FACTORING GHG EMISSIONS INTO OPTIONEERING: 90% REDUCTION FOR CAMBRIDGE WWTP

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ABSTRACT

The Paris Agreement on Climate Change catalysed legislative and policy changes across New Zealand, including the target of achieving Net Zero carbon emissions by 2050. Achieving this target requires engineering design to consider Greenhouse Gas (GHG) emissions in the optioneering phase for all infrastructure projects.

Whilst there are a number of methodologies available, estimating GHG emissions from Wastewater Treatment Plants (WWTPs) has a degree of uncertainty, and reducing this uncertainty requires onsite measurement to calibrate and refine current models and emissions factors. As international and New Zealand WWTPs verify and report their respective emissions factors for various wastewater treatment unit processes, the accuracy of predictive models will continue to improve. However, planning and design of WWTP upgrades or new WWTPs, requires designers to draw on existing data and models to inform engineering decision making.

Minimising GHG emissions was identified as a key criterion for the new Cambridge WWTP, along with other environmental, social, cultural, and technical criteria. In order to estimate GHG emissions for the shortlisted advanced Biological Nutrient Removal (BNR) treatment options being considered, an amalgamation of assessment methodologies was necessary. Methodologies included Water New Zealand's Carbon Accounting Guidelines for Wastewater Treatment: CH_4 and N_2O, the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the Ministry for the Environment's guidelines on measuring emissions, and outputs from the WWTP modelling software EnviroSim BioWin.

This paper outlines the operational GHG emissions estimate approach undertaken during the design optioneering phase of the Cambridge WWTP upgrade, including insights attainable via amalgamating these different methodologies. Additionally, this paper highlights the significant reduction in operational GHG emissions attainable for municipal WWTPs, via shifting from an anaerobic and aerated lagoon-based treatment process to a 4-stage Bardenpho Membrane Bioreactor (MBR) treatment process. Finally, the criticality of further research and monitoring to verify existing emissions guidelines and model parameters is stressed.

Notably, shifting from the status quo of an anaerobic and aerated lagoon-based treatment to the selected MBR treatment process was estimated to reduce the annual operational GHG emissions by approximately 90%. Further emissions reductions are likely with a proposed 1.5 ha solar array onsite. This significant reduction clearly aligned with Waipā District Council's overarching carbon reduction strategy and supported the “best for awa” approach to the long-term resource consenting of the Cambridge WWTP upgrade and the Waikato River receiving environment.

KEYWORDS

Wastewater treatment, Greenhouse Gas emissions, optioneering, BioWin, Biological Nutrient Removal

PRESENTER PROFILE

Derek is a civil and environmental engineer with 3 years’ experience at Pattle Delamore Partners Ltd. He has been involved in a range of wastewater treatment, water treatment, and stormwater design projects, and has a particular interest in the incorporation of carbon emissions assessments into the decision-making processes during design.

1.0 INTRODUCTION

In 2016, New Zealand (NZ) ratified its commitment to the Paris Agreement, a global agreement on climate change adopted by Parties under the United Nations Framework Convention on Climate Change (Ministry for the Environment, 2020). Taking effect in 2020, this catalysed legislative and policy changes across NZ, including the target of achieving Net Zero carbon emissions by 2050 (Ministry of Business, Innovation & Employment, 2022). This target seeks to address the first goal of the Paris Agreement; holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change (United Nations, 2015).

Achieving this target of Net Zero carbon emissions by 2050 requires engineering design to consider Greenhouse Gas (GHG) emissions in the design optioneering phase for all infrastructure projects. One such infrastructure project is the Cambridge Wastewater Treatment Plant (WWTP) upgrade, which identified minimisation of GHG emissions as a key criterion, along with other environmental, social, cultural, and technical criteria. This aligned with Waipā District Council’s (Waipā DC) overarching carbon reduction strategy and the “best for awa” approach applied for the long-term resource consenting for the continued discharge of treated wastewater into the Waikato River receiving environment.

Factoring GHG emissions into optioneering during the planning and design of WWTP upgrades or new WWTPs, requires designers to develop GHG emissions estimates using the range of methodologies available, as well as existing data and models to inform engineering decision making.

This paper outlines the operational GHG emissions estimate approach undertaken during the design optioneering phase of the Cambridge WWTP upgrade, including the insights attainable via amalgamating a range of estimation methodologies. Additionally, this paper highlights the significant reduction in operational GHG emissions attainable for municipal WWTPs, via shifting from an anaerobic and aerated lagoon-based treatment process to a 4-stage Bardenpho Membrane Bioreactor (MBR) treatment process. Finally, the criticality of further research and monitoring to verify existing emissions guidelines and model parameters is stressed.

2.0 BACKGROUND

2.1 GHG EMISSIONS FROM WWTPS

The treatment of wastewater contributes to global GHG emissions, due to methane (CH_4) and carbon dioxide (CO_2) emissions to the atmosphere, produced as by-products of the breakdown of organic material, and nitrous oxide (N_2O) emissions formed during the process of biological nitrification and denitrification (WaterNZ, 2021). Additionally, the interaction of discharged treated wastewater within the receiving environment, the production of the electricity used in the WWTP, and a range of other indirect offsite activities necessary to the functioning of the WWTP all represent further sources of GHG emissions. Note that CO_2 emissions are typically excluded from the total WWTP GHG emissions, due to being of biogenic origin (IPCC, 2019), and therefore considered related to the natural carbon cycle.

These sources of GHG emissions can be divided into three categories, as per the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019), as illustrated in Figure 1 and listed as follows:

- Scope 1: Direct GHG emissions from sources owned or controlled by the organisation (e.g., direct CH_4 and N_2O emissions from the WWTP);
- Scope 2: Indirect GHG emissions from the generation of purchased energy (in the form of electricity, heat or steam) e.g., electricity used to power the WWTP's aeration systems; and
- Scope 3: Other indirect GHG emissions occurring because of the activities of the organisation but generated from sources that it does not control (e.g., emissions from the decomposition of biosolids trucked to an offsite composting facility or landfill).

