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CARBON FOOTPRINT OF OPEN-CUT PIPELINES (NZ CONTEXT)

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ABSTRACT

Society is currently facing a climate crisis; our human activities, notably the burning of fossil fuels, emit greenhouse gases into the atmosphere. The constant addition of GHG emissions is resulting in climate change. Nearly all countries agreed in the Paris Agreement 2015 to limit the global temperature increase to well below 2°C above pre-industrial levels. Science-based projections depict a concerning future. Should there be a failure to adequately mitigate our emissions, the impacts on humans and other species could be catastrophic.

The Construction Industry is a vital sector that significantly contributes to a nation's economic and social development. It builds and maintains infrastructure and serves as a significant source of employment. Buildings and construction account for 39% of global emissions, with 36% attributed to global energy use. While most research focuses on emissions from construction buildings, a literature review shows a lack of information regarding global infrastructure emissions. Recent research by Thacker et al. (2021) addresses this gap; when they combine infrastructure, building and construction, the total global emission amounts to a significantly higher value of 79%. Focusing on the stormwater, water, and wastewater sectors (three waters), the emissions amount to 5% of all emissions. Although water/wastewater emissions are only 5% of the costs, adaptation costs in the water sector are estimated to account for 54% of all costs.

In Aotearoa, New Zealand, government and local authorities are making progress in capturing and reducing their carbon emissions. For instance, Auckland Council has set their goal to reduce greenhouse gas emissions by 50% by 2030, and Watercare aims to reduce its construction emissions by 40% by 2025; this is only two years away. Should local authorities impose the need to start reporting on carbon emissions on the construction industry, especially those in asset infrastructure delivery, research from the existing literature shows that the construction industry is not ready, not equipped, sees little need to do things differently, or does not know how to quantify carbon emission. The gaps in the research show that contractors should begin their carbon journey, and there are multiple carbon frameworks or standards without explicit critique on what works best. Understanding and knowing these standards takes time, and without a clear lead, information on critical inputs and variables required to represent the construction works accurately becomes muddy. As the standards were written to cater to different industries, the steps given are generic and do not go into detail about specific construction activities. Existing literature cautions that if the method and level of detail are unclear, final carbon footprint values can change.

Further, emission sources need to be measured and quantified. However, units of measurement for these activities and productivity durations are typically not published as knowledge of these

productivities is a trade secret and a competitive advantage to construction activity. To add to the complexity, the carbon science or emission factors that correspond to the emission activities are not readily available, and more research is needed to find local emission factor sources.

In response to these challenges, the research aims to create and develop a simplified methodology and a template for contractors to create their carbon inventory on installing three waters open-cut pipeline excavation.

A new Carbon Framework Methodology was developed based on the literature findings and data collection to fulfil the aim. A case study scenario was created where a 100ø PVC pipe is installed, and a 1.3m deep open-cut trench is excavated using standards based on Auckland Council stormwater and Watercare water and wastewater standards. An Excel-based carbon tool was created, and the steps in the carbon framework were followed. The final calculated carbon footprint values were verified using published Environmental Product Declarations (EPD). The carbon tool was presented to 18 participants from 1 tier one and multiple tier 2 contractors who have been installing water, wastewater and stormwater pipelines, with some contractors having over 20+ years in the industry.

The research found that creating a carbon inventory is complex, multi-disciplined, requires construction methodology knowledge, and cannot avoid the need to learn carbon principles and carbon science (emission factors).

The findings are significant as they discuss the implications of Carbon Accounting for Contractors, from knowing operation boundaries (Scope 1, 2 and 3) to the cost of upskilling, embedding, and implementing carbon management in construction projects. Minor findings were also discussed on the implications of Carbon Accounting for Designers and the heavy responsibility for Clients in ensuring that the capture of carbon emissions flows downstream to its value chain.

Keywords: Construction Pipeline, Carbon Footprint, Carbon Framework, NZ

CHAPTER 1 INTRODUCTION

1.1 Background

Climate Change - Human activities, mainly burning fossil fuels, emit greenhouse gases (GHG) into the atmosphere (IPCC, 2007). The amount of GHG emitted into the atmosphere by an individual, building, or organisation is defined simply as their Carbon Footprint (Chilana, 2011). Adding to the concern, some of these gases can endure in the atmosphere for extended periods, potentially hundreds to thousands of years. The constant addition of GHG emissions leads to the accumulation of these gases, resulting in climate change (IPCC, 1995). In response to climate change, the United Nations Environmental Programme (UNEP) and the World Meteorological Organisation, with the endorsement of the United Nations (UN) General, established the Intergovernmental Panel on Climate Change (IPCC) in 1988. Its goal at the time was to prepare a comprehensive review of the science, the social and economic impact and response to climate change (IPCC, 2023a). Since then, the IPCC has released six key assessment reports. These reports were instrumental documents in confirming without a doubt that our anthropogenic activities (human-induced) are changing our climate. The reports were also pivotal in adopting the Kyoto Protocol in 1997 and the Paris Agreement in 2015. Subsequently, in 1992, several countries created a treaty to combat climate change and the United Nations Framework on Climate Change (UNFCCC) was established. The idea of the UNFCCC was to have the developed countries lead the change (UNFCCC, 2023c).

In 1995, the UNFCCC operationalised the Kyoto Protocol. Using the IPCC SAR report, the Protocol identifies six key greenhouse gases. These are CO₂ – Carbon Dioxide, CH₄ – Methane, N₂O – Nitrous Oxide, SF₆ – Sulfur Hexafluoride, HFC's – Hydrofluorocarbons and PFC's – Perfluorocarbons. Ten years later, with the scientific input from the IPCC's AR5 report, the Paris Agreement was created in 2015. Nearly all countries around the world committed to limiting the global temperature increase to 1.5°C, well below the 2°C above preindustrial levels. Science-based projections depict a concerning future. Should there be a failure to mitigate our emissions sufficiently, the impacts on humans and other species could be catastrophic.

Construction - The Construction Industry is a vital sector that significantly contributes to a nation's economic and social development. It builds and maintains infrastructure and is a significant source of employment (Lopes, 2012; Ofori, 2015; Turin, 1980). According to reports by the IEA and UNEP (2018), buildings and construction account for 39% of global emissions, with 36% attributed to global energy use. The WorldGBC (2019) further categorises this into 28% of operational carbon and 11% as embodied carbon. While most research focuses on emissions from construction buildings, a review of the literature shows a lack of information regarding global infrastructure emissions, as it is often

grouped within construction emissions. Recent research by Thacker et al. (2021) addresses this gap; when they combined infrastructure, building and construction, the total global emission amounts to a significantly higher value of 79%. Focusing on the water sector, its global emissions amount to 5%. Although water is only 5%, the water sector has the highest level of investment due to climate change, the heightened risk of reduced water supply from droughts and desertification in various regions of the world, and the need for infrastructure projects to protect coastal cities from sea level rise. Adaptation costs in the water sector are estimated to account for 54% of all costs.

NZ GHG Emissions - From New Zealand's Greenhouse Gas Perspective, the Ministry for the Environment (MfE) is committed to reporting under the UNFCCC and the Kyoto Protocol, and they produce NZ's greenhouse gas inventory for the period 1990 - 2020 (StatsNZ, 2022). According to their latest records, there has been a net emission of 55.7 MtCO₂e. Their report from 1990 to 2020 shows that NZ emissions have remained relatively stable, which raises an important question: if emissions have neither increased nor decreased over the past 30 years, what actions must be taken to achieve our ambitious goal of reaching net zero emissions by 2050?

NZ Construction Emissions - Should NZ Construction emissions be required, additional research within the Energy Sector is needed as emissions from Construction are currently grouped with Manufacturing emissions and were 8.2% of NZ's overall total emissions. To obtain specific construction-related data, extracting, analysing, and manually calculating data from the Ministry for the Environment (MfE) time series emissions data is essential. The MfE follows UNFCCC reporting guidelines in their reporting. While the current reporting at a macro level provides a valuable indicator for identifying high-sector emitters, it is becoming increasingly important for specific sectors like Construction to have their dedicated category, which is the case in the UK and Internationally (Elhag, 2015). A dedicated Construction category would enhance transparency and offer a precise view of emissions within the construction sector, enabling industry and the central government to target and reduce emissions effectively. For instance, the NZ Government has invested in projects such as the arc furnace for NZ Steel, which is expected to reduce the country's emissions by 1% (MBIE, 2023). Given the potential for significant construction projects such as a new harbour bridge in Auckland, rail, motorways, or water infrastructure across New Zealand, there is a growing need for an official and transparent source of construction infrastructure emission data if the goal of achieving net zero emissions by 2050 is to be realised. Currently, such a source does not exist.

Sector Focus 3 Waters Construction Infrastructure - In April 2023, the Minister of Local Government in NZ, announced the launch of the "Affordable Water Reforms" or Water Services Reform Programme on July 1, 2026 (New Zealand Government, 2023). This reform was initiated by the NZ Government in

July 2020 to address challenges in delivering water, wastewater, and stormwater services (referred to as three waters) nationwide. The reasons for these reforms included aging infrastructure, population growth, climate change mitigation, and the need for reliable, affordable, and safe water services. Over the next 30 years, the estimated cost to address these challenges is between \$120 and NZD 185 billion. The reform involves 67 councils and will be overseen by ten entities. On a local level in Auckland, Entity A, under the Water Services Reform Programme, Auckland Council and Watercare have set GHG emissions targets. Auckland Council aims to halve their emissions by 2030 and achieve net zero emissions by 2050, while Watercare has three emission reduction targets related to construction and operational emissions. One of Watercare's goals is to reduce construction emissions by 40% by 2025, which is only two years away. However, the adoption of capturing emissions data in the construction industry has been slow for several reasons. It is technically challenging (Crompton, 2022) and complex (Elhag, 2015), and many companies focus on direct costs (Alsadi & Matthews, 2020), neglecting social and environmental impacts, which are difficult to quantify due to unknown or unavailable factors. Additionally, there is a general lack of awareness and no mandatory requirement to capture or report emissions data (BDO NZ, 2023).

Existing Literature - What the literature shows is that there are multiple carbon frameworks to quantify emissions. However, these can be complex, and depending on their methods and level of detail, they can potentially lead to different emission values (Elhag, 2015); this brings up the following questions:

- Is there a methodology or a simple template to help Contractors get on board and start recording their carbon inventory before aiming to reduce emissions? Is there a tool available?
- In the context of water conveyance for open-cut excavations in three waters, what are the sources of emissions?
- How could emissions be reduced, and what information is needed to be in the report?

As a result of these issues and to focus on the gaps in industry, the research focuses on capturing greenhouse gas emissions in the traditional method of constructing underground pipelines via the open-cut method for three waters infrastructure network.

1.2 Research Problems

The Construction Industry is a vital sector that contributes significantly to a nation's economic and social development. In New Zealand, 8.2% of our national emissions come from Construction and Manufacturing (Ministry for the Environment, 2023a). Should there be a need to know more or find out about our construction infrastructure emissions in water, wastewater, stormwater (referred to as three waters), or other infrastructure industries, the data will need to be extracted, analysed, or calculated from the Ministry of the Environment's data series. This information is lacking, not readily available, or may not be officially acknowledged by the industry.

From the literature review, NZ's GHG inventory from the last 30 years (1990 to 2020) has neither increased nor decreased NZ emissions. It is generally plateaued at a net emission of 55.7 MtCO_{2e} (StatsNZ, 2022). NZ's commitment is to half our emissions by 2030 and be net zero by 2050. If NZ aims to decrease emissions, drastic action is needed. Although local authorities who manage NZ three water infrastructure, such as Auckland Council and Watercare, have quickly created emissions targets, capturing emissions data in the construction industry has been slow for several reasons. It is technically challenging (Crampton, 2022) and complex (Elhag, 2015), and many companies focus on direct costs (Alsadi & Matthews, 2020), neglecting environmental impacts that are difficult to quantify due to unknown or unavailable factors.

Additionally, there is a general lack of awareness and no mandatory requirement to capture or report emission data (BDO NZ, 2023). If the problem is a lack of carbon awareness or training, avenues need to be available for the industry to know more, train, and begin their carbon journey. For the nation to achieve net zero by 2050, there must be a compelling reason for business to change their customary practices.

Between 1st July 2024 and 1st July 2026, the Water Services Reform Programme will go live via The Water Services Entities Amendment Act (New Zealand Government, 2023). The reforms plan to establish ten water service entities to maintain and improve our water services nationally. Over the next 30 years, the cost to meet these challenges will be between NZD \$120 billion and NZD \$185 billion. Suppose drastic action is taken via the Water Services Programme to record and reduce carbon emissions mandatorily. In that case, issues in the adoption of quantifying and reducing GHG emissions need to be resolved. Research from the existing literature shows that the construction industry is not ready, not equipped, sees little need to do things differently, or does not know how to quantify carbon. If these barriers hinder the construction industry, new research is required to investigate a simplified method for untangling the complexities of quantifying carbon.

When reading and comparing the literature, three key themes were observed when quantifying and accounting for carbon emissions. The first theme is the Carbon Framework, which describes what to follow. The second theme is Construction Methodology, which considers the construction method and potentially identifies the sources of emissions. The last theme is Carbon Accounting, where emission sources are quantified and calculated using the emission factors to obtain the final carbon emissions or carbon footprint.

Complexity starts with the Carbon Framework. Pandey et al. (2011) identified at least seven essential estimation methods in their research. Elhag (2015) identified three others. Other researchers have mentioned other carbon frameworks, but they were similar to Pandey et al. and Elhag's lists. However, the Carbon Frameworks are not the same. Some compute the life cycle of products and services, while others are made to suit their particular needs or a particular industry.

According to the literature, the Life Cycle Assessment (LCA) method is the most common Carbon Framework. Researchers such as Alsadi and Matthews (2020); Chilana et al. (2016); Khan and Tee (2015) used this full-scale method from 'Cradle to Grave' or 'Cradle to Cradle,' in LCA jargon from the start of gathering raw materials or product stage to construction, use, end of life and the possibility of downstream reuse, recovery and recycling. If a business needs to assess its carbon emissions but is only doing the construction stage, quantifying its emissions using the full LCA framework could be costly when they do not need to. The Carbon Footprint method, which identifies an activity and multiplies the activity by its emission factor, is simple and easy to calculate (Wiedmann & Minx, 2007). The GHG Protocol Corporate Accounting and Reporting Standard (GHG Protocol) and ISO 14064 use Carbon Footprint calculations and are recommended by the Ministry for the Environment (2022a). However, comprehending and knowing these standards takes time. A review of the standards, such as the GHG Protocol, identifies generic steps such as creating a "target baseline", but a new user may not be able to understand or are not in a position to do so. If they were at the start of their carbon journey, their focus would be to create an inventory first. If the contractor has multiple sites, they must learn how to manage and combine their inventories into one. There must be a simpler method to understand the standards for a new user to know how to create a carbon inventory.

When following a Carbon Framework such as the GHG Protocol or ISO 14064, the user will come across the section on steps in identifying and calculating GHG emissions. As the standard was written to cater to different industries, the steps given in the standard are generic. It does not go into detail about the specific construction activities that are needed to identify and analyse emission sources. This lack of detail is a gap in the current research. To identify emission sources, users must know and understand the construction process and what to quantify. Alsadi and Matthews (2020) illustrated the

construction process using a life cycle diagram. Ariaratnam and Sihabuddin (2009) went deeper and presented a detailed work breakdown structure. From the work breakdown structure, emission sources from plants, machinery, and resources used in a project can be identified and quantified. Elhag (2015) cautioned that the final carbon footprint emission values can change if the method and level of detail are unclear. Unclear methods and details are not a surprise as a review of key literature from Alsadi and Matthews (2020); Ariaratnam and Sihabuddin (2009); Chilana (2011) showed their data and construction methodologies are all different. Most researchers showed US and UK standards with varying parameters and geotechnical conditions in their open-cut trenches. It may be due to differences in depths, widths, and varying ground materials. It is also important to note that the researchers were in the United States.

Having a defined construction standard allows constructors a methodology to construct the designed infrastructure. A work breakdown structure (WBS) was created using this methodology. The WBS identifies the plant, machinery, and materials that go with construction work as emission sources. Therefore, these emission sources must be quantified and recognised as a gap in the research because to quantify the identified activities, users need to know what units need to be measured for the activity and the duration of the activity. These factors are typically not published because, for example, if a construction contractor provides a service, they would not give away their competitive advantage or let their competition know what makes them better. Regardless, the benefits of learning these factors would provide research material for creating a working template to interrogate, calibrate, and provide GHG emission data.

Once the emission sources have been quantified, the values are calculated with the corresponding emission factor, which results in the final GHG emissions or Carbon Footprint. In its simplified form, the final result where the final GHG emission is found is Carbon Accounting. From the literature, two other types of calculations account for carbon. The second method was used by Chilana (2011); Chilana et al. (2016); Khan and Tee (2015); Nandyala et al. (2019) and performed energy-based calculations. Those unfamiliar will initially find this method complex until the reader understands the science and math needed to compute it. This calculation is typically used in LCA frameworks. A simplified version of the energy calculation was used by Kim et al. (2012), who employed a three-stage energy calculation. The last method is direct measurement. Pandey et al. (2011) explained the instruments needed to measure GHG emissions directly from the source in their research. In addition, Pandey et al. (2011) mention that emission factors stored in databases vary by up to 40% for some products. Pandey et al. (2011) noted that the IPCC and the GHG Protocol recommend region-specific emission factors as region-specific emission factors are verified for their operation and geographical

context. A review of the literature shows that some emission factors are not locally available, and more research is needed to find more sources of information.

The current literature indicates a lot of research on building construction in New Zealand, but little research has been conducted on the construction of infrastructure. In particular, research is scarce or limited to local authorities in the three waters sector. At the time of writing, there were no clear or official national GHG emissions in the three-water sector. Significant infrastructure work is imminent in the next two years, and it is only a matter of time before accounting for carbon emissions in construction becomes mandatory. However, the findings in the literature suggest that a large portion of the construction industry is not ready, not equipped, sees little need to do things differently, and does not know how to quantify carbon. The literature attributes these challenges to several key factors: the technical complexity of Carbon Accounting, the availability of multiple frameworks without explicit critiques on what works best, the interdependence of various elements of the carbon accounting process, the non-transparent nature of knowledge and technical skills required to undertake a carbon inventory, and the lack of clear information on the key inputs and variables that are crucial in developing an accurate account of emissions. This study aims to address these challenges and provide a solution.

1.3 Research Aim and Objectives

This research aims to create and develop a simplified methodology and a template for Contractors to create their own Carbon Inventory on the installation of 3 waters open-cut pipeline excavation infrastructure.

The following objectives have been written to achieve the aim.

- Review literature on open-cut excavations and their emissions
- Develop work breakdown structure from local authority standards (Watercare and AC Standards) related to 3 waters open-cut excavation.
- Review local carbon emission factors applicable to 3 waters including Environmental Product Declarations (EPDs) and NZ-based emission databases.
- Identify what emissions must be reported to the relevant authorities for transparency and accountability.
- Develop a first principles tool to calculate the installation carbon emissions of a 100ø PVC pipe, 100m at 1.3m depth.
- Verify the developed GHG installation emission values calculated against EPD published values out in the industry.

1.4 Research Methodology

Literature Review – A comprehensive literature review was done to find previous research and gaps in the chosen research area (refer to section 2.2). To identify critical articles, keywords and their synonyms related to the aim and objectives were selected. These are “State-of-the-art”, ‘Carbon Footprint’, ‘Open-Cut’, ‘Pipes’, and ‘Construction’. The search engine considered was Discover and Scopus. To broaden the search, the feature “cited by” was used to dig deeper to find other academic articles. The search was then screened and selected. The articles' methodologies, data, and geographical location were grouped and analysed.

Preliminary research reveals that carbon quantification is complex and is a multidisciplinary practice. From the iterative review process, three key themes were dominant throughout the research area and became the research focus. The first subject is the Carbon Framework methodology (section 2.4). The second is a good understanding of the Construction Methodology (section 2.5), and the third is Carbon Accounting (section 2.6). These three interlinked subjects, when synthesised, create a comprehensive carbon inventory. Digging deeper into the literature revealed gaps in the literature. Additional supplementary research was done to fill in the gaps, and key literature sources are tabulated in Appendix 2, Table 39 to Table 42.

Development of the Carbon Framework Methodology – Based on a pragmatic approach, literature and data collection findings, the multiple standards from the literature were compiled, reviewed, and matched to see if it fulfils the aim.

By process of elimination the Carbon Framework was developed, as seen in section 3.5. Research from Pandey et al. (2011) and the Ministry for the Environment (2022a) recommended using the GHG Protocol. The standard PAS 2080:2016 carbon management system was investigated because it successfully reduced capital and operational carbon in the UK (Anglian Water) (Enzer, 2013). The GHG Protocol and PAS 2080:2016 steps in quantifying carbon were blended by inductive reasoning. Learnings from the literature were used to order and reinforce the steps to quantify carbon in section 3.3. The structure was finalised in section 3.4, and the final framework is shown in section 3.5, Figure 23: Final Construction Carbon Framework.

Creation of the Open-Cut Excavation Carbon Tool – To demonstrate the effectiveness of the Carbon Framework, a carbon tool was created using first principal calculations in Excel (Positivism). A simple case study was used as an example, and the framework was implemented. The case study was a 100m, open-cut excavation installing a 100ø PVC pipe. This could be used for water, wastewater or stormwater networks. Worksheets were created to guide the user to follow the steps in the Carbon Framework. There are dedicated diagrams for the specifications, study boundary and work breakdown

to show the user what steps they need to follow visually. Dedicated worksheets were also included for calculating quantities of the identified materials and sources. Lastly, there is a final calculation page where the final emission values or carbon footprint are calculated, and the quantified activities are multiplied by their corresponding emission factor. The carbon footprint is then categorised according to the standard's operational boundaries and presented as a chart for reporting.

Data Validation – The values of the carbon tool were checked with recent installation values published by local pipe suppliers' EPD documentation. The values were reviewed and compared to see how well the results from the carbon framework tool match or deviate from the values published and provide a reason why. The tool was also presented to tier 1 and tier 2 contractors who have installed stormwater, water, and wastewater pipes for the last 20-25 years. The contractors were asked to complete a questionnaire to check the tool's usefulness and effectiveness and whether the carbon tool fulfilled its purpose in assisting contractors in their carbon journey (Interpretivism).

Data Analysis – The data collected in this research was mainly quantitative and verified using recently published EPDs from the industry. The effectiveness of the new carbon framework and carbon tool was also done quantitatively to analyse the tool's effectiveness. The questionnaires were analysed using statistics in Microsoft Excel.

1.5 Scope and Limitations

There are multiple physical combinations of open-cut excavations for pipes. It may range from different depths, widths and lengths are sometimes designed uniquely to suit the excavation area's conditions. Therefore, to limit the complexity, the scope of works is on the open excavation of a 1000 PVC pipe, 100m long, 1.3m deep.

The excavation specifications for stormwater are as per Auckland Councils Stormwater Code of Practice. While the specifications for water and wastewater as per Watercare.

The scope of works is limited to "Cradle to Practical Completion" in terms of Life Cycle Terminology.

For detailed descriptions on this section, refer section 4.2.

1.6 Significance of the Study

The study contributes to NZ Construction by providing the following:

- Provides a novel carbon framework and a step-by-step guide to creating a carbon inventory from a construction/civil engineering perspective.
- It provides a visual reference for users to define the scope of their works and explore its limitations.
- Demonstrates the importance of having a construction methodology and creating a work breakdown structure to identify emission sources and quantify the recognised emission sources to create a carbon footprint.
- Informs construction companies who have yet to begin their carbon journey about the resources required and what they need to measure.
- While proprietary subscription-based resources are available in the market that provide emission factor databases, this research offers some resources on where to find local EN 15804-compliant EPDs within the geographical scope and manufacture in NZ.
- Provides a solid foundation to educate contractors on the why, what, and how to calculate the carbon footprint of open-cut excavation on three water infrastructures.
- Provides critical findings that could be implemented on the possible three water reforms program for capturing the carbon footprint of pipelines installed via open-cut excavation.

1.7 Structure of the Thesis

This thesis is structured into six chapters.

Chapter 1: Provides a background to the thesis, the research problems, the aims and objections, the methodology structure, its scope and limitations and the significance of the study to the industry.

Chapter 2: Gives the reader an in-depth critical review of the existing literature. The chapter has four parts: the first provides the background on climate change, followed by the Carbon Framework, Construction, and lastly, the Carbon Accounting.

Chapter 3: Discusses the development of the simplified Carbon Framework. The chapter systematically discusses how two essential standards created the novel framework and how the lessons from the existing literature were used to support and strengthen the framework's structure.

Chapter 4: Explains how the carbon tool was created. It uses the new framework as the structure and defines the carbon tool's scope and limitations. The steps required before gathering data and the information that must be quantified and researched.

Chapter 5: Discusses the findings and the results from the carbon tool created.

Chapter 6: This chapter provides the conclusions and recommendations.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Section 2.2 provides the steps on how existing literature was conducted. It goes through the keywords, the search engine, screening, and selection criteria. Here, the reader can see the existing literature and critical documents.

In section 2.3, explain what climate change is and why it needs to be addressed. It gives a purpose as to why this research is required. It discusses what the world is doing about it and the global agreements that aim to avoid a potentially warmer world. Despite the dangers in our climate, Construction continues as it helps nations to develop. This section explains how construction is affecting our climate. It continues by looking at NZ GHG emissions and its construction sector and what is needed to reduce our construction emissions potentially.

Section 2.4 discusses the different Carbon Frameworks currently available. It looks at their approaches, strengths, applicability, and differences and identifies which framework might be helpful to achieve the aims and objectives of this research. Overall, section 2.4 discusses what steps to take to quantify GHG emissions.

Section 2.5 provides an in-depth description of the construction process. It explains pipelines and the excavation process. It further explores and expands on its lifecycle and shows the open-cut construction process. It addresses some of the gaps in the literature and how knowledge from other sub-sectors is used to fill the gap. Finally, it discusses the construction standards that are used in this research.

Section 2.6, this section talks about Carbon Accounting. It looks at the quantified activities that go into construction, the science (emission factors), and how it is calculated to provide a carbon footprint.

2.2 Review of Existing Literature

2.2.1 Keywords

To identify critical articles for this research, keywords and synonyms related to the aim and objectives were entered into selected search engines to create an initial search. Table 1 below tabulates the keywords and their synonyms.

Table 1: Keyword synonym search

State of the Art	Carbon Footprint	Excavation	Greenhouse Gas	Pipes	Construction
highest development	Carbon Emissions	Open Cut	Greenhouse emissions	Pipelines	Construction
recent development					

2.2.2 Selected Engine

The database search engines considered are *Discover*, *Scopus*, and *Google Scholar*, as these databases contain scholarly, peer-reviewed journals, conference papers, books, and other articles.

When searching for articles in *Discover* and *Scopus*, there was little to no research in the chosen field. Hence, in this report, articles in *Scopus* and *Google Scholar* are used, but other results from other databases are also included if relevant to the study.

To broaden the search for other critical articles, the key feature in *Google Scholar*, “Cited by,” was used to dig deeper and find other academic articles that have been completed in the past.

2.2.3 Screening Rule and Selection Criteria

The search was screened using the following rules, and the reasons the rules were chosen are provided below:

- Limited to Keywords – “Carbon Footprint, open-cut excavation, construction and pipes” to keep the search focused on the chosen key area.
- Articles after 2007 are included in the analysis (15+ years); this is because carbon accounting is an emerging field, and though scholarly articles were likely initiated after the Kyoto Protocol

in 1997, studies might have gained momentum following the IPCC's fourth assessment report (FAR) in 2007, which unequivocally confirmed climate change (IPCC, 2007).

2.2.4 Data Retrieval Summary

Figure 1 below summarises the steps used.

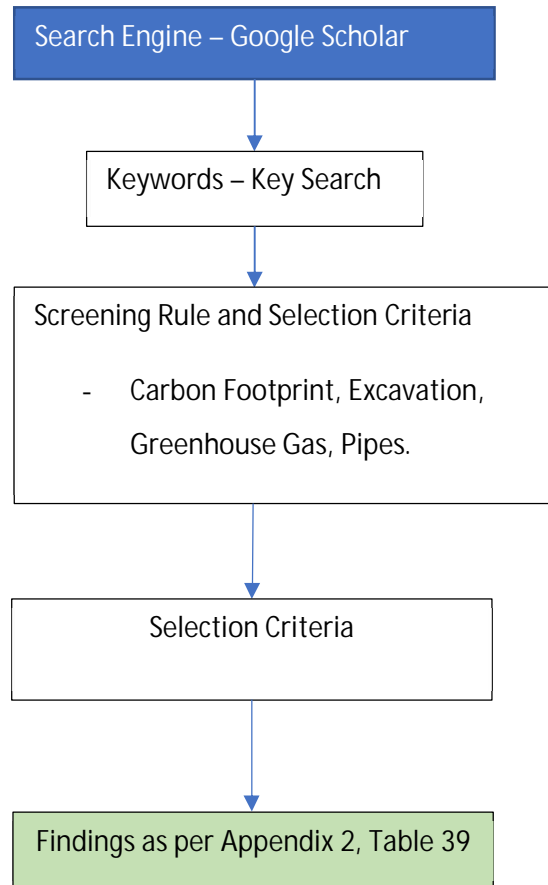


Figure 1: Data Retrieval Summary

2.2.5 Existing Research

From the data retrieved in the search, the relevant literature on the research topic on Carbon Footprint of Open-Cut Pipelines and a summary of the author's fundamental concepts are listed in Appendix 2, Table 39. Table 40 and Table 42 in Appendix 2 shows additional research to address the gaps in the literature.

2.3 Climate Change and Construction

2.3.1 Introduction

Section 2.3.1 to 2.3.5 defines climate change and looks at its causes. It discusses what the world has done in response to climate change and the action and inaction it has taken. It attempts to fill the knowledge gap and provides a compelling reason to quantify and reduce our emissions. Section 2.3.6 looks at Construction and its effects globally, and sections 2.3.7 to 2.3.11 look at NZ emissions and the required work.

2.3.2 Climate Change and Greenhouse Gas

It is worth knowing the definitions of weather, climate, and the greenhouse effect to understand climate change best.

The World Meteorological Organization defines weather as the state of the atmosphere at a particular time (WMO & OMM, 1966). The IPCC describes the climate as the average weather over a long period. It could range from months to thousands or millions of years. The period for averaging is typically 30 years, as defined by the World Meteorological Organisation. For simplicity, the weather is referred to as short-term, while climate is a long-term weather pattern. The weather has a baseline where it fluctuates either up or down. It is affected naturally by external forcings such as modulations of the solar cycles and volcanic eruptions or anthropogenic (human-caused) activities such as greenhouse gases (GHGs). The change in the state of the climate is called climate change (IPCC, 2018).

When the sun emits energy to the Earth, some is reflected into space. At the same time, short-wave solar radiation travels unrestricted and warms the Earth's surface and lower atmosphere. The heated surface of the earth radiates up to the atmosphere as long wavelengths where greenhouse gases such as Carbon Dioxide, Methane and Nitrous Oxide absorb and trap heat similar to a greenhouse, hence the term Greenhouse Effect. (Mitchell, 1990; NIWA, 2023a).

What's important to note is that not all GHG gases have the same effect. Carbon Dioxide, for example, can stay in the atmosphere for thousands of years, and others like Methane. However, it may not remain in the atmosphere as long as Carbon Dioxide and methane can absorb 28 times more energy, refer to section 2.6.2.1, Table 11, AR5. The more GHGs is emitted from anthropogenic activities, the warmer our atmosphere becomes.

2.3.3 *The Intergovernmental Panel on Climate Change*

In response to climate change, the United Nations Environmental Programme and the World Meteorological Organisation, with the endorsement of the UN General Assembly, established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC's goal at the time was to prepare a comprehensive review of the science, the social and economic impact and possible response to climate change (IPCC, 2023a).

The IPCC has released six key assessment reports, each comprising four separate reports. Three reports are done by Working Groups (WG) 1 to 3. WG1 is the science basis, WG2 is the social and economic basis, and WG3 is the response or mitigation. In contrast, the fourth report, the Synthesis Report, summarises the science and knowledge around climate change. The key topics of these documents are discussed below:

- a) The First Assessment Report (FAR) 1990 predicted global warming's pace without complex computer models and linked it to human-generated emissions. It noted a 0.6°C increase in global mean surface air temperature over a century (IPCC, 1992).
- b) The Second Assessment Report (SAR) 1995 reinforced the link between human activities and climate change, emphasising vulnerabilities in some communities due to environmental hazards such as storms, floods, and droughts in sensitive areas such as river basins and coastal plains. This report played a pivotal role in adopting the Kyoto Protocol in 1997, where the six key greenhouse gases were identified, refer to section 2.3.3. Annex B of the Kyoto Protocol shows that NZ was one of the developed countries or pioneers in the carbon reduction journey (IPCC, 1995).
- c) The Third Assessment Report (TAR) 2001 projected continued temperature and rising sea levels. It provided tables of Global Warming Potentials factors on different GHG gases critical values needed in GHG emission calculations (IPCC, 2001).
- d) The fourth assessment report (AR4) in 2007 confirmed without a doubt (unequivocal) that our climate system is warming as observed in the changes in the air and ocean temperatures, widespread melting of snow and rising of the global sea level (IPCC, 2007).
- e) The Fifth Assessment Report (AR5) in 2014 published that the emissions from human activities are higher than ever. It introduced four Representative Concentration Pathway (RCP)

scenarios, refer Figure 2. These scenarios outlined potential temperature increases based on emissions (IPCC, 2014) and were a critical document that provided the scientific input into the Paris Agreement (IPCC, 2023a), refer §2.3.5,

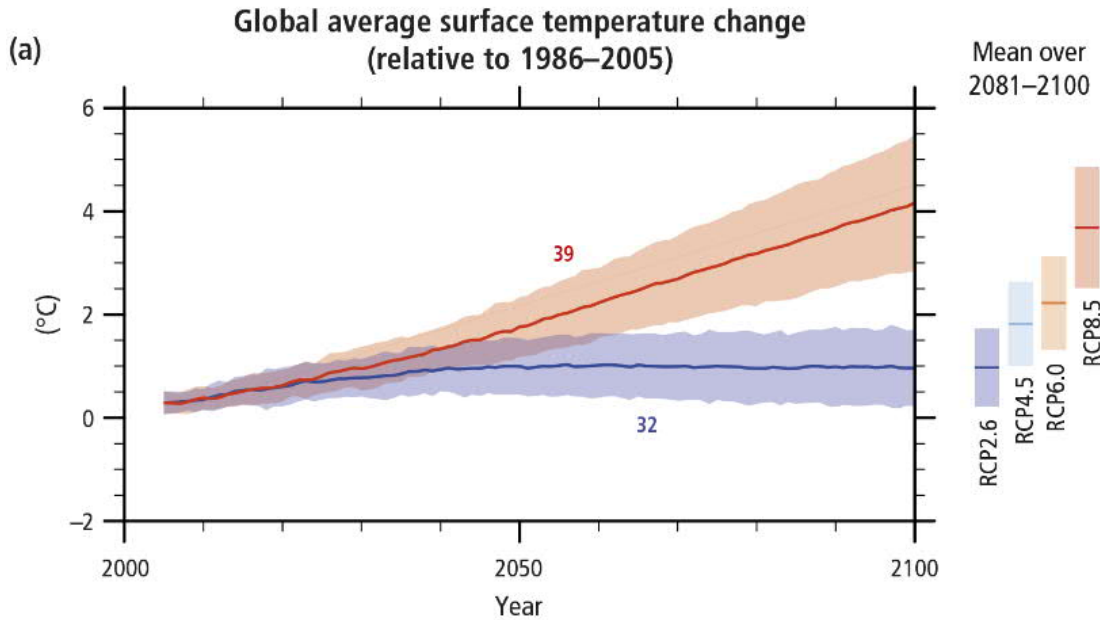


Figure 2: Climate Change Synthesis Report - Figure SPM.6 (IPCC, 2014)

- f) The Sixth Assessment’s Report (SAR) in 2023’s synthesis report emphasised insufficient efforts to combat climate change, predicting potentially catastrophic temperature increases if emissions are not significantly reduced. E.g. The global surface temperature had already risen by 1.1°C post 2020 compared to the 1850-1900 baseline (IPCC, 2023b).

2.3.4 UNFCC and the Kyoto Protocol

In 1992, several countries created a treaty to combat climate change and the United Nations Framework on Climate Change (UNFCC) was established. The UNFCC convention divided the countries into three main groups. Annex I was developed countries that are/ were part of the Organisation for Economic Co-operation and Development (OECD) and the Economies in Transition (EIT); Annex II consisted of the OECD members in Annex I only. While Non – Annex I mainly was developing countries. The idea of the UNFCC was to have the developed countries (Annex I) lead the change (UNFCC, 2023c).

In 1995, the countries strengthened their response to climate change, and the Kyoto Protocol was operationalised on the 11th of December 1997 (UNFCC, 2023a). Some of the critical clauses implemented by the Kyoto Protocol are:

- In Article 2, the clause required the parties in Annex I to achieve their quantified emission limitation and reduction commitments; they had to implement policies and measures such as protection of sinks and reservoirs of greenhouse gases, promotion of sustainable agriculture, promotion, research, develop new renewable forms of energy and limit greenhouse gases not controlled by the Montreal Protocol (Treaty about the substances that deplete the Ozone Layer and the agreements to protect and restore it) (UNFCC, 1997).
- Using the IPCC SARs Report, the Kyoto Protocol incorporated the six key greenhouse gases that must be reduced. These are CO₂ – Carbon Dioxide, CH₄ – Methane, N₂O – Nitrous Oxide, SF₆ – Sulfur Hexafluoride, HFC's – Hydrofluorocarbons and PFC's – Perfluorocarbons. It also identified sector and source categories of GHGs such as the energy, industrial processes, agriculture sectors and waste.
- The first mention of Emission Trading is the process of buying and selling carbon credits from one another. In the example of a forest owner, a forest owner can earn several carbon credits for their quantified portions of the forest as the forest sequesters or absorbs Carbon Dioxide. The forest owner may trade, sell, or keep the credits to a partner who would like to reduce their Carbon emission. This knowledge is essential as it reduces a stakeholder's (business, asset owner, contractor, or supplier) carbon emission.

2.3.5 The Paris Agreement 2015

The Paris Agreement was created ten years after the Kyoto Protocol and following the IPCC’s AR5 report. The Paris Agreement is a legally binding agreement by almost all the countries in the world (196 parties) at the United Nations Climate Change Conference (COP21) in Paris, France, on the 12th of December 2015. The UNFCCC (2023b) explains vital aspects of the Paris Agreement, such as strengthening the global response to climate change by keeping a global temperature rise well below 2°C above preindustrial levels and limiting the temperature to 1.5°C. Another is to increase countries' ability to deal with climate change's impacts and make finance flow consistent with a low GHG emission and climate resilient pathway. It also requires all parties to put forward their efforts through nationally determined contributions and report regularly on their emissions and implementations.

2.3.6 Construction and its Global Emissions

The Construction Industry is a vital sector that significantly contributes to a nation’s economic and social development. It builds and maintains infrastructure and is a significant source of employment (Lopes, 2012; Ofori, 2015; Turin, 1980). The global Gross Domestic Product (GDP) was 13% in 2020 and is expected to reach over 13.5% by 2030 (Robinson et al., 2021). However, the IEA and UNEP (2018) report that buildings and construction account for 39% of global emissions, with 36% as global energy use, refer to Figure 3. In their report, the WorldGBC (2019) accounts for 28% of operational carbon, while the balance of 11% is the energy used to produce building and construction material, referred to as embodied carbon.

