and new wastewater treatment plants to generate energy not just to meet the plants' total energy demands but also to boost supply to the electricity grid.

The risks, however, are lack of investment in renewable technologies largely due uncertainty in climate change and energy policy. Smaller WWTPs cannot adopt renewable energy technologies to be more efficient and Net-Zero-Energy due to high market value of energy, high construction and operating costs.

In wastewater treatment, energy demands depend on the technologies used in the treatment process and the treatment level at each treatment plant. Uncertainty in climate change and population growth continue to put upward pressures on water utilities to address energy efficiency in the wastewater treatment process by working toward net-zero-energy in all WWTPs. If successfully implemented, net-zero-energy WWTPs will not only help to increase energy supply but also help to drive down energy prices and reduce carbon footprint.

The main challenge would be determining suitable economic model and investment options to upgrade existing WWTPs in Australia to be energy self-sufficient. Studies from many treatment plants around the world suggest that Net-Zero-Energy in WWTPs can be achieved through process optimisation, food waste co-digestion and implementation of renewable energy. However, until the investment options have been identified and economic evaluation of these options have been carried out, upgrading all WWTPs in Australia may not be a viable option in which significant costs being invested in new technologies without achieving the desirable energy efficiency targets.

The main difficulty, as outlined in this study, is to identify factors influencing energy consumption and to accurately calculate the actual energy demand for different type of WWTPs which have different technologies, components, parts as well as different type of wastewater and concentration of chemicals.

This study also demonstrated that there is a direct correlation between electricity price and the internal rate of return of the project. The Net-Zero-Energy investment would only be viable and desirable with higher electricity prices in which the net benefits would be much higher than the combined costs.

Further studies are necessary to better understand the future of electricity demands and pricing in Australia which can be highly unpredictable subject to changes in government, government policies, climate change and the influence of climate change lobbyists. The demand for renewable energy is increasing at exponential rate and having significant influence in the outcomes of electricity pricing forecasts.

12 APPENDICES

12.1 Appendix A – Cost-Benefit-Analysis Calculations

Year	Costs	Benefits				8% Discounted		
		Elec.	Revenue	Energy Cert.	Carbon Prices	Costs	Benefits	Net Benefits
0	$ 87.2	$ -	$ -	$ -	$ -	$ 87.20	$ -	-$ 87.20
1	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.66	$ 10.11	$ 9.44
2	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.62	$ 9.36	$ 8.75
3	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.57	$ 8.67	$ 8.10
4	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.53	$ 8.03	$ 7.50
5	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.49	$ 7.43	$ 6.94
6	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.45	$ 6.88	$ 6.43
7	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.42	$ 6.37	$ 5.95
8	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.39	$ 5.90	$ 5.51
9	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.36	$ 5.46	$ 5.10
10	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.33	$ 5.06	$ 4.72
					NPV	$ 92.02	$ 73.26	-$ 18.75

Table 9: Malabar WWTP - Calculations of Costs & Benefits 2012 Values

Year	Costs	Benefits				3% Discounted		
		Elec.	Revenue	Energy Cert.	Carbon Prices	Costs	Benefits	Net Benefits
0	$ 87.2	$ -	$ -	$ -	$ -	$ 87.20	$ -	-$ 87.20
1	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.70	$ 10.60	$ 9.90
2	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.68	$ 10.29	$ 9.61
3	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.66	$ 9.99	$ 9.33
4	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.64	$ 9.70	$ 9.06
5	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.62	$ 9.42	$ 8.80
6	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.60	$ 9.14	$ 8.54
7	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.58	$ 8.88	$ 8.29
8	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.57	$ 8.62	$ 8.05
9	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.55	$ 8.37	$ 7.82

Table 10: Malabar WWTP - Calculations of Costs & Benefits 2012 Values (Low Risk)

10	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.53	$ 8.12	$ 7.59
					NPV	$ 93.32	$ 93.14	-$ 0.19