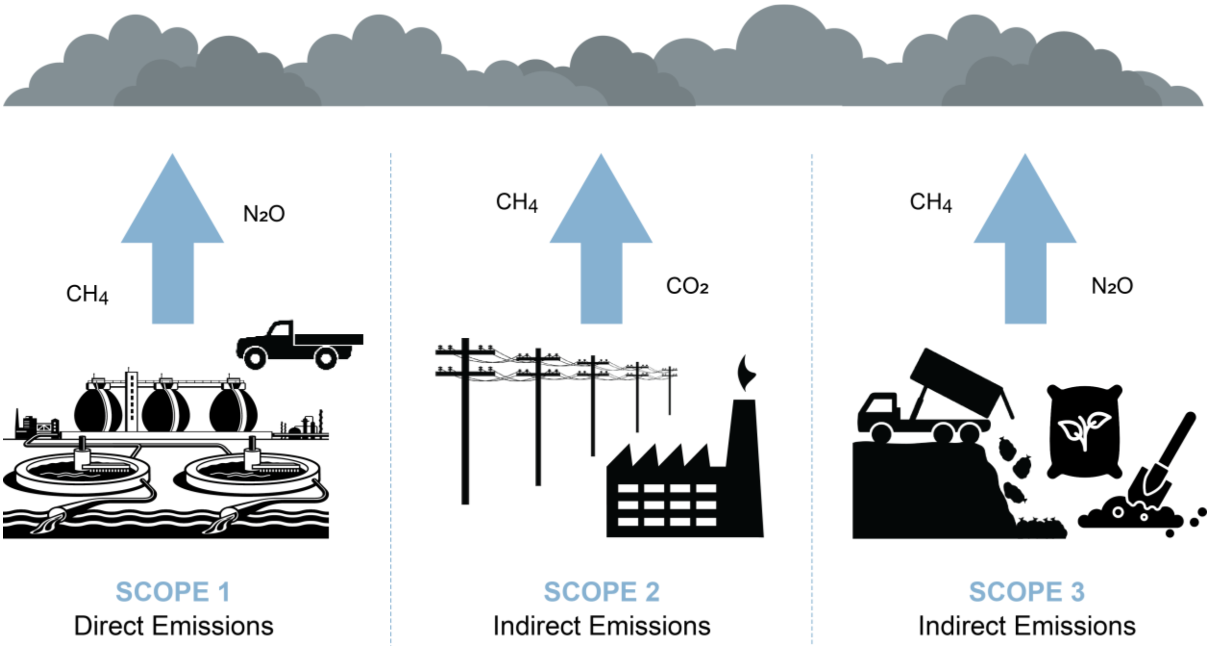


Figure 1: WWTP GHG Emissions Sources

With direct emissions from wastewater treatment forming an estimated 1.6% of total global emissions (IPCC, 2014), and 0.3% to 0.5% of New Zealand's total emissions (WaterNZ, 2021), estimating and factoring GHG emissions into optioneering will play a critical role in both national and global emissions reduction strategies. However, estimating and categorising GHG emissions from WWTPs has a degree of uncertainty that requires onsite measurement to calibrate and verify current models and emissions factors. This is an inherently iterative process, as global WWTPs must first estimate, measure, and then report emissions factors for various wastewater treatment unit processes and influent wastewater characteristics to enable the refinement of models and emissions factors. As this process continues, the accuracy of predictive models will continue to improve, thereby facilitating better estimates to inform design optioneering.

Therefore, whilst predictive models mature, factoring GHG emissions into optioneering for WWTP upgrades or new WWTPs necessitates an amalgamation of assessment methodologies to inform engineering decision making, as illustrated during the design optioneering phase of the Cambridge WWTP upgrade.

2.2 CAMBRIDGE WWTP UPGRADE PHILOSOPHY

The Cambridge WWTP is owned and operated by Waipā DC and treats domestic sewage, trade waste, and septage from the Cambridge area, including Leamington and Karapiro. In November 2020, Waipā DC received a short-term (6-year) consent, which improved the resilience of the existing lagoon-based WWTP and the treated wastewater quality with respect to phosphorus and *E.* coli and provided a timeframe for Waipā DC to develop a long-term standalone best-practicable wastewater treatment and discharge solution for Cambridge by November 2026. Seeking both to accommodate the significant population growth forecast for the Cambridge area and deliver a "best for awa" wastewater treatment and discharge solution, Waipā DC and key stakeholders, including the Kaitiaki Group, agreed to implement a 'design philosophy' similar to the recent Pukekohe WWTP upgrade. Here, Watercare obtained a 35-year consent on the basis of providing a best-practicable option for wastewater treatment and benchmarking the existing daily nutrient discharge loads as future limits. Detailed design of this significant upgrade is currently underway, and it is anticipated that a 35-year consent will be granted by Waikato Regional Council later this year.

2.3 LAGOON-BASED VERSUS MBR TREATMENT

The existing Cambridge WWTP consists of inlet screening, an anaerobic lagoon, an aerated lagoon, a sedimentation lagoon, constructed wetlands, and UV disinfection.

Facultative oxidation ponds are a lagoon-based wastewater treatment process in which both aerobic and anaerobic conditions exist through the water profile. Facultative lagoons typically consist of large, shallow basins containing populations of microorganisms which utilise biological processes to break-down contaminants, with heavier particles, including the microorganism growth (sludge produced from the treatment) settling, and clearer, treated wastewater forming the upper layer. This relatively cost-effective means of treatment does, however, produce higher levels of GHG emissions compared to other forms of wastewater treatment, due to the CH_4 production that occurs during the anaerobic decomposition of the organic matter deposited on the bottom of the lagoons (Ministry for Primary Industries, 2018). In New Zealand, it is estimated that 64% of all domestic wastewater treatment processes utilise lagoon or pond-based treatment, servicing approximately 15% of the total population (Ministry for the Environment, 2020).

Anaerobic lagoons are another lagoon-based treatment system comprising of deeper basins which receive higher organic loads per surface area of lagoon, where anaerobic conditions are enhanced and prevail. Anaerobic lagoons typically form a crust on the surface, which further limits oxygen transfer and enhances anaerobic conditions. Anaerobic lagoons are relatively common in New Zealand for treating industrial wastewater with high organic loads, and often include a polyethylene cover to further enhance anaerobic activity, and to facilitate the capture of CH_4, which can be combusted in a flare to reduce CH_4 emissions. Uncovered anaerobic lagoons tend to emit significant CH_4 load to the atmosphere.

As lagoon-based treatment system emit relatively higher CH_4 emissions compared to alternative technologies, an opportunity exists to upgrade these WWTPs, which, alongside other key success criteria, will minimise GHG emissions and thus contribute to New Zealand’s emissions reduction strategy and commitment to the Paris Agreement.

One such alternative treatment process, is an activated sludge based Biological Nutrient Removal (BNR) process, with an integrated Membrane Bioreactor (MBR), which utilises anoxic and aerobic conditions in dedicated reactor style tanks to optimise the microbial uptake of nitrogen and phosphorous, as well as the removal of nitrogen via nitrification and de-nitrification processes. MBR incorporates microfiltration or filtration to separate the beneficial bacteria from the treated effluent, as opposed to a conventional activated sludge plant, which uses gravity separation via a clarifier. Methane emissions for this type of WWTP are significantly less than for lagoon-based systems, as anaerobic conditions are avoided.

Due to the stringent nitrogen consent limits proposed for the Cambridge WWTP upgrade, the following four treatment options (all variations on the above general process selection) were shortlisted for design optioneering:

- Option 1 (**Selected WWTP Upgrade**): Membrane Bioreactor (MBR) Configured for Enhanced Biological Nitrogen Removal (EBNR);
- Option 2: MBR Configured for Enhanced Biological Phosphorous Removal (EBPR);
- Option 3: MBR with Primary Sedimentation Tank (PST), Anaerobic Digestion and Electricity and Heat Recovery via Biogas Combustion in a Combined Heat and Power (CHP) Engine; and
- Option 4: Membrane Aerated Biofilm Reactor (MABR) with Tertiary Ultrafiltration.