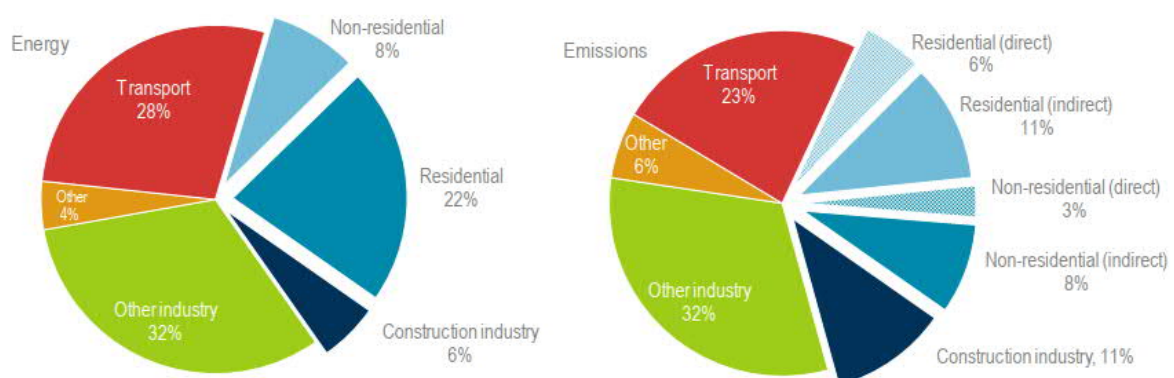


Figure 3: Global Share of Buildings and Construction (IEA & UNEP, 2018)

The MBIE (2020) explains that emissions produced by the life cycle of a building are put into two groups. These are:

- Operational Carbon – All GHG gas emissions during the use stage of the building’s life
- Embodied Carbon – emissions from the materials and products that form the building can occur across the building’s life cycle.

Figure 4 depicts the difference between operation and embodied carbon. As the research focuses on the installation of pipelines, only embodied carbon will be addressed.

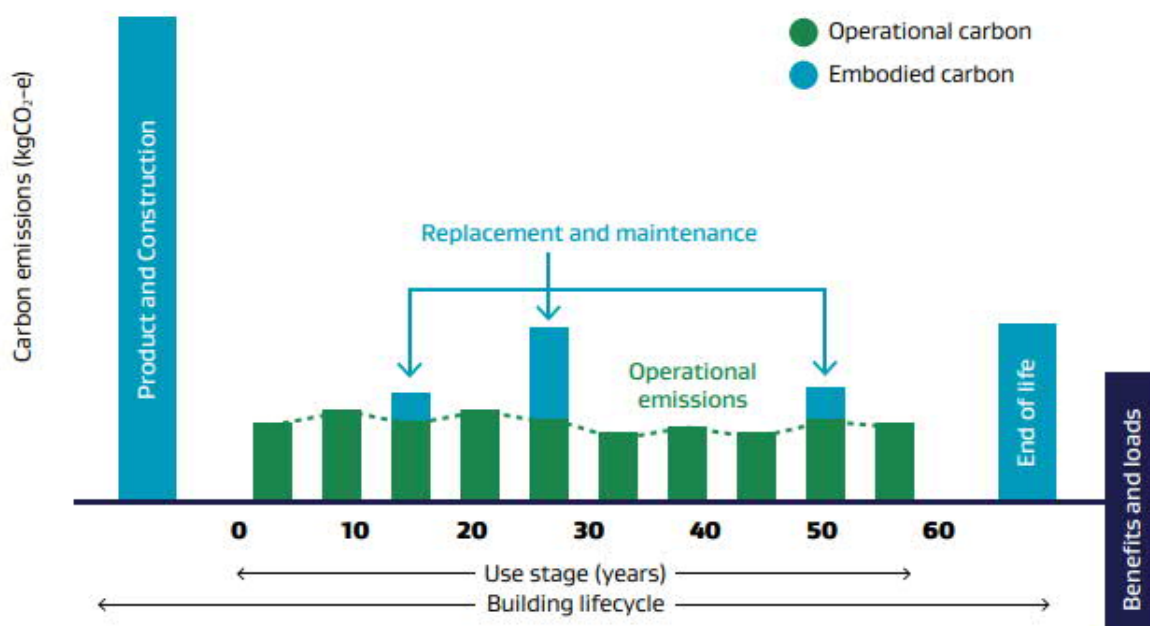


Figure 4: Operational and Embodied Carbon Emissions (MBIE, 2020)

As the focus of this research is on the construction of pipe infrastructure for water, wastewater, and stormwater, finding emission data on this sector was scarce because predominantly construction infrastructure is embedded in building and construction emissions or on the opposite side of the spectrum, pipeline construction companies do not evaluate their carbon emissions (Alsadi & Matthews, 2020) However, recent research from Thacker et al. (2021), expanded and included construction infrastructure. Their report showed construction infrastructure contributed to 79% of total greenhouse gases. 5% of the emissions are attributed to the Water Sector, refer to Figure 5.

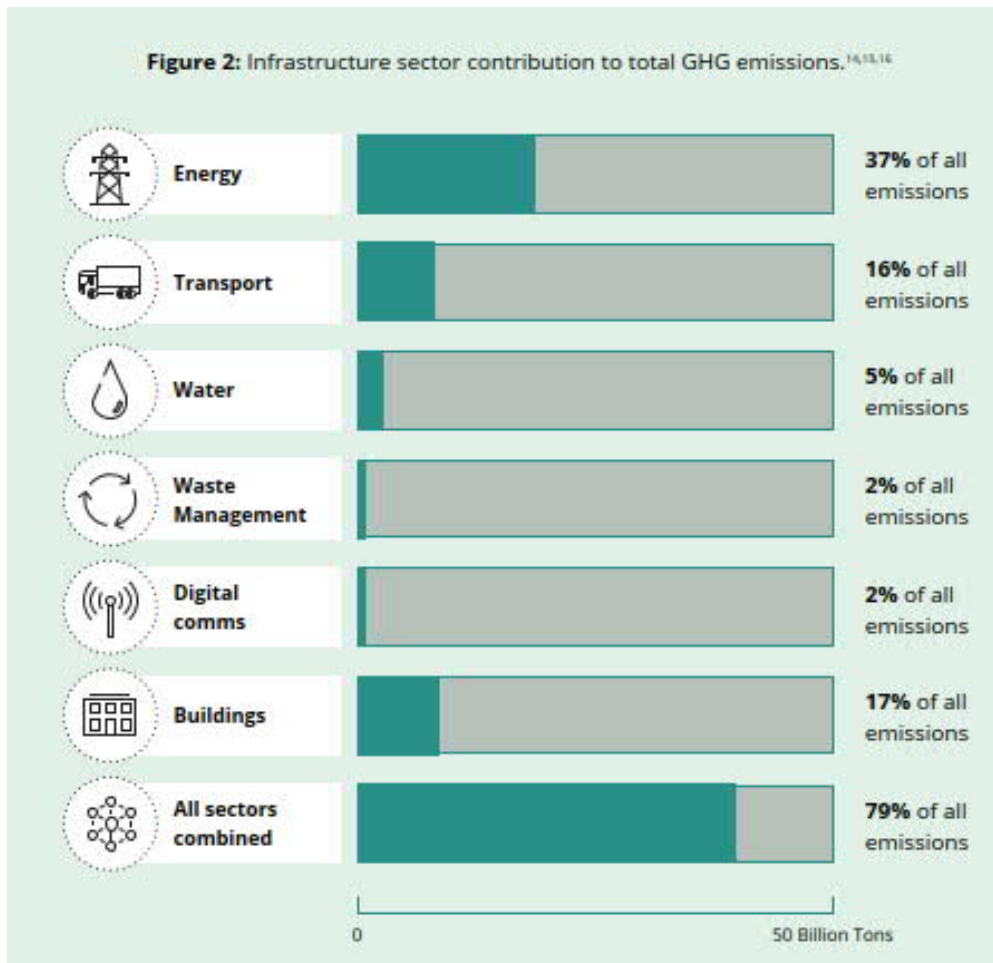


Figure 5: Infrastructure Sector Contribution to the total GHG emissions. (IBRD, 2010)

Although water is only 5% of all emissions, the water sector demands the highest level of investment as this is primarily attributed to the effects of climate change, including the heightened risk of water supply disruptions from droughts, desertification in various regions of the world, and the need for infrastructure projects aimed at protecting coastal cities from sea level rise. Adaptation costs in the water sector are estimated to account for 54% of all costs, as illustrated in Figure 6.

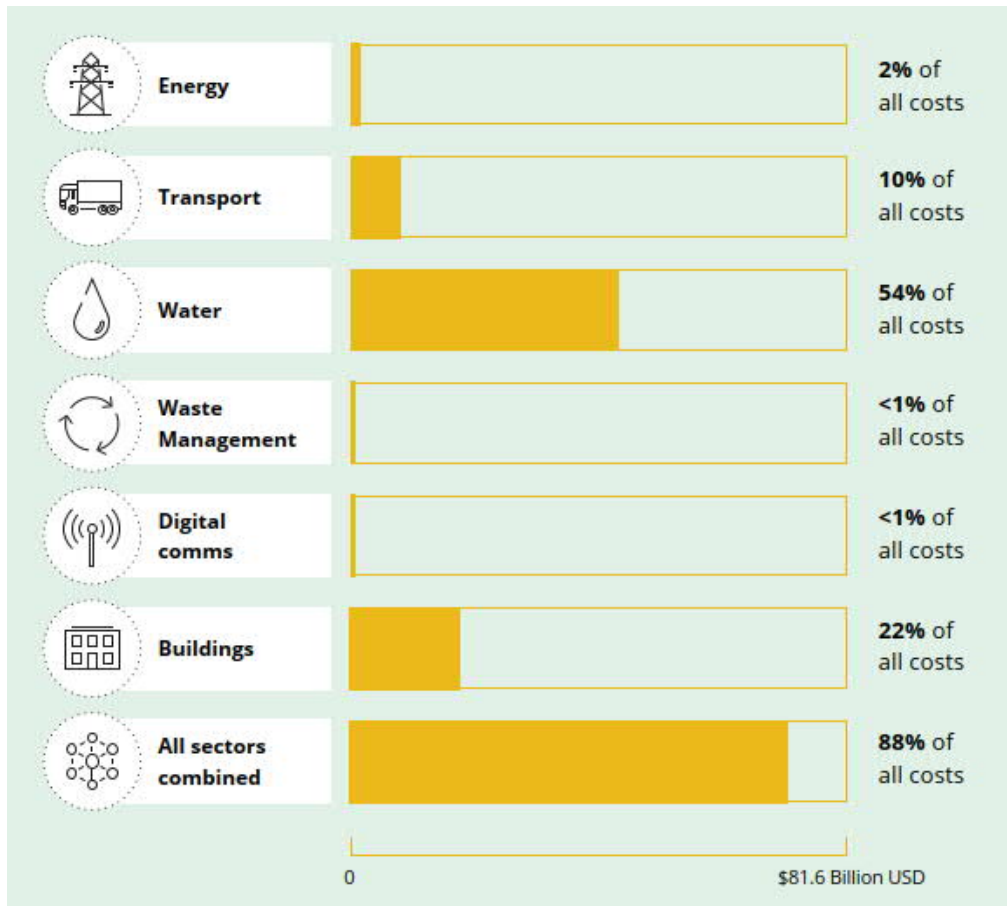


Figure 6: Infrastructure Sector Share of Global Climate Adaptation Cost ((IBRD, 2010)

2.3.7 NZ Greenhouse Gas Inventory 1990 – 2020 Sector

From New Zealand’s Greenhouse Gas Perspective, the Ministry for the Environment (MfE), as part of its commitment to reporting under the UNFCC and Kyoto Protocol, produces NZ’s greenhouse gas inventory from 1990 - 2020 (StatsNZ, 2022). Their latest records show a net emission of 55.7 MtCO₂e. Figure 7 below shows NZ’s 2030 and 2050 net zero targets, excluding biogenic methane. It can be seen that NZ’s emissions are stable; if, in the last 30 years, NZ emissions have not increased or decreased dramatically, what actions do we need to take to achieve the necessary reduction and reach our target of net zero GHG emissions by 2050?

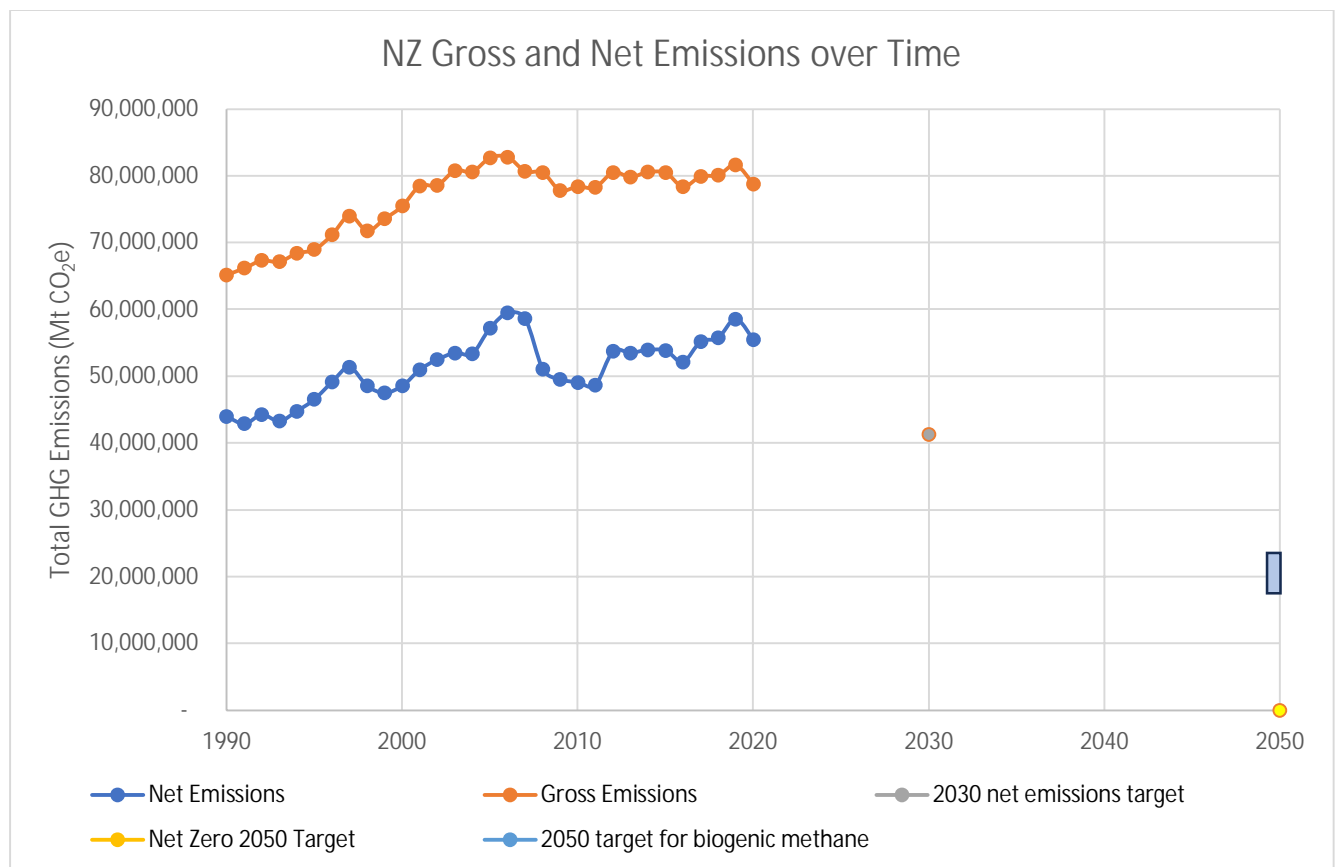


Figure 7: NZ Gross and Net Emissions over Time, sourced from StatsNZ (2022)

When looking at emissions by sector, they reported the following breakdown: 49% from Agriculture, 41% from Energy, 6% from Industrial processes and product use, 4.2% from Waste, and -27% from Land Use, Land-Use Change and Forestry. Within the Energy Sector, Manufacturing and Construction account for 20% (8.2% of the total 40.6%) as depicted in Figure 8. Considering the thesis’s focus on pipework infrastructure and construction, further investigations were undertaken to determine the percentage of construction-related emissions in New Zealand. However, finding specific construction data was complex as it is embedded and combined with other sectors or needed to be extracted, combined, and calculated, refer to section 2.3.8.

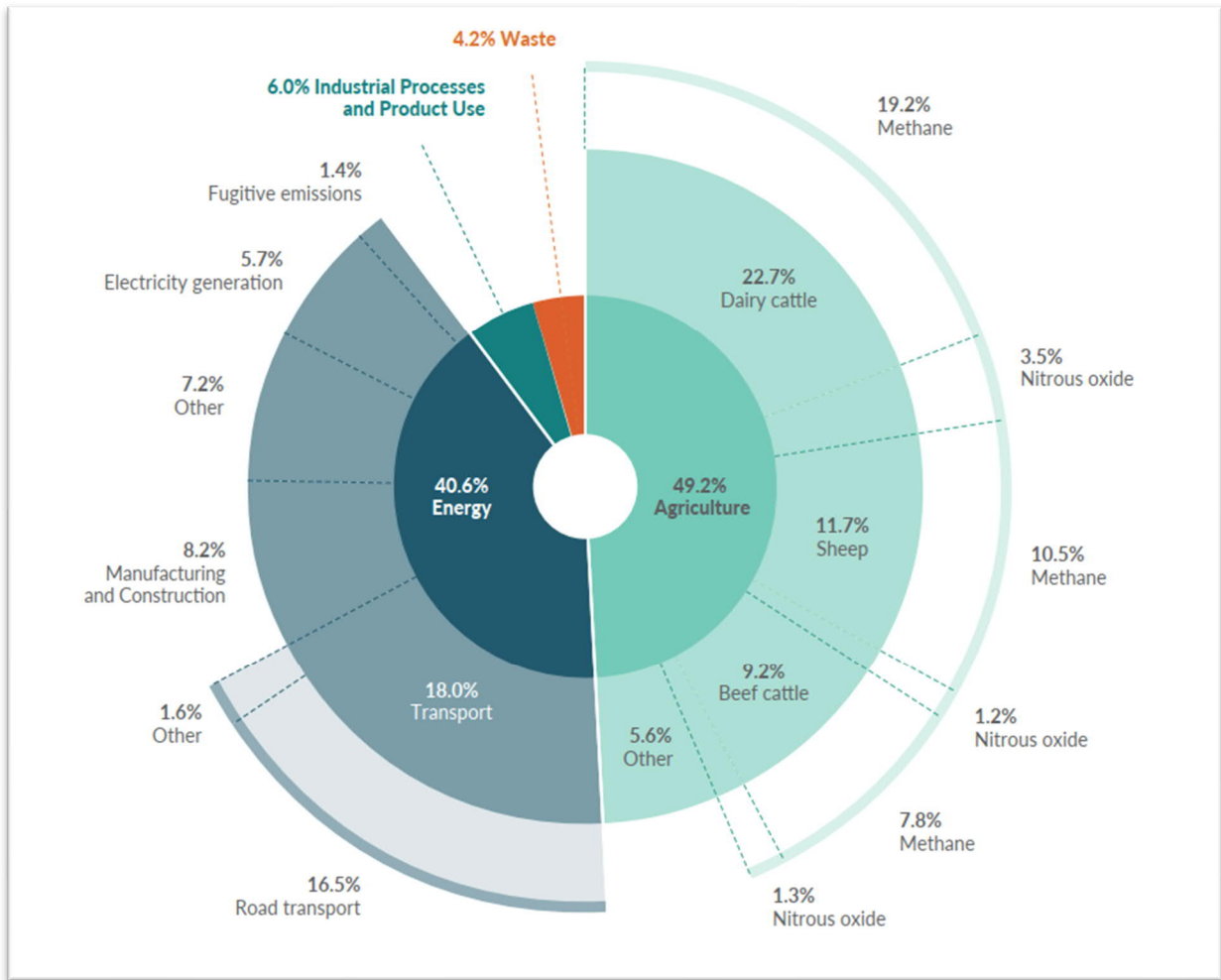


Figure 8: MfE NZ GHG Gas Inventory Snapshot 2021 (Ministry for the Environment, 2023b)

2.3.8 NZ GHG Inventory Reporting Emissions – gap and possible improvement?

Further research in the Energy Sector in the MfE’s GHG Inventory was pursued because Construction data is grouped with Manufacturing, as shown in Table 2 below. Drilling into the manufacturing and construction sector, the inventory is further categorised into specific materials such as Iron and Steel, Pulp and Paper, and Non-Metals, as indicated in Table 3. However, despite some data provided by the MfE, the emission sources in the inventory are fragmented.

Table 2: Ministry for the Environment (2022c), Table 3.1.1 Key Categories in the Energy Sector

CRF category code	IPCC categories	Gas	Criteria for identification
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO ₂	L1, T1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO ₂	L1, T1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Liquid Fuels	CO ₂	T1
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO ₂	L1, T1
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO ₂	T1
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO ₂	L1, T1
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO ₂	L1, T1
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO ₂	L1, T1
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO ₂	T1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO ₂	L1, T1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO ₂	L1, T1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO ₂	L1, T1
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO ₂	T1

Table 3: Time Series Emission Headings (Ministry for the Environment, 2023c)

1	[1. Energy]
1.AA	[1.AA Fuel Combustion - Sectoral approach]
1.A.1	[1.A.1 Energy Industries]
1.A.1.a	[1.A.1.a Public Electricity and Heat Production]
1.A.1.b	[1.A.1.b Petroleum Refining]
1.A.1.c	[1.A.1.c Manufacture of Solid Fuels and Other Energy Industries]
1.A.2	[1.A.2 Manufacturing Industries and Construction]
1.A.2.a	[1.A.2.a Iron and Steel]
1.A.2.b	[1.A.2.b Non-Ferrous Metals]
1.A.2.c	[1.A.2.c Chemicals]
1.A.2.d	[1.A.2.d Pulp, Paper and Print]
1.A.2.e	[1.A.2.e Food Processing, Beverages and Tobacco]
1.A.2.f	[1.A.2.f Non-metallic Minerals]
1.A.2.g	[1.A.2.g Other (please specify)]
1.A.3	[1.A.3 Transport]
1.A.3.a	[1.A.3.a Domestic Aviation]
1.A.3.b	[1.A.3.b Road Transportation]
1.A.3.c	[1.A.3.c Railways]
1.A.3.d	[1.A.3.d Domestic Navigation]
1.A.3.e	[1.A.3.e Other Transportation (please specify)]
1.A.4	[1.A.4 Other Sectors]
1.A.4.a	[1.A.4.a Commercial/Institutional]
1.A.4.b	[1.A.4.b Residential]
1.A.4.c	[1.A.4.c Agriculture/Forestry/Fishing]
1.A.5	[1.A.5 Other (Not specified elsewhere)]
1.A.5.a	[1.A.5.a Stationary (please specify)]
1.A.5.b	[1.A.5.b Mobile (please specify)]
Biomass	[Biomass]
Fossil fuels	[Fossil fuels]

Extracting, analysing, and manually calculating the data is necessary to get meaningful construction-related data from the MfE's time series emission data. The MfE clarifies that their reporting aligns with the requirements set by the UNFCCC reporting guidelines (Ministry for the Environment, 2023a). At a macro level, the current reporting provides a valuable indicator for focusing on high emitters. However, as more and more industries begin recording their emissions, specific sectors like Construction should have their category; this would increase transparency and provide a clear picture of emissions within the construction sector. Having a construction category would then assist industry or central government in their decision-making process and assist them in focusing on or reducing emissions in the construction sector. Such is the case in Elhag's research, where they saw a rise in carbon emission data generation across different sectors.

For instance, the NZ Government has invested in projects such as the arc furnace for NZ Steel, which is expected to reduce the country's emissions by 1% (MBIE, 2023). With major construction projects across motorways, roads, rail, and a potential for a new harbour bridge or new water Infrastructure throughout New Zealand, there will be a growing need for a clear and official source of construction infrastructure emission if we want to be net zero by 2050. Currently, there is no official or apparent source.

2.3.9 What are the repercussions of persisting with conventional business as practices?

NIWA (2023c) looked at climate change scenarios should human-induced changes persist to continue without change and what will happen to climate. Based on the Intergovernmental Panel on Climate Change Fifth Assessment Report, NIWA looked at the report's four representative concentration pathways (RCPs). RCPs are greenhouse gas concentrations split as RCP 2.6, 4.5, 6.0 and 8.5. RCP 2.6 is a mitigation pathway where some CO₂ is removed from the atmosphere. RCP 4.5 and 6.0 are potential increases with varying mitigations, and RCP 8.5 is business as usual. NIWA also looked at 41 different global climate models (GCMs), and six GCMs were used to statistically downscale to develop temperature and precipitation projections for NZ climate. The MfE report published "Climate Change Projections for New Zealand" results. Figure 9 below shows the RCPs and the projected near-surface air temperature corresponding to the year.

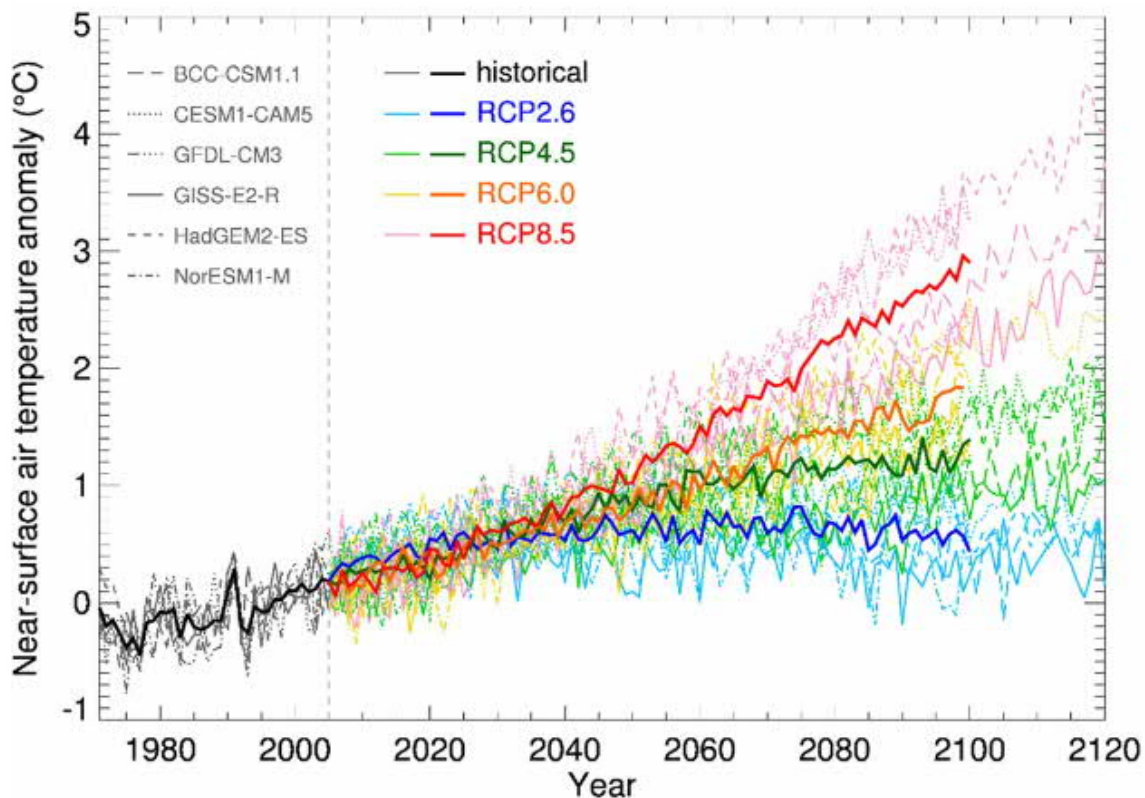


Figure 9: Climate Change Projections for NZ (Ministry for the Environment, 2018a)

Some of the key findings are written below:

- By 2110, temperatures are projected to increase by 0.7°C to 3.7°C

- Daily temperature extremes of frost will decrease by 30-50% by 2040. 30-90% by 2090
- Daily temperature extremes of hot days will increase by 40-100% by 2040. 40-300% by 2090.
- Precipitation will vary across the country and with the season.
- Drought will increase in severity and frequency by 2090 up to 50mm or more increase yearly.
- Extreme wind speeds up to 10% or more.

NZ's average annual temperature has risen by 1.13 (± 0.27) °C from 1909 to 2019. The Ministry for the Environment (2020) report, "Our Atmosphere and Climate 2020", observed 30 sites across NZ and the following observations were recorded:

- The annual average temperature in Aotearoa, NZ, continues to increase.
- Daily average high and low temperatures increased at many sites.
- The number of heatwaves has risen more than half the sites.
- Changes to rainfall are beginning to emerge where the annual rainfall has either decreased or increased on 80% of the sites.
- Changes to the frequency and intensity of drought
- The volume of ice in our NZ's glaciers has decreased.

The oceans are rising, warming, and becoming more acidic. NIWA (2023b) wrote the possible impacts for NZ range from:

- Health – The hotter temperatures and heatwaves may bring vulnerable groups such as babies, the elderly, and outdoor workers health issues. Anxieties may heighten due to extreme weather events such as flooding, storm surge or forest fires.
- Sea level rise – two-thirds of New Zealanders live within 5 km of the coast. The warming climate results in the sea levels rising. These will result in coastal retreat to all coastal species and create a habitat squeeze. Infrastructure such as roads may be altered to suit the level of access.
- Ecosystems – As our ecosystem is interconnected with plants and animals, all species within the ecosystem will likely be affected.
- Coastal and marine environments – The oceans absorb some CO₂ released from the atmosphere, making the oceans more acidic.
- Freshwater environment – precipitation changes will impact the recharging and discharging of water in our freshwater bodies, affecting the species on it. May it be fresh water for us humans, the fishes that live in it or the temperature change to spark a catalyst for algal blooms.

- Terrestrial environments – Due to the changing climate, the timing of seasonal species, such as migratory birds, will alter their breeding and growth. Invasive flora and fauna will change, and the conditions may favour other alien or invasive species rather than local species.
- Primary industries – droughts and extreme weather will affect many farming and fruit-growing activities.

If NZ does not play its part in reducing emissions, our way of life, environment, and work health will be severely impacted. If our current generations face this crisis, how will the next generation live after us? Then comes the problem: How does society continue to build or construct the needs of our communities and reduce our emissions?

2.3.10 NZ emissions compared to other countries.

The Ministry for the Environment (2023a) compares how NZ compares to other countries in the GHG Gas Inventory 1990 – 2019 Snapshot; NZ’s gross emissions contributed approximately 0.17% of the world’s gross emissions, this might seem small; however, in comparison to other Annex I countries, NZ are ranked 20th. Regarding all gases per capita, NZ is ranked 5th highest, refer to Figure 10. NZ also shows a unique emission profile as NZ is the only Annex I country where CO₂ emissions make up less than half the proportion of greenhouse gas (43.7% in 2020). What can be seen here is the effects of positive actions done by NZ in the past. As mentioned in section 2.3.4, NZ was one of the first countries that adopted the Kyoto Protocol in 1995. 25+ years later, as of 2021, NZ’s share of renewable electricity is at least 82%. As specific areas are targeted and reduced, other sectors with significant emissions become new hotspots for change. In the context of the high gas per capita, as shown in sections 2.3.7 Figure 8, and as presented by the MfE, most of our emissions are now in transport and agriculture. The MfE further explains that transport is a problem due to NZ’s small and widely distributed population and extended narrow geography.

Regarding the study of this thesis, the scope of agriculture is not part of this study. As construction via open-cut water conveyance is the main focus, transporting materials, plants, and labour is required. Therefore, there could be opportunities to explore ways to reduce construction transport emissions in this study.



Note: All emissions data in this section is from UNFCCC Data Interface (2022). Annex I data in these comparisons count the members of the EU separately, and exclude the EU as a whole.

The population data used to generate figure 7 was taken as 2020 population data from the UN Population Division.

Annex I countries (UNFCCC) are compared with Australia, Japan, New Zealand, the United Kingdom, and the United States of America. Each country shows two bars which represent 'CO₂ only per capita' and 'all gases'.

Figure 10: MfE NZ’s GHG Gas Inventory Snapshot 1990-2021, Figure 7 (Ministry for the Environment, 2023a)

2.3.11 Industry Need – National and Local Three Water Services

On an NZ national level, on April 2023, the Minister of Local Government, Hon Kieran McNulty, announced that on the first of July, 2026, the new “Affordable Water Reforms” or Water Services Reform Programme go live (New Zealand Government, 2023).

The Department of Internal Affairs (2023b) explained that the Water Services Reform Programme was created by the NZ Government in July 2020 in response to the challenges in delivering water, wastewater, and stormwater (summarised as three waters) services nationally. The reform is needed because:

- There are significant challenges in the delivery of the three water services nationally. The infrastructure is aging, and some areas of the country have grown; improvements and upgrades are required to tackle climate change.
- New Zealanders need reliable, affordable, and safe water services. Across the country, there are leaking water pipes, drinking water shortages or restrictions and raw sewage spills.
- Over the next 30 years, the cost to meet these challenges is between \$120 billion and NZD 185 billion.

The government has accounted for 67 councils nationwide and will be governed by ten entities; refer to Figure 11 below.

These works are required to ensure reliable, affordable, safe water services. The planned multi-billion works are needed across the country; however, it does not guarantee that the works will be free from anthropogenic activities. On the contrary, it is guaranteed that the works will create and result in more emissions and contribute to New Zealand's overall net emissions.

On a local level in Auckland, under the new Water Services Reform Programme as Entity A, the Auckland Council (2022) Climate Plan focuses on the following greenhouse gas emissions targets:

- Halving emissions by 2030 and reaching net zero emissions by 2050.

Auckland Watercare (2021) has three emission reduction targets:

- Reduce emissions from construction by 40% by 2025.
- Reduce operational emissions by 50% by 2030; and
- Achieve net zero emissions by 2050.

Although government and local authorities such as Auckland Council (AC) and Watercare have been quick on creating emission targets, time is quickly passing by; Watercare's aim to reduce emissions

from construction by 40% is only two years away at the time this research study is proposed to be completed (2023), yet from observation in the wider construction industry, capturing carbon emission data has not yet been widely adopted by grassroots Contractors.

Reasons as to why adopting the capture of emissions data is slow are:

- Carbon accounting is technically difficult (Crampton, 2022).
- It is complex (Elhag, 2015).
- Most companies consider direct costs and ignore the social and environmental impacts as quantifying them is challenging as many factors are unknown or unavailable (Alsadi & Matthews, 2020).
- There is a general lack of know-how or little to no need to make a change, as there currently is no mandatory requirement to capture or report emissions data (BDO NZ, 2023)

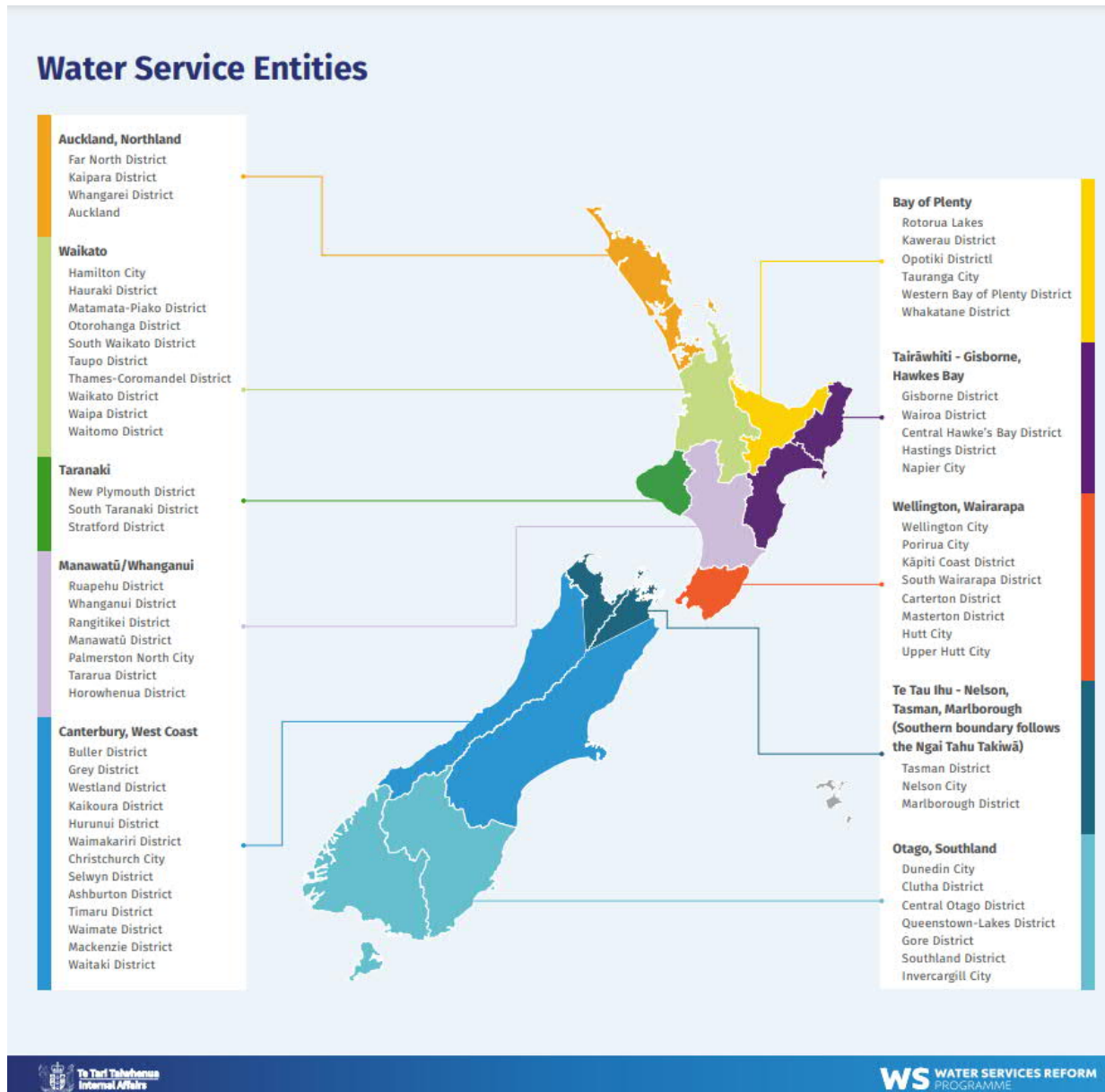


Figure 11: Water Services Entities (New Zealand Government, 2023)

From the given emissions targets, whether it was Auckland Council or Watercare, it is clear from the policies that Auckland's three water emissions will need to be quantified, and emissions must be reduced. It is also clear from Watercare's perspective that construction emissions must be reduced. It can be inferred from the information given if Contractors want to construct or tender work from these authorities, they must quantify and provide/report their emissions.

2.3.12 Construction Industry Enterprises

Statistics New Zealand breakdown NZ's construction enterprises and employee. They provided the following essential information:

- 64% of the industry is self-employed or 1-man bands. 25% are enterprises with 1-5 employees. 5% are employees with 6-9 employees. Together, these three bands equate to 94% of the construction industry.
- Enterprises with 50+ employees and above equate to approximately 0.5% of the industry.

Local authorities such as Watercare, who have 50+ employees (0.5% of the industry), have started their carbon journey and have the resources to do so (Watercare, 2019). Yet, 94% of the construction industry may not have the resources or are yet to start. Fundamentally, can the 1-man band or a business with 1 to 5 employees have the resources to do their job, meet health and safety requirements, and undertake carbon accounting? This research aims to create a simplified template to assist low-resourced businesses in getting started on their carbon journey.

2.4 Carbon Framework Methodology

2.4.1 Introduction

In carbon measurement, researchers employ various carbon frameworks as systematic methods to assess, calculate and track their carbon emissions. The framework can be simplified into two parts. The first part is the Construction Methodology, and the methodology looks at the construction method and the sources of emissions. The second part is calculating the emissions from the sources. The procedure that directs the steps of a user from start to finish is the framework. This section critiques the framework literature, while section 2.5 goes into detail on the Construction Methodology, and section 2.5.7 discusses the calculating method.

Pandey et al. (2011) researched seven estimation methods for estimating carbon. They listed the following:

- GHG Protocol
- ISO14064-1:2015
- PAS2050
- 2006 IPCC guidelines
- Carbon Trust UK
- ISO14025 and ISO14067

Pandey et al. (2011) suggested the GHG Protocol, Carbon Trust and PAS2050 as the frameworks to use. Elhag (2015) had a similar list to Pandey et al., but they also had the UK's BRE environmental profile methodology, BS EN 15804, and ISO 14040/44, which is similar to PAS2050 to the list. Ariaratnam and Sihabuddin (2009) used the EPA non-road model, while Tavakoli et al. (2017) used their framework. While these frameworks assist in calculating emissions, they have the potential to yield different emission values due to variations in their methods and levels of detail (Elhag, 2015).