Year	Costs	Benefits				10% Discounted		
		Elec.	Revenue	Energy Cert.	Carbon Prices	Costs	Benefits	Net Benefits
0	$ 87.2	$ -	$ -	$ -	$ -	$ 87.20	$ -	-$ 87.20
1	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.65	$ 9.93	$ 9.27
2	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.59	$ 9.02	$ 8.43
3	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.54	$ 8.20	$ 7.66
4	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.49	$ 7.46	$ 6.97
5	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.45	$ 6.78	$ 6.33
6	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.41	$ 6.16	$ 5.76
7	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.37	$ 5.60	$ 5.23
8	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.34	$ 5.09	$ 4.76
9	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.30	$ 4.63	$ 4.33
10	$ 0.72	$ 3.90	$ 2.37	$ 3.04	$ 1.61	$ 0.28	$ 4.21	$ 3.93
					NPV	$ 91.61	$ 67.09	-$ 24.52

Table 11: Malabar WWTP - Calculations of Costs & Benefits 2012 Values (High Risk)

Year	Costs	Benefits				8% Discounted		
		Elec.	Revenue	Energy Cert.	Carbon Prices	Costs	Benefits	Net Benefits
0	$ 100.2	$ -	$ -	$ -	$ -	$ 100.16	$ -	-$ 100.16
1	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 7.67	$ 17.65	$ 9.98
2	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 7.10	$ 16.34	$ 9.24
3	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.58	$ 15.13	$ 8.56
4	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.09	$ 14.01	$ 7.92
5	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 5.64	$ 12.97	$ 7.34
6	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 5.22	$ 12.01	$ 6.79
7	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 4.83	$ 11.12	$ 6.29
8	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 4.48	$ 10.30	$ 5.82
9	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 4.14	$ 9.54	$ 5.39
10	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 3.84	$ 8.83	$ 4.99
					NPV	$ 155.74	$ 127.91	-$ 27.83

Table 12: Malabar WWTP - Calculations of Costs & Benefits 2019 Values

Year	Costs	Benefits				3% Discounted		
		Elec.	Revenue	Energy Cert.	Carbon Prices	Costs	Benefits	Net Benefits
0	$ 100.2	$ -	$ -	$ -	$ -	$ 100.16	$ -	-$ 100.16
1	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 8.04	$ 18.51	$ 10.47
2	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 7.81	$ 17.97	$ 10.16
3	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 7.58	$ 17.44	$ 9.86
4	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 7.36	$ 16.94	$ 9.58
5	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 7.15	$ 16.44	$ 9.30
6	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.94	$ 15.96	$ 9.03
7	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.73	$ 15.50	$ 8.76
8	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.54	$ 15.05	$ 8.51
9	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.35	$ 14.61	$ 8.26
10	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.16	$ 14.18	$ 8.02
					NPV	$ 170.82	$ 162.60	-$ 8.21

Table 13: Malabar WWTP - Calculations of Costs & Benefits 2019 Values (Low Risk)

Year	Costs	Benefits				10 Discounted		
		Elec.	Revenue	Energy Cert.	Carbon Prices	Costs	Benefits	Net Benefits
0	$ 100.2	$ -	$ -	$ -	$ -	$ 100.16	$ -	-$ 100.16
1	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 7.53	$ 17.33	$ 9.80
2	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.85	$ 15.75	$ 8.91
3	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 6.22	$ 14.32	$ 8.10
4	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 5.66	$ 13.02	$ 7.36
5	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 5.14	$ 11.84	$ 6.69
6	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 4.68	$ 10.76	$ 6.08
7	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 4.25	$ 9.78	$ 5.53
8	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 3.86	$ 8.89	$ 5.03
9	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 3.51	$ 8.08	$ 4.57
10	$ 8.28	$ 11.00	$ 2.72	$ 3.49	$ 1.85	$ 3.19	$ 7.35	$ 4.16
					NPV	$ 151.06	$ 117.13	-$ 33.93

Table 14: Malabar WWTP - Calculations of Costs & Benefits 2019 Values (High Risk)