3.0 CAMBRIDGE WWTP GHG EMISSIONS ASSESSMENT

3.1 ASSESSMENT APPROACH

During the design optioneering phase of the Cambridge WWTP upgrade, a Multi-criteria Assessment (MCA) was undertaken to compare the four shortlisted MBR treatment options against one another and thus inform engineering decision making. Consultation with Waipā DC and the Kaitiaki Group identified minimisation of GHG emissions as a key criterion, alongside other environmental, social, cultural, and technical criteria, detailed as follows:

- Population Growth – a modular system that can accommodate future upgrades;
- Effluent Quality – achieves the required treatment standard in alignment with consenting outcomes and the “best for awa” approach;
- Chemical Consumption – minimises chemical consumption;
- Electricity Consumption – minimises electricity consumption;
- Solids Production – minimises solids production;
- Odour Impact – minimises the potential for odours;
- GHG Emissions – minimises GHG emissions in alignment with Waipā DC’s overarching carbon reduction strategy;
- Risks – minimises the overall risk profile;
- Reuse of Existing Infrastructure – maximises opportunities to reuse existing infrastructure;
- Footprint – minimises the site footprint such as to maximise the available area for site remediation and repurposing and provisions space for future upgrades;
- Capital Cost – minimises capital cost;
- Operating Cost – minimises operating cost; and
- Whole of Life Cost – minimises whole of life cost.

Informing the GHG emissions criterion of the MCA was a high-level GHG emissions assessment. Annual operational GHG emissions were estimated for the four shortlisted upgrade options against the existing treatment process as the ‘status quo’, thus providing a benchmark to compare the upgrade options against. Note that this assessment was not formally audited or verified. Additionally, embodied carbon associated with the construction of the WWTP upgrade was excluded from the assessment, noting that it was likely to be similar for all of the shortlisted options. Crucially, to ensure the applicability and comparability of the estimates, an amalgamation of methodologies was used, including:

- Water New Zealand's Carbon Accounting Guidelines for Wastewater Treatment: CH_4 and N_2O (WaterNZ, 2021);
- The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019);
- The Ministry for the Environment's guidelines on measuring emissions (MfE, 2020); and
- Outputs from the WWTP modelling software EnviroSim BioWin (Version 6.2 released 2021).

As recommended by the Water NZ Guidelines (2021) and ISO 14064-1:2018 (ISO, 2018), the latest 100-year Global Warming Potentials (GWP) has been applied; AR5 GWP100 with climate carbon feedbacks:

- CO_2 = 1;
- CH_4 = 34; and
- N_2O = 298.

To provide commonality when assessing the shortlisted upgrade options against the existing WWTP, influent and effluent flows and loads were linearly extrapolated from the present Cambridge population of 20,000 Population Equivalent (PE) to the Stage 1 design horizon of 37,000 PE. This, alongside various design assumptions, formed the basis for the design inputs for the amalgamation of aforementioned estimation methodologies. These methodologies were applied in a stepwise fashion to each unit process of the respective wastewater treatment processes for each option and the existing WWTP, as summarised in Table 1. Further details of this process and the insights attained are outlined in the following sections.

Table 1: Summary of Methodologies Applied to the Cambridge WWTP GHG Emissions Assessment

Parameter	Shortlisted WWTP Upgrade Options	Existing WWTP
Plant CO_2 Emissions (excluded)	EnviroSim BioWin	WaterNZ (2021)
Plant CH_4 Emissions		
Plant N_2O Emissions		
CH_4 Production in the Receiving Environment	WaterNZ (2021)	
N_2O Production in the Receiving Environment		
Emissions from Purchased Electricity	IPCC (2019)	
Emissions from Biosolids Transport	MfE (2020)	

Emissions from Biosolids Decomposition in Offsite Vermicomposting Facility Managed by Others	WaterNZ (2021)
Emissions from Electricity Distribution Losses	MfE (2020)

3.1.1 EMISSIONS GUIDELINES

Excluding EnviroSim BioWin, there are three emissions guidelines listed in Table 1. Typically, the methodologies in those guidelines have been developed by aggregating a range of existing data to develop standardised average emissions factors and calculation methodologies for the high-level estimation of GHG emissions from various processes associated with the treatment of wastewater. In general, emissions factors are multiplied by the influent BOD and TN load to each unit process to provide a conversion into the kilograms of CH_4 and N_2O released, respectively. Wherever practicable, verified New Zealand-specific emissions factors have been employed to reflect local conditions, noting, however, that international guidance is still useful and at times more applicable, due to the greater quantity of data it draws upon.

3.1.2 BIOWIN MODELLING

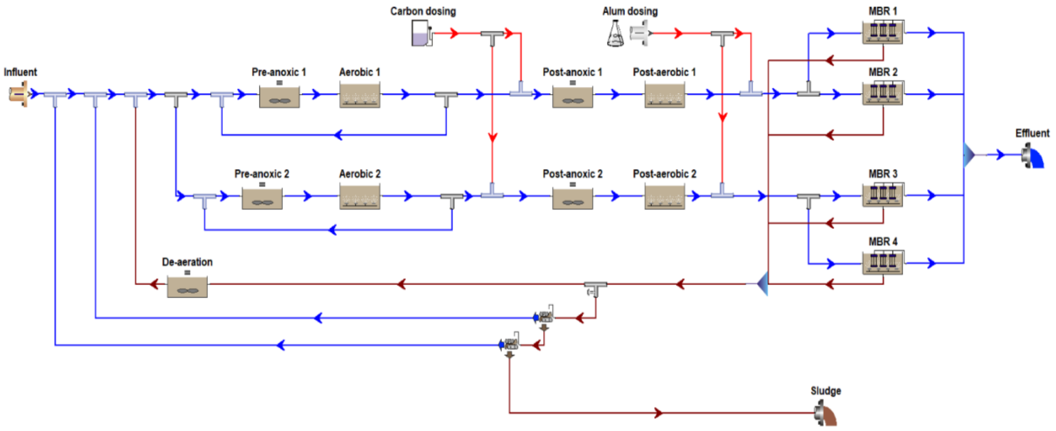
Preliminary wastewater treatment process modelling was undertaken using the proprietary EnviroSim BioWin software package (Version 6.2 released 2021) to quantify direct CH_4 and N_2O emissions from the WWTP process units for each treatment option.