Although these methods assist in calculating emissions, they can potentially lead to different CF values due to their methods and level of detail.

Other researchers such as Alsadi and Matthews (2020); Chilana et al. (2016); Khan and Tee (2015) used the LCA framework, which is the complete process; in LCA terminology, it is from "Cradle to Grave" or Start to End as their carbon estimation framework, referring 2.4.3. They did not mention what LCA standard they used for their research, but potentially, it could have been a standard similar to PAS 2050, which is the assessment of the life cycle greenhouse gas emissions of goods and services, ISO 14040/44, or the British Standard BS EN 150804: 2012.

The beauty of the LCA framework, such as the British Standard BS EN 150804:2012, is that it provides an excellent visual tool to see the different stages of a product's life. The problem with it is that it is complex when you go through the life of a product (Elhag, 2015; Weidema et al., 2008).

As the research aims specifically for contractors in the installation phase, analysis using the complete LCA framework is not required. The LCA approach in this research is used only as a visual tool to define the carbon systems boundary. Regarding the LCA language, the stages researched are from Cradle to Practical Completion.

ISO 14025 is for suppliers, and ISO 14067 is suited for products. The Carbon Trust and the 2006 IPCC guidelines are relevant; however, these standards are almost 20 years old, and other standards, such as the GHG Protocol, have been recommended. Pandey et al. (2011) suggest the GHG Protocol. In NZ, for example, the MfE recommends using either the GHG Protocol or ISO 14064 as carbon frameworks to create a carbon inventory (Ministry for the Environment, 2022a). Reviewing the GHG Protocol and ISO 14064 framework standards yields an accounting method where a study boundary can be isolated and calculated without calculating a complete LCA or what other researchers call Carbon footprinting (Weidema et al., 2008).

What can be seen from the literature is that there are multiple carbon frameworks. It is complex, and depending on its methods and level of detail, it can potentially lead to different emission values. If an LCA is not required, the GHG protocol and ISO 14064 standard can be used to calculate specific stages or boundaries. To simplify the complexity and differences in methods, the GHG Protocol and ISO 14064 standard were the frameworks used and developed in this research. From researching and understanding ISO 14064 Scope 3, the GHG Protocol Scope 3 was also investigated and compared for its strengths and weaknesses.

In section 2.4.2, the definition of carbon footprint is given, as this needs to be measured. Section 2.4.3 looks at the life cycle from a carbon emissions perspective and provides a visual idea of the boundaries of what needs to be measured. Section 2.4.4 dives deep into the GHG Protocol and discusses what sections are adapted and excluded in this research. Section 2.4.5 to 2.4.6 looks at GHG Protocol ISO 14064 and GHG Protocol – Scope 3 standard. Section 2.4.7 discusses the standard PAS2080, a Carbon Management standard, and a management system for managing a carbon inventory.

2.4.2 Carbon Footprint

In section 2.3.2, it was discussed that natural and anthropogenic or human-caused activities such as GHGs are affecting and changing our climate. The amount of GHG emitted into the atmosphere annually by an individual, household, building, organisation, or country is defined as a Carbon Footprint (CF) (Chilana, 2011). Another definition of Carbon Footprint from Wiedmann and Minx (2007) is the total amount of Carbon Dioxide emissions directly and indirectly caused by an activity or accumulated over a product's life stages.

A great visual representation of capturing carbon over the life stages of a product can be seen in the British Standard BS EN 15804:2012—section 2.4.3.

The final total calculated emission in this research is called the carbon footprint.

2.4.3 Life Cycle Assessment Approach

A review of the literature provides multiple standards on how emission is calculated, the principles that go with it and guidelines to follow. One approach is the Life Cycle Approach (LCA). The LCA approach looks at the beginning, from raw materials to the end of their life to disposal. A good visual representation of the Life Cycle Approach in the British Standard BS EN 15804: 2012, refer to Figure 12. In comparison, the ISO 14040 series standards provide principles and guidelines for the LCA methodology.

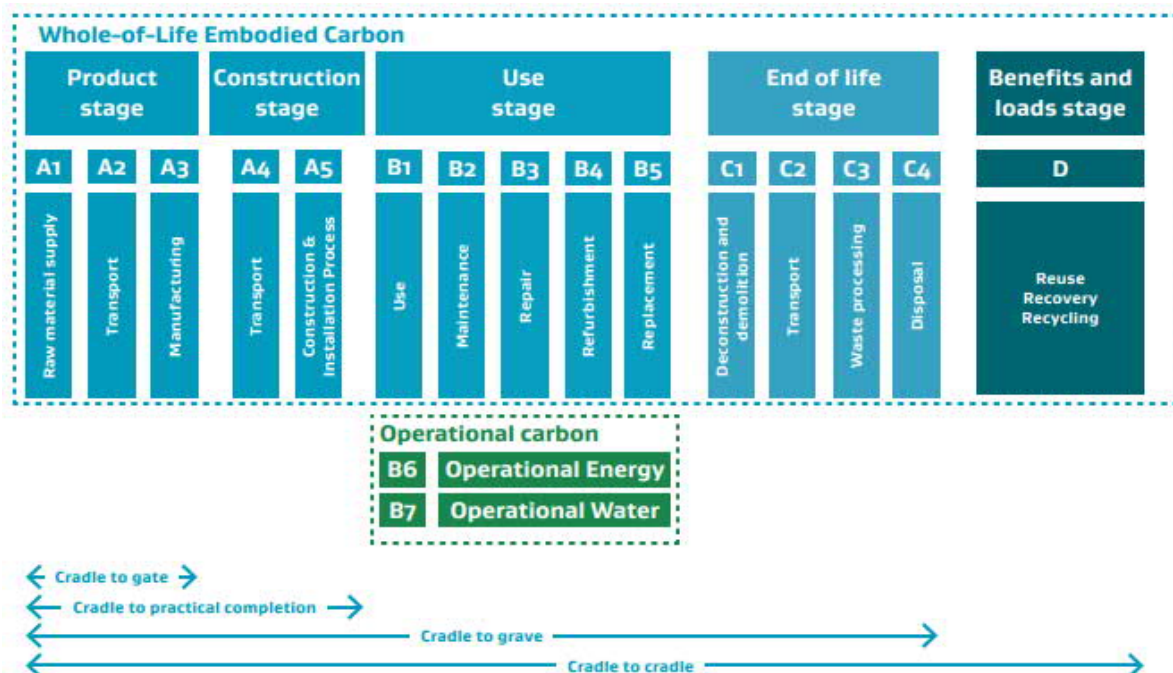


Figure 12: Principles from BS EN 15804:2012 - Extracted from MBIE (2020)

From the literature, Alsadi and Matthews (2020); Chilana et al. (2016); Forsythe and Ding (2014); Khan and Tee (2015) used the life cycle assessment (LCA) approach. Some of the reasons why they use the LCA is because LCA offers a methodology for assessing the environmental impacts associated with products and processes, from raw materials to the disposal of waste from products and processes; this is considered the 'cradle to grave' approach. Another reason they mentioned is that LCA can assist construction decision-making by identifying and addressing problems ranging from excessive consumption of resources to the pollution of the surrounding environment. The MBIE (2020) explains in their report that the LCA is typically used to calculate embodied emissions. It is either done by an LCA specialist or designers using software tools. These specialists deal with the methodology per the standards to ensure conformity or conceal the underlying complexities.

The LCA is a great visual tool for determining what stage to quantify and calculate emissions for this research. Depending on the chosen procurement strategy by the client, a contractor may only be involved from "Cradle to practical completion". Once the contractor has built and commissioned the asset, the handover is returned to the client for use. There is no need to quantify operation carbon or the use stage. For this research, the study scope is from "Cradle to practical completion".

2.4.4 GHG Protocol

2.4.4.1 Introduction

The GHG Protocol describes itself as a step-by-step guide for companies to quantify and report their emissions, a standard from the perspective of a business developing their GHG inventory. Its contents are a wealth of knowledge and are used as a critical document to define and form the carbon methodology of this research.

Table 4 below summarises the chapters in the standard. Key components of the GHG Protocol Corporate accounting standard will be summarised in subsequent sections.

Table 4: Chapter summary of the GHG Protocol Corporate Accounting and Reporting Standard

Chapter	Topic	Summary
1	GHG Accounting and Reporting Principles	Fundamental principles to adopt to have a successful company's GHG emission
2	Business Goals and Inventory Design	It is essential to have a GHG inventory and design the inventory so that the information can be used by its stakeholders now and in the future. It is knowing the emissions and identifying opportunities to reduce them. What gets measured gets managed.
3	Setting Organizational Boundaries	Select an approach for accounting and consolidating GHG emissions and applying the approach to the business operations.
4	Setting Operational Boundaries	Defines key types of emissions – Scope 1 to 3
5	Tracking Emissions Over Time	Explains the importance of setting out the inventory for possible future changes.
6	Identify and Calculate GHG Emissions	It gives steps for identifying and calculating GHG emissions
7	Managing Inventory Quality	Guides a system to how to manage the inventory quality
8	Accounting for GHG Reductions	Guidance on GHG reductions
9	Reporting GHG Emission	What is required to go in a GHG report
10	Verification of GHG Emissions	Explains the goals and common reasons for undertaking a verification, assessing material discrepancy

11	Setting a GHG Target	This step follows after developing a GHG inventory
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As seen in Table 4, the GHG Framework requires several steps before a carbon inventory is made. The document is significant; it needs to be understood, learned and applied. Once the inventory is made, other inventories (if there are multiple sites) can be compiled. A baseline is created if a chosen date exists, and the emissions can be tracked and reduced. As the GHG Protocol is a significant process, it intends to get a user, contractor, or business to start their carbon journey. Therefore, Chapter 5 - Tracking Emission Over Time is not used because it requires measuring baselines. Chapter 6 – Identifying and Calculating GHG emissions is bypassed as the chapter discusses Carbon Offsets. Section 2.5.7 of this report discusses the carbon accounting method. Chapter 10 - Verification of GHG is not used as the user starting their carbon journey would not be in the stage where they need their emissions verified for potential offsets. Chapter 11 - Setting a GHG target is the next step a user can take from the results of this research.

2.4.4.2 GHG Accounting and Reporting Principles

Table 5 below tabulates the GHG Protocol's generally accepted accounting principles. The principles ensure the reported information represents an accurate and fair account of a company's GHG emissions. These serve as principles to follow.

Table 5: GHG Protocol General Accepted Principles

Relevance	<p>The GHG inventory appropriately reflects the company's emissions and serves the stakeholders' needs (internal and external).</p> <ul style="list-style-type: none"> • GHG report is relevant and contains the information that users, both internal and external to the company, need for their decision-making. • The inventory boundary reflects the substance and economic reality of the company's business.
Completeness	<p>Account for all GHG emission sources and activities chosen inventory boundary. Disclose and justify any specific exclusions.</p> <ul style="list-style-type: none"> • Companies need to make a good-faith effort to provide a complete, accurate, and consistent accounting of their GHG emissions.
Consistency	<p>Use consistent methodology to allow comparisons of emissions over time.</p> <ul style="list-style-type: none"> • Users of GHG information will want to track and compare GHG emissions over time to identify trends and assess the performance of the reporting company. • The GHG information for all operations within an organisation's inventory boundary needs to be compiled to ensure that the aggregate information is internally consistent and comparable over time. • If there are changes in the data, methods, inventory boundary or any factors, they need to be justified and documented.
Transparency	<p>Address relevant issues factually and coherently, based on a clear audit trail.</p> <ul style="list-style-type: none"> • Information that enables internal and external review must be compiled, recorded, and analysed. • Specific exclusions or inclusions need to be identified and justified with references for the applied methodologies.

Accuracy	<p>Ensure that the GHG emissions are quantified systematically. It is neither over nor under actual emissions.</p> <ul style="list-style-type: none">• Data should be sufficiently precise with reasonable assurance and credibility to enable the users to make decisions.
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2.4.4.3 Business Goals and Inventory Design

The GHG Protocol mentions creating a baseline. A baseline is simply the emission from a particular start to an endpoint; for example, all the emissions accounted for from a start point of March 2022 to April 2023. A contractor starting their carbon journey would be more concerned about what to do and how they are meant to capture their emissions. They won't be ready, so it is better to create an inventory for this initial step; this could be measuring and quantifying for a particular site. Once more experience is known, other sights and locations can be added to create a baseline. Opportunities to reduce emissions and other improvements on the inventory could be implemented.

2.4.4.4 Setting Organisational Boundaries

This section of the GHG Protocol pertains more to big businesses with multiple arms, different operations or ownership, and shares of the business. As the target of this study is for small contractors, this study is simplified to tailor for contractors whose businesses have 100% control of their business and not multi-national. Regarding carbon emissions, 100% of the GHG emissions are their emissions and not split with other businesses. The Equity share approach is described per the GHG Protocol standard for other businesses with different equity shares.

2.4.4.5 Identify and Calculate GHG Emissions

This part of the GHG Protocol is essential as it provides the steps for identifying and calculating GHG emissions; refer to Figure 13 below.

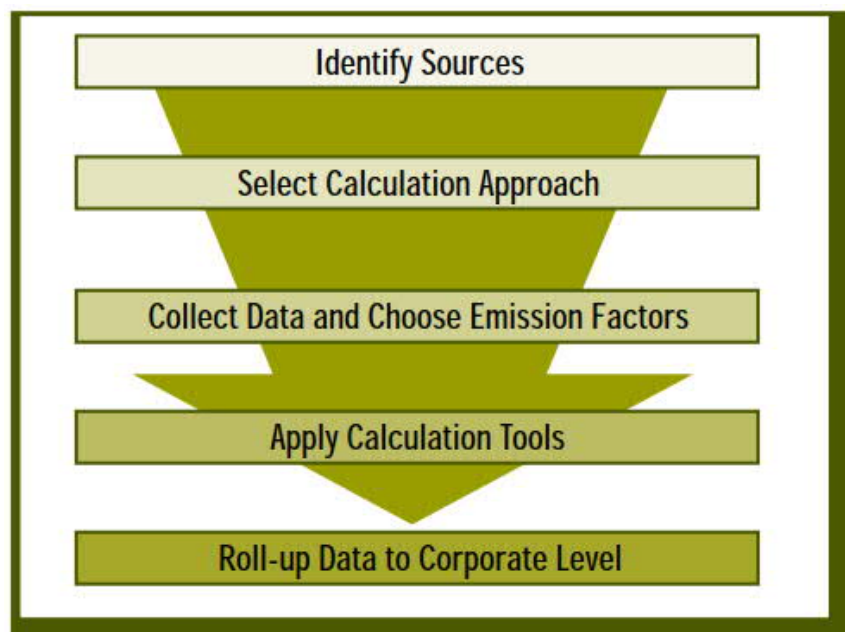


Figure 13: Steps in identifying and calculating GHG emissions (World Resources Institute, 2004)

2.4.4.6 Setting Operational Boundaries

Once the emissions have been identified, the emissions are grouped into two types of scopes – Direct and Indirect Emissions. Table 6 below defines the emission types and provides examples of the emission type and its emission source. Under the GHG Protocol, Scope 1 and 2 are compulsory emissions that must be recorded. Scope 3 emissions are optional. Allocating emissions into its scope is an important step that must be correct as assigning an emissions source to its emission type will provide the final output in the report; refer to section 2.4.4.9 on reporting of GHG emissions.

Figure 14 below gives a complete visual representation of the scopes across the value chain. In this figure, it can also be seen that Scope 3 indirect emissions have more categories upstream and downstream. These are covered in section 2.4.6 GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard.

Table 6: GHG Protocol Direct and Indirect Emissions (World Resources Institute, 2004)

Emission Type	Scope	Definition	Example
Direct Emissions	1	Emissions that are owned or controlled by the company	<ul style="list-style-type: none"> • Company-owned vehicles • Factory machines such as boilers • Transportation of materials, products, waste, and employees
Indirect Emissions	2	Emissions from the generation of purchased electricity or emissions that physically occur at the facility	Use of purchased electricity, steam, heating, or cooling
	3	Other indirect emissions – is an optional reporting category	Value chain

In the context of this study construction from a contractor’s perspective, there will be two main operational boundaries.

- a) The first boundary is for office staff, considered overheads who go to and from the office. The day-to-day office operations are Scope 1 and 2. Scope 1 is the staff with company cars who travel to and from work. The office's materials, products and waste are also grouped as Scope 1. At the same time, the electricity in the office is grouped as Scope 2.

b) The second boundary is when a Contractor wins a construction contract, the contractor's plant, labour, and materials associated with the new construction contract are separated as the new construction contract is considered scope three by the client. The emissions from the activities that occur from the construction project are attributed to the construction project. Therefore, from a contractor's perspective, they need additional resources like a quantity surveyor or a site engineer to quantify and record the emissions associated with the construction project and hence the second boundary.

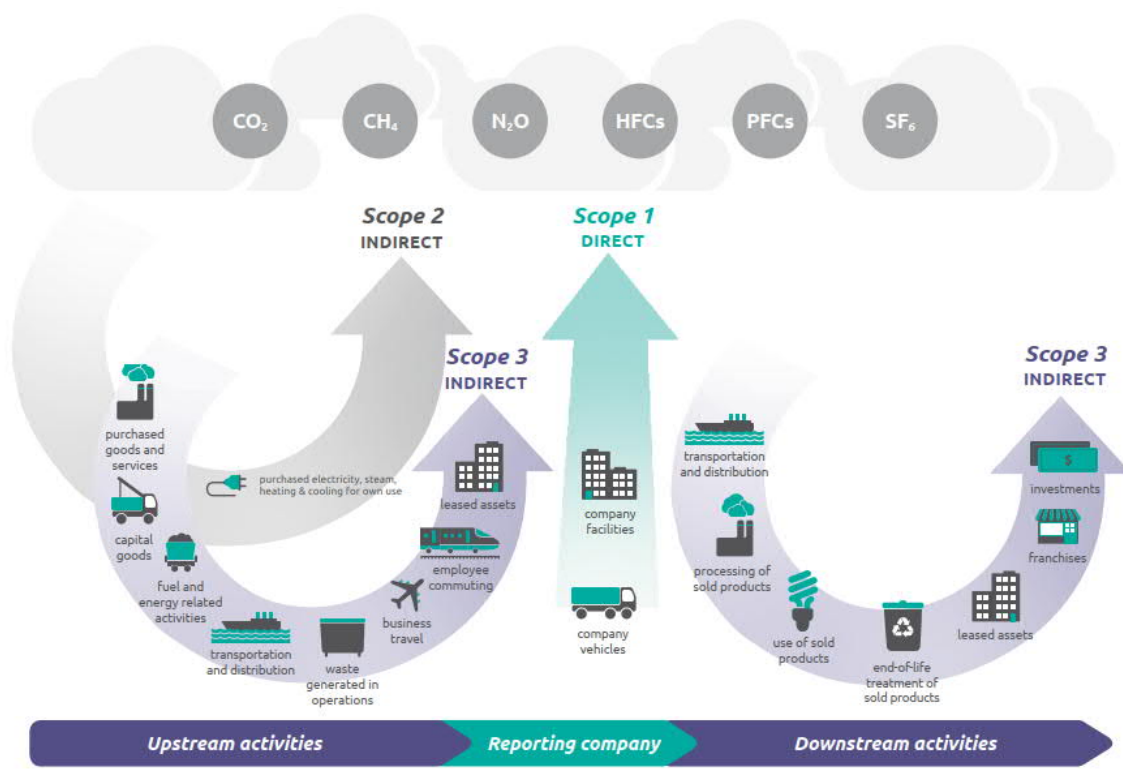


Figure 14: GHG Protocol Scope 3 (World Resources Institute, 2011)

2.4.4.7 Managing Inventory Quality

The GHG Protocol Corporate Standard discussed an inventory quality management system to help companies develop and implement their quality management system onto their inventory, see Figure 15. Having an inventory quality management system becomes a crucial step once an inventory or a baseline is complete because the quality management system provides a systematic process for correcting and preventing errors. It also identifies opportunities for improvement and preparation for compliance with regulations via reports as required.



Figure 15: GHG Protocol Inventory Quality Management System (World Resources Institute, 2011)

The GHG Protocol mentions that a quality management system for a company should address four inventory components.

- Data - Basic information on activity levels. Develop data collection procedures that allow the same data to be efficiently collected in future years.
- Methods - technical aspects of the inventory preparation
- Inventory Processes and Systems - institutional, managerial, and technical procedures
- Documentation - Records of methods and data

An alternative management inventory system used in the UK with successful results is the PAS 2080. In the NZ context, Watercare Services Ltd. implements carbon management structures outlined in the Infrastructure Carbon Review and PAS2080 in NZ (Conley, 2021). As PAS2080 is being implemented in NZ, highlights of PAS2080 are discussed in 2.4.5.

2.4.4.8 Setting a GHG target, reductions, and tracking emissions over time

After a company has developed their GHG inventory, they are at the stage where they can form a GHG target. They can also focus on hotspots and work on reducing or tracking their emissions over time.

The emissions factors may change as more information and better science are found. Tracking emissions over time will be part of inventory management as per section 2.4.4.7 Managing Inventory Quality.

2.4.4.9 Verification and Reporting of GHG emissions

If the company must offset their emissions, then its inventory system must be verified and reported. The target of this study is for small companies to get their GHG emission inventory and building to a baseline. There is no mandatory requirement for contractors in the three waters sector to reduce their emissions. Hence, it is less likely that 3rd party verification is required. However, should verification be required, the GHG Protocol recommends verifiers have appropriate experience and have the following:

- Previous experience and competence in undertaking GHG verifications
- understanding of GHG issues, including calculation methodologies
- Understanding of the company’s operations and industry
- objectivity, credibility, and independence.

Reporting can be presented as shown in Figure 16 and Table 7 below. These examples assist in giving guidance as to what needs to be delivered.

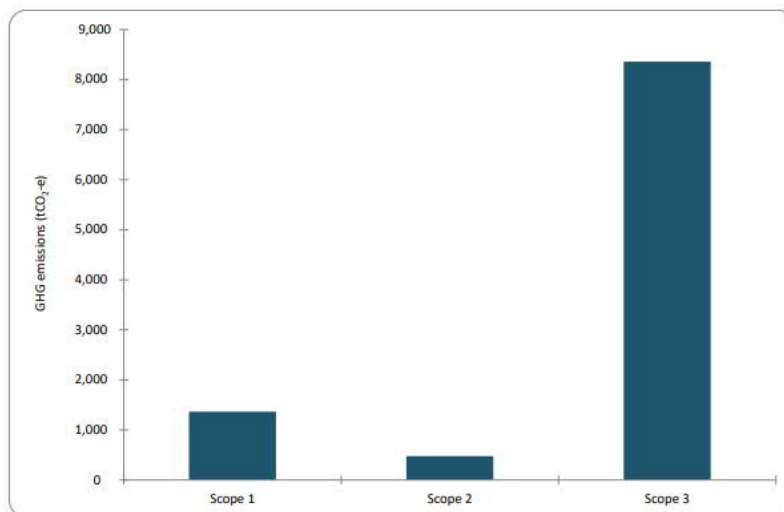


Figure 16: GHG Emissions by Scope from the Ministry for the Environment (2018b)

Table 7: Example of Emissions from the Ministry for the Environment (2018b)

Component gas (expressed as tCO ₂ e)							
	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	Total tCO ₂ e
Scope 1	1,195.93	133.60	6.95	14.12	-	-	1,350.60
Scope 2	224.82	10.6	0.21	-	-	-	235.63
Scope 3	8,321.91	19.96	118.91	-	-	-	8,460.78
Total	9,742.66	164.16	126.07	14.12	-	-	10,047.01

2.4.5 ISO 14064

The ISO 14064 standard has similar principles and guidelines to the GHG protocol. What makes ISO 14064 relevant is its additional categories on its operational boundaries. In section 2.4.4.6, the GHG Protocol describes direct Scope 1, indirect Scope 2, and Scope 3 emissions. The ISO 14064 standard has expanded the Scope 3 emissions into four more categories; see Table 8. The additional categories in Scope 3 are good because they give Scope 3 indirect emissions more depth and define other emission categories that could be measured and reduced. These emission categories are the outputs required to be reported.

Table 8: ISO 14064: Scope Categories

Scope 1	C1	Direct GHG Emissions and Removals - Fuel
Scope 2	C2	Indirect GHG emissions from imported energy
Scope 3	C3	Indirect GHG emissions from Transportation - Freight Transport - Employee Commute
	C4	Indirect GHG emissions from products an organisation uses - Materials and waste
	C5	Indirect GHG emissions (use of products from the organisation)
	C6	Indirect GHG emissions (other sources)

2.4.6 GHG Protocol – Scope 3

The Greenhouse Gas Protocol: Corporate Value Chain (Scope 3) Accounting and Reporting standard was researched to find the differences in Scope 3 between ISO 14064 and GHG Protocol. As seen in Table 9 below, the GHG Protocol Scope 3 has 15 categories. Scope 3 in the GHG Protocol is divided from C1 to C8 as Upstream Activities and C9 to C15 as Downstream Activities. The downstream activities are more for production, product-based, or what happens after the product is sold. The upstream activities C1 to C8 are similar to ISO 14064. The advantage of the GHG Protocol Scope 3 is that it has more categories to define and reduce indirect emissions. The weaknesses are that typically, scope 3 is down the value chain or subcontractors. If a client aims to capture their scope 3 emissions downstream of its value chain, it may face difficulties if their subcontractors don't know how or do not want to record or track their emissions.

Table 9: GHG Protocol Scope 3 Categories (World Resources Institute, 2011)

Scope 1		Direct GHG Emissions and Removals - Fuel
Scope 2		Indirect GHG emissions from imported energy
Scope 3	C1	Purchased Goods and Services
	C2	Capital Goods
	C3	Fuel and Energy Related Activities (Not included in Scope 1 or 2)
	C4	Upstream Transportation and Distribution
	C5	Waste Generated in Operations
	C6	Business Travel
	C7	Employee Commuting
	C8	Upstream Leased Assets
	C9	Downstream Transportation and Distribution
	C10	Processing of Sold Products
	C11	Use of Sold Products
	C12	End-of-Life Treatment of Sold Products
	C13	Downstream Leased Assets
	C14	Franchises
	C15	Investments

2.4.7 Carbon Management Process - PAS2080

As mentioned in section 2.4.4.7, the local water authority in Auckland, NZ - Watercare Services Ltd, is implementing a Carbon Management process known as PAS2080. The PAS2080 is a carbon management process for use in infrastructure delivery. Unlike the GHG Protocol, where its management system sits with the asset owner, PAS2080 shares the responsibility of the associated carbon emissions with its value chain members.

PAS2080 aims to set out a carbon management process for use in infrastructure delivery for all parties (client, contractor, designers, and suppliers) in the value chain and be undertaken collaboratively.

The PAS2080 does the following:

- Provide specifications for infrastructure carbon management.
- PAS2080: 2016 provides steps in quantifying emissions.
- Bring consistency and encourage wider uptake on carbon management.
- Help the infrastructure value chain to become more efficient. – Reduce capital carbon
- Improve the accuracy, transparency, consistency, relevance and complement of carbon management and GHG emission quantification.

Another point that PAS2080 does, which potentially could be the most crucial factor about PAS 2080, is it gives a clear outline of the responsibilities of all value chain members (client, contractor, designers, and suppliers). Everyone in the system plays their part by implementing and being part of PAS 2080. The standard has already reduced capital carbon by up to 39% and operational carbon by 34% (Anglian Water) (Enzer, 2013).

As Watercare is part of Auckland Council and with the potential for these local authorities to be one entity under the “Affordable Water Reforms – 3 Waters, there is a high potential that a Carbon Management Process such as PAS2080 may be implemented or rolled out to the industry in the future.

The success of PAS 2080 may be triumphant in the UK, but it may not be successful elsewhere. The uniqueness and advantage of PAS 2080 is its transparent allocation of responsibilities for all value chain members. Should the responsibilities be imposed on the value chain, if they don't have a clear or compelling reason why they need to do it, they may not accept the tasks or request it as a variation. Due to this knowledge gap, research was done in section 2.3 to understand and find a compelling reason why measuring carbon emissions is required.

2.5 Construction/Engineering Literature

2.5.1 Introduction

In section 2.4, the Carbon Framework was discussed, and the recommendations from critical researchers and the MfE were to use the GHG Protocol or the ISO 14064 standard. Going through the standards step by step, a new user will come across the section on steps in identifying and calculating GHG emissions. As the standard was written to cater for different industries, the steps given in the standard are generic. It does not detail the specific construction activities needed to identify and analyse emission sources, which is a gap in the research. The standard mentions setting up the operational boundary, but what is required is an understanding of the processes of the operational boundary of the user's construction life cycle. Without knowing the processes, stages, or phases of the construction, identifying sources of emissions and the resources that produce emissions may not be thoroughly captured.

To solve the problem, Alsadi and Matthews (2020) visually showed a diagram of the life cycle stages. Their article is an excellent example of studying and focusing on a particular life cycle stage or working inside an operational boundary. Ariaratnam and Sihabuddin (2009) went deeper and showed a detailed work breakdown structure. From the work breakdown structure, emission sources and resources used in the project can be identified and quantified. Knowing the boundary and the work breakdown structure is vital because, according to Elhag (2015), the final carbon footprint emission values can change if the method and detail level are unclear. For example, Elhag mentioned that the water and wastewater industry has multiple standards and methodologies to calculate construction projects, as seen in the critical literature in section 2.2.5. When comparing the data from Alsadi and Matthews (2020); Ariaratnam and Sihabuddin (2009); Chilana (2011), and other key literature, their data and construction methodologies are all different. The majority of the researchers show varying parameters in the open-cut trench. It may range from differences in depths, widths, and varying ground materials. It is also important to note that the researchers are in the United States. Elhag (2015) warns that a different methodological scenario can deviate carbon footprint values up to 53% for concrete pipes and 85% for plastic pipes when calculating emission values using the ICE database.

To address the gap in the construction methodology, section 2.5.3 provides a visual scope of the required stage boundary studied. Section 2.5.2 shows a typical open-cut process diagram in which a thorough work breakdown structure (WBS) can be developed. Yan et al. (2010) showed examples of first-principles calculations on Carbon emissions by calculating the activity data multiplied by the emission factors. This calculation method is discussed in detail in section 2.6. However, knowing the study boundary and the WBS is not enough; it is only the earlier stage. Activity data on plants and equipment and the resources identified in the WBS must be quantified.

There are, however, challenges/gaps in the literature. When quantifying the fuel (diesel) an excavator uses, the duration and fuel consumption rate will need to be defined. For example, how many days will the excavator work, and how many litres will it burn per hour? For example, an activity with a 7.5t excavator runs for 2 days at 8 hours per day, and the machine burns diesel at 10L/hr; the total amount of litres is $2 \text{ days} \times 8 \text{ hours} \times 10\text{L/hr} = 160\text{L}$ of diesel used.

The complexity here is that different plants and machinery consume varying fuel rates. Depending on the machine used, the fuel consumption changes. The other issue is how long will the machine run. To address the fuel consumption gap, values are available online on fuel consumption on various plants and machinery. However, there was little published data on plants and machinery used in open-cut trenching. However, there was data on roading construction activities. Some plants and machinery used in roading construction are employed in horizontal construction. In section 2.5.5, Deloitte (2020) showed the Industrial Classification Standard to group industries with similar productive activities. Roading construction was grouped with Civil Engineering (three waters pipelines); hence, under the NZ Industrial Classification, the roading plant activities share productive activities with infrastructure civil construction. Therefore, fuel consumption data used in the roading sector by Kim et al. (2012) were investigated and used in this research.

Addressing the gap in knowledge regarding the duration of running a plant or machinery was also a problem. Speaking with pipe installers and asking how fast they can excavate the pipe and what resources they use was like asking a successful hot dog seller what their secret sauce is or akin to asking the Hot dog seller about their competitive advantage and sharing it with their competition. To address the gap in not knowing installation activity, first principles calculation was used using the excavator's digging parameters and productivity on the installation of pipe on water, wastewater and stormwater labour constants published by NZIQS, The Quantity Surveyor's Handbook 2022 - Drainage was used.

To quantify the resources such as pipes and aggregates, research was needed to define the standard to use in the research. The standards used in this research are discussed in section 2.5.7. The resources or materials required will be described in the standard by defining the standard used.

2.5.2 Pipelines and Excavation Background

Water pipelines are essential in water as they move volumes of water from lakes, rivers and reservoirs and transfer it to areas in need (Chilana, 2011). Due to consistent global growth, insufficient maintenance, replacement planning and climate change, the world's aging water lines are under pressure. Infrastructure reinvestment is required, and critical decisions on operations and processes are expected (VanBriesen et al., 2014). Inversely, water used turns to wastewater and will also be under pressure. In the context of stormwater, cities across the globe are also preparing for aging stormwater pipe infrastructure, as not only does it convey stormwater flows from rain but also has combined stormwater and wastewater lines (Kessler, 2011).

Forsythe and Ding (2014) mentioned that the building construction process is a well-known source of pollution and excess consumption of resources. Horizontal or Vertical builds that require site clearance, levelling, foundations or buried services typically require excavations. Excavations intrinsically change the site by removing vegetation, disturbing, revealing and removing the required soil and depositing new aggregates. It is machine-intensive due to the reliance on excavators, rollers, trucks, and other equipment.

2.5.3 Life Cycle Phase for a Pipeline

In their study, Alsadi and Matthews (2020) provided a life cycle phase for a pipeline from fabrication to installation, operation, and disposal. Their life cycle was laid on top of the BS EN 15804 LCA diagram as shown in Figure 17 below.

As the scope of the study is limited to pipe installers, only the activities and their emissions or carbon footprint in the Fabrication and Installation phase are captured. The LCA cycle phases are still used but only to identify the study boundary.

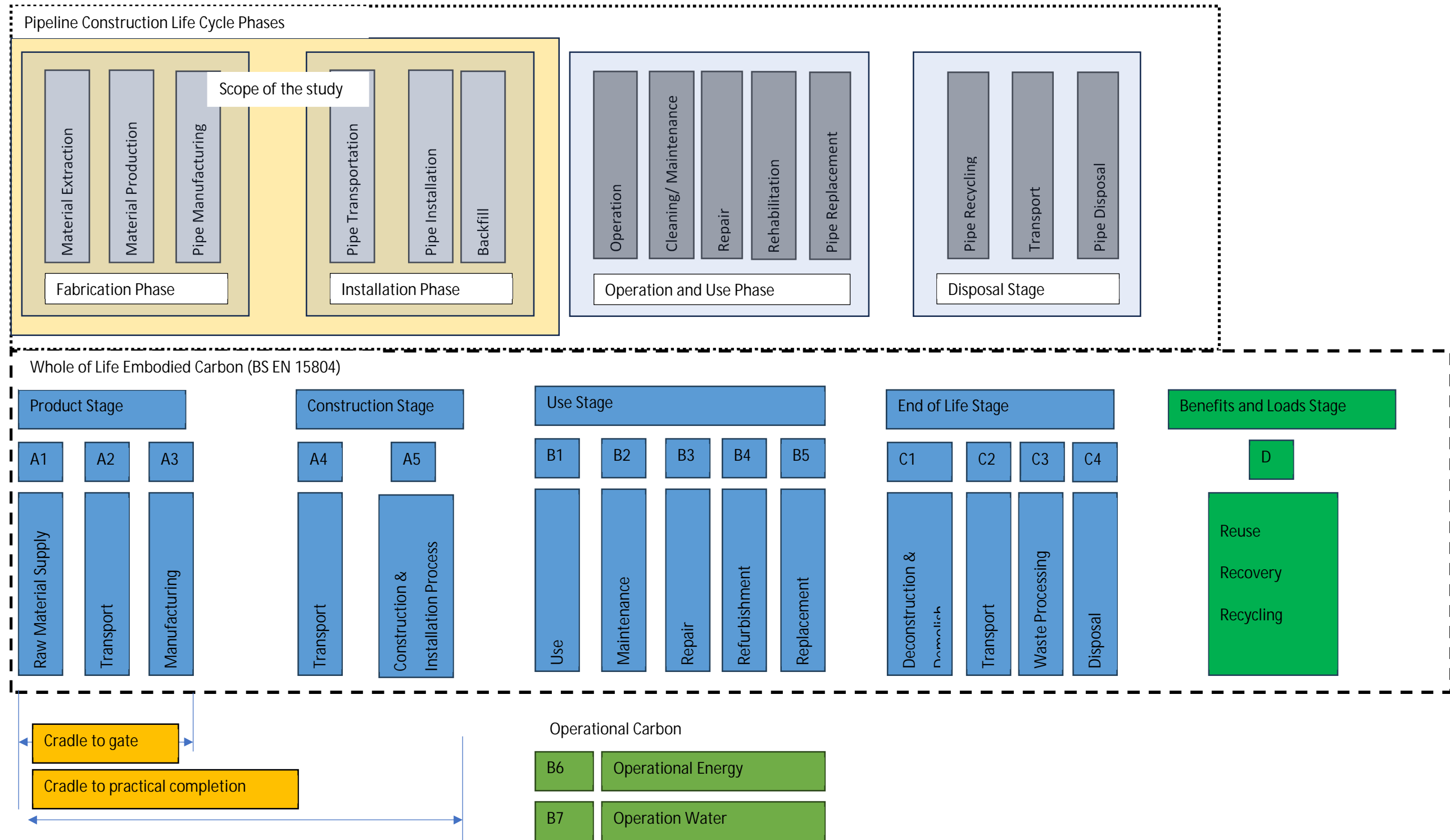


Figure 17: Pipeline Construction Life Cycle Phases

2.5.4 Open-cut Construction Process

The most traditional method for installing underground utilities such as water, wastewater and stormwater pipes is the open-cut method. Figure 18 below shows a typical open-cut construction process with resources and activity (Figure adapted from Ariaratnam and Sihabuddin (2009)).

The construction process with resources and activity does the following:

- Completeness – It defines the work boundary and assists in identifying the emission sources and duration of the activities.
- Relevance – As the resources and activities of the construction process are identified, the resources and activities become visible to internal and external stakeholders.
- Consistency – it shows the critical elements of the methodology and allows comparison of sources of emissions.
- Transparency – the process can be analysed, and possible improvements can be suggested to reduce emissions.

Overall, this process ensures that the emissions are systematically quantified and accurate.

Knowing the construction process well and having a visual aid such as the process shown in Figure 18 assist in identifying and revealing the resources used and the sources of emissions from burning fuel/energy from an activity.

From Figure 18, the plant (2x excavators, 1x truck) and machinery (1x compactor) were identified as sources of emissions. In contrast, the resources identified and used are the pipes and the aggregates. What is not known is the duration of the activities for the plant and machinery and what needs to be measured. As there was little published research on the duration or productivity of the construction plant and machinery, research was done on vertical construction activities, refer to section 2.5.5.

To determine what needs to be measured, local authority standards from Watercare and Auckland Council were used; refer to section 2.5.7.