12.2 Participating Water Utilities

		Number of WWTPs	
State	**Water Utility**	**Incl. in this study**	**States Sub-total**
ACT	Icon Water	2	2
NSW	Hunter Water	17	44
	MidCoast Water	2	
	Sydney Water	25	
QLD	Cairns Regional Council	6	61
	City of Gold Coast Council	4	
	Logan City Council	2	
	QUU	27	
	Townsville Water	5	
	UnityWater	17	
SA	SA Water	12	12
TAS	Taswater	10	10
VIC	Barwon Water	6	93
	Central Highlands Water	5	
	City West Water	1	
	Coliban Water	10	
	East Gippsland Water	1	
	Gippsland Water	13	
	Goulburn Valley Water	4	
	GWM Water	8	
	Lower Murray Water	2	
	Melbourne Water	2	
	North East Water	9	
	South East Water	5	
	South Gippsland Water	7	
	Wannon Water	4	
	Western Water	7	
	Westernport Water	1	
	Yarra Valley Water	8	
WA	Water Corporation	21	21
NZ	Watercare	2	2
	Total	**245**	

12.3 Plant Types and Size Classes

Type	Main Features	Notes
Type 1 **(PST + Act. Sludge + An. Dig. + Cogen.)**	*Activated sludge treatment with separate sludge stabilisation, including those with primary sedimentation, anaerobic digestion and on-site co-generation (on-site energy produced from biogas).*	*Alternative sludge stabilisation includes:* • *Incineration* • *Covered anaerobic lagoons* • *Chemical (e.g. Lime) treatment* • *etc.*
Type 2 **(PST + Act. Sludge + An. Dig.)**	*Activated sludge treatment with separate sludge stabilisation, including those with primary sedimentation, anaerobic digestion but without on- site co-generation (no on-site energy produced from biogas).*	*Same as Type 1 but without co-generation. Biogas might be produced but is not used for energy generation. Biogas might or might not be captured and flared.* *Alternative sludge stabilisation includes:* ▪ *Incineration* ▪ *Covered or uncovered anaerobic lagoons* ▪ *Chemical (e.g. Lime) treatment*
Type 3 **(Extended Aeration Act. Sludge)**	*Extended aeration activated sludge, including aerobic digestion*	*Sub-types recognised:* *Sub-type 3.1:* *Compartmentalised (all types, including those for biological nutrient removal configurations) and with clarifiers, but excluding Subtypes 3.2 to 3.5 defined below* *Sub-type 3.2:* *Oxidation ditch-type activated sludge (including ditches with external compartments such as anaerobic or selector reactors) and with clarifiers* *Sub-type 3.3:* *Intermittent activated sludge processes (e.g. SBR/IDEA/IDAL)* *Sub-type 3.4: Membrane bioreactors (MBR)* *Sub-type 3.5:* *Moving bed biofilm bioreactors (MBBR), where main aeration zone is MBBR (e.g. excludes tertiary MBBR)*
Type 4	*Trickling filters*	*Sub-types recognised:* *Sub-type 4.1: Trickling filters only* *Sub-type 4.2:* *Trickling filters in combination with activated sludge*
Type 5	*Lagoon and/or wetland systems*	*Sub-types recognised:* *Sub-type 5.1: Aerated lagoons* *Sub-type 5.2:* *Lagoon and/or wetland systems without aeration*
Type 6	*Rotating biological contactors*	*None*

Supplements		**Notes**
S1	Tertiary Effluent treatment	Sub-types are recognised: **S1.1:** Filtration using Sand or Granular Media **S1.2:** Membrane filtration, including Ultrafiltration but *excluding Reverse Osmosis* **S1.3:** Membrane bioreactor (MBR) **S1.4:** Ultraviolet (UV) light, including UV disinfection systems **S1.5:** Ozone treatment systems **S1.6:** Cloth filtration, including cloth media disc systems
S2	Sludge drying	Thermal or solar drying systems, *excluding conventional open-air drying beds, pans or lagoons*
S3	High pumping requirements (>4 m head)	Sub-types are recognised: **S3.1:** High influent pumping **S3.2:** High effluent pumping

Size Class (SC)	**EP Range**
SC1	≤ 1,000 EP
SC2	1,001 – 5,000 EP
SC3	5,001 - 10,000 EP
SC4	10,001 - 100,000 EP
SC5	>100,000 EP

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