BioWin is widely employed in the wastewater industry as a tool for process analysis, which can assist with the design or improvement of WWTPs. By incorporating and solving a series of mass-balance models of biological and physical treatment units, it offers the capability to forecast fugitive CH_4 and N_2O emissions. Whilst CH_4 production can be estimated through the anaerobic digestion of waste, the determination of N_2O emissions is more complex, estimated in BioWin using the following three main mechanisms:

- Nitrification by-products: The partial oxidation of ammonia to nitrous oxide, due to the conditions of limited oxygen or excess ammonia;
- Nitrifier Denitrification: Where free nitrous oxides (FNA) are used as an electron acceptor to remove nitrite, thereby producing nitrous oxide, and;
- Denitrification: Where nitrous oxide is produced as a byproduct, due to incomplete denitrification.

By default, BioWin uses a general Activated Sludge / Anaerobic Digestion (ASDM) model. This model is recognized by the International Water Association (IWA) (Seco, et al., 2020). Whilst BioWin modelling has been shown to accurately represent reality (Dhar, Elbeshbishy, Hafez, Nakhla, & Ray, 2011), it is predominately a guide for process design, which should be optimised and verified with live measurements. Note that the modelled N_2O emissions by BioWin have not been verified, with limited research in this sphere to date. Therefore, the intent of the modelling of the shortlisted BNR upgrade options for the Cambridge WWTP was to provide a comparison of the estimated annual operational GHG emissions from each option. By running steady state simulations of the influent wastewater characteristics, the off gas CH_4 and N_2O emissions were estimated for each option, whilst ensuring the target quality of the treated effluent was met. The models utilised are shown schematically below in Figure 2, for Option 1, 2, 3, and 4, respectively.

(A)



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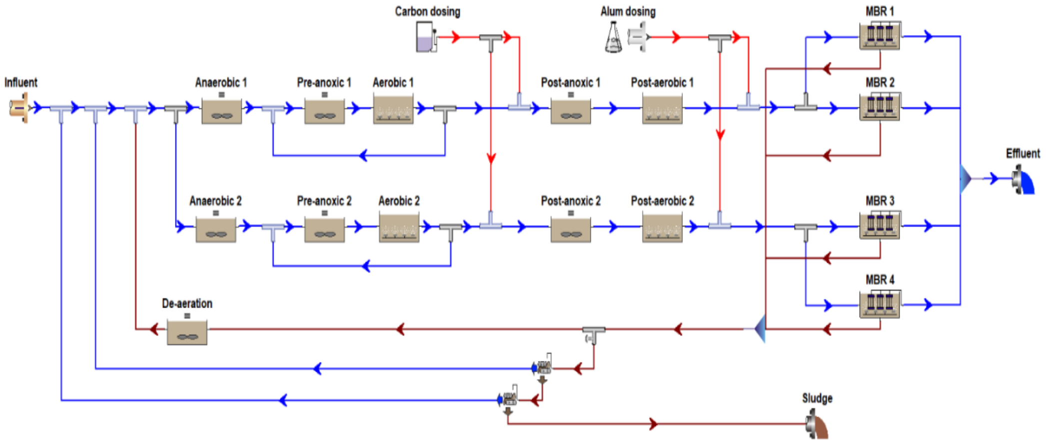

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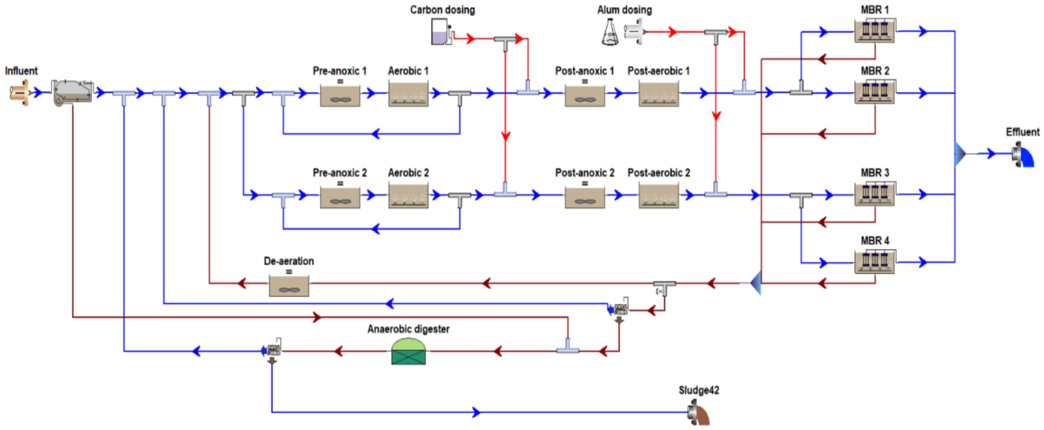

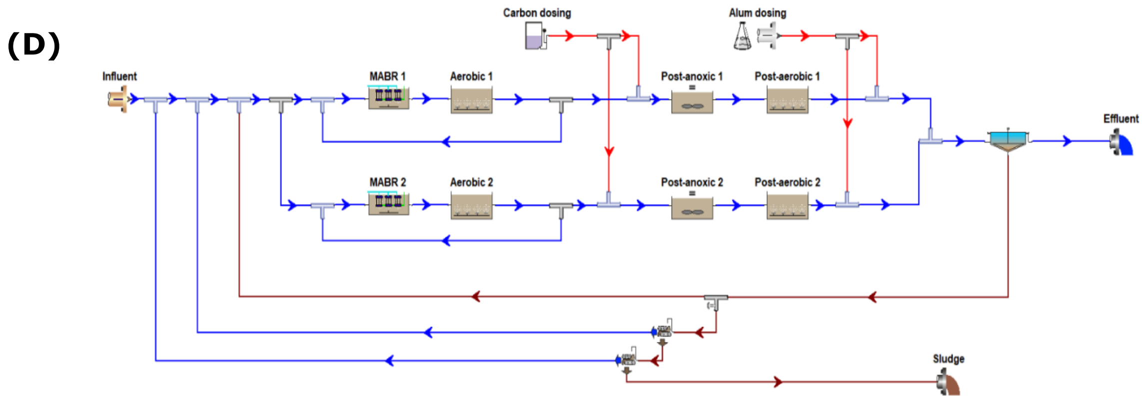

Figure 2: Schematic of Modelled Options on BioWin (A) Option 1: EBNR (B) Option 2: EBPR (C) Option 3: EBNR with Anaerobic Digestion (D) Option 4: MABR with BNR

3.2 DESIGN OPTIONEERING

The results of the aforementioned annual GHG emissions assessment undertaken for the four shortlisted upgrade options is displayed in Figure 3.