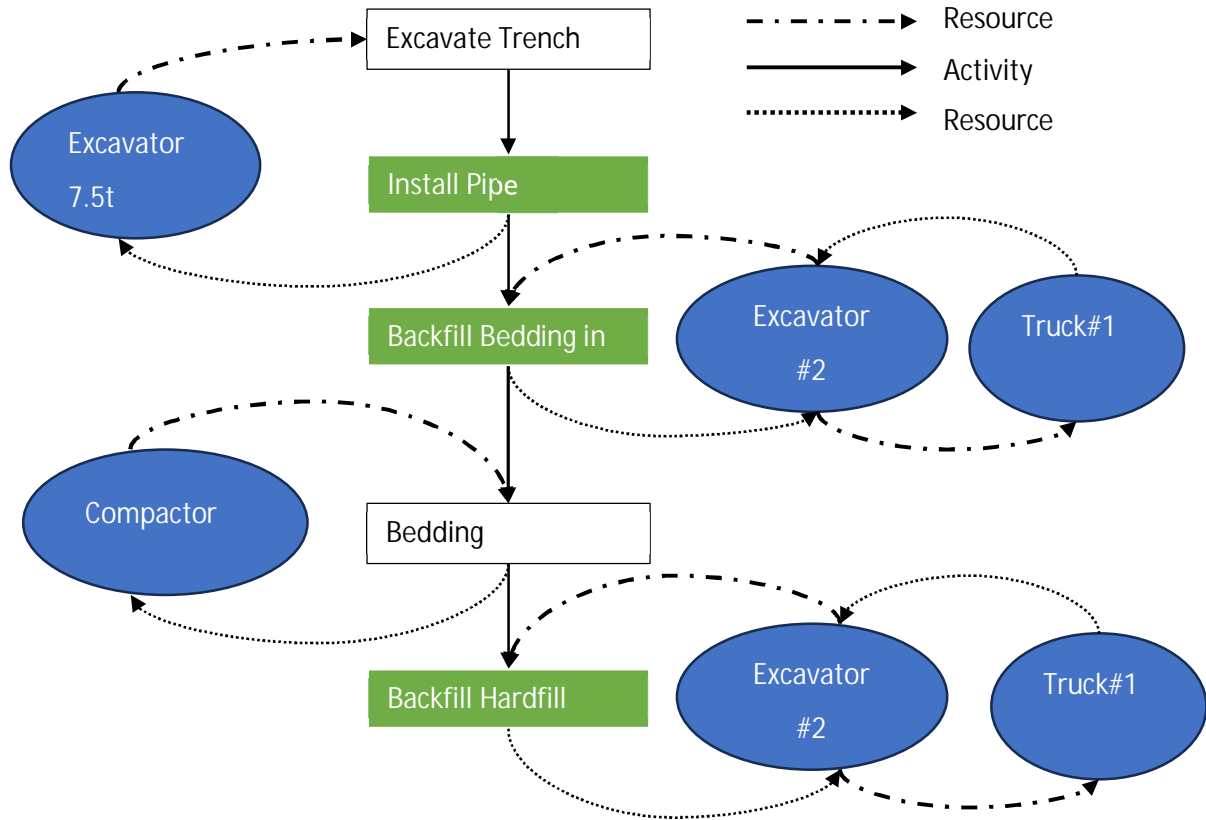
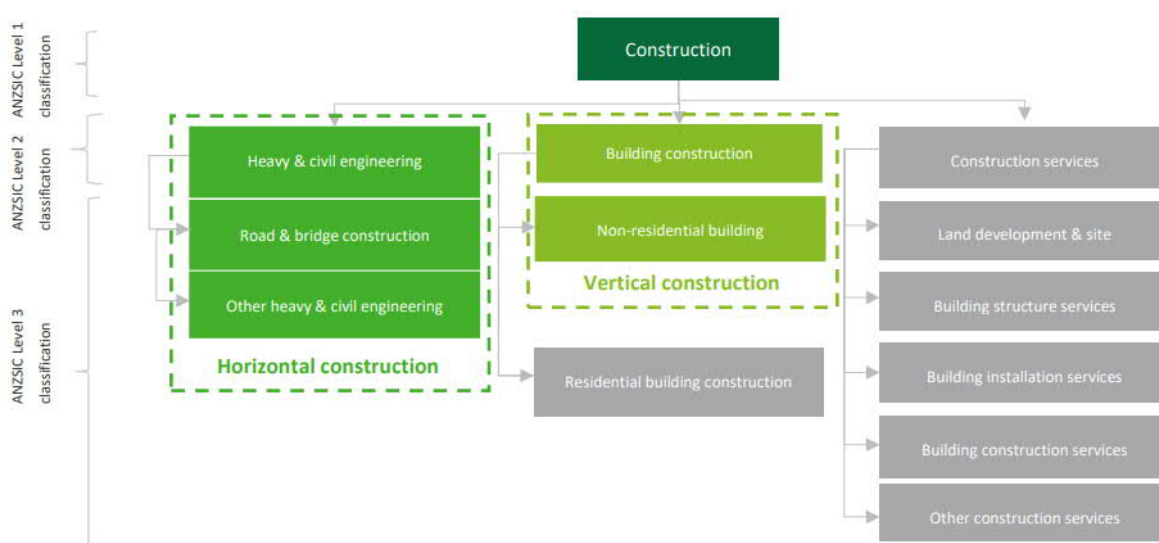


Figure 18: Typical Open-Cut Process Map (WBS)

2.5.5 Defining the type of construction for the chosen study

This section provides a background on the two significant types of construction in the industry, which are Horizontal and Vertical Construction.

Deloitte (2020) was commissioned by The New Zealand Infrastructure Commission to undertake a COVID-19 recovery study in the construction sector. Their study used the Australian and New Zealand Standard Industrial Classification (ANZSIC) used by Statistics New Zealand to define construction and its sub-sectors. The standards are used as a framework in which industries carrying out similar productive activities are grouped.



Source: Deloitte based on Statistics New Zealand

Figure 19: The Australian and New Zealand Standard Industrial Classification (Deloitte, 2020)

Figure 19 shows two major construction sub-sectors: Horizontal and Vertical construction. It also indicates residential and other construction-related activities. Horizontal construction is non-building construction such as roads, bridges, utilities, and other civil works. In contrast, Vertical construction is defined as building types different from residential buildings.

As per ANZSIC level 3, pipeline excavation falls in the classification of civil engineering. It is grouped in the Horizontal construction sub-sector with road & and bridge construction. Limited information on pipeline excavation emissions exists, so other literature in the horizontal construction sub-sector is pursued. For example, some of the methodology in excavating soil and aggregate on the road is similar to the traditional excavation of open-cut trenching. Although road and pipe trench widths differ, the materials, machinery, trucks, etc., used in the excavation process are similar. Therefore, lessons learned in other fields in the Horizontal construction sector are adapted to the chosen study.

2.5.6 Vertical Construction

BDO NZ (2023) surveyed shareholders, directors, and senior staff from sectors of the vertical construction industry (buildings built vertically). It comprises 60% head contractors, 20% sub-contractors and others. In section 3 of their report, “A Sustainable Construction Sector”, they surveyed businesses and their clients, focusing on Environmental, Social and Governance (ESG).

From the information given, approximately 20% of companies who perform ESG are winning most of the work. In contrast to those who do not, 80% of the companies who do not perform ESG are not winning ESG-related work. While 20% of companies are on their way or have an idea of what to do next, approximately 60% of the market has either no idea or is unable to compete in ESG work. These statistics may apply to Horizontal Construction, but from a literature review, there is little research in the Horizontal Construction sector, highlighting the need for more research.

2.5.7 Auckland, NZ Water, Wastewater and Stormwater Standards

The Water Services Reform Programme is in the process of consolidating 45 water codes, guides and standards and developing NZ's National Engineering Design Standards (NEDS) for water, wastewater, and stormwater. The standards are planned to be completed by 2024 (The Department of Internal Affairs, 2023).

Post the reform program, Auckland Council (Stormwater) and Watercare (Water and Wastewater), which currently oversee Auckland's three water infrastructure systems, may be merged into a single entity as part of Entity A – Council Group, which includes Auckland, Far North, Kaipara, Whangarei (Department of Internal Affairs, 2023a). As both entities are in New Zealand's largest city (Auckland), there is a high probability that standards from these local entities may be prominent in the new NEDS. Hence, in the interim period, standards from Auckland Council (Stormwater) and Watercare (Water and Wastewater) standards are used for this research.

Stormwater standard drawing SW02 from Auckland Council is attached in Appendix 3

Watercare water standard drawing WS2 is attached in Appendix 3.2, and the wastewater drawing WW2 is in Appendix 3.3.

2.6 Carbon Accounting

2.6.1 Introduction

In section 2.5, it was discussed the importance of knowing the construction methodology and its WBS. From the WBS, emission sources can be identified and quantified. The next step is attributing the quantified emission source to an emission factor (carbon science) and calculating the final emission value. The emission factor is a factor that amounts to the greenhouse gas emitted by an individual, business or organisation from a unit of activity (World Resources Institute, 2004); section 2.6.2 shows an example of the calculation. This final process is referred to in this section as Carbon Accounting.

From the literature, there are two primary sources to find emission factors. The first source is from a Carbon Database; the other is from suppliers with an Environmental Product Data Sheet (EPD). An EPD is a third-party verified document communicating its environmental impact and following the ISO 14025 standard.

Looking at emission factors via databases, Chilana (2011); Chilana et al. (2016); Khan and Tee (2015); Nandyala et al. (2019) used the emission factors in the Inventory of Carbon and Energy (ICE) database. Alsadi and Matthews (2020) used e-calc software, and Ariaratnam and Sihabuddin (2009) created their tool using the EPA/USEPA factors and the Clean Air Act.

Focusing on the ICE database, in particular, contains multiple materials and their associated emission factor. The database is versatile but adds to the complexity of specifying two emission coefficient types. The first type is embodied energy, and the other is embodied carbon (Hammond et al., 2011). In this research, the embodied carbon coefficient defined in the ICE Database is called an Emission Factor. While other researchers are satisfied with the emission factors in the ICE database, Elhag (2015), in particular, cautions against using the ICE database and warns if users are checking its data quality and representativeness. Elhag records considerable differences in the values recorded in various databases, with some sources varying up to 40% for some products.

In using Emission Factors, Pandey et al. (2011) recommend using region-specific emission factors as recommended by the IPCC and the GHG Protocol, as these emission factors are verified to its operation and geographical context. In essence, one can interpret Pandey et al. recommendations to imply the use of EPDs from local suppliers, which are region-specific and verified by a third party.

Based on the literature, the simplest carbon accounting method to use is the embodied calculation method. For the calculation to work, quantified emission sources are multiplied with their corresponding local (region-specific) emission factor. Section 2.6.2 shows the methods of calculation. The calculation cannot be made without the activities and resources identified from the construction methodology. Therefore, understanding the construction methodology in section 2.5 is crucial. Section 2.6.3 provides the data sources for local emission factors.

2.6.2 GHG Emission – Measured and Calculated

Section §2.6.1 introduced the concept of calculating emission resulting in the Carbon Dioxide Equivalent (CO₂e) unit. The idea was to quantify an emission or ratio to a greenhouse gas defined in today's atmosphere and compare it with an equal quantity of CO₂ or Carbon Dioxide Equivalent.

In section 2.6.2.1, an additional method, the direct measure calculation, is introduced. Should other sources and fugitive emissions be required, direct measurements should be applied. Pandey et al. (2011) researched whether direct measurement is needed; there are optical, chemical, and biological sensors, such as photoacoustic infrared sensors, and other instruments and techniques like collecting gases to analyse through IR spectroscopy for CO₂ and gas chromatography for all GHG. Table 10 below shows an example of a measured calculation that requires a good understanding of chemical science. Not all stakeholders or engineers will understand this level of science or the calculation that goes with it, nor will they have the equipment to measure the emissions. Therefore, this section is for information only.

The second type is the calculated method using Emission Factors (EF), refer to 2.6.2.2. EF are calculated conversion factors and represent a pollutant released to the atmosphere per unit of activity. It is typically expressed as carbon dioxide equivalents (CO₂e). For this research, the calculation method via the product of emission factors and unit activity will be used to get Carbon Dioxide equivalents. Emission factors will be taken from supplier-supplied EPDs and published scientific and government-accepted data.

2.6.2.1 Measured Emission

When combusted, a fictitious gas named Gas X with a measured volume of 1000m³ emits CO₂, CH₄, N₂O and HFC-152a gas. Its emission factor compared to an equal quantity of CO₂ is shown below. Once the values are multiplied by the volume, the values are multiplied by its global warming potential. The result is the Carbon Dioxide Equivalent, refer to Ministry for the Environment (2022a), Appendix B – Method B.

Table 10: Emission Factor and CO₂ Equivalent Calculation

Volume (m ³)	Emission Factors	Total	Global Warming Potential (AR5 values) *	CO ₂ equivalent
1000	3000g CO ₂ /m ³	3,000,000 g CO ₂	1	3t
1000	0.100g CH ₄ /m ³	100g CH ₄	28	0.0028t
1000	0.050g N ₂ O/m ³	5g N ₂ O	265	0.001325t
1000	0.001g HFC-152a/m ³	1g HFC-152a	138	0.000138t
Total Emission of Gas X.				3.004t CO ₂ e

*The GHG Protocol has summarised GWP values from the IPCC SAR, AR4 and AR5 reports. The three key GHG gases have been extracted in Table 11 below. The other values have been removed and can be seen in Appendix 1.

Table 11: GWP values from GHG Protocol

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Carbon dioxide	CO ₂	1	1	1
Methane	CH ₄	21	25	28
Nitrous oxide	N ₂ O	310	298	265

2.6.2.2 Calculated Emissions

The calculation method using Emission Factors is calculated from the formula below (Ministry for the Environment, 2022a, p. 18).

$$E = Q \times F \text{ (Equation 1)}$$

Where:

E = emissions from the emission source in kg CO₂e

Q = activity data (e.g. quantity of fuel)

F = emission factor for emissions source

Variable Q is the independent variable, while E is the dependent variable.

Independent variable (Q)	Function (F)	Dependent variable (E)
(Input) Activity Data	x Emission Factor (Regular Petrol)	= (Output) Emissions
5 litres	x 2.46 kg CO ₂ e/litre	= 12.3 kg CO ₂ e

The independent variable or the activity data will come from the emission sources identified in the WBS; refer to section 2.5.4 Open-cut Construction Process.

This study uses a variation or a hybrid to Equation 1 to calculate different fuel consumption rates. Kim et al. (2012) used a three-step embodied carbon calculation in their research. The first is the estimated number of hours of the plant or machinery. The second step is choosing the fuel consumption rate associated with the plant or machinery. Instead of Kim et al. using a conversion factor developed by the IPCC to convert the value to Carbon, the final step is replaced by local emission factors. This hybrid equation estimates plant or equipment carbon footprint if the total fuel consumption is unknown.

The hybrid equation is defined as follows:

$$H_i^j = \frac{X^j}{Q_i^j} = \frac{m^3}{\left(\frac{m^3}{\text{cycle}} \times \frac{\text{cycle}}{\text{hour}}\right) \times (e_i^j = \%)} \quad (\text{Equation 2 – Stage 1})$$

Where:

H_i^j = the working hours of plant or equipment i , for activity j

X^j = the total quantity for activity j

Q_i^j = the quantity per one cycle of plant or equipment i , for activity j

e_i^j = production efficiency of equipment of plant or equipment i , for activity j

$$\text{Energy}_i^j = H_i^j \times C_i = \text{hour} \times \frac{\text{litre}}{\text{hour}} \quad (\text{Equation 2 – Stage 2})$$

Where:

C_i = the energy consumption of plant of equipment i , per unit time

$$E = H_i^j \times C_i \times F = \text{hour} \times \frac{\text{litre}}{\text{hour}} \times \text{Emission Factor} \quad (\text{Equation 2 – Stage 3 Final})$$

Where:

E = emissions from the emission source in kg CO₂e

H_i^j = the working hours of plant or equipment i , for activity j

C_i = the energy consumption of plant of equipment i , per unit time

F = emission factor for emissions source

2.6.3 Data Collection Methods

The essential data sources needed for this research and their accessibility are shown in Table 12 below.

Table 12: Data Sources and their Discipline

Discipline	Data Source	Accessibility	Comments
Carbon Emission Factors	BRANZ – BRANZ_CO2NSTRUCT	P	Downloaded for free (DFF)
	EPD Australasia https://epd-australasia.com/	P	DFF
	Ministry of Environment https://environment.govt.nz/publications/measuring-emissions-a-guide-for-organisations-2023-emission-factors-summary/	P	DFF
	Building Transparency	P	DFF
Construction/ Engineering	ACSCOP – SW01, SW02, SW03	P	Local standards will dictate the plant, machinery and resources needed.
	Watercare - WS2, WW2	P	Local standards will dictate the plant, machinery and resources needed.
Quantity Surveying	NZIQS – The Quantity Surveyor’s Handbook, labour constants	P	DFF
	CCNZ – Blue Book Plant Hire Rates	P	They are shared in confidence by the industry. Gives typically rates but fluctuates depending on market conditions. Used as a check
	Kennards/ Hirepool – Plant and Equipment	P	Accessible via the internet

CHAPTER 3 Development of Carbon Framework Methodology

3.1 Introduction

From the literature review, multiple frameworks were reviewed and discussed in section 2.4.1. Pandey et al. (2011) and the Ministry for the Environment (2022a) recommended the GHG Protocol. Although the MfE suggested ISO 14064, the ISO 14064 standard was similar to the GHG Protocol. What made ISO 14064 appealing is its information on allocating emission sources to an expanded operational boundary for scope 3. Where scope 3 is split into 4 categories, refer to section 2.4.5. The GHG Protocol Scope 3 Supply Chain standard was also the same, but instead of 4 categories with ISO 14064, the GHG Protocol Scope 3 value chain expanded to 15 categories, refer to 2.4.6. So, in the context of Carbon Frameworks, the leading framework used in this research is the GHG Protocol Corporate Standard, ISO 14064 and the GHG Protocol Scope 3 value chain operational boundaries, which are adopted into the new methodology. However, the standards are used in final reporting only where emission sources are allocated to their emission categories.

Recent articles from Enzer (2013) showed Anglian Water achieving their emission reduction targets (capital carbon by 39% and operation carbon by 34%) by implementing the PAS 2080, refer to section 2.4.7. PAS 2080:2016 is a carbon management system and provides steps for quantifying emissions. With recommendations of a Carbon Accounting Framework from literature and the proven success of a management system, the GHG Protocol and PAS 2080 were considered standards worth pursuing by inductive reasoning.

The following sections compare the GHG Protocol and the PAS2080: 2016 in their steps in quantifying carbon emissions. As both methods have vital steps that have been checked and followed, if specific steps are omitted or ignored, it could potentially represent a false account of the company's GHG emissions. To avoid this scenario, the following section below explains the similarities of these standards and the unique, perhaps investigated and integrated steps to create an accurate, relevant, and complete account of a company's GHG emissions.

The key learnings from the literature review are then reviewed and incorporated into the carbon framework to create a new simplified carbon framework methodology model.

3.2 GHG Protocol method vs. PAS2080:2016 steps in quantifying emissions

When comparing the GHG Protocol (Figure 20) and PAS2080's steps in quantifying emissions (Figure 21) below, there are the white steps common in both standards and the yellow and orange steps unique to each one. The white steps are shared between both standards; the steps are accepted and adopted. The yellow steps are key independent steps and should be combined as one. Figure 22 in section 3.4 shows the final combined steps in quantifying emissions.

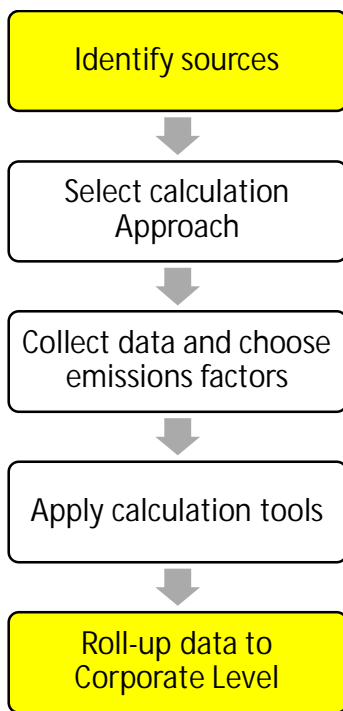


Figure 20: GHG Protocol steps in identifying and calculating GHG emissions

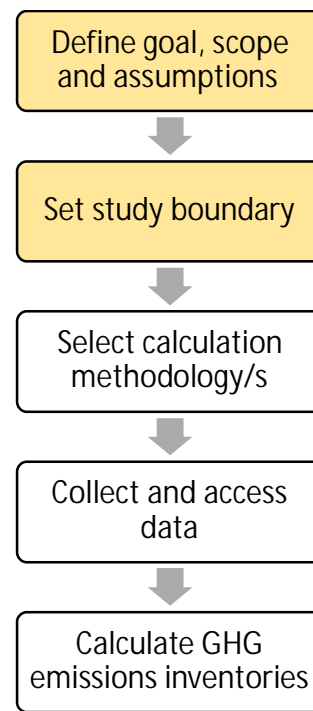


Figure 21: PAS2080: 2016 steps in quantifying emissions

3.3 Learnings from the Literature

Learnings from the literature assisted in ordering and reinforcing the steps to quantify carbon. Table 13 tabulates the steps, learnings, and section references.

Table 13: Learnings from the Literature embedded in the Framework steps.

Steps	Learnings from the literature matched the steps from the standards	Section Reference
Define Goals, Scope, and Assumptions	Once a goal is chosen, check the design standard. The design standard might yield ideas for creating a construction methodology and potentially reveal plants and materials that could be emission sources.	2.5.1
Set Study Boundary	Use or develop an LCA diagram and use it as a visual tool to see the different stages of the life cycle of a product. The study boundary. From here, the study boundary can be defined, and the scope and limitations can be set. From here, a construction methodology can be created.	2.4.1
Work Breakdown Structure	From the construction methodology, a thorough work breakdown structure is created. Knowing the process well and having a visual aid would assist in identifying and revealing emission sources from plants, machinery and materials used.	2.5.4, Figure 18
Identify Sources	Identified emission sources will need to be quantified. The units to be measured are dependent on the associated emission factor.	2.5.1, 2.5.4, Figure 18
Select Calculation Approach	Calculation using the embodied carbon multiplied by the corresponding emission factor.	2.6.2.2
Collect data and choose emission factors	If possible, data from NZ databases or local EPD emission factors will be used.	2.6.1, 2.6.3
Calculation GHG emission	Emission sources will be allocated to emission categories per the operational boundaries Scope 1, 2 and 3. Scope 3 depends on client requirement (the default chosen is ISO 14064)	2.4.4.9, 2.4.5, 2.4.6
Roll up data/ Reporting	The report presented shows direct Scope 1 and indirect Scope 2 and Scope 3.	2.4.4.9,

3.4 Combined GHG Protocol and PAS2080:2016

Figure 22 below shows the ordered and combined steps from GHG and PAS2080 and explains why they are required. An essential addition not mentioned in both standards is knowing the work breakdown structure. To identify emissions, the construction activity must be broken down sufficiently to identify emission-causing resources or activities.

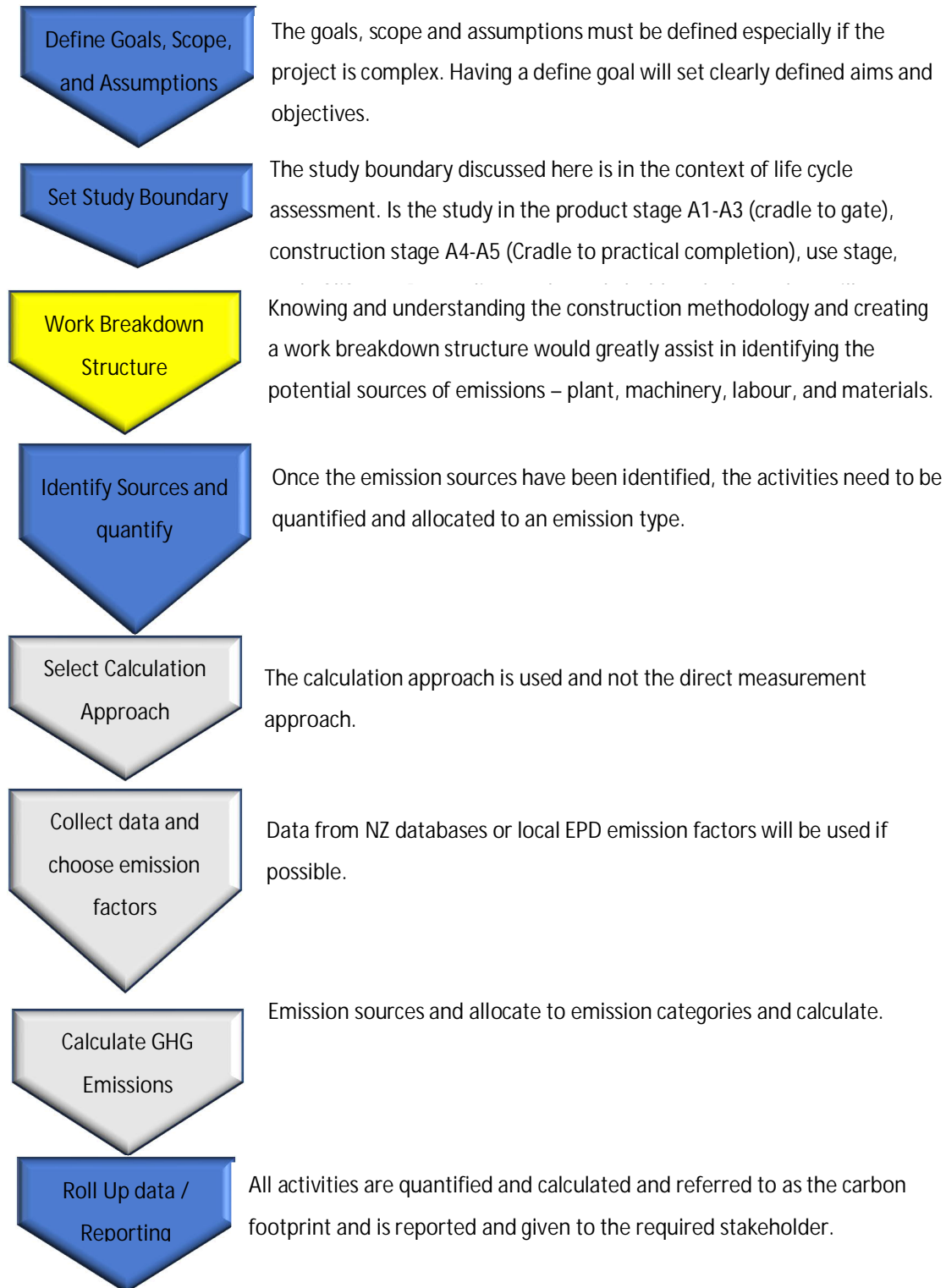


Figure 22: Structured steps finalised

3.5 Final Carbon Framework Methodology

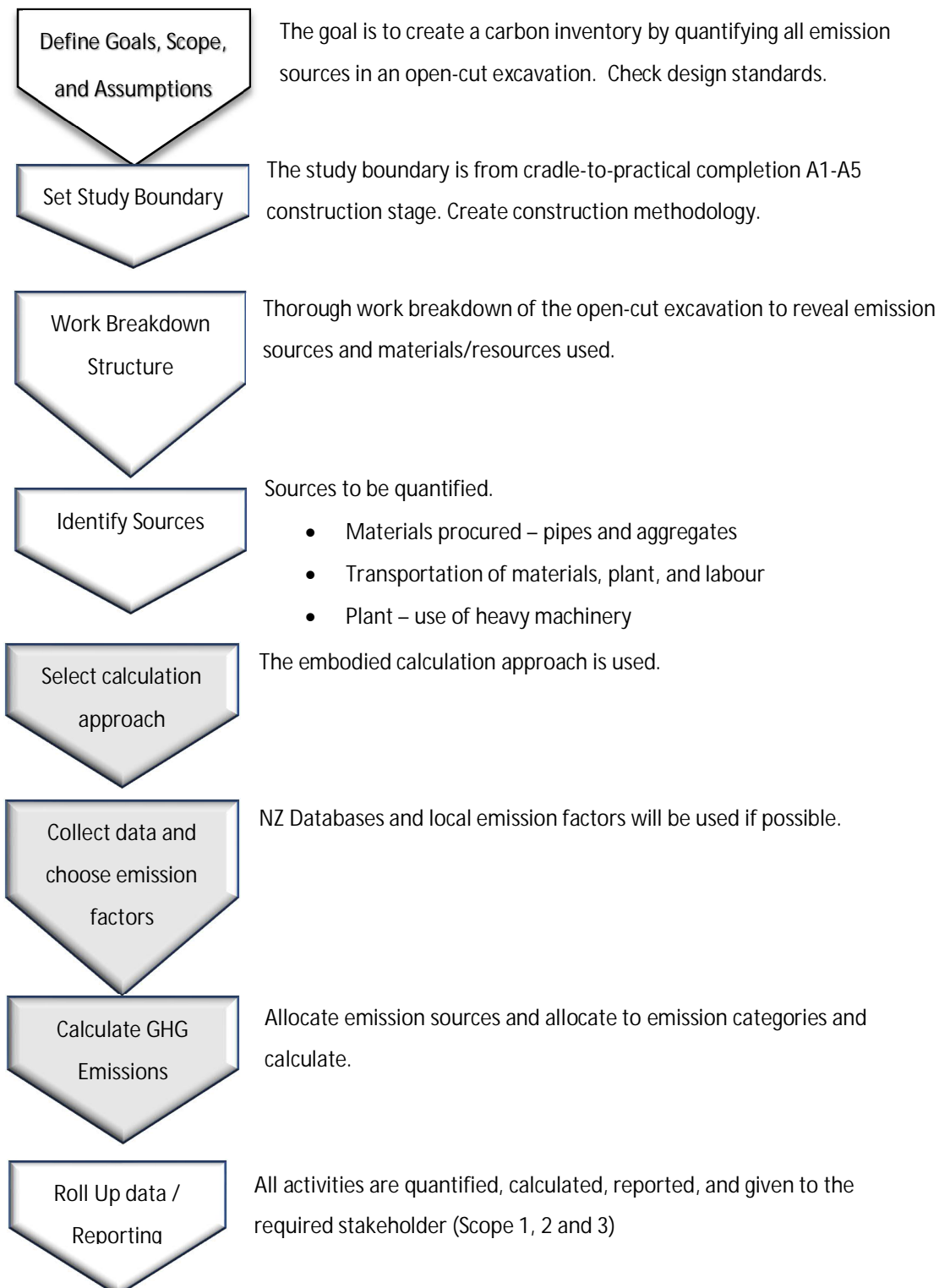


Figure 23: Final Construction Carbon Framework (Open-Cut Excavations NZ)

CHAPTER 4 Creation of Open-Cut Excavation Carbon Tool via Case Study

4.1 Introduction

Multiple combinations of plant, equipment and labour are required to install water, wastewater, and stormwater pipes. Capturing the carbon footprint of all possible scenarios is too large for the scope of this research, and therefore, the scope is limited to a case study, and limitations were put in place, as discussed in the next section.

To demonstrate the effectiveness of the Carbon Framework (as shown in section 3.5), the following case study examples in Table 14 were used in developing the Carbon Tool. These examples were chosen as they are typical pipe sizes that closely resemble typical residential and small commercial buildings. The case study examples intend to teach Contractors how to create their carbon inventory. Once they have developed their knowledge, they can use and modify the template for their needs.

Table 14: Case Study Examples

	Pipe ø	Type	Pipe Length (m)	Depth (m)	Standard
Stormwater	100	Non-pressure – DN100, SN16100.6RJ	100	1.3	Auckland Council
Water	100	Pressure – 800.150.PN9.6SJ	100	1.3	Watercare
Wastewater	100	Non-pressure – DN100, SN16100.6RJ	100	1.3	Watercare

In the construction of pipes, there are multiple standards and specifications for installing water, wastewater, and stormwater pipes. For example, in establishing a wastewater pipe, the pipe may be installed in a driveway, vehicle crossing or footpath. The construction standards to build and install the pipe will be by the local authority, such as Watercare. Still, if the pipe is installed on a carriageway, the reinstatement of the road must be by Auckland Transport or to the standards of the Roding Authority of the project. To limit the complexity of multiple construction methodologies, the next section, section 4.2, describes the limitations of the scope. Once a level of understanding is achieved, the user can add elements and increase the complexity more suited to their project needs.

4.2 Scope, Specifications and Limitations

To demonstrate the effectiveness of the Carbon Framework, sections 4.2.1 and 4.2.5 describes the specifications and limitations used.

4.2.1 Framework Limitations

- In Life Cycle Terminology, the inventory will be measured by “Cradle to Practical Completion”. The Environmental Indicator assessed is only the Global Warming Potential.
- As the contractor who builds a construction project is usually only involved up to Practical Completion, the focus will be Embodied Carbon, not Operational Carbon.
- As the target for this research is grassroots contractors, instead of the complete list of greenhouse gases listed in the IPCC, carbon dioxide equivalent will only be used in this research, and other gases will be ignored for simplicity.
- As this research is for contractors, it does not focus on GHG removals, such as carbon offsets via the Emission Trading Scheme.

4.2.2 Water, Wastewater and Stormwater Specifications

There are multiple physical combinations of open-cut excavations for pipes. It may range from different depths, widths and lengths are sometimes designed uniquely to suit the excavation area's conditions. Therefore, to limit the complexity, the following limits were applied:

Stormwater

- Auckland Council Stormwater Code of Practice Drawings, version 3, SWCoP, W01 and SW02 was used for flexible pipe Polyvinyl Chloride (PVC)
- PVC Pipe (none pressurized) – sizes 100ø and 150ø nominal diameter was entered. Bedding pockets underneath the sockets are allowed as part of the additional factor for bedding losses and overbreak.
- Non-carriageway conditions used: Vehicular load (Carriageway) is not used as it will require additional specifications to Auckland Transport (Surface Course)
- Trench conditions and embankment conditions are not used; pipes will be installed using the trench condition.

Water

- Watercare Code of Practice for Land Development and Subdivision – water drawings set DW02, rev 2.1, 28/08/2020 – Dwg No.2010069.001D, Reference WS 2, issue 28-09-2017.

- PVC Pipe (none pressurized) – sizes 100ø and 150ø nominal diameter was entered. Bedding pockets underneath the sockets are allowed as part of the additional factor for bedding losses and overbreak.
- Grass Area Reinstatement used: Footpath Reinstatement, Driveway Reinstatement and Footpath/Vehicle Crossing, Carriageway Reinstatement not used as it will require additional specifications to Auckland Transport Code of Practice.
- Granular Surround was used; granular bedding and concrete surround were not used.

Wastewater

- Watercare Code of Practice for Land Development and Subdivision – wastewater drawing set DW01, rev 2.1, 12/08/2019 - Drawing 2010070.001C, Reference WW2, issue 06-03-2017,
- PVC Pipe (none pressurized) – sizes 100ø and 150ø nominal diameter was entered. Bedding pockets underneath the sockets are allowed as part of the additional factor for bedding losses and overbreak.
- Grass Area Reinstatement used: Footpath Reinstatement, Driveway Reinstatement and Footpath/Vehicle Crossing, Carriageway Reinstatement not used as it will require additional specifications to Auckland Transport Code of Practice.
- Granular Surround was used; granular bedding and concrete surround were not used.

Variables standard to all three examples:

- General All Passing (GAP) 7 or GAP7 is the bedding material. The density value was taken from Winstone Aggregates; refer to Appendix 5.
- Excavated native material replaced with GAP7 or tipping is assumed to lay on-site free of lumps >150mm and not tipped offsite.
- Road transportation for mobilisation and demobilisation of heavy plant and transportation of pipes and GAP7 Aggregates are via heavy goods vehicles 7,500kg < 10,000 kg, pre-2010 fleet.
- Labour for the works is assumed to be performed by a 3-person crew team - 1x Truck Driver, 1x Excavator Operator, and 1x Skilled Operative inside the trench.
- Employee Commuting Vehicles are considered Road Freight: light commercial vehicles, as typically, site engineers have work utes that bring light machinery, materials, tools, etc.
- Pipe laying labour constants are from NZIOS Quantity Surveyors Handbook – Drainage; refer to Appendix 6.
- It is assumed that there are no existing services in the excavation area.

4.2.3 *Methodology Limitations*

- The plant used for the excavation is a 5T excavator with a fuel consumption rate of 11.6L/hr from Kim et al. (2012)
- The small machinery used is a foot wacker with a fuel consumption rate of 0.7L/hr from Kim et al. (2012)
- Small machinery vibrating plate fuel consumption rate of 1.0 L/hr from Kim et al. (2012)
- The trucks used for transport are 6W Trucks with a capacity of 9T payload.
- Tipping is assumed to be used on-site.
- Excavation is limited to no greater than 1.3m dept. Therefore, no benching or trench shields are required.
- The radius for travel is 40km.

4.2.4 *Emission Factors*

- Fuel and freight emission factors are sourced from the Ministry of the Environment.
- Aggregate emission factors are sourced from NZ Winstone Aggregates, EN 15804 compliant EPD, manufactured in NZ.
- Pipe emission factors are sourced from NZ RXP, EN 15804 compliant EPD, manufactured in NZ.

4.2.5 Transportation Distance

In section 2.3.7, Figure 8, the MfE shows that NZ GHG transport emissions are 18%. Almost 1/5 of NZ's total emissions. In the context of the material supply of GAP7, aggregates typically come from quarries away from urban areas. Works sites are also not typically built in one area or an industrial zone. Infrastructure construction sites are sporadic and are needed when there are developments. As seen in Figure 24, travel from a north quarry to the central city is about 45km. In Figure 25, travel from a south quarry to the central city is about 49km. In this research, it was elected to use 40km per one-way travel. For example, transportation of heavy vehicles begins from the supplier yard (SY) to the contractors' yard (CY), then to the site and return, 40km (SY) + 40km (CY) + 40km (site) = 120km one way, 240km return trip.

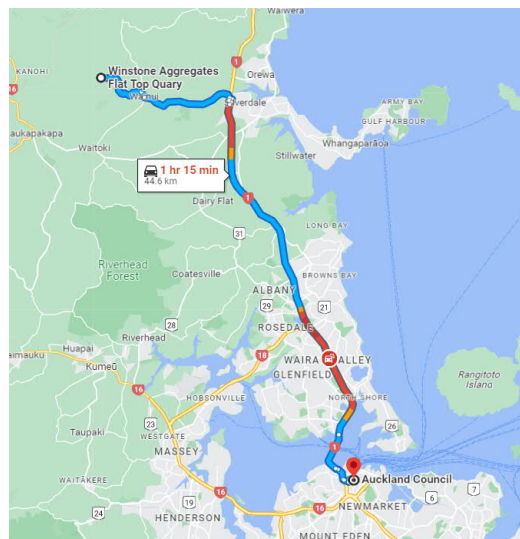


Figure 24: North Shore to City 45km (Google Maps)

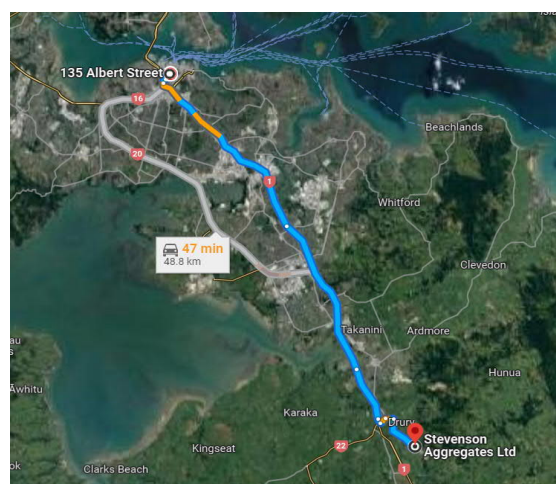


Figure 25: City to South 49km (Google Maps)

4.3 Study Boundary and WBS

A separate worksheet was created with a life cycle diagram, as shown in Figure 17, section 2.5.3. The worksheet was added to show the user visually a general open-cut pipeline construction life cycle. The users can then visually see the scope and their study boundary, e.g., Cradle to gate or Cradle to practical completion. The scope of the case study examples will be from Cradle to Practical Completion.

A dedicated worksheet was created showing a WBS; refer to Figure 26. The WBS offers the steps from mobilisation, excavation, installation of pipes, bedding, backfill, and surface finishing to the final demobilisation. The diagram intends to visually show the user that they can identify the emission sources by breaking down the work. In the example, the sources of emissions are trucks, excavators, minor plants, bedding material – GAP7, and pipe. Also, from the WBS, the user can start identifying the operational boundaries of Scopes 1, 2 and 3. As the example is site-based, the operational boundary is only scope 1 direct and scope 3 indirect emissions (supply chain).