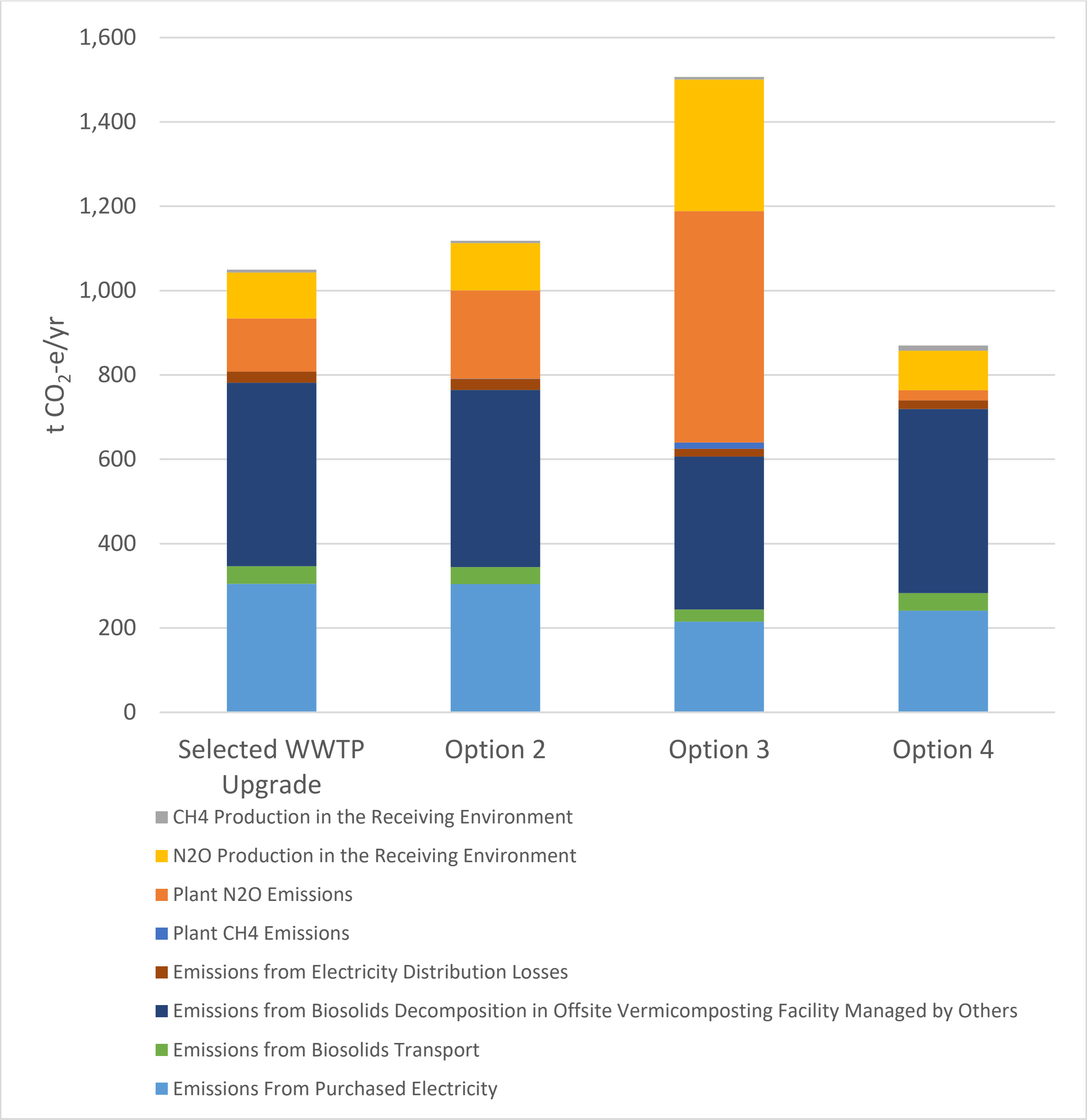

Figure 3: Cambridge WWTP Annual Operational GHG Emissions Comparison - Upgrade Options

For the GHG emissions criterion in the MCA assessment, Option 4 received the highest score, with marginally lower GHG emissions compared to the other options. It was closely followed by the Selected WWTP Upgrade (Option 1) and then Option 2, with Option 3 bringing up the rear, predominately due to the large Scope 1 emissions associated with the poorer standard of nitrogen in the treated effluent (TN ~ 12 g/m^3) compared to the other options. The major emissions sources across all four shortlisted upgrade options are emissions from biosolids decomposition in the offsite vermicomposting facility managed by others, and emissions from purchased electricity, ranging from 24-50% and 14-29% of total emissions contribution, respectively.

For Scope 1 emissions, when excluding plant CO_2 emissions as biogenic, N_2O production in the receiving environment had the highest relative contribution across the options. Hence, the lower Total Nitrogen (TN) effluent concentrations (circa 4 g/m^3) produced by all the options except Option 3 (circa 12 g/m^3 without acetic acid dosing), resulted in lower overall Scope 1 emissions. Similarly, the effluent Biochemical Oxygen Demand (BOD) concentration for Option 4 was double the other options, as reflected in its higher production of CH_4 emissions in the receiving environment. Note that the generic emissions factors listed in the WaterNZ (2021) Guidelines for secondary BNR treatment do not distinguish between the different types of BNR treatment (i.e., anoxic-oxic based, 4 stage Bardenpho, or otherwise). Thus, to facilitate optioneering, the BioWin modelled plant emissions were reported, as the model factors in the specific process configuration, influent parameters, and recycle rates.

Scope 2 emissions depend on the electricity demand of each option, including any offsetting of demand provided by re-use of energy or renewal generation on site. Option 3 and 4 outperform the other options, with the former including a Combined Heat and Power (CHP) engine to recover energy via combusting the methane produced by the Anaerobic Digester, and the latter taking advantage of the improved aeration efficiency afforded by the emerging MABR process. Note that subsequent to this assessment, renewable electricity generation onsite via a proposed 1.5 ha solar array has been proposed to further reduce the GHG emissions from purchased electricity, as a key contributor to the annual operational GHG emissions footprint for the Selected WWTP Upgrade.

For Scope 3 emissions, the emissions from the biosolids decomposition in an offsite vermicomposting facility managed by others had the highest relative contribution across all the options. An identical two-stage thickening and dewatering process was assumed for all options, thus, the BioWin modelled volume of biosolids generated was the key factor in determining the quantity of emissions produced. Hence, Option 3, with its Anaerobic Digester, had the lowest Scope 3 GHG emissions, and therefore the highest score, with the other options performing relatively similarly.

When considering all of the environmental, social, cultural, and technical criteria, Option 1, the Selected WWTP Upgrade, received the highest overall MCA score. It scored strongly across all of the criteria, typically either first or marginally second, as observed in the above assessment, and crucially was assessed to be capable of delivering the required <4 g/m^3 of TN in the treated effluent on a mean annual basis, necessary to deliver the "best for awa" consenting solution for the Cambridge WWTP upgrade. Notably, this assessment, and others like it undertaken during the optioneering phase that quantified and analysed the relative differences between the four shortlisted upgrade options, provided confidence in the engineering decision making process and the determination of the Selected WWTP upgrade. Furthermore, the insights attained stimulated further exploration into GHG emissions reduction opportunities, such as the proposed solar array, which has the added benefit of providing a return on investment via operational savings through reduced purchased electricity over the lifespan of the site.

3.3 EMISSIONS REDUCTION ATTAINED

Compared to the status quo of anaerobic and aerated lagoon-based treatment, all four of the shortlisted MBR upgrade options were estimated to significantly reduce the annual operational GHG emissions, thus aligning with Waipā DC's overarching carbon reduction strategy. As illustrated in Figure 4, at the 2035 Stage 1 design horizon of 37,000 PE, this reduction was estimated to be approximately 90% for the Selected WWTP Upgrade.

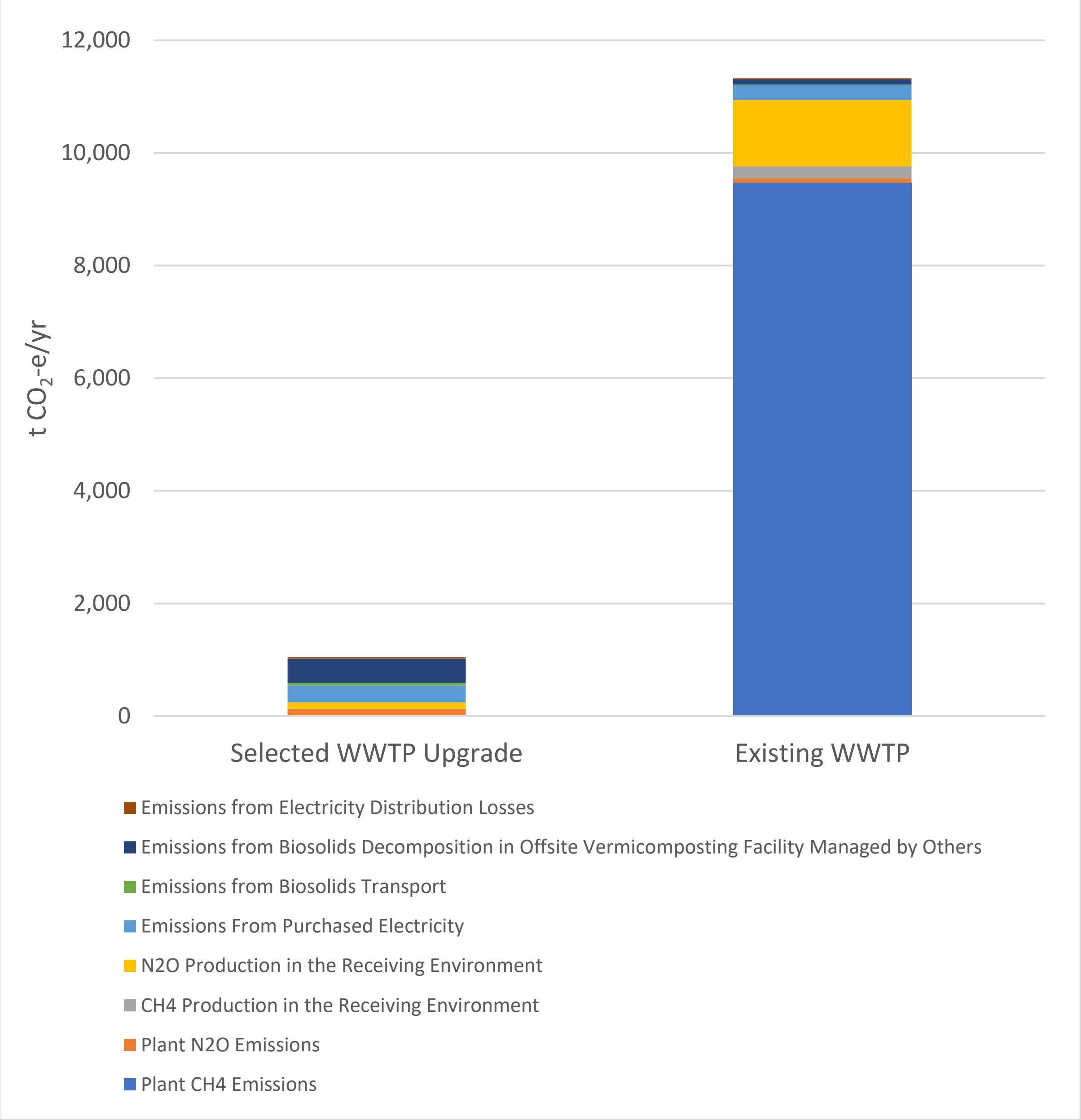

Figure 4: Cambridge WWTP Annual Operational GHG Emissions Comparison - Existing versus Selected Upgrade

The significant difference observed was primarily due to the higher Scope 1 GHG emissions estimated for the existing WWTP. Notably, the uncovered anaerobic lagoon was a significant source of CH_4 emissions, forming 84% of the total GHG emissions estimated. As discussed in Section 2.3, CH_4 is emitted during the anaerobic decomposition of the organic matter within the anaerobic lagoon, and, as it is uncovered, the gas freely discharges to the atmosphere, albeit some CH_4 will be removed via biological oxidation within the natural surface crust layer. Secondly, the lower standard of treatment provided by the status quo treatment system results in higher TN and BOD loads being discharged to the receiving environment, and thus greater N_2O and CH_4 emissions within the receiving environment, respectively.

Scope 2 emissions for the existing WWTP were slightly less than the selected WWTP upgrade, which was to be expected, noting the direct correlation between the energy demanded by the treatment process and the quality of treated effluent delivered.

As per the four shortlisted upgrade options, the existing WWTP biosolids were also assumed to be disposed of to the same offsite vermicomposting facility managed by others, with biosolids production estimated based on standard conversion ratios for sludge production as a function of the influent BOD load to the anaerobic and aerated lagoons. The Scope 3 GHG emissions from the biosolids decomposition in this existing facility were notably lower than the selected WWTP upgrade. This once again directly correlates to the lower quality of treated effluent delivered, with higher loads of nutrients being discharged to the receiving environment and being decomposed to CH_4, as opposed to being removed as sludge and disposed of to the aforementioned facility, as was the case for the Selected WWTP Upgrade.

GHG emissions quantities, in tonnes of CO_2 equivalent, and the percent contributions of each emissions source to the total annual operational emissions for the selected WWTP upgrade and existing WWTP at the 2035 Stage 1 design horizon are displayed in Figure 5 and Figure 6, respectively.