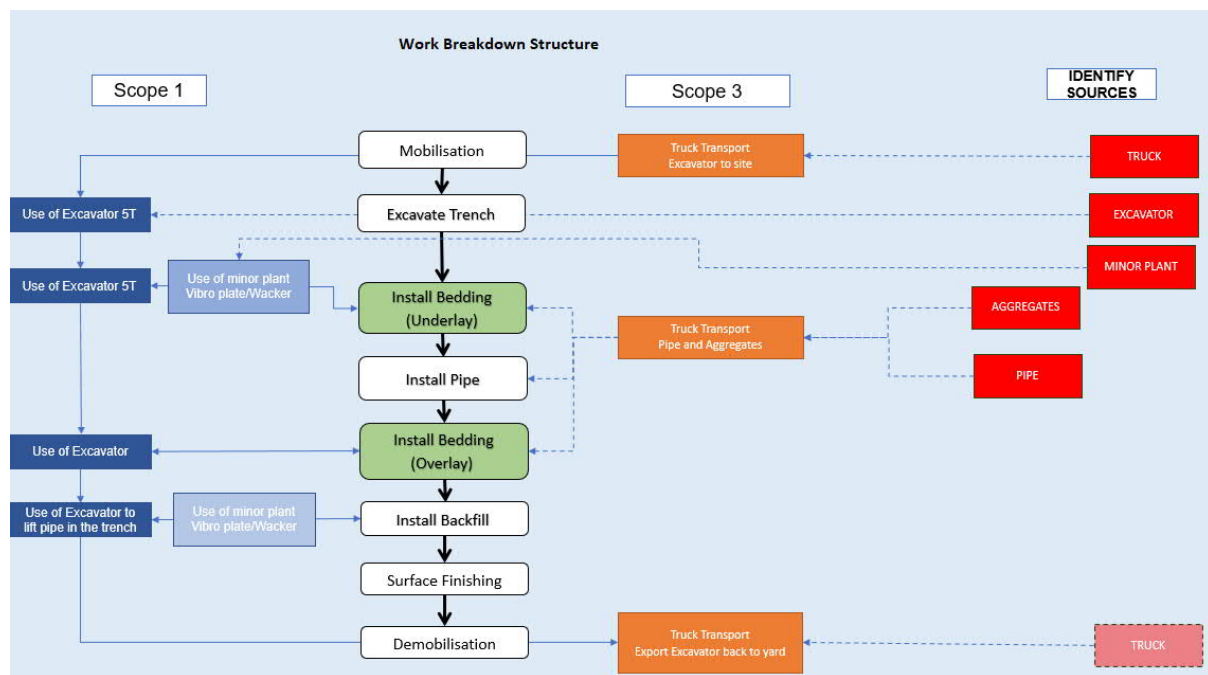


Figure 26: Work Breakdown Structure

4.4 Calculations

Based on the standards from Auckland Council and Watercare, the materials identified that need to be quantified are the pipes and the bedding material. To get the mass, the bedding material was quantified using first-principles calculations using areas, volumes, and density.

Emission calculations are calculated per the embodied calculations described in section 2.6.2.2, where the quantified activities are multiplied by their attributed emission factors.

4.5 Emission Factors

Table 15 to Table 19 tabulates the Emission Factors to be used as per the scope and limitations written in section 4.2.

Table 15: PVC Pipe Emission Factor

Type	Pipe	Supplier	Life Cycle	*Density kg/m	GWP Emission Unit (kg CO ₂ e/kg)	GWP Emission Unit (kg CO ₂ e/meters)
PVC	Stormwater/ Wastewater - Non-Pressure - DN100 DWV Series 100, SN16100.6RJ	RXP	A1-A3	2.178	2.38 [†]	5.184
PVC	Water - Pressure - 800.100.PN9.6SJ	RXP	A1-A3	2.368	2.63 [‡]	6.228

Refer Appendix 4.1

*RXP New Zealand (2022, p. 37 Appendix B)

†RXP New Zealand (2022, p. 16 Table 8, A1-A3)

‡RXP New Zealand (2022, p. 33 Appendix A)

Table 16: Aggregate GAP 7 Emission Factor

Material	Abbreviated Name	Description	Product Group	Product Group Acronym	GWP Emission Unit (kg CO ₂ e/tonne)
GAP7	GAP 7	General All Passing 7	Aggregate – Tertiary Crushing & Screening, Unwashed	ATSCW	3.59*

Refer Appendix 4.2

* Winstone Aggregates (2022, p. 29)

Table 17: Direct Emission Fuel Use

Variable	Description	Product Group	GWP Emission Unit (kg CO ₂ e/litre) *
Diesel	Fuel - Stationary	Stationary Combustion of Fuels: Industrial Use	2.69
Petrol	Regular Petrol	Fuel	2.46

Refer Appendix 4.3

*Ministry for the Environment (2022b, pp. 7-8, Table 3 & 4)

Table 18: Road Heavy Goods Vehicles

Variable	Description	Product Group	GWP Emission Unit (kg CO ₂ e/km)
HGV Diesel	Heavy Goods Vehicle 7,500 -<10,000kg	Pre-2010 fleet	0.624

Refer Appendix 4.3

Ministry for the Environment (2022b, p. 21 Table 26)

Table 19: Road Freight: Default Light Vehicles

Variable	Description	Product Group	GWP Emission Unit (kg CO ₂ e/km)
Petrol	Road Freight 2000<3000cc	Light Commercial Vehicles	0.317

Refer Appendix 4.3

Ministry for the Environment (2022b, p. 20 Table 24)

4.6 Reporting

Section 2.4.4.9, Figure 16 shows how GHG emissions are reported by scope. While Table 7 shows tabulated results on the emission summary. Both are critical examples given by the MfE on what to write. In this research, the operational boundaries of Scope 3 are expanded to include the categories of ISO 14064 and GHG Protocol Scope 3 standards. Table 20 below shows the categories that apply to the case study in the carbon tool.

Table 20: Reporting using the Standards Scope Boundaries

GHG Protocol		ISO14064		GHG Protocol - Scope 3	
Scope 1	Direct GHG Emissions and Removals - Fuel	Scope 1	C1	Scope 1	Direct GHG Emissions and Removals - Fuel
Scope 2	Indirect GHG emissions from imported energy	Scope 2	C2	Scope 2	Indirect GHG emissions from imported energy
Scope 3	Indirect GHG emissions (Optional)	Scope 3	C3	Scope 3	C1
			C4		C2
			C5		C3
			C6		C4
					C5
					C6
					C7
					C8
					C9
					C10
					C11
					C12
					C13
					C14
					C15

4.7 Quantitative and Qualitative Validation

4.7.1 Quantitative Validation

To verify the carbon tool's results, the carbon tool's installation emission values are compared to the construction and installation process - A5 emission values published on the by local pipe supplier EPDs. Table 21 below shows other information within the EPD which could be used to compare results from the carbon tool.

Table 21: Quantitative Comparison of Carbon Tool vs EPD

Stage	Number	Description	Supplier EPD	Comments
Product Stage	A1 to A3	Raw Material Supply Supply Manufacturing	Given in EPD	Supplier EPD Used
Construction Stage	A4	Transport	Given in EPD	Researched derived
Construction Stage	A5	Construction & Installation Process	Given in EPD	Research derived and compared to supplier EPD

4.7.2 Mix Qualitative and Quantitative Validation

To check the efficacy of the carbon tool, the tool was presented to contractors who have been installing three waters infrastructure in the industry. A questionnaire was prepared to receive industry feedback to see their opinions on the tool. Appendix 7 contains the approved low-risk Ethics Form, Information Sheet, Consent Form, and Questionnaire.

The questionnaire in Appendix 7.4 is qualitative, asking how the participants think about the carbon tool. However, their response was designed so that they could give their response quantitatively to allow statistical analysis.

CHAPTER 5 Results, Discussion, and Analysis

5.1 Introduction

This chapter shows the results of the Carbon Tool and discusses and analyses the results.

Section 5.2 shows two parts. The first part shows how the emissions sources were quantified, while the second part summarises the final calculations in a simple table and charts.

Section 5.3 discusses and analyses the results. Section 5.3.1 shows the final emissions and is presented in the different Carbon Standards. The standards are discussed depending on the chosen standard; key advantages exist in using one from the other. Section 5.3.2 discusses the learnings, the factors influencing the results and the challenges faced in each category. It also compares the construction installation emissions against published EPD values in the industry. Section 5.3.3 discusses and presents the feedback from offering the carbon tool to the industry. The carbon tool was introduced to tier 1 and multiple tier 2 contractors, with some having 20+ years of experience in stormwater, water, and wastewater pipeline infrastructure.

5.2 Results

5.2.1 Emission Sources Quantified

5.2.1.1 Excavation and Bedding (GAP7) Calculations

Table 22 below shows the calculation and result for GAP7 in tonnes.

Table 22: Excavation calculations

	Stormwater	Water	Wastewater
Pipe length (m)	100.000	100.000	100.000
Pipe size nominal (m)	Ø = .100	Ø = .100	Ø = .100
Pipe invert (m)	1.300	1.300	1.300
Backfill depth (m)	1.100	1.050	1.050
Full depth with embedment (m)	1.375	1.400	1.450
Embedment (m)	$l_b = 0.075$	0.100	0.150
Overlay (m)	$L_o = .100$	0.150	0.150
Side width (m)	$L_c = .100$	0.300	0.300
Trench width (m)	.300	.700	0.700
Bedding height (m)	.275	.350	0.400
Area of pipe (m ²)	0.008	0.008	0.008
*Bedding area (m ²) *Without pipe area	0.075	0.237	0.272
Tipping area (m ²) * *Full area of trench Trench width * bedding height	0.083	0.245	0.280
Backfill area (m ²)	0.330	0.735	0.735
Bedding volume (m ³)	7.465	23.715	27.215
Tipping volume (m ³)	8.250	24.500	28.000
Backfill volume (m ³)	33.000	73.500	73.500
Pipe volume (m ³)	0.785	0.785	0.785
Total excavated volume (m ³)	41.250	98.000	101.500
Bedding overbreak @ 10% (m ³) *Bedding Volume x 10%	0.746	2.371	2.721
Bedding losses @ 10% (m ³) *Bedding Volume x 10%	0.746	2.371	2.721
Total bedding volume (including bedding overbreak and losses) (m ³)	8.958	28.458	32.658
GAP7 density (t/m ³) * *Winstone Aggregates, refer to Appendix 5	1.540	1.540	1.540
Compaction factor	1.600	1.600	1.600
GAP7 mass (tonnes)	<u>22.071</u>	<u>70.119</u>	<u>80.468</u>

5.2.1.2 Labour Productivity Calculations

Table 23 shows the calculation for excavating a 100ø pipe, 100m open-cut excavation, 1.3m deep. Getting actual productivity from contractors was challenging as this information was their proprietary trade secret. This calculation was attempted to show the complexity required for an estimate pre-contract. This productivity calculation is an estimate and not based on actuals and is typical of what Estimators/Quantity Surveyors must do pre-contract. Expert consultation was given by contractors who do drainage, and they mentioned, "If site staff were to give actuals, they would never win the job".

Table 23: Labour Productivity Calculations

Excavator	5 tonne			
Bucket	0.3 m ³			
Pipe Diameter (m)	.100			
Description	Unit	Stormwater	Water	Wastewater
Start	seconds	10	10	10
Excavation	seconds	50	50	50
Rotate to the truck and unload	seconds	50	50	50
Rotate back to the trench	seconds	50	50	50
Delay	seconds	30	30	30
Total cycle	seconds	<u>190</u>	<u>190</u>	<u>190</u>
Total cycle* <small>*almost 1 min per solid bucket</small>	minutes/ per bucket	<u>3.167</u>	<u>3.167</u>	<u>3.167</u>
Total Excavation* <small>Refer Table 22</small>	m ³	41.250	98.00	101.50
Bucket size	m ³	0.3	0.3	0.3
No of buckets* <small>*Total excavation/bucket size</small>	No of buckets	138	327	339
Estimated excavation time* <small>*Total cycle * no of buckets</small>	minutes	437	1036	1074
Total Excavation Time	Hours	<u>7.28</u>	<u>17.26</u>	<u>17.89</u>
Length of Trench	meters	100	100	100
Laying, jointing, and testing of pipe only* <small>*NZIQS, refer Appendix 6 (water assumed same as wastewater)</small>	hour	0.20	0.25	0.25
Total Pipe Installation Time	Hours	<u>20</u>	<u>25</u>	<u>25</u>
Trench width	meters	0.30	0.70	0.70
Length of Trench	meters	100	100	100
Total backfill area	m ²	30	70	70
500kg vib plate length	meters	0.55	0.55	0.55
500kg vib plate width	meters	0.90	0.90	0.90
Vib plate area	m ²	0.50	0.50	0.50
Productivity (Assumed)	seconds/ per m ²	30	30	30
Productivity in minutes/ per vib plate area	min/ per m ²	0.5	0.5	0.5
Vib plate total time* <small>*total backfill area/vib plate area x productivity in min</small>	mins	30.3	70.71	70.71
Total compaction time per layer in hours	hours	<u>0.51</u>	<u>1.18</u>	<u>1.18</u>
Bedding depth	meters	0.28	0.35	0.40
Layer thickness	meters	0.300	0.30	0.30
No of layers* <small>*rounded up</small>	number	1	2	2
Total Bedding Compaction Time* <small>*Total compaction time* no of layers</small>	hours	<u>0.51</u>	<u>2.36</u>	<u>2.36</u>
Backfill depth	meters	1.10	1.05	1.05
Layer thickness	meters	0.30	0.30	0.30
No of layers* <small>*rounded up</small>	number	4	4	4
Total Backfill Compaction Time* <small>*Total compaction time* no of layers</small>	hours	<u>2.02</u>	<u>4.71</u>	<u>4.71</u>
Summary	Unit	Stormwater	Water	Wastewater
Total Excavation Time	hours	7.28	17.26	17.89
Total Pipe Installation Time	hours	20.00	25.00	25.00
Total Bedding Compaction Time* <small>*Total compaction time* no of layers</small>	hours	0.51	2.36	2.36
Total Backfill Compaction Time* <small>*Total compaction time* no of layers</small>	hours	2.02	4.71	4.71
Total Installation Time	hours	<u>29.81</u>	<u>49.33</u>	<u>49.96</u>
Assuming two staff inside the trench, 1x truck driver	Increased efficiency due to 2 staff in the trench	50%	50%	50%
Total Installation Time with two staff		<u>14.90</u>	<u>24.66</u>	<u>24.98</u>

5.2.1.3 Direct Emissions

Table 24 below shows the calculation for the Excavator, small plant wacker and vib plate emissions.

Table 24: Direct Emission Calculations

Description	Unit	Stormwater	Water	Wastewater	
Total hours	hr	29.81	49.33	49.96	
No of staff	No#	2	2	2	
Efficiency	%	50	50	50	
Total Hours	hr	<u>14.90</u>	<u>24.66</u>	<u>24.98</u>	
Excavator Fuel	Total hours	hr	14.90	24.66	24.98
	Rate* *Kim et al. (2012)	L/hr	11.6	11.6	11.6
	Quantity* Total hours * Rate	L	173	286	290
	Emission Factor* *ref Table 17	kg CO ₂ e/ L	2.69	2.69	2.69
	Total Emissions	kg CO₂e	<u>465</u>	<u>770</u>	<u>780</u>
Small Plant Wacker	Total hours	hr	14.90	24.66	24.98
	Rate* *Kim et al. (2012)	L/hr	0.7	0.7	0.7
	Quantity* Total hours * Rate	L	10.43	17.27	17.49
	Emission Factor* *ref Table 17	kg CO ₂ e/ L	2.46	2.46	2.46
	Total Emissions	kg CO₂e	<u>26</u>	<u>42</u>	<u>43</u>
Small Plant Vib Plate	Total hours	hr	14.90	24.66	24.98
	Rate* *Kim et al. (2012)	L/hr	1	1	1
	Quantity* Total hours * Rate	L	14.90	24.66	24.98
	Emission Factor* *ref Table 17	kg CO ₂ e/ L	2.46	2.46	2.46
	Total Emissions	kg CO₂e	<u>37</u>	<u>61</u>	<u>61</u>
Overall Summary	Descriptions	Unit	Stormwater	Water	Wastewater
Excavator	Total Emissions	kg CO ₂ e	<u>465</u>	<u>770</u>	<u>780</u>
Small Plant – Wacker	Total Emissions	kg CO ₂ e	<u>26</u>	<u>42</u>	<u>43</u>
Small Plant – Vib Plate	Total Emissions	kg CO ₂ e	<u>37</u>	<u>61</u>	<u>61</u>

5.2.1.4 Indirect Emission Calculations

Table 25 and Table 26 below tabulate the calculations for calculating material indirect emissions.

Table 25: Material - Pipe Emissions

Indirect GHG Emission	Description	Unit	Stormwater	Water	Wastewater
Material Pipe	Pipe length	m	100	100	100
	Emission Factor* *ref Table 15	kg CO ₂ e/ m	5.18	6.37	5.18
	Total Emissions	kg CO ₂ e	<u>518</u>	<u>637</u>	<u>518</u>

Table 26: Material – GAP7 Emissions

Indirect GHG Emission	Description	Unit	Stormwater	Water	Wastewater
Material GAP7	GAP 7	Tonne	22.1	70.1	80.5
	Emission Factor* *ref Table 16	kg CO ₂ e/ t	3.59	3.59	3.59
	Total Emissions	kg CO ₂ e	<u>79</u>	<u>252</u>	<u>289</u>

Table 27 and Table 28 show essential calculations for the total cycle distance and the number of trips required to transport the plant material to the site and return. Table 29 shows the complete calculation of the transportation indirect emissions.

Table 27: Transportation Total Cycle Distance

Transportation	Unit	Truck yard to Contractor's/ Suppliers yard	Contractors/ Suppliers Yard-to-Site Construction	Site, return to the Truck yard	Total Cycle Distance
Truck Mobilisation	km	40	40	80	160
Transport – Aggregate	km	40	40	80	160
Transport Pipe	km	40	40	80	160
Truck Demobilisation	km	40	40	80	160

Table 28: No of Trips for GAP7 Aggregate (9T Payload)

Aggregate Transportation Trips	Unit	Stormwater	Water	Wastewater
GAP7	Tonnes	22	70	80
Truck 6-Wheeler	9T payload	9	9	9
No of trips* *Tonnes/ 9T payload	Trips	3	8	9

Table 29: Transportation Fuel Calculations

Indirect GHG Emission	Description	Unit	Stormwater	Water	Wastewater
Truck Mobilisation (Excavator to site)	Total Cycle distance	km	160	160	160
	No of trips	trips	1	1	1
	Total distance	km	160	160	160
	Emission Factor* *ref Table 18	kg CO ₂ e/ L	0.624	0.624	0.624
	Total Emissions	kg CO ₂ e	<u>100</u>	<u>100</u>	<u>100</u>
Transport Aggregate GAP7	Total Cycle distance* *ref Table 27	km	160	160	160
	No of trips	trips	3	8	9
	Total distance	km	480	1,280	1,440
	Emission Factor* *ref Table 18	kg CO ₂ e/ L	0.624	0.624	0.624
	Total Emissions	kg CO ₂ e	<u>300</u>	<u>799</u>	<u>899</u>
Transport Pipes and Small Machinery	Total Cycle distance	km	160	160	160
	No of trips	trips	1	1	1
	Total distance	km	160	160	160
	Emission Factor* *ref Table 18	kg CO ₂ e/ L	0.624	0.624	0.624
	Total Emissions	kg CO ₂ e	<u>100</u>	<u>100</u>	<u>100</u>
Truck De-Mobilisation (Excavator returns to the yard)	Total Cycle distance	km	160	160	160
	No of trips	trips	1	1	1
	Total distance	km	160	160	160
	Emission Factor* *ref Table 18	kg CO ₂ e/ L	0.624	0.624	0.624
	Total Emissions	kg CO ₂ e	<u>100</u>	<u>100</u>	<u>100</u>
Summary	Description	Unit	Stormwater	Water	Wastewater
Mobilisation	Total Emissions	kg CO ₂ e	<u>100</u>	<u>100</u>	<u>100</u>
Transport Aggregate	Total Emissions	kg CO ₂ e	<u>300</u>	<u>799</u>	<u>899</u>
Transport Pipe	Total Emissions	kg CO ₂ e	<u>100</u>	<u>100</u>	<u>100</u>
Demobilisation	Total Emissions	kg CO ₂ e	<u>100</u>	<u>100</u>	<u>100</u>

Table 30 below shows the calculation of the employee commuting indirect emissions.

Table 30: Employee Commuting Calculations

Indirect GHG Emission	Description	Unit	Stormwater	Water	Wastewater
Employee Commuting	No of staff	Staff	<u>3</u>	<u>3</u>	<u>3</u>
	Home to site	km	40	40	40
	Site to home	km	40	40	40
	Total distance	km	<u>80</u>	<u>80</u>	<u>80</u>
	Installation time* *Table 23	hours	15	25	25
	Workday = 7 hours	days	<u>3</u>	<u>4</u>	<u>4</u>
	Total distance* *No of staff x total distance x workday	km	720	960	960
	Emission Factor* *ref Table 19	kg CO ₂ e/ km	0.317	0.317	0.317
	Total Emissions	kg CO ₂ e	<u>228</u>	<u>304</u>	<u>304</u>

5.2.2 Final Calculated Total Emissions

Table 31 below shows the quantified emission sources with their emissions values calculated and allocated to the Carbon Framework categories. Table 32 shows the summarised final carbon footprint values and is visually presented using the GHG Protocol Standard in Figure 27, ISO 14064 in Figure 28 and the GHG Protocol Scope 3 in Figure 29.

Table 31: Summary of Emission Categorised to Standards

Life Cycle			GHG Protocol Standard	ISO 14064		GHG Protocol – Scope 3		Three Waters			
Stage	Number	Description	Scopes	Category	Description	Category	Description	Description	Stormwater (kg CO ₂ e)	Water (kg CO ₂ e)	Wastewater (kg CO ₂ e)
Product Stage	A1 - A3	Raw Material Supply Transport Manufacturing	Scope 3	C4	Indirect GHG emissions from products an organisation uses - Materials and waste.	C1	Purchased Goods and Services	Pipe Material	518	637	518
								GAP7 Material	79	252	289
Construction Stage	A5	Construction & Installation Process	Scope 1	C1	Direct GHG Emissions and Removals - Fuel	C3	Fuel and Energy Related Activities (Not included in Scope 1 or 2)	Excavator Fuel	465	770	780
								Small Plant - Wacker	26	42	43
								Small Plant - Vibro	37	61	61
Construction Stage	A4	Transport	Scope 3	C3	Indirect GHG emissions from Transportation - Freight Transport - Employee Commute	C4	Upstream Transportation and Distribution	Truck - Mobilisation	100	100	100
								Transport - Aggregates	300	799	899
								Transport - Pipe	100	100	100
								Truck - Demobilisation	100	100	100
						C7	Employee Commuting	Employee	228	304	304

Table 32: Final Carbon Footprint Emission Values

Life Cycle			GHG Protocol Standard	ISO 14064		GHG Protocol – Scope 3		Three Waters		
Stage	Number	Description	Scopes	Category	Description	Category	Description	Stormwater (kg CO ₂ e)	Water (kg CO ₂ e)	Wastewater (kg CO ₂ e)
Product Stage	A1 - A3	Raw Material Supply Transport Manufacturing	Scope 3	C4	Indirect GHG emissions from products an organisation uses - Materials and waste.	C1	Purchased Goods and Services	598	889	807
Construction Stage	A5	Construction & Installation Process	Scope 1	C1	Direct GHG Emissions and Removals - Fuel	C3	Fuel and Energy Related Activities (Not included in Scope 1 or 2)	527	873	884
	A4	Transport	Scope 3	C3	Indirect GHG emissions from Transportation - Freight Transport - Employee Commute	C4	Upstream Transportation and Distribution	599	1098	1198
						C7	Employee Commuting	228	304	304

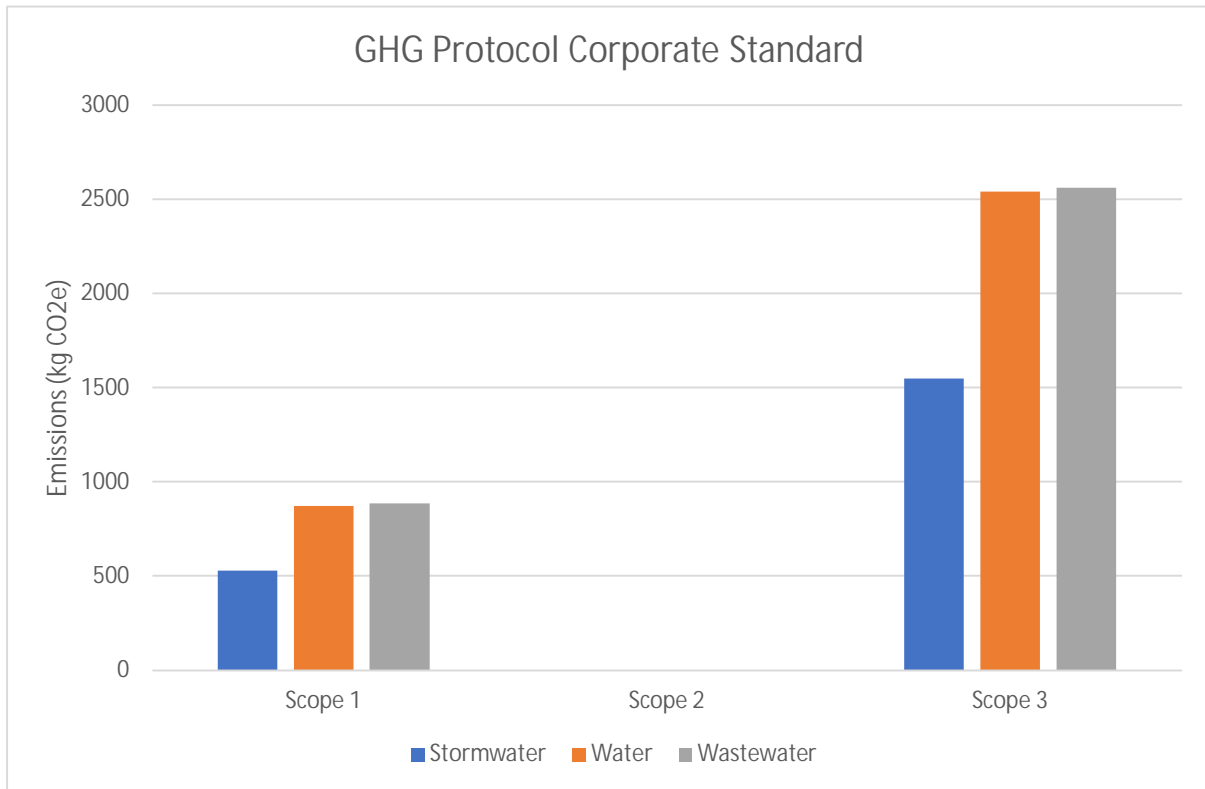


Figure 27: Carbon Footprint values shown in GHG Protocol Standard Scopes

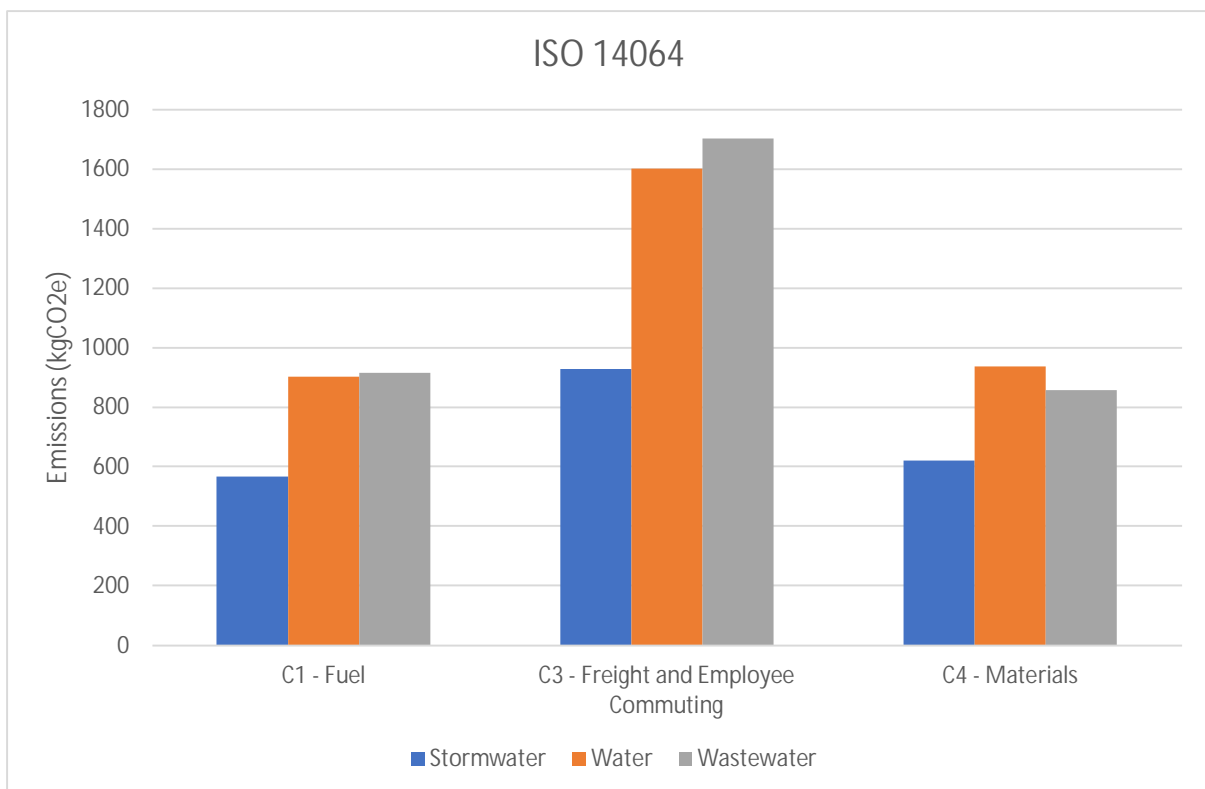


Figure 28: Carbon Footprint values shown in ISO 14064

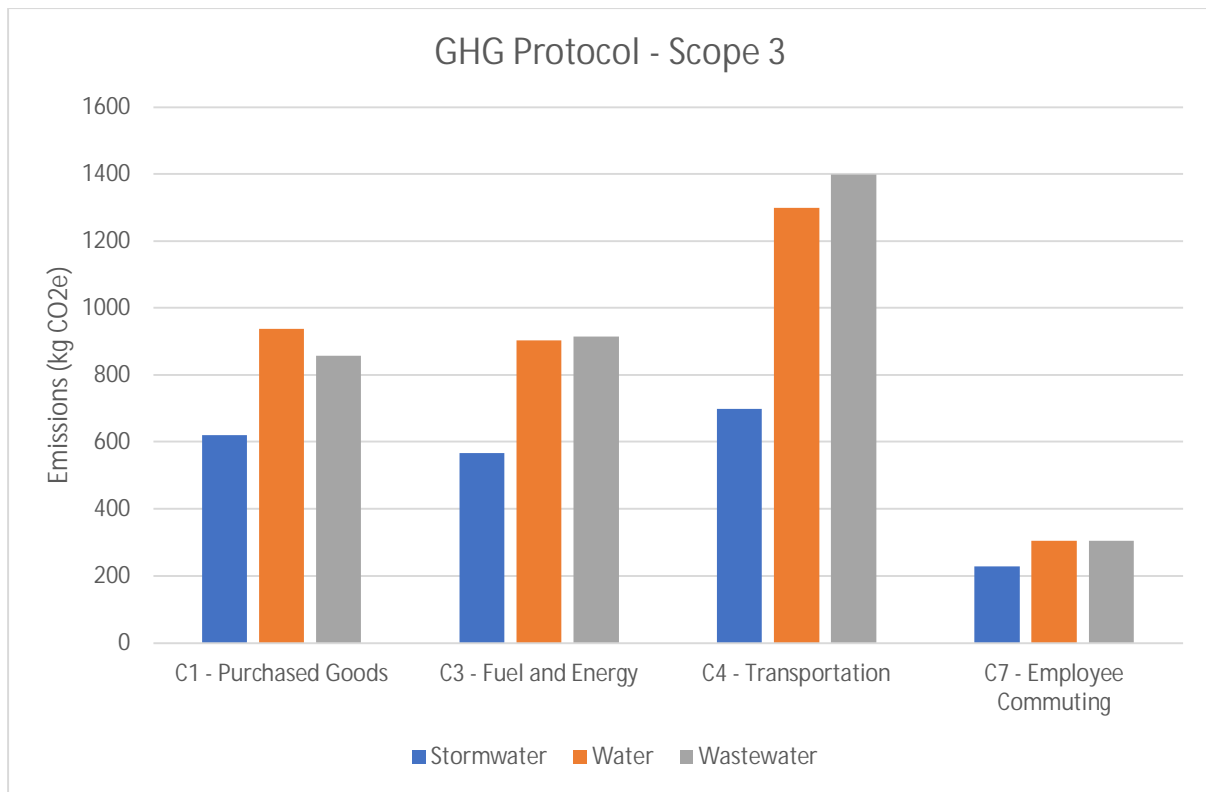


Figure 29: Carbon Footprint values as shown using the GHG Protocol Scope 3

5.3 Discussions and Analysis

5.3.1 Final Emissions – Reporting and the Different Carbon Standards

As seen in Figure 27: Carbon Footprint values shown in GHG Protocol Standard Scopes, Figure 28: Carbon Footprint values shown in ISO 14064 and Figure 29: Carbon Footprint values as shown using the GHG Protocol Scope 3, there are multiple ways to present the final carbon emissions or carbon footprint.

In Figure 27, where the GHG Protocol Standard is used, the user can quickly focus at a macro level on where the bulk of the emissions are coming from. In the figure, it was Scope 3 - supply chain. Using the GHG Protocol Standard, users can focus on reducing their direct scope one emissions first and potentially focus on their supply chain scope 3 emissions later. If the user wanted to reduce their Scope 3 emissions, they would have to look at the other standards as it defines Scope 3 into categories.

Figure 28 presents the emissions in the ISO 14064 categories. When looking at the final emissions in Table 32, Scope 3, the most emissions are on indirect transportation freight and employee commuting (ISO14064 C3). At the same time, the purchase of materials pipe and aggregate (ISO 14064 – C4) and direct emissions Scope 1 or Fuel (ISO 14064 – C1) are almost the same. To further define scope 3 emissions, Figure 29 GHG Protocol – Scope 3 defines employee commuting to its category. Thereby showing each emission source into its category, assisting the user on which emission category to target and reduce. Looking generally at Figure 29 and focusing on Water emissions, ranking the emissions from the greatest to the least. C4 - Transportation as the most followed by C1 – Purchased Goods, C3 Fuel and Energy and C7 employee commuting as the least.

Reducing emissions on transportation C4, employee commuting C7 or fuel and energy C3 may mean investing in newer construction vehicles with better plant efficiencies or changing reliance on fossil fuel-dependent machines to electric vehicles.

The GHG Protocol Standard is an excellent macro tool for visually seeing direct scope 1 and indirect scope 2 and 3 emissions. The GHG Protocol Scope 3 Value chain provides more emission categories to get a detailed breakdown of the emission sources. The extra categories help users zone in on the specific category and aim their efforts on potentially reducing their target category.

5.3.2 Final Emission – Calculations and A5 Validation

5.3.2.1 GHG Scope 3 C1 – Life Cycle A1-A3

In calculating the emissions for materials, care needs to be taken when measuring the materials, especially its units. The unit of measure for the materials is attributed to its emission factor. Section 4.5 shows Table 15: PVC Pipe Emission Factor and Table 16: Aggregate GAP 7 Emission Factor. The pipe emission factor unit is in kilograms, while the emission factor for the GAP 7 aggregate is in tonnes.

In the case of the emission factor for the pipe, a conversion density factor was needed to convert the mass (kg) to meters for ease. The mass is not in kilograms but in tonnes when looking at aggregates. Therefore, as a precaution, it is prudent to check as the units of measure for the materials come from the emission factor.

5.3.2.2 GHG Scope 3 C4 and C7 – Life Cycle A4

Similar to the discussion in section 5.3.2.1, the units of measure for transport are attributed to the emission factor. For example, from the MfE emission factors for Diesel, an emission factor is attributed to an activity that captures the litres used, kilometres travelled or by calculation by tonne-kilometres. In terms of practically measuring the fuel units, will the driver record the number of litres they fill up their tank, or do they create a logbook and record the start of their odometer before travelling and after? Alternatively, there are options for automatically capturing the distance travelled by GPS. As each site is unique, the distance travelled will vary from site to site. It is not constant and is expected to be dynamic.

Another critical observation regarding fuel emission factors is how newer heavy goods vehicles have lower emission factors, refer to Figure 30. The changing emission factors highlight the need for emission factors to be centralised rather than decentralised. Emission factors are dynamically changing and should not be embedded in them. Having the emission factors separated means that should future changes be required in a template, the values can be changed easily rather than digging and finding the information.

Emission source		Unit	Pre-2010 fleet kg CO ₂ -e	2010–2015 fleet kg CO ₂ -e	Post-2015 fleet kg CO ₂ -e
HGV diesel	<5,000 kg	km	0.446	0.423	0.421
	5,000– <7,500 kg	km	0.510	0.484	0.477
	7,500– <10,000 kg	km	0.624	0.592	0.583

Figure 30: MfE Road Freight HGV Emission Factors (Ministry for the Environment, 2022b)

5.3.2.3 GHG Scope 3 C3 – Life Cycle A5

This section discusses the quantitative validation of the calculated construction installation emissions. As a reminder, the case study scenario calculated below is for excavating a 100ø PVC pipe, 100m long, done in an open-cut excavation, 1.3m deep. As seen in Table 33 below, the difference between the calculated emissions and the published EPD data varies from 79.3% for Stormwater to 6.9% compared to Wastewater. To explain the percentage differences in the different pipes, the factors affecting the construction and installation process are discussed, and the lack of information from the supplier EPD is discussed below.

Table 33: Installation Emission vs Published EPD Data

Life Cycle			GHG Protocol – Scope 3		Three Waters		
Stage	Number	Description	Category	Description	Stormwater (kg CO ₂ e)	Water (kg CO ₂ e)	Wastewater (kg CO ₂ e)
Product Stage	A1 - A3	Raw Material Supply Transport Manufacturing	C1	Purchased Goods and Services	598	889	807
Construction Stage	A5	Construction & Installation Process	C3	Fuel and Energy Related Activities (Not included in Scope 1 or 2)	527	873	884
	A4	Transport	C4	Upstream Transportation and Distribution	599	1098	1198
			C7	Employee Commuting	228	304	304
Construction Stage	A5	Construction and Installation Process	C3	Fuel and Energy for 100m of pipe	527	873	884
Construction & Installation Emissions Calculated for 1m of Pipe				Fuel and Energy For 1m of pipe	5.27	8.73	8.84
RXP Construction emission for 1m of pipe				RXP A5 Installation* *Appendix 4.1	9.45	2.43	9.45
Percentage Difference					79.3%	-72.1%	6.9%

Three main factors affecting fuel and energy are summarised in Table 34 below. The first factor is the physical size of the trench; the second is the operation or how fast the plant and other machines and resources can install the physical works. The last factor is the fuel efficiency of the plant. The more fuel-efficient the plant or machine is, the less fuel it burns.

Table 34: Factors affecting fuel and energy.