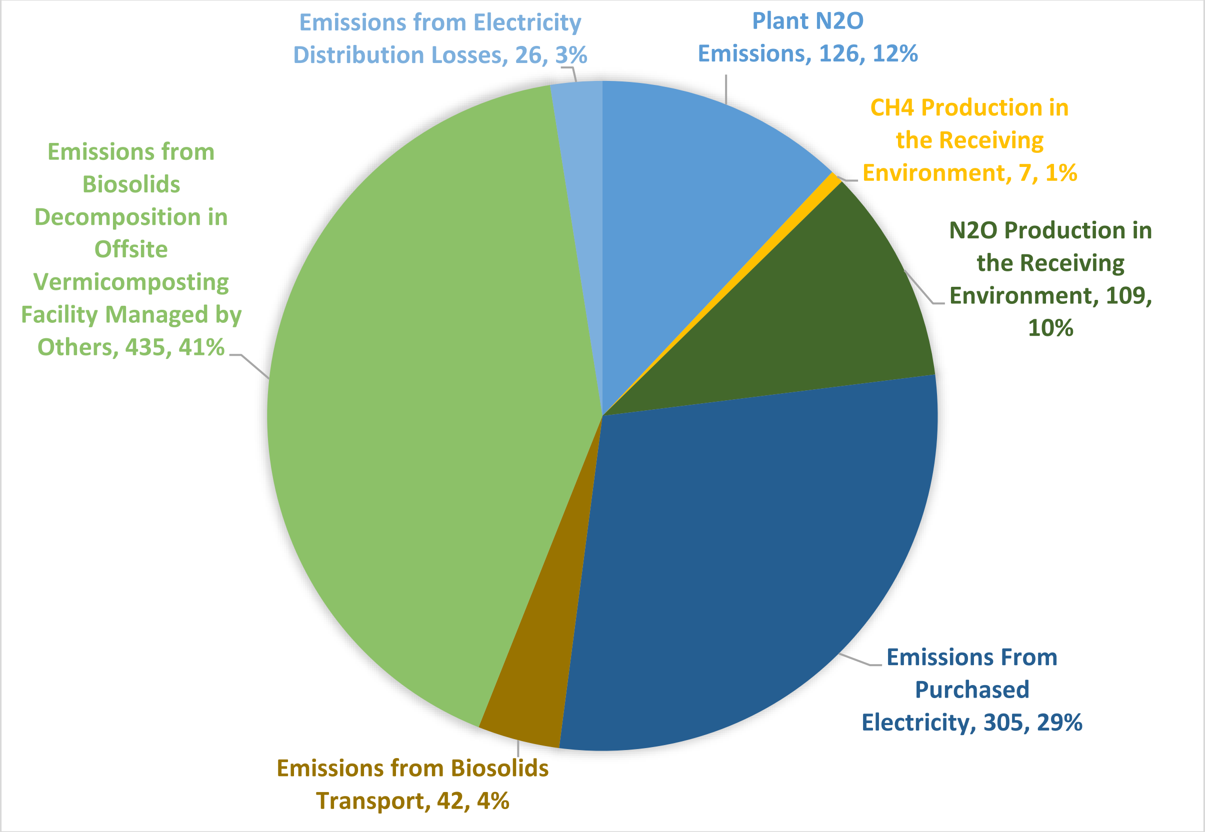

Figure 5: Selected WWTP Upgrade Operational GHG Emissions Summary

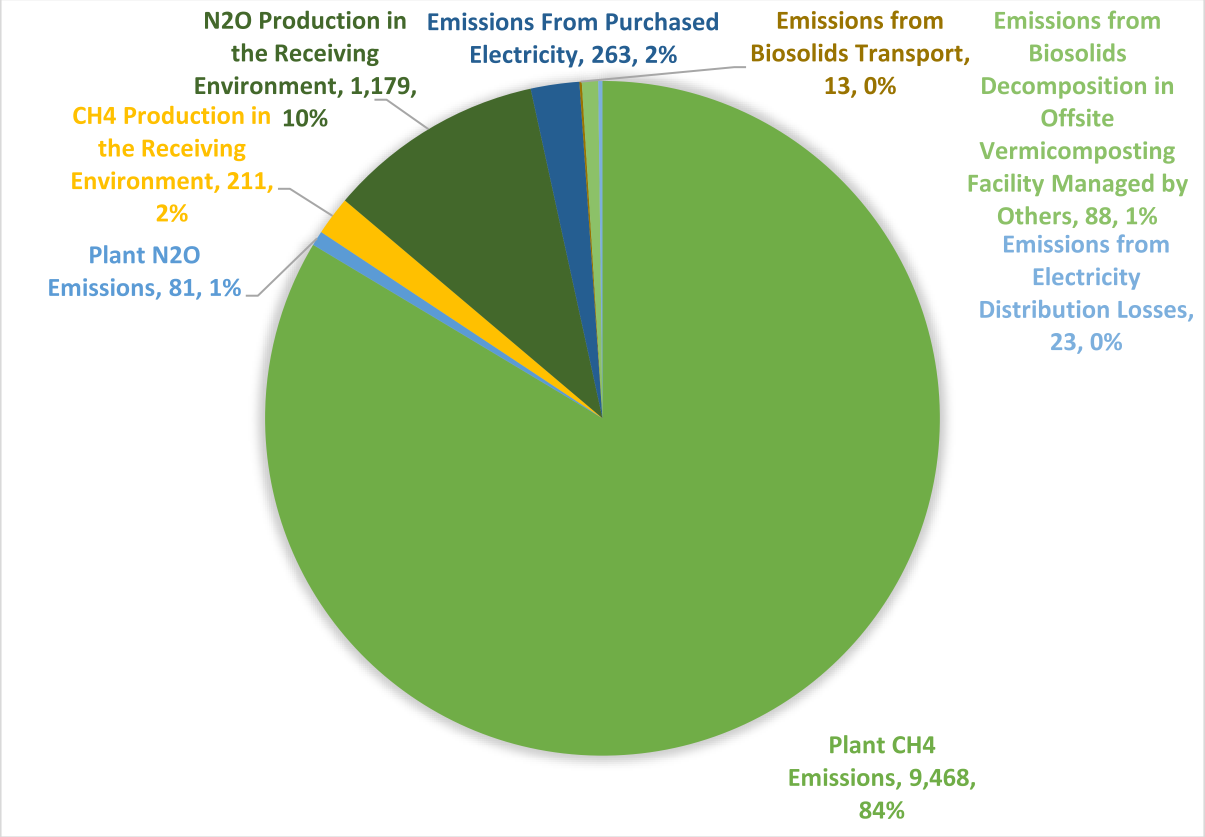

Figure 6: Existing WWTP Operational GHG Emissions Summary

To provide perspective, the difference in total annual operational GHG emissions between the selected WWTP upgrade and the existing WWTP is equivalent to replacing approximately 4,500 petrol engine vehicles (PEVs) with battery electrical vehicles (EVs), based upon the emission figures presented by ECCA (2015). Similarly, the difference between the selected WWTP upgrade and Option 4, was the equivalent of replacing 80 PEVs with EVs, in Option 4's favour. This, alongside comparisons to the other shortlisted upgrade options, is displayed in Figure 7 below.