	Stormwater	Water	Wastewater
Data extracted from Table 22. The physical trench area and volume are less in Stormwater and increase in Water, with Wastewater having the most significant physical area and volume.			
Backfill depth (m)	1.100	1.050	1.050
Full depth with embedment (m)	1.375	1.400	1.450
Trench width (m)	.300	.700	0.700
Bedding height (m)	.275	.350	0.400
Area of pipe (m ²)	0.008	0.008	0.008
*Bedding area (m ²) *Without pipe area	0.075	0.237	0.272
Tipping area (m ²) * *Full area of trench Trench width * bedding height	0.083	0.245	0.280
Backfill area (m ²)	0.330	0.735	0.735
Bedding volume (m ³)	7.465	23.715	27.215
Tipping volume (m ³)	8.250	24.500	28.000
Backfill volume (m ³)	33.000	73.500	73.500
Pipe volume (m ³)	0.785	0.785	0.785
Total excavated volume (m ³)	41.250	98.000	101.500
Data extracted from Table 23 The operation of the plant and machinery needs to be considered as to how fast it needs to work.			
Total Installation Time with two staff (hrs.)	<u>14.90</u>	<u>24.66</u>	<u>24.98</u>
Data extracted from Table 24 The fuel efficiency or the plant and machine consumption rate must be considered. The more fuel-efficient the machines are, the less fuel it would burn.			
Excavator emissions @ 100m excavation (kgCO ₂ e)	<u>465</u>	<u>770</u>	<u>780</u>
Small Plant – Wacker @ 100m excavation (kgCO ₂ e)	<u>26</u>	<u>42</u>	<u>43</u>
Small Plant – Vib Plate @ 100m excavation(kgCO ₂ e)	<u>37</u>	<u>61</u>	<u>61</u>
	<u>527</u>	<u>873</u>	<u>884</u>

For the emission factor for water, the EPD supplier shows an emission factor of 2.43 kgCO₂e. The supplier has a note mentioning that the first ranges of the pipes have a significantly lower impact as the pipe size is not buried, see Appendix 4.1, results for module A5. Consequently, excavation is not required and has a lower emission factor.

When looking at the supplier's EPD, a description of what they have allowed for in their installation stage is given. However, upon closer inspection, it does not provide much detail, refer Appendix 4.1 - RXP Installation Stage. It does not provide the exact physical dimensions of the trench, what Excavator they used, its productivity or fuel consumption. It is challenging to compare emissions without knowing how they calculated their installation value. However, when comparing wastewater emission from the calculated values against the supplier EPD, the percentage difference is only 6.9%. Considering that water does not include excavation, it could have similar emission values to wastewater. The stormwater trench calculated has a smaller physical trench than the values calculated in the EPD. Thus, the estimated emissions and the factors that make up the final emission are explained in more detail and follow a similar pattern to the values published in the EPD.

Further sensitivity analysis was done by using the carbon tool, changing the size of the pipe to 150 in diameter (see Table 35 below) and check the supplier's maximum physical dimensions. The result in the Carbon Tool was compared to the EPD values. The results show that when the physical size of the trench is increased (more material – more prolonged time to use plant and machines), and the fuel efficiency is decreased (higher use of fuel/hr), the closer the carbon tool's results are to the EPD's values. It can be concluded that the EPD's values are conservative as the parameters used in the carbon tool are more than what it was designed for in the chosen standards. The Carbon Tool's values closely follow the values and patterns of the supplier's EPD. It is concluded that the carbon tool created is a functioning and working tool that can calculate the carbon footprint of open-cut pipelines.

Table 35: 150ø Pipe Comparison vs RXP Installation Emissions

		Stormwater	Water	Wastewater
Construction & Installation Emissions Calculated for 1m of Pipe, the diameter of the pipe is 150ø	Fuel and Energy For 1m of pipe	Smaller Trench	9.65	9.78
RXP Construction emission for 1m of pipe	RXP A5 Installation* *Appendix 4.1		10.6	10.8
Percentage Difference			9.8%	10.4%

5.3.3 Questionnaire Results

5.3.3.1 Participant's Role and Experience

The Carbon Tool was presented to a single Tier 1 and multiple Tier 2 contractors installing three water pipe infrastructures. Table 36 and Figure 31 show the participant's role and years of working experience in the construction industry. All participants are from private companies (not government or local authorities such as Watercare or Auckland Council) and have worked in Civil Infrastructure Projects.

Table 36: Participants and their working experience

No	Participant Role	Working Experience Construction Field
1	Administrator	1-5 years
2	Administrator Assistant	1-5 years
3	Bid Writer	1-5 years
4	Business Manager	6-10 years
5	CEO/Director	Over 20 years
6	Company Director Accountant	11-15 years
7	Continued Improvement Advisor	16-20 years
8	Director/Project Engineer	6-10 years
9	Environmental Manager	Over 20 years
10	Estimator	Over 20 years
11	Estimator	11-15 years
12	Estimator	16-20 years
13	General Manager	11-15 years
14	Project Manager	11-15 years
15	Project Manager	11-15 years
16	Quantity Surveyor	6-10 years
17	Quantity Surveyor	6-10 years
18	Sustainability and Operations	1-5 years

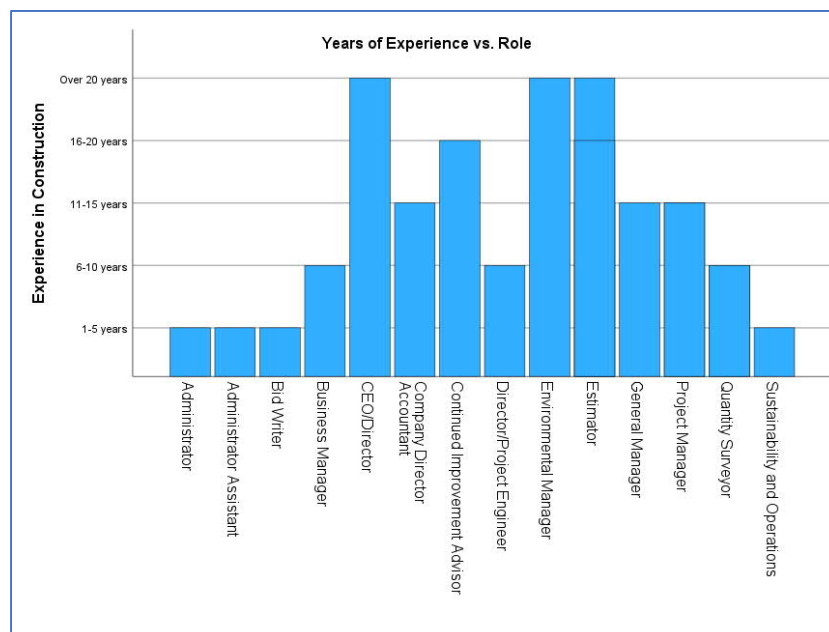


Figure 31: Participants and their experience

5.3.3.2 Carbon Tool in assisting the understanding of Carbon (knowledge)

The questionnaire asked the participants on a scale of 1 to 5 (1 as a beginner, 2 – improver, 3 – intermediate, 4 – advanced, 5 – expert) if the carbon tool assisted their understanding of Carbon before and after presenting to them the carbon tool.

The blue box and whiskers show their understanding before with a mean of 2.5 (improver level) and compared to after showing the mean elevating to 3.5 (intermediate), which is the orange box and whiskers, refer Figure 32. What can also be seen is a beginner (1) was elevated to intermediate (3), with the majority being elevated from an improver- intermediate (2-3) to an advanced level (3-4). Hence, the carbon tool is a tool that elevates a participant's understanding of carbon to a higher level than when they first started to begin with.

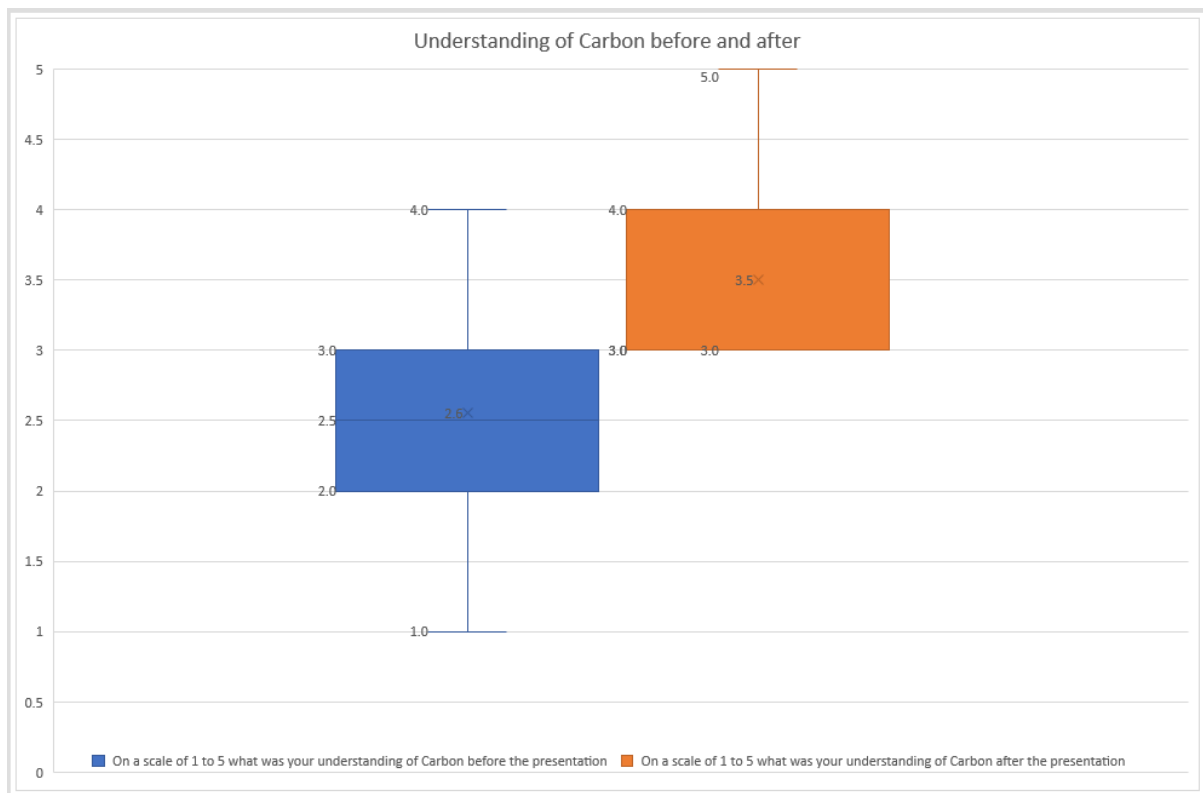


Figure 32: Box and Whisker Chart showing before and after

5.3.3.3 Carbon Accounting, WBS and Emissions Factors

The questionnaire asked the participants various questions ranging from whether the carbon tool helped them understand carbon accounting, identify emission sources and what to measure, emission factors and ways to determine what emission to reduce. A scale of 1 to 5 was given (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree). Table 37 below summarises the results.

Table 37: Combined Summary of Carbon Tool Impact

	Mean	Median	Mode	Range	Minimum	Maximum
<i>The carbon emission tool has been useful in helping me understand carbon accounting</i>	4.28	4.00	4.00	1.00	4.00	5.00
<i>The tool has assisted me in understanding the need to capture a work breakdown structure to understand to identify emissions</i>	4.33	4.00	4.00	1.00	4.00	5.00
<i>The carbon emission tool has assisted me in understanding what emission sources I need to measure.</i>	4.22	4.00	4.00	2.00	3.00	5.00
<i>The tool has helped me understand Emission Factors</i>	4.22	4.00	4.00	2.00	3.00	5.00
<i>The tool has assisted me in identifying what emissions I can reduce</i>	3.89	4.00	4.00	3.00	2.00	5.00

From the results, most participants (median at 4) found that the carbon tool helped them understand carbon accounting, identify emissions and what to measure, understand emission factors and what emissions can be reduced.

The result of some participants giving neutral feedback (3) on emission factors and what emission sources need to be measured is unsurprising. To identify emissions sources, the user needs to understand the WBS and be aware of what variables are carbon emission sources, e.g. materials, plant, equipment, and transport vehicles. How emission sources get quantified is attributed to the corresponding unit specified by the emission factor. Without the user getting these key concepts, they may struggle to understand what to measure and the emission factor corresponding to the activity.

4 out of 18 (22%) scored low on what emissions could be reduced (2). 1 out of the 18 participants gave a 2 – disagree, while 3 out of the 18 participants were 3 - neutral, refer to Appendix 8 Questionnaire Combined Raw Data. These particular participants and their replies were not the expected result as the emission sources to be reduced are displayed visually as shown in Figure 27: Carbon Footprint values shown in GHG Protocol Standard Scopes to Figure 29: Carbon Footprint values as shown using the GHG Protocol Scope 3. One of the participants, in particular, wrote the following: “Clear to show

where the emissions come from and give a source where you can best target reduction” – quote from Participant 8, refer Appendix 8.

It can only be explained by the lack of understanding by the participant or an overload of information. The presentation of the carbon tool to the participants was at least 20 minutes. For them to understand every aspect of the newly developed carbon tool, its processes, and complexities within 20 minutes might be a stretch for some.

The user needs to know about the different Carbon Frameworks/Standards to understand what emissions must be reduced. They will need training. Suppose the user does not understand the operation boundaries (Scope 1, 2 and 3) and the allocation of emission sources to their respective category. In that case, they won't understand what emission source needs to be reduced.

As the final emissions were presented as graphs at the end, the participants might have been tired, or potentially, the carbon tool was not explained well in this area.

Overall, most participants agreed that the carbon tool helped them understand carbon accounting, identify emissions and what to measure, understand emission factors and what emissions could be reduced.

5.3.3.4 Comments from the participants about the Carbon Tool

Direct feedback was given by the participants on what features of the carbon tool they found valuable. Some of the critical comments are written in Table 38 below. A complete list of what they found valuable or unique outputs they would like to see or improve on the carbon tool is tabulated in Appendix 8.

Table 38: Direct Comments from Participants

<p>#4 - <i>"Scope 1-3 How to report correctly".</i></p> <p>#5 - <i>"Specific documents needed for recording"</i></p> <p>#7 <i>"Simplicity understanding the three reporting structures."</i></p> <p>#8 - <i>"Clear to show where the emissions come from and give a source where you can best target reduction."</i></p> <p>#9 - <i>"The standards which you can measure against".</i></p> <p>#11 - <i>"The why, why we need to track carbon".</i></p> <p>#13 - <i>"Helpful step-by-step tool which has helped me to understand the mission and end goal."</i></p> <p>#14 - <i>"I've been working with Toitu over the last few months, but this presentation (tool) has simplified the whole process".</i></p> <p>#16 - <i>"...clarity of method"</i></p> <p>#18 - <i>"The simple ability to visualise emissions data in a structure and clear format that allows for ease of use and training functionality."</i></p>
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One of the final questions asked in the questionnaire is, "Would they use the carbon tool?". Out of the 18 participants in the questionnaire, 100% responded yes.

5.3.4 Implications of Carbon Accounting to Industry

From the created carbon framework to the carbon tool and results, it can be seen that Carbon Accounting is complex. Quantifying carbon requires several procedures: time to gather data, analysis, and resources to complete the work. For example, from a contractor's pre-contract perspective, they may need an estimator or a quantity surveyor to identify emission sources. They may need a site or project engineer to quantify the activities and apply emission factors during the works. At the end of the month, as they submit their payment claim, they may need a Quantity Surveyor to compile the results track and potentially report on the emissions.

The literature review in section 2.3.12 on Construction Industry Enterprises explained that almost 64% of the industry are one-person workers (single owner-operator), and 25% are employees with 1-5 employees. They are 89% of the industry. If clients want carbon accounting to be done correctly, they will need contractors who can do the work safely and have the resources to do carbon accounting; this means that clients could potentially interact most with less than 4% of the construction industry (companies with employees ten and above). This becomes even more of an issue if the project becomes highly complex, as more resources may be needed to identify sources and quantify its activities.

As construction projects become more complex and the project needs to have a solid collaborative or relationship approach with the contractor, the delivery methods get reduced to even a select few suppliers/ contractors. There is a danger here because if the supplier/contractor does not believe or have the same mindset as the client in reducing emissions, what is to say if the supplier/contractor provides a genuine, complete, and accurate report of its construction emissions? If our nation want to reduce our emissions, everyone needs to do their part and should not just be a select few.

CHAPTER 6 Conclusion and Recommendations

6.1 Introduction

This section presents the conclusion and recommendations from the findings of this research. Section 6.2 describes the fulfilment of the research aim and objectives. Section 6.3 explains critical knowledge, skills and responsibilities when creating a carbon inventory. It also recommends actions for Contractors, Designers and the Client.

6.2 Conclusion and Fulfillment of the Research Aim and Objectives.

This research aimed to create and develop a simplified methodology and a template for Contractors to create their own Carbon Inventory on the installation of 3 waters open-cut pipeline excavation infrastructure. To meet the aim, seven objectives were designed to achieve the aim.

The first objective was to research literature on open-open cut excavations and their emissions and identify gaps in the literature. The gaps identified were when doing Carbon Accounting, there are multiple frameworks without explicit critiques on what works best; this leads to a lack of clear information on critical inputs and variables required to represent the construction works accurately. Key literature recommended using the GHG Protocol Standard and ISO 14064, while the Carbon management process standard recommended was the PAS 2080:2016. These recommended standards and the lack of clarity on the procedures or methods to follow led to the creation of a new carbon framework. The newly developed framework highlighted the non-transparent nature of knowledge and technical skills required to undertake a carbon inventory. It was found that knowledge of construction design standards starts the carbon accounting process as it yields ideas for creating a construction methodology and potentially reveals emission sources. Knowing technical knowledge of LCA diagrams can assist a user in setting their study boundary and defining the scope and limitations.

To practically demonstrate meeting the other objectives, a simple case study was chosen where a 150Ø PVC pipe is installed in an open-cut excavation, 1.3m deep.

The second objective was to create a work breakdown structure to identify emission sources. A work breakdown structure was built from the design standards (Watercare and AC Standards). The WBS showed the steps from mobilisation, excavation, installation of pipes, bedding, backfill, and surface finishing to the final demobilisation. The sources of emissions were identified from materials (pipes and GAP7 aggregate) to trucks (transportation), plants (excavator) and minor plants (vib plant and wacker). These sources needed to be measured and quantified.

The third objective was to research local carbon emission factors applicable to 3 waters as required. A critical website that provides local Environmental Product Declarations is EPD Australia. From the website, NZ EPDs were chosen. Winstone Aggregates EPD was used for GAP7, and RXP New Zealand was used to get emission factors for PVC Pipe. The MfE was used to get fuel emission factors for industrial use of stationary combustion of fuels, heavy goods vehicles, road freight and light commercial vehicles.

The fourth objective was identifying what emissions must be reported to the relevant authorities for transparency and accountability. Using the GHG Protocol Corporate Standard, ISO 14064 and GHG Protocol Scope 3 standard categories. The emission sources identified can be grouped into any of the mentioned standards emission categories. The GHG Protocol is best used to identify direct Scope 1 and indirect emission sources Scope 2 and 3. The ISO 14064 expands Scope 3 into four categories, while the GHG Protocol Scope 3 Value Chain standard provides the most categories in identifying particular emissions. The scope of the research is limited to creating a carbon inventory and does not go into depth in creating a baseline, 3rd party verification or carbon offsets.

The fifth objective was to create a first principles tool or GHG quantification model to calculate emission values. A carbon tool was made using Excel and can calculate, analyse, and report on open-cut excavations of 100 and 150Ø PVC pipe up to 1.3m deep.

The sixth objective was identifying areas where carbon footprint emissions could be mitigated or reduced. The category recognises the area that could be mitigated by having the emissions categories to a particular standard mentioned in objective four—E.g. GHG Protocol Scope 3 – C1 Purchased Goods or C4 Transportation. If the emissions on C4 Transportation show the highest emissions, then C4 is the area to target.

The seventh objective was verifying the GHG values calculated against published values in the industry. The construction installation emissions from the carbon tool were compared to installation emission values from supplier EPDs, showing that the carbon tool's values were consistent and similar. In Wastewater emissions, the difference between the carbon tool and the EPD value was 7% on 100Ø diameter pipe. Further study to expand the carbon tool to other sizes, pipes, depths, etc, could be investigated should the need arise.

6.3 Contribution to Knowledge

6.3.1 Carbon Accounting Key Knowledge, Skills, and Responsibilities

This section suggests critical knowledge, skills, responsibilities, and procedures when creating a carbon inventory.

6.3.1.1 Complexity of Carbon Accounting

The research found that creating a carbon inventory is complex; it is a multi-disciplined role and requires new knowledge about Carbon, construction knowledge on how a project is constructed and calculations that require carbon science (emission factors). To start, four main knowledge themes need to be understood, or the user will struggle or be unable to complete a carbon inventory.

Why measure Carbon and Climate Change – Before starting a user in their Carbon Journey, they must have a compelling reason for measuring Carbon Emissions. Not knowing the purpose will result in the user performing their task substandardly and may result in missing emission values, be inaccurate or erroneous.

Carbon Framework – The Carbon Framework gives the background on Carbon and provides a user with a step-by-step guide on what to follow. It requires understanding Carbon Framework Standards such as the GHG Protocol Corporate Standard, ISO 14064 and GHG Protocol Scope 3 – Value Chain.

Construction/ Engineering Process – A good understanding of the engineering methodology followed by a good work breakdown structure ensures that sources of emissions from plant, labour, materials, and transport will be captured.

Carbon Accounting – Once the sources of emissions have been identified, these sources need to be quantified and multiplied by their emission factor (Carbon Science). When presented with a Carbon Standard such as ISO 14064, the calculation result must be allocated and summed to the standard emission category. The emission category identifies the emission areas and the higher the emission on a particular category, which means that category will be the area that requires emission reduction.

6.3.1.2 The need for upskilling and GHG education

Users must understand and have a compelling reason why they need to measure and quantify carbon emissions. Participants must be trained and educated on climate change (greenhouse effect) and the potential catastrophic scenarios of the world warming past 2°. Education must be given on NZ greenhouse gas inventory, and an explanation must be given if, in the last 30 years, NZ emissions have neither increased nor decreased. Drastic and urgent action is needed should NZ aim to be net zero by 2050.

Users wanting to know about Carbon may already have a strong knowledge of Construction Methodology. They will need some basic knowledge of Carbon Standards and their processes; the most crucial part is for the user to understand how to set operational boundaries. For example, when using the GHG Protocol, they must realise Scope 1 – Direct Emissions and Scope 2 and 3 – Indirect Emissions. For other standards, there are the following:

- For life cycle assessment, it is embodied and operational carbon.
- Different stages of the life cycle assessment to define the scope and limitations.
 - Cradle to gate
 - Cradle to practical completion
 - Cradle to grave
 - Cradle to Cradle
- For ISO 14064, there are the categories 1 to 6
- GHG Protocol Scope 3 Value chain – the categories 1 to 15.

Workshops could be given on quantifying emission sources and the knowledge required to search for available local EPDs. The key lesson here is that the unit of measure for the emission sources is attributed to the emission factors.

6.3.1.3 Implications of Carbon Accounting for Contractors

6.3.1.3.1 Operational Boundary and the Inventories

For local authorities such as Auckland Council and Watercare, infrastructure not constructed in-house and contracted out to their value chain regarding GHG protocol emission type is considered indirect scope 3 emissions. From a Contractor's perspective, the Contractor will have to prepare two types of inventories if they are already voluntarily recording their direct emissions. The first emission inventory is for the Contractor office staff going to and from the office building for voluntary reporting. The other inventory is for the Construction site-specific work for the client.

6.3.1.3.2 Cost of upskilling and education

Should the client implement a Carbon Management Process such as PAS2080:2016, or if the client mandates to compulsory record carbon footprint emissions if the client is providing free carbon training, then the contractor must either attend client-provided upskilling and education workshops or the contractor must provide their in-house training or pay for an external training provider to fill gaps in their Carbon knowledge and skills.

6.3.1.3.3 Embedding Carbon Management in Construction Projects

Pre-Contract – At the tender stage, estimators and the project team (operations and project engineers) would have developed a construction methodology to construct the works. Having the methodology documented early ensures emission sources are identified early. These sources, quantified and calculated with their emission factors (high-level estimation), can be provided immediately and for carbon budgeting purposes in an Early Contractor Involvement delivery model.

During Construction - Site Engineers or Project Engineers will need to collect data on emission sources. Procedures and systems will need to be established and put in place. When recording fuel consumption data, knowing the excavator size (5T), bucket size, and productivity can be recorded against its fuel use to calculate efficiency (fuel consumption rate L/hr) and for trucks having a logbook and recording the km travelled at the start and the km at the end of the shift. The packing list shows the number of materials used on site (pipe, aggregates).

Payment Claim/ Reporting – At the end of a construction period or when a payment claim is required, if the client mandatorily requires a carbon report or carbon tracking. The contractor must compile the quantified and calculated emission values and report them to the client.

6.3.1.3.4 Cost of Implementation of Carbon

As described in the previous section, capturing, quantifying and calculating construction carbon emissions, resulting in a carbon footprint requires resources. Cost to allow additional human resources to capture, quantify and calculate emissions during the construction works must be allowed. Companies must also develop and implement carbon management processes into their internal systems to make it the norm.

Allowance or cost to measure plant equipment may be automated via other parties, such as automatic GPS, which records the distance travelled automatically. Other initiatives, such as changing plant and other fossil fuel-dependent machines to electric, may reduce carbon emissions; however, implementing these changes to the company's fleet could be costly.

For businesses/enterprises who would like co-funding and support to switch from fossil fuels to cleaner renewable energy, there is the Government Investment in Decarbonising Industry (GIDI) Fund. The GIDI is funded by the Emissions Trading Scheme, and it helps by investing in businesses instead of buying offsets overseas (Energy Efficient & Conservatory Authority, 2023).

6.3.1.4 Implications of Carbon Accounting to Designers

Designers are in a position where they know the design standards. They should make it easy for contractors by identifying emission sources, especially materials used and their emission factor.

6.3.1.5 Implications of Carbon Accounting for Clients

Carbon accounting increases in complexity as the project becomes more significant with more complex methodologies, variables, and emission sources. Potentially, clients may only interact with less than 4% of the construction industry. If clients award contracts to a select few, they should award contracts to contractors who understand and want to implement carbon. There must be a flow-down effect on the supply chain. If NZ aims to reduce carbon emissions by 2050, it will take all of us, not just a few, to make changes for the better.

6.4 Recommendations

Once users have developed their maturity in creating an inventory, they may explore an inventory management system, as discussed in section 2.4.4.7. An inventory management system is essential, especially if the project's duration is long and multiple inventories are required. The system would provide a systematic process for correcting and preventing errors. It also identifies opportunities for improvement and preparation for compliance with regulations via reports as required.

Another goal to consider is creating a complete carbon baseline.

6.5 Future Research Opportunities

The following future research opportunities would potentially confirm and strengthen the results of the carbon tool.

- It would be great to investigate or collaborate with EPD producers and seek further clarification on how they build their construction installation emission factors.
- Use the tool on other pipe-laying operations, such as trenchless methodology.

Investigate or work with the Ministry for the Environment to separate GHG Construction Emissions from Manufacturing in the GHG inventory. Having Manufacturing and Construction emissions divided may assist policymakers who would like to invest in Construction-related emission reduction projects a reality.

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APPENDIX

Appendix 1 GHG Protocol Global Warming Potential Values


**GREENHOUSE
GAS PROTOCOL**

Global Warming Potential Values

The following table includes the 100-year time horizon global warming potentials (GWP) relative to CO₂. This table is adapted from the IPCC Fifth Assessment Report, 2014 (AR5)¹. The AR5 values are the most recent, but the second assessment report (1995) and fourth assessment report (2007) values are also listed because they are sometimes used for inventory and reporting purposes. For more information, please see the IPCC website (www.ipcc.ch). The use of the latest (AR5) values is recommended. Please note that the GWP values provided here from the AR5 for non-CO₂ gases do not include climate-carbon feedbacks.

Global warming potential (GWP) values relative to CO₂

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Carbon dioxide	CO ₂	1	1	1
Methane	CH ₄	21	25	28
Nitrous oxide	N ₂ O	310	298	265
Substances controlled by the Montreal Protocol				
CFC-11	CCl ₃ F	3,800	4,750	4,660
CFC-12	CCl ₂ F ₂	8,100	10,900	10,200
CFC-13	CClF ₃		14,400	13,900
CFC-113	CCl ₂ FCClF ₂	4,800	6,130	5,820
CFC-114	CClF ₂ CClF ₂		10,000	8,590
CFC-115	CClF ₂ CF ₃		7,370	7,670
Halon-1301	CBrF ₃	5,400	7,140	6,290
Halon-1211	CBrClF ₂		1,890	1,750
Halon-2402	CBrF ₂ CBrF ₂		1,640	1,470
Carbon tetrachloride	CCl ₄	1,400	1,400	1,730
Methyl bromide	CH ₃ Br		5	2
Methyl chloroform	CH ₃ CCl ₃	100	146	160


 GREENHOUSE
 GAS PROTOCOL

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second assessment report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
HCFC-21	CHCl ₂ F			148
HCFC-22	CHClF ₂	1,500	1,810	1,760
HCFC-123	CHCl ₂ CF ₃	90	77	79
HCFC-124	CHClFCF ₃	470	609	527
HCFC-141b	CH ₃ CCl ₂ F	600	725	782
HCFC-142b	CH ₃ CClF ₂	1,800	2,310	1,980
HCFC-225ca	CHCl ₂ CF ₂ CF ₃		122	127
HCFC-225cb	CHClFCF ₂ CClF ₂		595	525
Hydrofluorocarbons (HFCs)				
HFC-23	CHF ₃	11,700	14,800	12,400
HFC-32	CH ₂ F ₂	650	675	677
HFC-41	CH ₃ F ₂	150		116
HFC-125	CHF ₂ CF ₃	2,800	3,500	3,170
HFC-134	CHF ₂ CHF ₂	1000		1,120
HFC-134a	CH ₂ FCF ₃	1,300	1,430	1,300
HFC-143	CH ₂ FCHF ₂	300		328
HFC-143a	CH ₃ CF ₃	3,800	4,470	4,800
HFC-152	CH ₂ FCH ₂ F			16
HFC-152a	CH ₃ CHF ₂	140	124	138
HFC-161	CH ₃ CH ₂ F			4
HFC-227ea	CF ₃ CHFCF ₃	2,900	3,220	3,350
HFC-236cb	CH ₂ FCF ₂ CF ₃			1,210
HFC-236ea	CHF ₂ CHFCF ₃			1,330
HFC-236fa	CF ₃ CH ₂ CF ₃	6,300	9,810	8,060
HFC-245ca	CH ₂ FCF ₂ CHF ₂	560		716
HFC-245fa	CHF ₂ CH ₂ CF ₃		1,030	858
HFC-365mfc	CH ₃ CF ₂ CH ₂ CF ₃		794	804
HFC-43-10mee	CF ₃ CHFCF ₂ CF ₃	1,300	1,640	1,650


 GREENHOUSE
 GAS PROTOCOL

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second assessment report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Perfluorinated compounds				
Sulfur hexafluoride	SF ₆	23,900	22,800	23,500
Nitrogen trifluoride	NF ₃		17,200	16,100
PFC-14	CF ₄	6,500	7,390	6,630
PFC-116	C ₂ F ₆	9,200	12,200	11,100
PFC-218	C ₃ F ₈	7,000	8,830	8,900
PFC-318	c-C ₄ F ₈	8,700	10,300	9,540
PFC-31-10	C ₄ F ₁₀	7,000	8,860	9,200
PFC-41-12	C ₅ F ₁₂	7,500	9,160	8,550
PFC-51-14	C ₆ F ₁₄	7,400	9,300	7,910
PCF-91-18	C ₁₀ F ₁₈		>7,500	7,190
Trifluoromethyl sulfur pentafluoride	SF ₃ CF ₃		17,700	17,400
Perfluorocyclopropane	c-C ₃ F ₆			9,200
Fluorinated ethers				
HFE-125	CHF ₂ OCF ₃		14,900	12,400
HFE-134	CHF ₂ OCHF ₂		6,320	5,560
HFE-143a	CH ₃ OCF ₃		756	523
HCFE-235da2	CHF ₂ OCHClCF ₃		350	491
HFE-245cb2	CH ₃ OCF ₂ CF ₃		708	654
HFE-245fa2	CHF ₂ OCH ₂ CF ₃		659	812
HFE-347mcc3	CH ₃ OCF ₂ CF ₂ CF ₃		575	530
HFE-347pcf2	CHF ₂ CF ₂ OCH ₂ CF ₃		580	889
HFE-356pcc3	CH ₃ OCF ₂ CF ₂ CHF ₂		110	413
HFE-449sl (HFE-7100)	C ₄ F ₉ OCH ₃		297	421
HFE-569sf2 (HFE-7200)	C ₄ F ₉ OC ₂ H ₅		59	57
HFE-43-10pccc124 (H-Galden 1040x)	CHF ₂ OCF ₂ OC ₂ F ₄ OCHF ₂		1,870	2,820
HFE-236ca12 (HG-10)	CHF ₂ OCF ₂ OCHF ₂		2,800	5,350

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second assessment report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
HFE-338pcc13 (HG-01)	CHF ₂ OCF ₂ CF ₂ OCHF ₂		1,500	2,910
HFE-227ea	CF ₃ CHFOCF ₃			6,450
HFE-236ea2	CHF ₂ OCHF ₂ CF ₃			1,790
HFE-236fa	CF ₃ CH ₂ OCF ₃			979
HFE-245fa1	CHF ₂ CH ₂ OCF ₃			828
HFE 263fb2	CF ₃ CH ₂ OCH ₃			1
HFE-329mcc2	CHF ₂ CF ₂ OCF ₂ CF ₃			3,070
HFE-338mcf2	CF ₃ CH ₂ OCF ₂ CF ₃			929
HFE-347mcf2	CHF ₂ CH ₂ OCF ₂ CF ₃			854
HFE-356mec3	CH ₃ OCF ₂ CHFCF ₃			387
HFE-356pcf2	CHF ₂ CH ₂ OCF ₂ CHF ₂			719
HFE-356pcf3	CHF ₂ OCH ₂ CF ₂ CHF ₂			446
HFE 365mcf3	CF ₃ CF ₂ CH ₂ OCH ₃			<1
HFE-374pc2	CHF ₂ CF ₂ OCH ₂ CH ₃			627
Perfluoropolyethers				
PFPME	CF ₃ OCF(CF ₃)CF ₂ OCF ₂ OCF ₃		10,300	9,710
Hydrocarbons and other compounds - direct effects				
Chloroform	CHCl ₃	4		16
Methylene chloride	CH ₂ Cl ₂	9	8.7	9
Methyl chloride	CH ₃ Cl		13	12
Halon-1201	CHBrF ₂			376

IPCC data sources for more information:

- AR4 values: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html
- AR5 values: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf (p. 73-79)

¹ Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Appendix 2 Existing Research

Table 39: Research on existing literature on pipeline excavation

No	Reference	Location of Study	Topic	Construction Domain	Carbon Framework Methodology	Data, Standards and Construction Methodology	Carbon Accounting – Science Factors (GHG Data), Calculation Method
1	Alsadi and Matthews (2020)	United States of America (USA)	Evaluation of Carbon Footprint of Pipeline Materials during Installation, Operation, and Disposal Phases	Horizontal	The lifecycle of a pipeline is ideal to provide a good understanding of the work breakdown structure of the chosen study. LCA – Installation, Operation and Disposal	Simplified construction methodology <ul style="list-style-type: none"> American Standard Open-cut parameters vary, with different depths (3m) and materials. Various plants and equipment are used. 	Science Factors requires access to electronic calculation (e-calc) software. <ul style="list-style-type: none"> The calculation method described was the product of the emission factor and activity data.
2	Ariaratnam and Sihabuddin (2009)	USA	Comparison of emitted emissions between Trenchless Pipe Replacement and Open-cut Construction* Note - Wastewater line	Horizontal	Environmental Protection Agency (EPA) document EPA420-P02-016 - a non-road model for estimating emissions* *Note – Installation phase	Provided details of the construction process and work breakdown structure. <ul style="list-style-type: none"> American Standard Open-cut parameters vary, with different depths and materials. Trenchless Various plants and equipment used 	Used United States Environmental Protection Agency (EPA) factors and Clean Air Act Amendment 1990. <ul style="list-style-type: none"> The calculation was done using proprietary tools in MS Excel and Visual Basic; therefore, checking the calculations was not possible as it requires access to a proprietary calculator. The calculation method described was the product of the emission factor and activity data.
3	Chilana (2011)	USA	Carbon Footprint Analysis of large diameter Water Pipeline Installation	Horizontal	Lifecycle Analysis (LCA) Split with embodied and operational carbon	Provided construction methodology as a boundary condition. <ul style="list-style-type: none"> American Standard Open-cut parameters varying Various plants and equipment used 	Used the Inventory of Carbon and Energy (ICE) The calculation method described was the Energy Calculation Method
4	Chilana et al. (2016)	USA	Comparison of carbon footprints of steel versus concrete pipelines for water transmission	Horizontal	LCA – Material Production and Pipeline Fabrication, Pipe Transportation, Pipe Installation and Pipeline Operation only.	Methodology as required by the existing project called Integrated Pipeline project. <ul style="list-style-type: none"> American Standard Concrete and Steel Pipes The case study used on a planned water transmission pipeline 	Used the Inventory of Carbon and Energy (ICE) The calculation method described was the Energy Calculation Method

5	Elhag (2015)	United Kingdom (UK)	The 'carbon footprint' of sewer pipes: risk of inconsistency	Horizontal	Compared different Carbon Accounting Frameworks	Applied and compared other pipe materials and scenarios.	Used the Inventory of Carbon and Energy (ICE) Building Research Establishment (BRE) Ecovent, GaBi database and INIES
6	Kaushal et al. (2020)	USA	Environmental Impacts of Conventional Open-Cut Pipeline Installation and Trenchless Technology Methods: State-of-the-Art Review	Horizontal	Compared Carbon Framework <ul style="list-style-type: none"> • LCA • GHG Protocol • PAS 2050 	Compare various pipeline construction methods against each other. It compares different methods but does not go into detail on open-cut excavations.	Summarises their literature and mentions that GHG emissions are calculated using Emission Factors for pipelines.
7	Khan and Tee (2015)	Canada	Quantification and comparison of carbon emissions for flexible underground pipelines	Horizontal	LCA – Carbon Framework used similar to Chilana (2011)	Construction Methodology used similar to Chilana (2011)	Used the Inventory of Carbon and Energy (ICE) The calculation method described was the Energy Calculation Method
8	Nandyala et al. (2019)	USA	Comparison of Life Cycle Carbon Footprints of Steel and Concrete Pressure Pipes	Horizontal	A similar method to Chilana et al. (2016)	A similar method to Chilana et al. (2016), but instead of water, they used wastewater.	Used the Inventory of Carbon and Energy (ICE) A similar method to Chilana et al. (2016)
9	Tavakoli et al. (2017)	USA	Comparison of Carbon Footprint of Trenchless and Open-Cut Methods for Underground Freight Transportation	Horizontal	Used their methodology	Used methodology specific to underground freight transportation. <ul style="list-style-type: none"> • American Standard • Open-cut parameters varying 	The factors and calculation method were unclear, but statistical data factors were mentioned.

Table 40: Additional research on climate change

No	Author	Topic	Research gap addressed	Background	Summary
1	IPCC (1992, 1995, 2001, 2007, 2014, 2023a, 2023b)	The Reports IPCC First Assessment Report 1992 IPCC Second Assessment Report 1995 IPCC Third Assessment Report 2001 IPCC Fourth Assessment Report 2007 IPCC Fifth Assessment Report 2014 IPCC Sixth Assessment Report	Provides compelling scientific data as to why we need to quantify carbon.	Carbon Science <ul style="list-style-type: none"> • Kyoto Protocol – defines the six key greenhouse gases that must be reduced. • Defines Global Warming Potential: this is a crucial definition that defines emission factors. 	Historical documents that provide scientific unequivocal evidence that climate change is changing our planet. <ul style="list-style-type: none"> • Critical documents used as inputs for the Kyoto Protocol and Paris Agreement
2	UNFCCC (2023b)	United Nations Framework Convention on Climate Change, Key aspects of the Paris Agreement	“As per above.”		<ul style="list-style-type: none"> • The need for a global effort to reduce emissions.
3	Ministry for the Environment (2023a)	NZ Emissions compared to other countries	“As per above.”		Looks at NZ’s emission compared to other countries
4	Ministry for the Environment (2022c)	NZ Greenhouse Gas Inventory 1990-2020 Sector	“As per above.”		NZ current GHG Inventory and emission in construction.
5	NIWA (2023b, 2023c)	National Institute of Water and Atmospheric Research (NIWA) – “Climate Change Scenarios for New Zealand” “Climate change and possible impacts for New Zealand”	“As per above.”		Explains in a NZ context what happens when we continue business as usual.
6	Kessler (2011)	Stormwater strategies: cities prepare aging infrastructure for climate change	Construction implication on climate change	Stormwater construction required	The need for stormwater construction
7	VanBriesen et al. (2014)	Sustainable urban water supply	“As per above.”	Water supply construction required	The need for water construction
8	New Zealand Government (2023)	Three water reforms	“As per above.”	Three water infrastructures are required	NZ need for three waters construction

Table 41: Additional Research on Carbon Accounting Framework

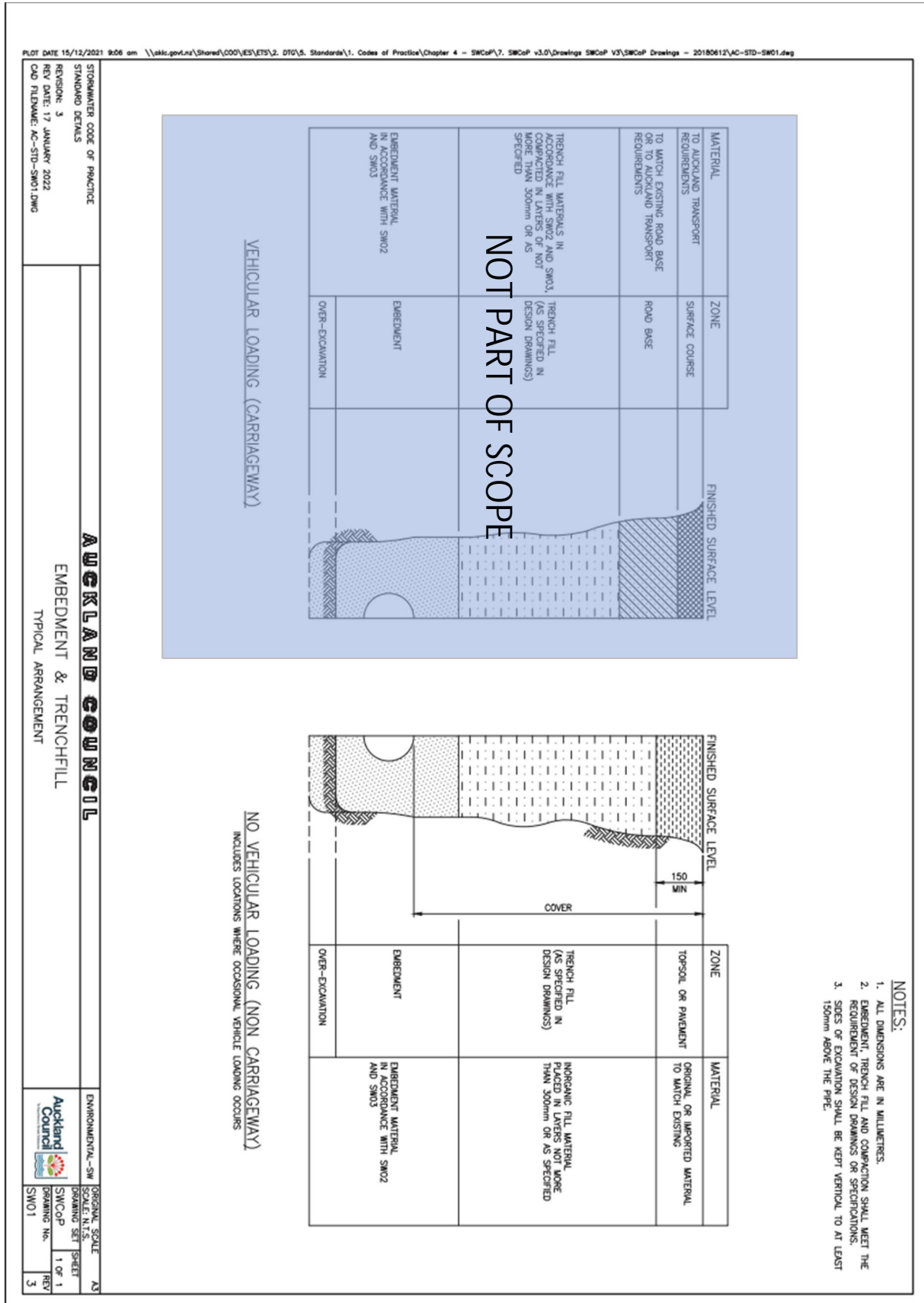
No	Author	Topic	Research gap addressed	Carbon Accounting	Summary
1	Pandey et al. (2011)	Carbon Footprint: current methods of estimation	Variation to the carbon accounting framework	<ul style="list-style-type: none"> • GHG Protocol • ISO14064 • PAS 2050 • 2006 IPCC 2006 guidelines for National Greenhouse Gas Inventories • ISO 14025 procedure for developing Type III environmental declarations • ISO 14067 Carbon footprint of products. 	Provides other methods of estimation rather than the LCA method.
2	World Resources Institute (2004)	The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (Revised (2015)	Carbon Framework Standard	GHG Protocol Standard	Detailed framework on how to create a Carbon Inventory.
3	International Organization for Standardization (2018)	ISO 14064-1:2018 Greenhouse gases - Part 1: Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals	Carbon Framework Standard	Alternative Standard	Detailed framework on how to create a Carbon Inventory.
4	Ministry for the Environment (2022a)	Ministry for the Environment, Measuring emissions: A guide for organisations: 2022 detailed guide	Variation to the carbon accounting framework	GHG Protocol and ISO 14064	Recommendation by the NZ government as to what Carbon Framework to use

Table 42: Additional Research on Construction

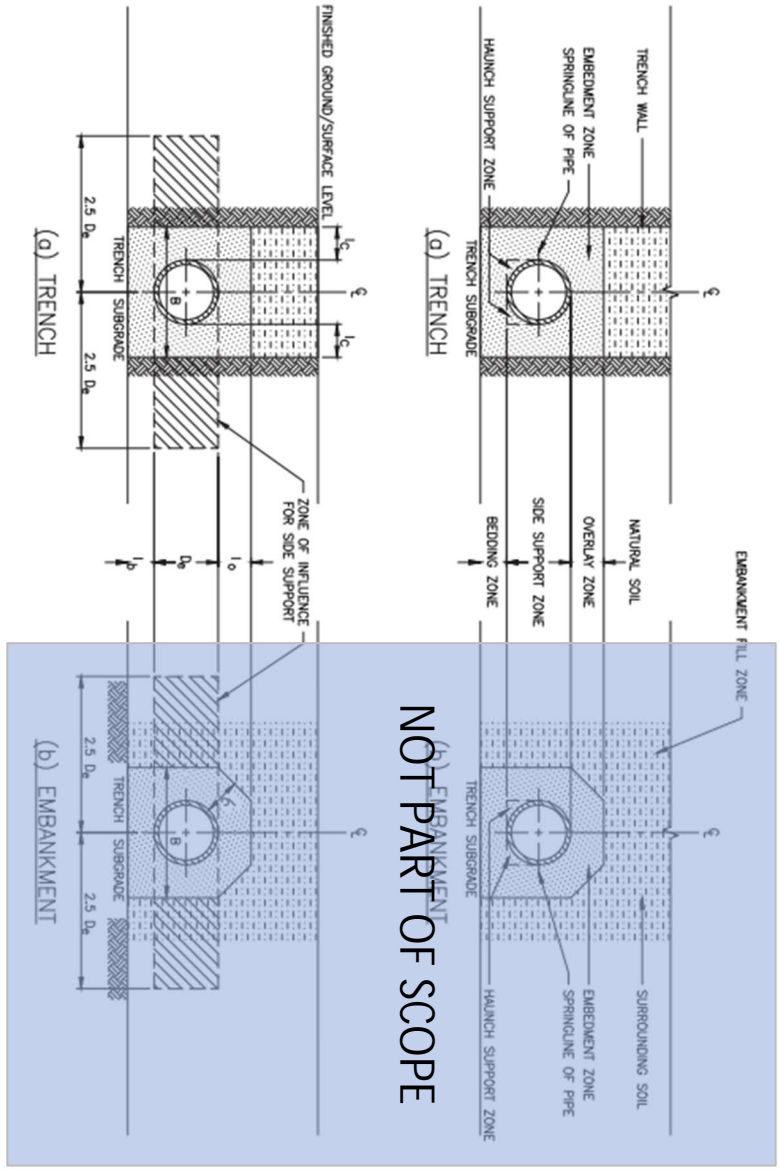
No	Author	Topic	Research gap addressed	Summary
1	Forsythe and Ding (2014)	GHG emissions from excavation on Residential Construction Sites	Carbon Accounting	Provided an example of carbon calculation
2	Kim et al. (2012)	GHG emissions from Onsite Equipment Usage in Road Construction	Construction/Carbon Accounting - Activity data on plant and equipment missing	Provided activity data on plant and equipment
3	Yan et al. (2010)	GHG gas emissions in building construction: A case study of One Peking in Hong Kong	Carbon Accounting	Provided detailed method on first principles carbon calculations
4	Deloitte (2020)	The New Zealand Infrastructure Commission (Te Waihanga), Construction Sector COVID-19 Recovery Study, Building the Road to Recovery Together	Construction/Carbon Accounting - Activity data on plant and equipment missing	Check on the Industrial Classification Standard used to group industries that carry out similar activities and use it to verify the use of vertical construction equipment in horizontal construction.

Appendix 3 Auckland and Watercare Standards

Appendix 3.1 Auckland Council – Stormwater Drawing SW01, SW02 and SW03



PLOT DATE 15/12/2021 9:07 am \\lakk.govt.nz\Shared\COO\IES\ETS\2_DTO\5_Standards\1_Codes of Practice\Chapter 4 - SWCoP\7_SWCoP v3.0\Drawings SWCoP V3\SWCoP Drawings - 20180612\AC-STD-SW02.dwg



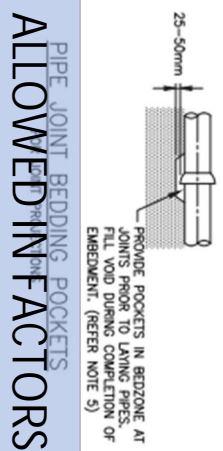
NOT PART OF SCOPE

MINIMUM EMBEDMENT ZONE DIMENSIONS					
D _e (mm)	MINIMUM DIMENSION (mm)				
	l _b	l _c	l _o	B = D _e + 2l _c	
75 ≤ D _e ≤ 150	75	100	100	275 - 350	
150 < D _e ≤ 300	100	150	150	450 - 600	
300 < D _e ≤ 450	100	200	150	700 - 850	
450 < D _e ≤ 900	150	300	150	1050 - 1500	
900 < D _e ≤ 1500	150	350	200	1600 - 2200	
1500 < D _e ≤ 4000	150	0.25D _e	300	2250 - 6000	

DEFINITIONS OF SYMBOLS USED:

- B TRENCH WIDTH
- D_e EXTERNAL DIAMETER OF PIPELINE.
- l_b DEPTH OF BEDDING UNDER BARREL OF PIPELINE.
- l_c MINIMUM DISTANCE BETWEEN SPRINGLINE OF PIPE AND PERMANENT SIDE OF TRENCH.
- l_o MINIMUM DEPTH OF COVER OVER SOFTT OF PIPELINE.

- NOTES:**
1. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH SW01.
 2. FLEXIBLE PIPES INCLUDES PVC, GRP, PP AND PE.
 3. PLACEMENT OF EMBEDMENT, TRENCH-FILL & COMPACTON SHALL MEET THE REQUIREMENTS OF DRAWINGS AND SPECIFICATIONS.
 4. EXCAVATE OR COMPACT TRENCH FLOOR TO PROVIDE A FLAT FIRM BASE TO SUPPORT BEDDING MATERIAL AND MINIMISE PIPELINE SETTLEMENT. REPLACE EXCAVATED MATERIAL WITH SUITABLE GRANULAR MATERIAL FOR BEDDING.
 5. ENSURE THAT THE BEDDING IS DEEP ENOUGH SO THAT PIPE JOINT PROJECTIONS (SOCKETS, FLANGES) DO NOT TOUCH THE TRENCH FLOOR (SEE DETAIL BELOW).
 6. BEDDING MATERIALS SHALL BE C₁₀/S₁₀ < 12.
 7. THIS DRAWING IS BASED ON AS/NZS 2566 PART 2: 2002 BARRIED FLEXIBLE PIPELINES & INSTALLATION AND REPRODUCED WITH THE PERMISSION OF STANDARDS NEW ZEALAND.



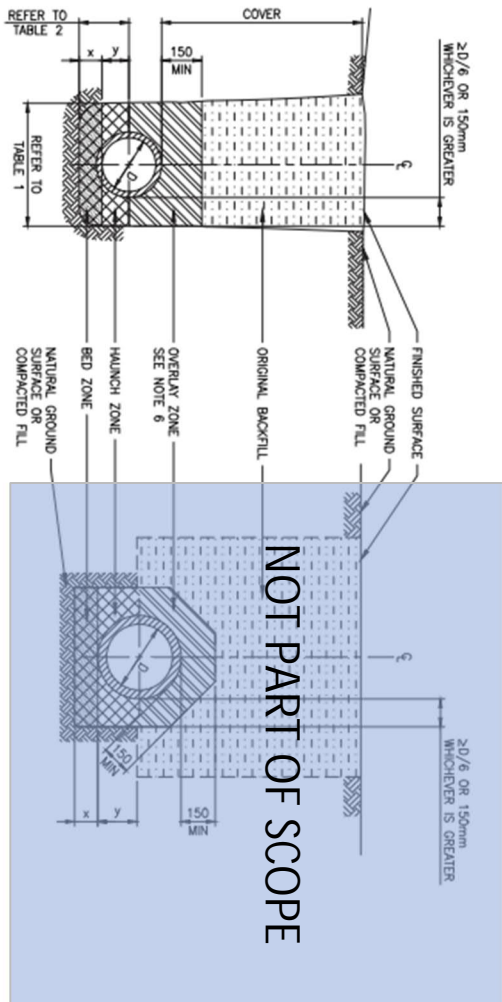
PIPE JOINT BEDDING POCKETS ALLOWED IN FACTORS

STORMWATER CODE OF PRACTICE
STANDARD DETAILS
REVISION: 3
REV DATE: 17 JANUARY 2022
CWD FILENAME: AC-STD-SW02.DWG

AUCKLAND COUNCIL
PIPE EMBEDMENTS
STANDARD EMBEDMENT FOR FLEXIBLE PIPES

ENVIRONMENTAL-SW	ORIGINAL SCALE	AS
Auckland Council	SCALE: N.T.S.	
SWCoP	DRAWING SET	SHEET
SW02	DRAWING No.	1 OF 1
	REV	3

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TRENCH CONDITION

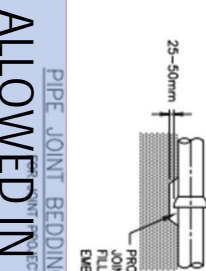
EMBANKMENT CONDITION

H2 TYPE BEDDING – CONCRETE PIPES

TABLE 1

MAXIMUM PERMISSIBLE TRENCH WIDTHS (IF TRENCH WIDER, USE EMBANKMENT CONDITION)						
NORMAL INTERNAL PIPE DIAMETER (mm)	150	225	300	375	450	525
MAXIMUM TRENCH WIDTH (mm)	600	600	700	800	900	1000
						1100
						1200
						1300
						1400
						1500
						1600
						1800
						00+700

NOT PART OF SCOPE



PROVIDE POCKETS IN BED ZONE AT JOINTS PRIOR TO LAYING PIPES. FILL VOID DURING COMPLETION OF EMBEDMENT. (REFER NOTE 5)

ALLOWED IN FACTORS

H2 SUPPORT TYPE	MINIMUM DEPTH (mm)	
	x	y
100 IF D ≤ 1500 150 IF D > 1500	100	150
	150	200

STORMWATER CODE OF PRACTICE
STANDARD DETAILS
REVISION: 3
REV DATE: 17 JANUARY 2022
CNO FILENAME: AC-STD-SW03.DWG

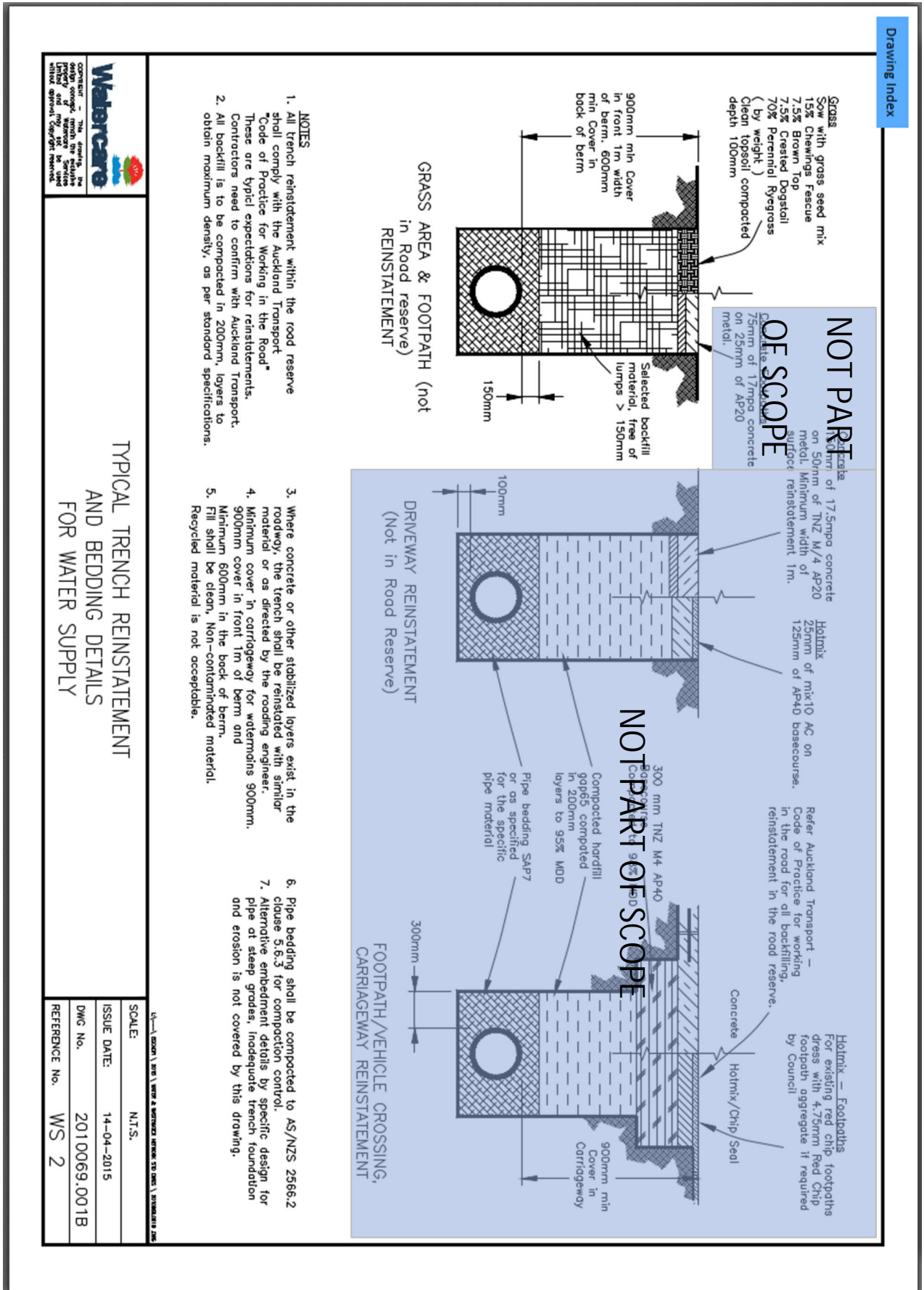
AUCKLAND COUNCIL
PIPE EMBEDMENTS
STANDARD EMBEDMENT FOR CONCRETE PIPES

ENVIRONMENTAL-SW
Auckland Council
ORIGINAL SCALE
SCALE: N.T.S.
DRAWING SET SHEET
SWCoP 1 OF 1
DRAWING NO. SW03
REV 3

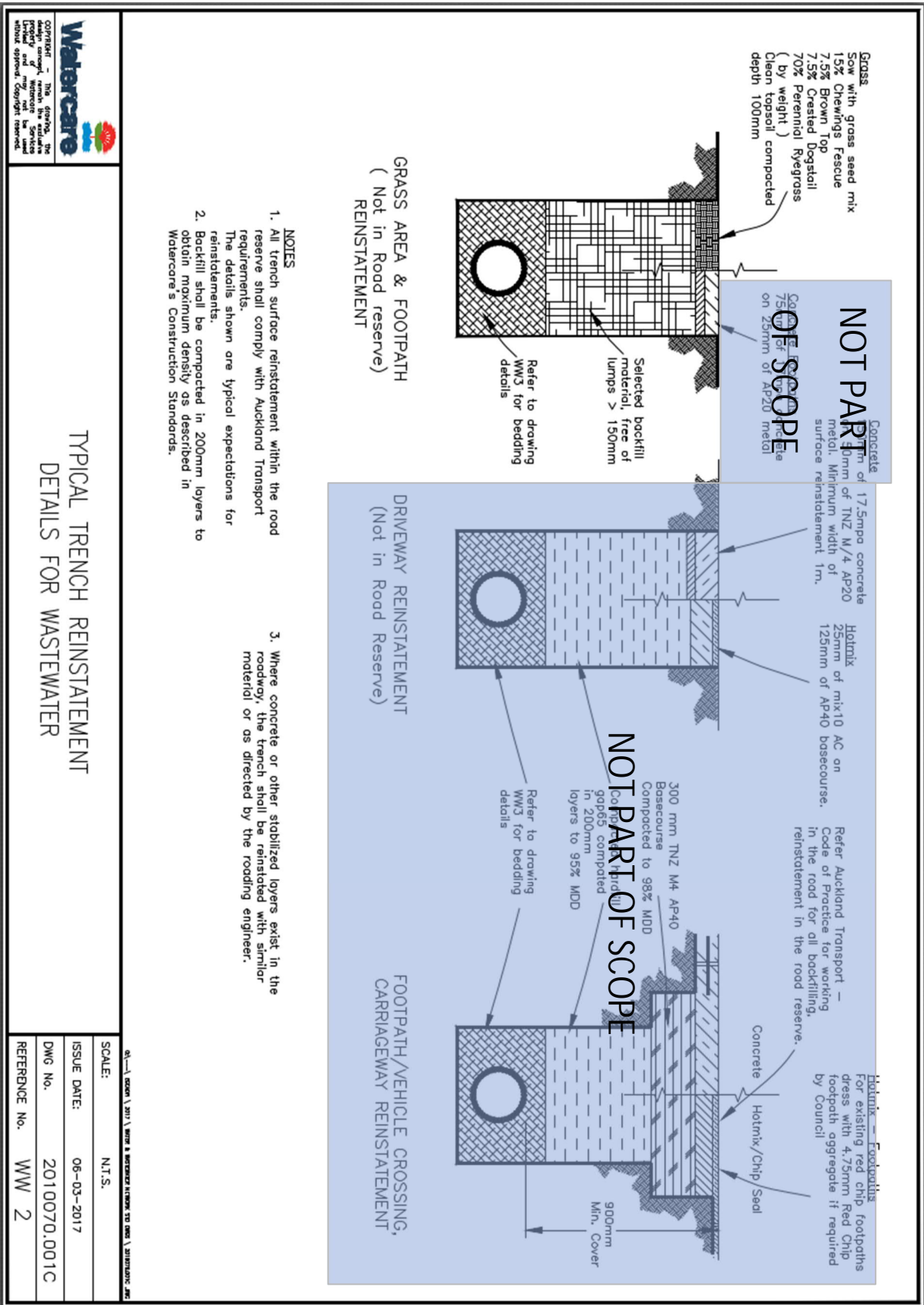
NOTES:

- THIS DRAWING SHALL BE READ IN CONJUNCTION WITH SW01.
- CONCRETE PIPE CLASS SHALL BE DESIGNED IN ACCORDANCE WITH AS/NZS 3726: 2007 USING H2 BEDDING. TO CONSTRUCTION OR FINAL CONDITION LOADINGS, WHICHEVER IS GREATER.
- PLACEMENT OF EMBEDMENT, TRENCHFILL, & COMPACTION SHALL MEET THE REQUIREMENTS OF DRAWINGS AND SPECIFICATIONS.
- EXCAVATE OR COMPACT TRENCH FLOOR TO PROVIDE A FLAT FIRM BASE TO SUPPORT BEDDING MATERIAL AND MINIMISE PIPELINE SETTLEMENT.
- REPLACE EXCAVATED MATERIAL WITH SUITABLE GRANULAR MATERIAL FOR BEDDING.
- ENSURE BEDDING IS DEEP ENOUGH THAT PIPE JOINT PROJECTIONS (SOCKETS) DO NOT TOUCH TRENCH FLOOR (SEE DETAIL BELOW).
- OVERLAY ZONE TO BE GAPPED. OTHER INORGANIC FILL MATERIAL MAY BE SPECIFIED FOR NON-CARRIAGEWAY AREAS.
- MATERIAL SHALL BE COMPACTED AS NECESSARY TO PREVENT EXCESSIVE SETTLEMENT IN THE GROUND SURFACE LEVEL OVER THE INSTALLED PIPE.
- WHERE REQUIRED BY SITE CONDITIONS SPECIFIC DESIGN OF PIPE EMBEDMENT MAY BE REQUIRED. THIS SHOULD BE UNDERTAKEN IN ACCORDANCE WITH AS/NZS 3726: 2007 TO THE APPROVAL OF AUCKLAND COUNCIL.
- EMBEDMENT FOR 'RIGID PIPES' OTHER THAN CONCRETE IS SUBJECT TO SPECIFIC DESIGN AND APPROVAL.

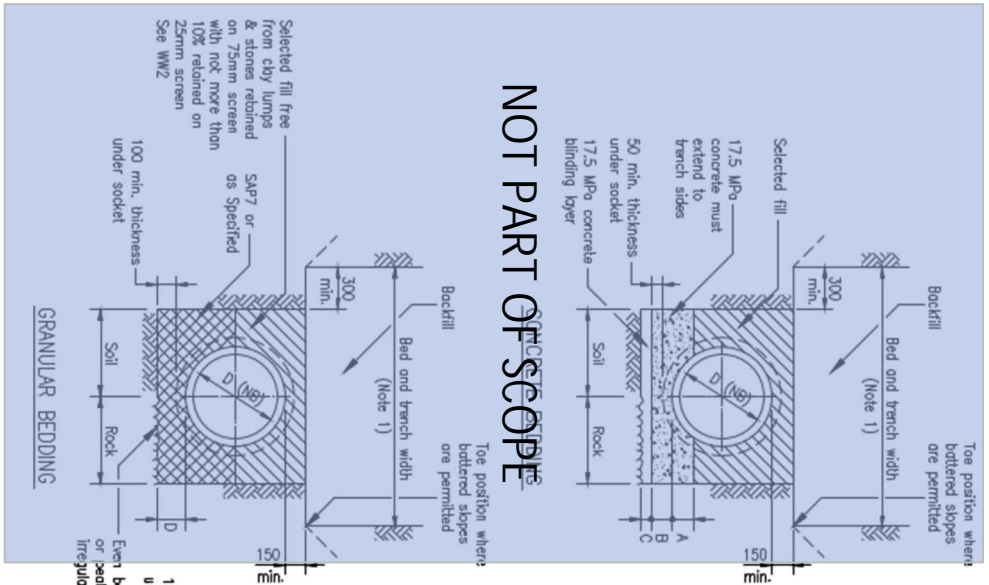
Appendix 3.2 Watercare – Water Drawing WS2



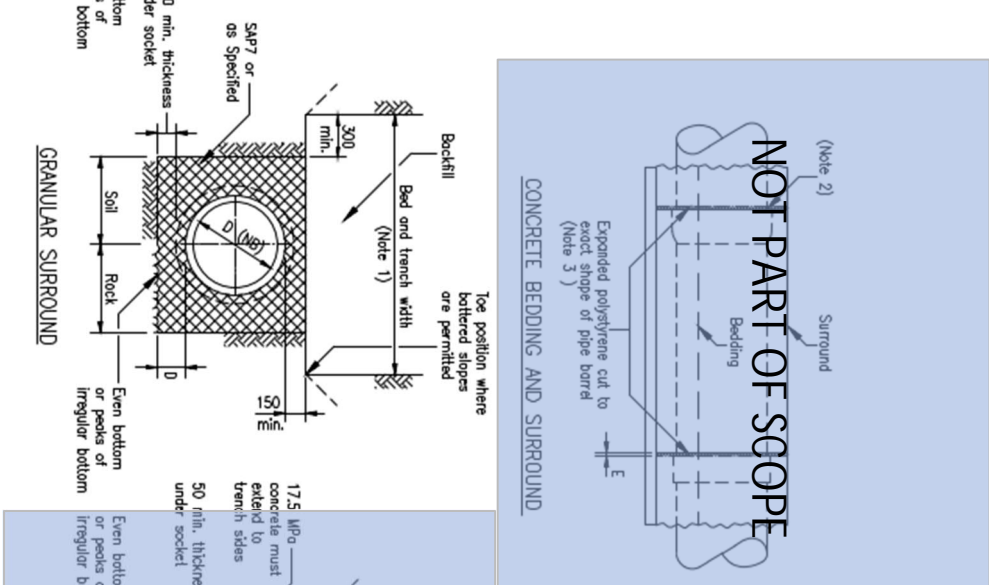
Appendix 3.3 Watercare – Wastewater Drawing WW2



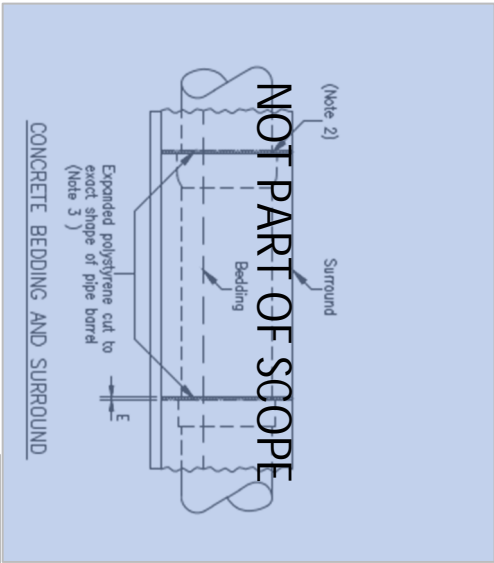
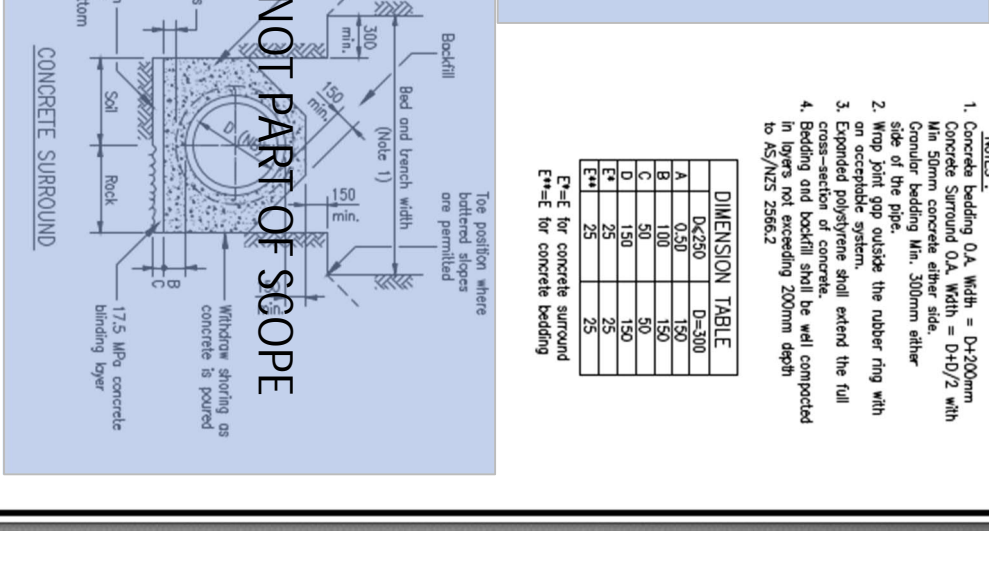
NOT PART OF SCOPE



NOT PART OF SCOPE



NOT PART OF SCOPE



- NOTES:**
- Concrete Bedding O.A. Width = D+200mm
Concrete Surround O.A. Width = D+D/2 with Min 50mm concrete either side.
Granular bedding Min. 300mm either side of the pipe.
 - Wrap joint gap outside the rubber ring with an acceptable system.
 - Expanded polystyrene shall extend the full cross-section of concrete.
 - Bedding and backfill shall be well compacted in layers not exceeding 200mm depth to AS/NZS 2566.2

DIMENSION TABLE

D	290	D=300
A	0.50	150
B	1.00	150
C	50	50
D	150	150
E*	25	25
E**	25	25

E*=E for concrete surround
E**=E for concrete bedding

BEDDING DETAILS

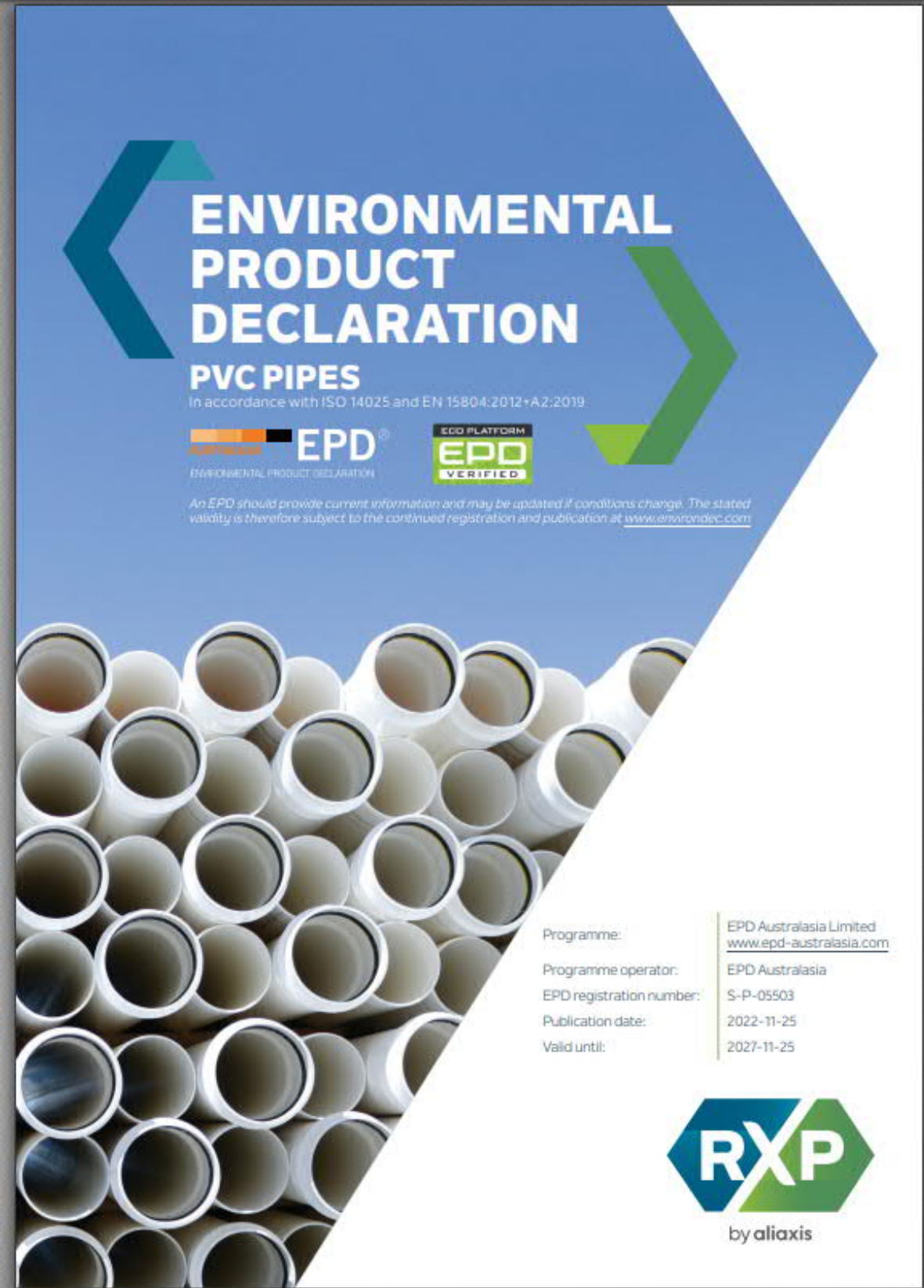


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SCALE:	N.T.S.
ISSUE DATE:	23-01-2017
DWG NO.	2010070.005C
REFERENCE NO.	WW 3

Appendix 4 Environmental Product Declarations


Appendix 4.1 RXP – PVC




**ENVIRONMENTAL
PRODUCT
DECLARATION**

PVC PIPES


In accordance with ISO 14025 and EN 15804:2012+A2:2019.

 **EPD**[®]
ENVIRONMENTAL PRODUCT DECLARATION

 **EPD
VERIFIED**

An EPD should provide current information and may be updated if conditions change. The stated validity is therefore subject to the continued registration and publication at www.environdec.com

Programme:	EPD Australasia Limited www.epd-australasia.com
Programme operator:	EPD Australasia
EPD registration number:	S-P-05503
Publication date:	2022-11-25
Valid until:	2027-11-25


by **aliaxis**



Manufacturing Stage

RXP PVC pipes are manufactured in two sites:

- Manurewa, Auckland - North Island
- Tinwald, Ashburton - South Island

The plastics PVC pipes are produced using extrusion technology and process that is sophisticated and highly controlled.

Basically, PVC products are formed from raw PVC resin by a process of heat and pressure, additional materials used are additives, including calcium carbonate, titanium dioxide, calcium-based stabiliser, lubricants, and pigments.

The PVC resin is the main ingredient in the PVC pipe feed mix but internal PVC pipe scrap from production can be fed back into the feed mix to ensure wastage is minimised.

The heart of the process is the extruder where the PVC passes through a number of zones which compress, homogenise and vent the melt stream. The final zone increases the pressure to extrude the melt through the head and die set.

Once the pipe leaves the extrusion die, it is sized by external vacuum, final cooling is done in a controlled water bath.

An in-line printer marks the pipes at regular intervals, with identification according to size, class, type and date. An automatic cut-off saw cuts the pipe to the required length.

The final part of the process of manufacturing a PVC is to create a socket so the lengths can be joined. This is done automatically in line with the extrusion process where the cut length is passed into the socketing machine where one end of the pipe is re-heated and shaped over a mandrel to make a solvent socket or rubber ring socket to allow the pipes to be joined together in the field.

Finally, the lengths of pipe are palletised, packaged with a softwood timber frame, and PET strapping.

Distribution Stage

RXP distributes to New Zealand's major markets. Figures for this stage were calculated with a weighted average based on volume production in each manufacturing sites and the distribution centres for each of the different products.

An average distance of 30kms was assumed from manufacturing site to distribution centres, products transported via rigid truck.

Installation Stage

PVC pipes with a small diameter are typically used above ground. In residential applications, these are located in wall and floor cavities and for commercial and industrial applications they are often left exposed suspended from floor and ceiling surfaces. The smaller pipes are carried by person, cut by hand saw and positioned by hand – no machinery being required.

Larger sizes are typically buried to connect the building to the sewer or stormwater drainage infrastructure provided by water and council agencies.

Generally and depending on the scenario, pipes with a DN >80mm and ≤100mm (for non-pressure pipe) or 50mm (for pressure pipe) are generally laid in excavated trenches. The depth of the trench varies and pipes require a 600mm deep trench and a width of twice the pipe diameter. It is assumed that a compact track loader with a trench cutter attachment is used to install these pipes.

Pipes with DN>100 require a trench depth of 750 mm plus the pipe's height and a width based on the values shown in Figure 2. It is assumed that the trenches are done by using a mechanical excavator.