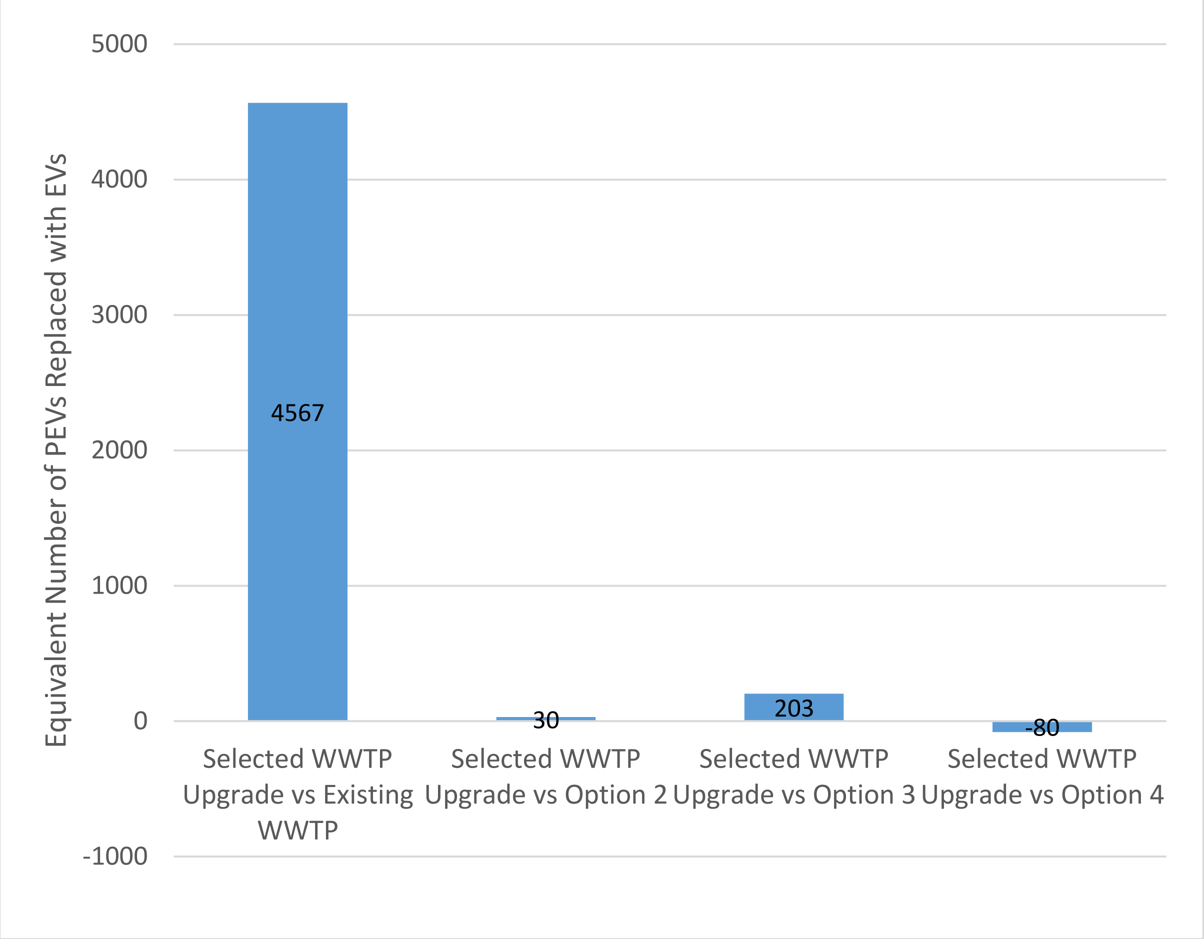

Figure 7: Equivalent Reduction of Replacing Petrol Engine Vehicles (PEVs) with Electric Vehicles (EVs)

The total annual operational GHG emissions reduction that is estimated to occur as a result of shifting from the status quo of anaerobic and aerated lagoon-based treatment to the selected MBR treatment process for the Cambridge WWTP upgrade demonstrates the importance of factoring GHG emissions into design optioneering for WWTP upgrades or new WWTPs, especially when considering New Zealand's target of achieving Net Zero carbon emissions by 2050 and global efforts to honour the Paris Agreement.

4.0 FURTHER RESEARCH AND VERIFICATION

As engineering design increasingly seeks to factor GHG emissions into the optioneering phase for infrastructure projects, such as WWTP upgrades or new WWTPs, it is critical for the accuracy and reliability of the existing data and predictive models underpinning these assessment methodologies to continue to improve. As outlined in Section 2.1, this inherently iterative process relies upon global WWTPs first estimating and then measuring and reporting emissions factors for various wastewater treatment unit processes and influent wastewater characteristics. With further research and verification of model parameters, the accuracy of the predictive models informing the GHG emissions estimates utilised during design optioneering will continue to improve, and, by extension, so also will the ability of designers to make informed decisions. Such an opportunity presents itself for the Cambridge WWTP upgrade, which, once construction and commissioning is complete, could measure the actual operational GHG emissions emitted to calibrate, verify, and improve the accuracy of the emissions factors and models utilised to estimate emissions during the design phase, thus contributing to the iterative improvement of predictive models and emissions factors for WWTPs.

5.0 CONCLUSION

The Paris Agreement on Climate Change catalysed legislative and policy changes worldwide, with countries like New Zealand setting carbon reduction targets aimed at holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.

Achieving these targets requires engineering design to consider GHG emissions in the design optioneering phase for all infrastructure projects. With direct emissions from wastewater treatment forming an estimated 1.6% of total global emissions (IPCC, 2014), and 0.4% of New Zealand’s total emissions (WaterNZ, 2021), estimating and factoring GHG emissions into the design optioneering of WWTP upgrades or new WWTPs, will play a critical role in both national and global emissions reduction strategies.

As illustrated by the Cambridge WWTP upgrade project, shifting from the status quo of an anaerobic lagoon-based treatment to the selected 4-stage Bardenpho MBR process configured for EBNR is estimated to reduce the annual operational GHG emissions by approximately 90%. This significant reduction of GHG emissions clearly aligned with Waipā DC’s overarching carbon reduction strategy and supported the “best for awa” approach applied for the long-term resource consenting for the continued discharge of treated wastewater into the Waikato River receiving environment. Hence, for WWTP upgrades or new WWTPs, and in particular the 64% of New Zealand wastewater treatment processes still utilising lagoon or pond-based treatment (Ministry for the Environment, 2020), it both sets a clear precedent for, and pathway towards, GHG emissions reductions.

Further research and monitoring are necessary to verify the GHG emissions estimates developed, including the refinement of both existing GHG emissions guidelines and predictive models, such as BioWin. This assessment, has attempted to quantify the relative differences between the Cambridge WWTP upgrade options and the status quo, thereby informing the engineering decision making process and determination of the Selected WWTP Upgrade. With further emissions reductions likely via a proposed 1.5 ha solar array onsite, the Selected WWTP Upgrade for Cambridge will significantly reduce the annual operational GHG emissions compared to the status quo, delivering a “best for awa” consenting solution, and demonstrating a viable method of factoring GHG emissions into design optioneering.

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