Recommended Trench Widths		
Size DN	Minimum (mm)	Maximum (mm)
100	320	650
125	340	675
150	360	725
175	400	875
200	425	900
225	450	925
300	575	1000
375	600	1200

Minimum Cover	
Loading	Cover (mm)
Roadward streets	750
Driveway and similar areas subject to traffic	600
Footpaths, gardens	500
Construction traffic	750

Figure 2. Recommended trench width and minimum cover

EPD Results - PVC non-pressure

Results for modules A1-4, C - D

Table 8. Results for 1kg of Series 100 - DWV

Indicator	Unit	A1-A3	A4	C1	C2	C3	C4	D	
Environmental Impacts	GWP-fossil	kg CO ₂ eq	2.35E+01	6.98E+01	5.24E+05	3.20E+05	-2.33E+01	3.69E+01	-5.42E+01
	GWP-biogenic	kg CO ₂ eq	-1.75E+02	3.52E+04	1.75E+09	1.07E+05	-8.10E+03	4.02E+04	-2.65E+03
	GWP-succ	kg CO ₂ eq	2.20E+03	6.88E+05	7.24E+03	2.32E+06	-5.17E+04	2.44E+05	-6.00E+04
	GWP-total	kg CO ₂ eq	2.30E+03	6.88E+05	5.24E+05	5.22E+05	-2.42E+01	3.66E+01	-5.46E+01
	ODP	kg CFC-11 eq	9.63E+07	3.73E+08	7.67E+15	3.16E+09	-6.21E+06	6.04E+09	-2.41E+07
	AP	mol H ⁺ eq	1.79E+02	1.78E+03	4.64E+07	3.33E+05	-4.59E+03	3.09E+04	-2.56E+03
	EP-freshwater	kg PO ₄ ³⁻ eq	2.95E+03	1.81E+04	6.62E+08	5.75E+06	6.75E+06	1.49E+04	-6.54E+04
	EP-freshwater	kg P eq	7.00E+04	1.27E+05	3.91E+11	3.93E+07	2.27E+06	7.54E+06	-1.52E+04
	EP-marine	kg N eq	2.34E+03	4.39E+04	2.02E+07	1.38E+05	9.16E+05	2.96E+04	-5.20E+04
	EP-terrestrial	mol N eq	2.35E+02	4.87E+03	2.20E+06	1.48E+04	1.27E+08	1.76E+08	-5.33E+08
	POCP	kg NMVOC eq	6.22E+03	1.98E+03	5.75E+07	3.33E+05	-1.62E+04	5.66E+04	-1.36E+03
	ADP-minerals/rocks	kg Sb eq	2.54E+05	5.70E+07	1.78E+12	1.75E+08	3.04E+07	1.92E+07	-7.94E+06
	ADP-fossil*	MJ	4.81E+01	2.50E+03	1.93E+05	7.74E+02	-1.04E+01	3.12E+01	-1.15E+01
	WCP	m ³	2.00E+03	8.31E+03	2.70E+05	2.55E+04	-1.12E+01	2.44E+01	-2.67E+01
Resource use	FERR	MJ	4.54E+03	2.89E+02	4.54E+07	8.96E+04	-1.09E+02	2.42E+02	-4.23E+01
	FERRM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	FERT	MJ	4.54E+03	2.89E+02	4.54E+07	8.96E+04	-1.09E+02	2.42E+02	-4.23E+01
	FERRM	MJ	5.17E+01	2.89E+03	1.94E+05	8.22E+02	-1.12E+01	3.32E+01	-1.23E+01
	FERRM	MJ	3.28E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	FERT	MJ	8.40E+01	2.89E+03	1.94E+05	8.22E+02	-1.12E+01	3.32E+01	-1.23E+01
	SM	kg	0.00E+00	0.00E+00	0.00E+00	1.02E+00	2.02E+00	3.02E+00	4.02E+00
	RSP	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	RSPF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	FW	m ³	1.87E+02	1.34E+04	3.59E+09	3.84E+06	3.86E+04	3.39E+03	-4.23E+01
Waste	Hazardous waste disposed	kg	3.36E+05	6.48E+06	5.29E+12	2.02E+07	4.87E+07	8.22E+07	-2.67E+06
	Non-hazardous waste disposed	kg	3.73E+07	1.25E+01	7.37E+06	3.90E+03	9.87E+02	4.94E+02	-7.01E+02
	Recyclable waste disposed	kg	6.43E+05	1.62E+05	5.91E+14	5.03E+07	1.23E+09	1.64E+06	-1.57E+05
Output Flows	Components for re-use	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.02E+00	0.00E+00
	Materials for recycling	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.69E+07	0.00E+00	0.00E+00
	Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Exported energy electricity	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Exported energy thermal	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Results for modules A5

Table 9 shows the results(A5) for PVC non- pressure pipes ranges 20 to 500. The significantly lower impact for the first range (DN=40) is due to pipes of this size range not being buried, and therefore not requiring excavation and fill which account for the highest impact in the installation stage.

Table 9. EPD Results for 1m of installed PVC non-pressure pipe

		DN and DN range (mm)								
Indicator	Unit	40	90	110	160	225	315	400	500	
		20-80	90	100-110	150-176	200-250	300-315	375-400	475-500	
Environmental impacts	GWP-fossil	kg CO ₂ eq	756E-03	2.23E+00	3.43E+00	5.05E+01	337E+01	165E+01	2.04E+01	2.44E+01
	GWP-biogenic	kg CO ₂ eq	4.85E-05	3.38E-02	4.99E-02	5.70E-02	7.96E-02	8.83E-02	1.09E-01	1.28E-01
	GWP-total	kg CO ₂ eq	1.07E-06	1.33E-03	4.72E-03	5.53E-03	1.02E-02	8.47E-03	1.04E-02	1.24E-02
	GWP-intel	kg CO ₂ eq	7.60E-03	2.25E+00	3.10E+00	1.09E+01	337E+01	165E+01	2.05E+01	2.46E+01
	ODP	kg CFC-11 eq	2.36E-10	2.45E-07	8.83E-07	1.02E-06	1.31E-06	1.57E-06	1.91E-06	2.30E-06
	AP	mgH ⁺ eq	1.44E-05	1.67E-02	2.27E-02	8.77E-02	1.04E-01	1.25E-01	1.55E-01	1.86E-01
	EP-brackwater	kg PO ₄ ³⁻ eq	4.27E-06	3.31E-03	3.38E-02	1.17E-02	1.99E-02	2.26E-02	2.36E-02	3.54E-02
	EP-freshwater	kg P eq	6.23E-07	4.21E-04	1.52E-03	1.75E-03	2.24E-03	2.61E-03	3.32E-03	3.94E-03
	EP-marine	kg N eq	5.93E-06	5.93E-03	2.85E-02	3.00E-02	3.78E-02	4.55E-02	5.67E-02	6.75E-02
	EP-terrestrial	mg N eq	3.40E-05	6.40E-02	2.39E-01	3.32E-01	4.78E-01	5.03E-01	6.10E-01	7.46E-01
	POCP	kg NMVOC eq	1.34E-05	1.17E-02	1.35E-02	8.34E-02	1.05E-01	1.26E-01	1.56E-01	1.87E-01
	ADP-minerals & metals*	kg Sb eq	2.30E-08	1.01E-05	3.65E-05	4.21E-05	5.39E-05	6.48E-05	7.99E-05	9.50E-05
	ADP-fossil*	MJ	5.79E-02	2.28E+01	8.25E+01	9.53E+01	1.22E+02	1.40E+02	1.81E+02	2.16E+02
	WCP	m ³	4.50E-03	1.50E+00	6.11E+00	7.00E+00	8.94E+00	1.07E+01	1.32E+01	1.58E+01
Resource use	PERE	MJ	1.06E-02	1.06E+00	3.82E+00	4.41E+00	5.64E+00	6.77E+00	8.34E+00	9.90E+00
	PERM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	PEIT	MJ	1.06E-02	1.06E+00	3.82E+00	4.41E+00	5.64E+00	6.77E+00	8.34E+00	9.90E+00
	PEFRE	MJ	6.23E-02	2.42E+01	8.75E+01	1.01E+02	1.29E+02	1.56E+02	1.92E+02	2.29E+02
	PERNM	MJ	0.00E+00	6.24E+01	9.32E+01	1.19E+02	1.39E+02	1.64E+02	1.97E+02	2.33E+02
	PEIRT	MJ	6.23E-02	9.66E+01	1.81E+02	2.38E+02	3.19E+02	3.20E+02	3.42E+02	3.55E+02
	DM	kg	0.00E+00	1.03E+00	2.00E+00	3.00E+00	4.00E+00	5.00E+00	6.00E+00	7.00E+00
	RSP	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	NRSP	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	PW	m ³	6.34E-05	1.62E-02	5.81E-02	6.73E-02	8.63E-02	1.04E-01	1.28E-01	1.53E-01
Waste	Hazardous waste disposed	kg	3.47E-08	1.75E-05	2.80E-04	3.23E-04	4.33E-04	4.95E-04	6.10E-04	7.23E-04
	Non-hazardous waste disposed	kg	8.89E-04	8.30E-01	3.00E+00	3.46E+00	4.42E+00	5.30E+00	6.54E+00	7.76E+00
	Recyclable waste disposed	kg	7.62E-05	1.32E-04	4.77E-04	5.51E-04	7.05E-04	8.45E-04	1.04E-03	1.24E-03


Results for modules A5

Table 11. EPD results for 1m of installed PVC pressure pipe

		DN and DN range (mm)									
Indicator	Unit	25	100	125	150	175	225	300	375	450	
		15-80	100	125	150	175	200-250	300	375	450	
Environmental impacts	GWP-fossil	kg CO ₂ eq	3.7E-01	8.8E+00	1.0E+01	1.0E+01	1.1E+01	1.3E+01	1.6E+01	4.4E+02	2.2E+01
	GWP-biogenic	kg CO ₂ eq	3.6E-05	1.6E-02	5.3E-02	5.6E-02	6.3E-02	7.6E-02	9.7E-02	4.8E+00	1.1E-01
	GWP-luluc	kg CO ₂ eq	7.9E-01	1.6E-03	5.1E-03	5.4E-03	6.1E-03	7.6E-03	9.4E-03	4.4E-01	1.1E-02
	GWP-total	kg CO ₂ eq	3.7E-01	2.4E+00	1.0E+01	1.0E+01	1.1E+01	1.3E+01	1.6E+01	4.4E+02	2.2E+01
	ODP	kg CFC 11 eq	1.6E-10	2.7E-07	9.4E-07	1.0E-06	1.1E-06	1.3E-06	1.6E-06	6.0E-05	2.1E-06
	AP	molH ⁺ eq	1.0E+00	3.8E-02	7.8E-02	8.5E-02	9.7E-02	1.0E-01	1.2E-01	3.0E+00	1.0E-01
	EP-freshwater	kg PO ₄ eq	2.2E-08	3.6E-03	1.4E-02	1.5E-02	1.7E-02	1.9E-02	2.3E-02	7.9E-01	3.2E-02
	EP-freshwater	kg P eq	3.7E-07	4.7E-04	1.6E-03	1.7E-03	1.9E-03	2.2E-03	2.6E-03	1.4E-01	3.6E-03
	EP-marine	kg N eq	2.8E-06	6.2E-03	2.5E-02	2.6E-02	3.0E-02	3.7E-02	4.4E-02	8.5E-01	5.6E-02
	EP-terrestrial	molN eq	2.1E-05	6.3E-02	3.1E-01	3.2E-01	3.6E-01	4.3E-01	4.9E-01	9.7E+00	6.6E-01
	POCP	kg PMVOC eq	1.4E-06	1.7E-02	7.6E-02	8.2E-02	9.7E-02	1.0E-01	1.2E-01	2.3E+00	1.7E-01
	ADP-minerals & metals*	kg Sb eq	7.6E-08	1.1E-05	3.9E-05	4.1E-05	4.6E-05	5.3E-05	6.4E-05	3.0E-03	8.7E-05
	ADP-fossil*	MJ	5.4E-02	2.5E+01	8.8E+01	9.3E+01	1.0E+02	1.2E+02	1.4E+02	6.3E+03	1.9E+02
	WOP	m ³	2.7E-03	1.6E+00	6.5E+00	6.9E+00	7.7E+00	8.8E+00	1.0E+01	4.7E+02	1.4E+01
	Resource use	PERE	MJ	1.4E-03	1.9E+00	4.0E+00	4.3E+00	4.8E+00	5.6E+00	6.7E+00	3.7E+02
PERM		MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERT		MJ	1.4E-03	1.9E+00	4.0E+00	4.3E+00	4.8E+00	5.6E+00	6.7E+00	3.7E+02	9.1E+00
PERSE		MJ	5.5E-02	2.7E+01	9.9E+01	9.9E+01	1.1E+02	1.2E+02	1.5E+02	6.3E+03	2.0E+02
PERM		MJ	0.00E+00	7.0E+01	1.3E+02	1.3E+02	1.3E+02	1.6E+02	1.9E+02	1.9E+02	1.9E+03
PERT		MJ	5.5E-02	1.0E+02	2.1E+02	2.2E+02	2.4E+02	2.7E+02	3.4E+02	6.6E+03	1.7E+03
SM		kg	0.00E+00	1.0E+00	2.0E+00	3.0E+00	4.0E+00	5.0E+00	6.0E+00	7.0E+00	8.0E+00
EcF		MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
HRSP		MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PW		m ³	2.9E-05	1.8E-02	6.7E-02	6.6E-02	7.4E-02	8.8E-02	1.0E-01	5.8E+00	1.3E-01
Waste	Hazardous waste disposed	kg	2.4E-08	6.7E-05	3.0E-04	3.1E-04	3.5E-04	4.1E-04	4.9E-04	2.3E-02	6.6E-04
	Non-hazardous waste disposed	kg	3.4E-04	9.3E-01	1.2E+00	1.4E+00	1.6E+00	1.8E+00	2.2E+00	2.0E+02	7.9E+00
	Radioactive waste disposed	kg	5.9E-08	1.5E-04	5.5E-04	5.4E-04	6.1E-04	7.3E-04	8.3E-04	3.6E-02	1.4E-03



PVC pressure

EPD results for 1kg of Series 800-Small (Water Supply)

Indicator	Unit	A1-A3	A4	C1	C2	C3	C4	D
Environmental impacts	GWP-fossil	kg CO ₂ eq	1.83E+02	5.79E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	GWP-biogenic	kg CO ₂ eq	1.67E+02	1.13E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	GWP-MULC	kg CO ₂ eq	2.47E+03	2.20E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	GWP-total	kg CO ₂ eq	2.65E+03	3.40E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ODP	kg CFC-11 eq	1.66E+06	1.20E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	AP	mol H ⁺ eq	1.46E+02	3.70E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	EP-freshwater	kg PO ₄ ³⁻ eq	3.36E+03	6.00E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	EP-freshwater	kg P eq	7.67E+04	4.83E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	EP-marine	kg N eq	2.90E+03	1.41E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	EP-terrestrial	mol N eq	2.95E+02	1.54E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	POCP	kg NMVOC eq	7.79E+03	3.73E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ADP-minerals/metals*	kg Sb eq	1.71E+05	1.83E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ADP-fossil*	MJ	5.46E+01	6.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	WDP	m³	2.05E+00	2.67E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Resource use	PERE	MJ	4.27E+00	9.21E+03	0.00E+00	0.00E+00	0.00E+00
PERM		MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERT		MJ	4.27E+00	9.21E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERRE		MJ	3.99E+01	8.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERRM		MJ	3.56E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERTT		MJ	9.43E+01	8.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM		kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSP		MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RRSP		MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PW		m³	2.07E+02	3.97E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Waste	Hazardous waste disposed	kg	1.10E+04	2.08E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Non-hazardous waste disposed	kg	3.91E+01	4.02E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Radioactive waste disposed	kg	7.67E+05	5.20E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Output flows	Components for re-use	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Material for recycling	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Material for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Exported energy: electricity	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported energy: thermal	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	



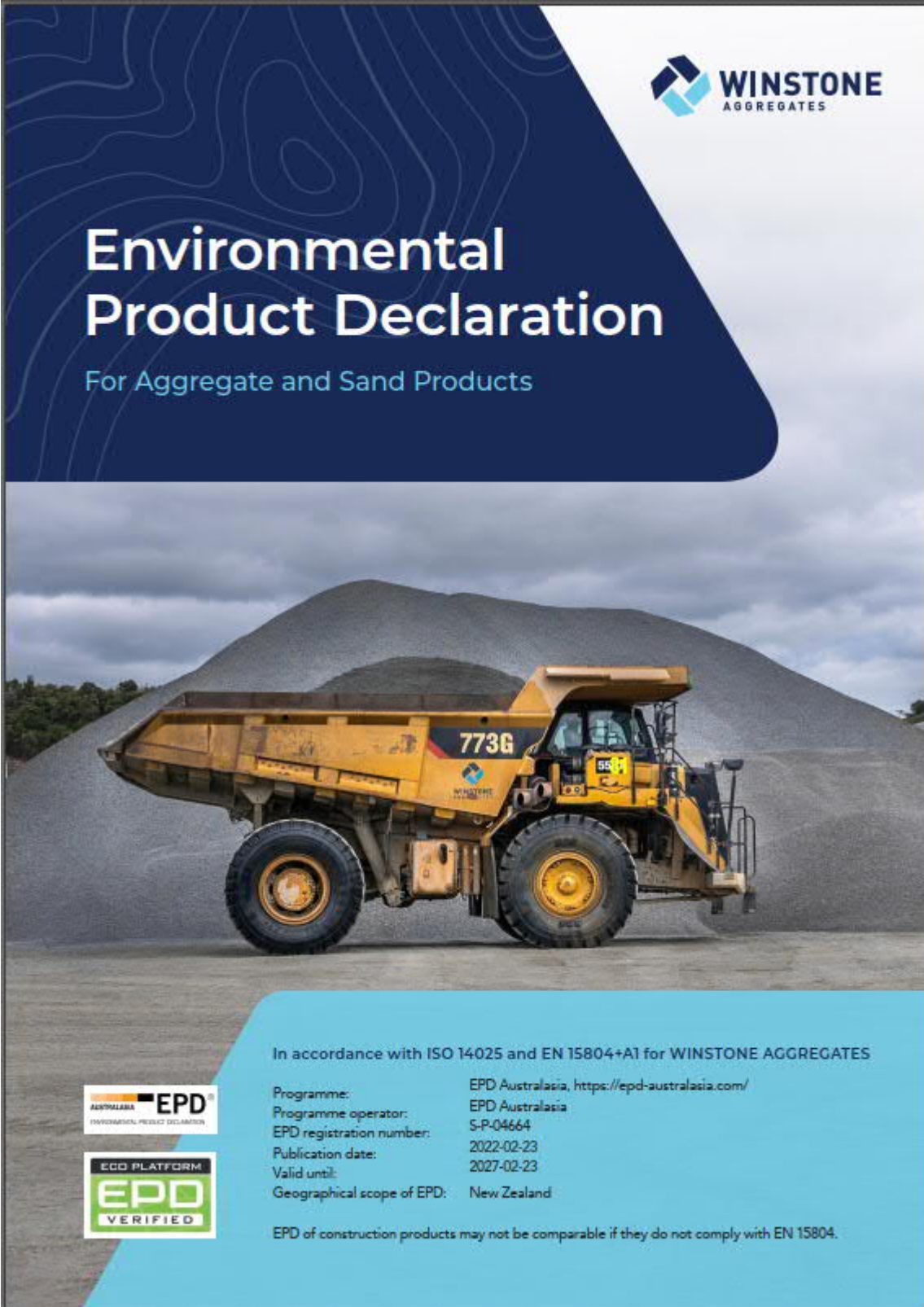
Appendix B – Product Detail


Table 1 and Table 2 show product details for RXP pipe products included in this study. Other product specifications are available on their website.

Table 1. PVC non-pressure products

Series	Application	DN Nominal Size (mm)	Density (kg/m)	Length (m)	Product Code
100	DWW	32	0.344	6	100.32.6S.J
100	DWW	40	0.437	6	100.40.6S.J
100	DWW	50	0.612	6	100.50.6S.J
100	DWW	65	0.865	6	100.65.6S.J
100	DWW	80	1.205	6	100.80.6S.J
100	DWW	100	1.915	4	100SN10.100.4R.J
100	DWW	100	1.915	6	100SN10.100.6R.J
100	DWW	100	1.915	6	100SN10.100.6S.J
100	DWW	100	2.178	6	100SN16.100.6R.J
100	DWW	150	4.65	6	100SN16.150.4R.J
100	DWW	150	4.65	6	100SN16.150.6R.J
300	DWW	150	4.65	6	100SN16.150.6S.J
100	DWW	175	7.079	6	100SN16.175.6R.J
300	DWW	225	11.185	6	100SN16.225.6R.J
100	DWW	300	17.688	4	100SN16.300.4R.J
300	DWW	300	17.688	6	100SN16.300.6R.J
100	DWW	375	28.747	4	100SN16.375.4R.J
300	DWW	375	28.747	6	100SN16.375.6R.J
100	DWW	475	46.66	6	100SN16.475.6R.J
700	DWW	150	2.924	6	100SN4.150.6R.J
100	DWW	150	2.924	6	100SN4.150.6S.J
100	DWW	175	4.568	6	100SN4.175.6R.J
100	DWW	225	7.303	6	100SN4.225.6R.J
100	DWW	300	11.365	6	100SN4.300.6R.J
100	DWW	100	1.575	6	100SN6.100.6R.J
100	DWW	100	1.575	6	100SN6.100.6S.J
700	DWW	150	3.682	6	100SN8.150.6R.J
100	DWW	175	6.153	6	100SN8.175.6R.J
700	DWW	225	9.03	6	100SN8.225.6R.J
100	DWW	300	14.77	4	100SN8.300.4R.J
700	DWW	300	14.77	6	100SN8.300.6R.J
100	DWW	375	23.097	4	100SN8.375.4R.J
700	DWW	375	23.097	6	100SN8.375.6R.J
100	DWW	475	33.39	4	100SN8.475.4R.J
100	DWW	475	33.39	6	100SN8.475.6R.J
2700	Electrical	150	3.179	6	2700.150.LD.6S.J
2700	Electrical	50	0.609	6	2700.50.6S.J
550	Culvert	110	1.211	6	550.110.6S.J
550	Culvert	160	2.496	6	550.160.6S.J
550	Culvert	200	3.088	6	550.200.6S.J
550	Culvert	250	4.953	6	550.250.6S.J
550	Culvert	315	7.837	6	550.315.6S.J
550	Culvert	400	12.532	6	550.400.6PE.TD
550	Culvert	400	12.532	6	550.400.6S.J
550	Culvert	400	12.532	6	550.400.6S.J.TD
550	Culvert	500	19.91	6	550.500.6S.J
550	Culvert	160	2.496	6	550WH.160.6S.J
550	Culvert	250	4.953	6	550WH.250.6S.J.TD
700	Stormwater	100	1.392	6	700SN4.100.6S.J
700	Stormwater	160	2.945	6	700SN4.160.6S.J
700	Stormwater	225	7.245	6	700SN4.225.6R.J
700	Stormwater	90	0.972	6	700SN4.90.6S.J

Appendix 4.2 Winstone – Aggregate and Sand Products




WINSTONE
 AGGREGATES


Environmental Product Declaration


For Aggregate and Sand Products

In accordance with ISO 14025 and EN 15804+A1 for WINSTONE AGGREGATES

Programme:	EPD Australasia, https://epd-australasia.com/
Programme operator:	EPD Australasia
EPD registration number:	S-P-04664
Publication date:	2022-02-23
Valid until:	2027-02-23
Geographical scope of EPD:	New Zealand

EPD of construction products may not be comparable if they do not comply with EN 15804.





Full Product List

A full list of products, and their relevant group are presented in table 2.

Table 2: Full product names and product groups

Full product name	Product abbreviated name	Product group
Cyclone Sand	CYCL	Manufactured Sand
Concrete Sand	SANDC	Manufactured Sand
Filter F/2	F2	Natural Sand
Gravel 5mm	GRAVEL	Natural Sand
Pumice Overs	PUMOVERS	Natural Sand
No 1 Sand	SAND1	Natural Sand
No 3 Sand	SAND3	Natural Sand
SAND - 5MM	SAND5MM	Natural Sand
General Purpose Sand	SANDGP	Natural Sand
Rapid Sand	SANDR	Natural Sand
Breaker	BREAKER	Aggregate - No Processing
Brown Rock	BRR	Aggregate - No Processing
Face Metal	FACE	Aggregate - No Processing
Filling	FILL	Aggregate - No Processing
Face Rock	FROCK	Aggregate - No Processing
Gabion 300-400	GAB400	Aggregate - No Processing
Hardfill ex Face	HFF	Aggregate - No Processing
Over Run	OR	Aggregate - No Processing
RipRap	RIPRAP	Aggregate - No Processing
River Run	RR	Aggregate - No Processing
Spalls ex Face	SPF	Aggregate - No Processing
Spalls Selected	SPS	Aggregate - No Processing
Self Selected Rocks 800-500	SPS500	Aggregate - No Processing
Self Selected Rocks >800	SPS800	Aggregate - No Processing
Stripping	STRIP	Aggregate - No Processing
TOPSOIL	TOP	Aggregate - No Processing
Basecourse Domestic 40mm	BCD40	Aggregate - Primary Crushing & Screening
Basecourse Standard 40mm	BCS40	Aggregate - Primary Crushing & Screening
All Passing 100 Crushed Brown	BROWN100	Aggregate - Primary Crushing & Screening
All Passing 65 Crushed Brown	BROWN65	Aggregate - Primary Crushing & Screening
General All Passing 100	GAP100	Aggregate - Primary Crushing & Screening
General All Passing 100 Face	GAP100F	Aggregate - Primary Crushing & Screening
General All Passing 150	GAP150	Aggregate - Primary Crushing & Screening

Full product name	Product abbreviated name	Product group
Road Metal 65mm	RM65	Aggregate - Primary Crushing & Screening
Scalpings	SCALP	Aggregate - Primary Crushing & Screening
TG Metal 65mm	TGM65	Aggregate - Primary Crushing & Screening
TGTopcourse 20mm Standard	TGS20	Aggregate - Primary Crushing & Screening
TGS40mm	TGS40	Aggregate - Primary Crushing & Screening
Topcourse Domestic 20mm	TOP20D	Aggregate - Primary Crushing & Screening
Topcourse 20mm Standard	TOP20S	Aggregate - Primary Crushing & Screening
Scalped 40mm	SCALP40	Aggregate - Primary Screening Only
Scalped 65mm	SCALP65	Aggregate - Primary Screening Only
TGFILL 65mm+	TGFILL65+	Aggregate - Primary Screening Only
Basecourse 40mm R	BC40R	Aggregate - Secondary Crushing & Screening
Bedding Mix	BEDM	Aggregate - Secondary Crushing & Screening
Cribwall Backfill 40-20	CRIB40	Aggregate - Secondary Crushing & Screening
Cribwall Backfill 80-20	CRIB80	Aggregate - Secondary Crushing & Screening
Drainage 150/40	DRAIN15040	Aggregate - Secondary Crushing & Screening
Drainage 25	DRAIN25	Aggregate - Secondary Crushing & Screening
Drainage 40	DRAIN40	Aggregate - Secondary Crushing & Screening
Drainage 40-20	DRAIN4020	Aggregate - Secondary Crushing & Screening
Drainage 65-19	DRAIN65	Aggregate - Secondary Crushing & Screening
Drainage 65-40	DRAIN6540	Aggregate - Secondary Crushing & Screening
Filter B	FILB	Aggregate - Secondary Crushing & Screening
Gabion Stone	GABION	Aggregate - Secondary Crushing & Screening
Gabion 100-250	GABION100	Aggregate - Secondary Crushing & Screening
General All Passing 10	CAP10	Aggregate - Secondary Crushing & Screening
General All Passing 20	CAP20	Aggregate - Secondary Crushing & Screening
General All Passing 25	CAP25	Aggregate - Secondary Crushing & Screening
General All Passing 40	CAP40	Aggregate - Secondary Crushing & Screening
General All Passing 65	CAP65	Aggregate - Secondary Crushing & Screening
Hardfill 150-65	HF150-65	Aggregate - Secondary Crushing & Screening
Local Roads AP40	LR40	Aggregate - Secondary Crushing & Screening
Local Roads AP40 PP	LR40PP	Aggregate - Secondary Crushing & Screening
Local Roads AP65	LR65	Aggregate - Secondary Crushing & Screening
Local Roads AP65 PP	LR65PP	Aggregate - Secondary Crushing & Screening
Main Alignment AP65	PP65	Aggregate - Secondary Crushing & Screening
TGAP65	TGAP65	Aggregate - Secondary Crushing & Screening
WHAP65	WHAP65	Aggregate - Secondary Crushing & Screening
Asphaltic Sand	AS	Aggregate - Tertiary Crushing & Screening, Unwashed
Pap 7 ASP	ASP PAP7	Aggregate - Tertiary Crushing & Screening, Unwashed
Builders Mix 20	BM20	Aggregate - Tertiary Crushing & Screening, Unwashed
Crusher Fines	CRF	Aggregate - Tertiary Crushing & Screening, Unwashed
General All Passing 7	GAP7	Aggregate - Tertiary Crushing & Screening, Unwashed
Premium All Passing 7	PAP7	Aggregate - Tertiary Crushing & Screening, Unwashed
TGAP40	TGAP40	Aggregate - Tertiary Crushing & Screening, Unwashed



System Boundaries

This EPD is of the 'cradle-to-gate' type with options. The life cycle of a building product is divided into three process modules according to the General Program Instructions (GPI) of the Australasian EPD Programme (EPD Australasia, 2018) and one module for transport during product distribution according to EN 15804.

Other life cycle stages (Modules A5, B1-B7, C1-C4, and D) are dependent on particular scenarios and best modelled at the building level.

Table 5: Modules declared in the scope of the EPD

PRODUCT STAGE		CONSTR. PROCESS STAGE		USE STAGE				END-OF-LIFE STAGE				RECOVERY STAGE				
Raw material supply	Transport	Manufacturing	Transport	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport	Waste processing	Disposal	Future reuse, recycling or energy recovery potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

(X = declared module; MND = module not declared)

Life Cycle Assessment (LCA) Methodology

Declared Unit

The products covered in this study include 118 variations of regular aggregates, cement stabilised aggregates, and sand products used in a variety of applications across the building and construction industry. The declared unit for each product group is indicated in table 6.

Table 6: Details of LCA

PRODUCT CHARACTERISTICS	
Declared unit	1 tonne of product, delivered to site
Geographical coverage	New Zealand
LCA scope	Cradle to gate with options

This EPD has been produced in conformance with the requirements of the standards listed below:
 Product Category Rules 2012:01 v2.33 Construction Products and Construction Services (EPD International, 2019)
 European Standard 15804:2012+A1:2013 (CEN, 2013)
 ISO 14025 Environmental labels and declarations (ISO, 2006a)
 ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines (ISO, 2006c)
 Instructions of the Australasian EPD Programme V3.0 (EPD Australasia, 2018)
 General Programme Instructions for the International EPD® System v3.01 (EPD International, 2019)

Reference Service Life

The reference service life is not declared because the scope of the study excludes use phase modules, and high variation in service life is expected depending on product application.



Environmental Performance

Auckland/ Northland – non-stabilised products – Module A1-A3

Indicator	Unit	ANP	APS	APSC	ASSC	ATSC	ATSCW	NS	MS
Environmental impacts									
GWP	kg CO ₂ eq.	3.31	3.24	3.61	4.12	3.65	3.59	3.00	3.57
ODP	kg CFC 11 eq.	2.34E-15	2.19E-15	2.94E-15	2.86E-15	3.87E-15	3.89E-15	1.44E-15	3.20E-15
AP	kg SO ₂ eq.	0.0245	0.0240	0.0265	0.0303	0.0254	0.0250	0.0223	0.0262
EP	kg PO ₄ ³⁻ eq.	0.00625	0.00611	0.00677	0.00770	0.00643	0.00636	0.00566	0.00670
POCP	kg C ₂ H ₄ eq.	0.00248	0.00245	0.00267	0.00310	0.00258	0.00253	0.00233	0.00260
ADPE	kg Sb eq.	8.26E-08	8.12E-08	9.86E-08	1.09E-07	1.36E-07	1.33E-07	6.72E-08	1.00E-07
ADPF	MJ	44.5	43.7	48.5	55.5	48.8	48.0	40.7	47.7
Resource use									
PERE	MJ	0.694	1.53	2.30	4.28	14.6	13.5	1.71	1.49
PERM	MJ								
PERT	MJ	0.694	1.53	2.30	4.28	14.6	13.5	1.71	1.49
PENRE	MJ	44.8	44.0	48.9	55.9	49.2	48.4	40.9	48.2
PENRM	MJ	0	0	0	0	0	0	0	0
PENRT	MJ	44.8	44.0	48.9	55.9	49.2	48.4	40.9	48.2
SM	kg	0	0	0	0	0	0	0	0
RSF	MJ	0	0	0	0	0	0	0	0
NRSF	MJ	0	0	0	0	0	0	0	0
FW	m ³	0.0108	0.0136	0.0117	0.0180	0.0483	0.986	0.960	0.595
Waste categories and output flows									
HWD	kg	1.48E-09	1.36E-09	1.87E-09	1.74E-09	2.34E-09	2.38E-09	8.12E-10	2.08E-09
NHWD	kg	0.00621	0.00602	0.00698	0.00688	0.00810	0.00813	0.00503	0.00732
RWD	kg	1.31E-04	1.13E-04	1.58E-04	1.29E-04	1.15E-04	1.27E-04	5.81E-05	1.85E-04
CRU	kg	0	0	0	0	0	0	0	0
MFR	kg	0	0	0	0	0	0	0	0
MER	kg	0	0	0	0	0	0	0	0
EEE	MJ	0	0	0	0	0	0	0	0
EET	MJ	0	0	0	0	0	0	0	0

Waikato – non-stabilised products – Module A1-A3

Indicator	Unit	ANP	APSC	ASSC	ATSC	ATSCW	MS
Environmental impact							
GWP	kg CO ₂ eq.	4.37	4.50	4.68	4.92	4.92	4.39
ODP	kg CFC 11 eq.	1.87E-15	2.44E-15	3.02E-15	3.60E-15	3.60E-15	1.98E-15
AP	kg SO ₂ eq.	0.0329	0.0333	0.0341	0.0353	0.0353	0.0330
EP	kg PO ₄ ³⁻ eq.	0.00835	0.00844	0.00864	0.00893	0.00893	0.00836
POCP	kg C ₂ H ₄ eq.	0.00344	0.00348	0.00356	0.00368	0.00368	0.00344
ADPE	kg Sb eq.	9.10E-08	1.10E-07	1.29E-07	1.49E-07	1.49E-07	9.47E-08
ADPF	MJ	59.3	60.9	63.3	66.3	66.3	59.6
Resource use							
PERE	MJ	0.582	5.05	9.54	14.0	14.0	1.48
PERM	MJ	0	0	0	0	0	0
PERT	MJ	0.582	5.05	9.54	14.0	14.0	1.48
PENRE	MJ	59.6	61.2	63.6	66.6	66.6	59.9
PENRM	MJ	0	0	0	0	0	0
PENRT	MJ	59.6	61.2	63.6	66.6	66.6	59.9
SM	kg	0	0	0	0	0	0
RSF	MJ	0	0	0	0	0	0
NRSF	MJ	0	0	0	0	0	0
FW	m ³	0.00909	0.0204	0.0317	0.0429	0.587	0.556
Waste categories and output flows							
HWD	kg	1.05E-09	1.39E-09	1.73E-09	2.07E-09	2.07E-09	1.12E-09
NHWD	kg	0.00428	0.00498	0.00571	0.00644	0.00644	0.00442
RWD	kg	8.61E-05	8.66E-05	8.71E-05	8.77E-05	8.77E-05	8.62E-05
CRU	kg	0	0	0	0	0	0
MFR	kg	0	0	0	0	0	0
MER	kg	0	0	0	0	0	0
EEE	MJ	0	0	0	0	0	0
EET	MJ	0	0	0	0	0	0



Measuring emissions: A guide for organisations

2022 summary of emissions factors

Using data from the 2020 calendar year



Fuel emission factors

Table 1: Stationary combustion of fuels: Residential use

Residential fuel emission Source	Unit	kg CO ₂ -e/unit
Coal – default	kg	2.10
Coal – bituminous	kg	2.86
Coal – sub-bituminous	kg	2.15
Coal – lignite	kg	1.54

Table 2: Stationary combustion of fuels: Commercial use

Commercial fuel emission source	Unit	kg CO ₂ -e/unit
Coal – default	kg	2.01
Coal – bituminous	kg	2.66
Coal – sub-bituminous	kg	2.01
Coal – lignite	kg	1.43
Diesel	litre	2.67
LPG	kg	3.03
Heavy fuel oil	litre	3.02
Light fuel oil	litre	2.96
Natural gas	kWh	0.195
	GJ	54.1

Table 3: Stationary combustion of fuels: Industrial use

Industrial fuel emission source	Unit	kg CO ₂ -e/unit
Coal – default	kg	1.93
Coal – bituminous	kg	2.66
Coal – sub-bituminous	kg	2.01
Coal – lignite	kg	1.43
Diesel	litre	2.66
LPG	kg	3.02
Heavy fuel oil	litre	3.02
Light fuel oil	litre	2.92
Natural gas	kWh	0.194
	GJ	54.0

Table 4: Transport fuels

Transport fuel type	Unit	kg CO ₂ -e/unit
Regular petrol	litre	2.46
Premium petrol	litre	2.48
Diesel	litre	2.69
LPG	litre	1.64
Heavy fuel oil	litre	3.04
Light fuel oil	litre	2.94
Aviation fuel (Kerosene) / Jet A1	GJ	70.6
	litre	2.63
Aviation gasoline	GJ	68.3
	litre	2.31

Table 5: Biofuels

Biofuel type	Unit	kg CO ₂ -e/unit
Bioethanol	GJ	3.42
	litre	0.000807
Biodiesel	GJ	3.42
	litre	0.000125
Wood – residential	kg	0.06696
Wood – industrial	kg	0.01496

Table 6: Transmission and distribution losses for natural gas and electricity

Transmission and distribution losses source	Unit	kg CO ₂ -e/unit
Natural gas used	kWh	0.012
	GJ	3.212

Light commercial vehicle travel emission source	Unit	Pre-2010 kg CO ₂ -e	2010-2015 kg CO ₂ -e	Post-2015 kg CO ₂ -e
2000- <3000 cc	km		0.128	0.122
	km		0.130	0.123
Diesel plug-in hybrid electric vehicle (PHEV) – electricity consumption	<1350 cc	km	0.010	0.010
	1350- <1600 cc	km	0.010	0.010
	1600- <2000 cc	km	0.011	0.011
	2000- <3000 cc	km	0.012	0.012
	≥3000 cc	km	0.015	0.014
Electricity: BEV (battery electric vehicle)	Very small	km	0.021	0.021
	Small	km	0.023	0.022
	Medium	km	0.026	0.025
	Large	km	0.032	0.031
	Very large	km	0.038	0.036

Table 25: Road freight: Default light commercial vehicles

Emission source	Unit	kg CO ₂ -e/unit
Petrol	km	0.317
Diesel	km	0.296
Petrol hybrid	km	0.250
Diesel hybrid	km	0.265

Table 26: Road freight: Heavy goods vehicles

Emission source	Unit	Pre-2010 fleet kg CO ₂ -e	2010-2015 fleet kg CO ₂ -e	Post-2015 fleet kg CO ₂ -e	
HGV diesel	<5,000 kg	km	0.446	0.423	0.421
	5,000- <7,500 kg	km	0.510	0.484	0.477
	7,500- <10,000 kg	km	0.624	0.592	0.583
	10,000- <12,000 kg	km	0.740	0.702	0.692
	12,000- <15,000 kg	km	0.841	0.798	0.786
	15,000- <20,000 kg	km	0.982	0.957	0.955
	20,000- <25,000 kg	km	1.308	1.274	1.271
	25,000- <30,000 kg	km	1.460	1.423	1.420
≥30,000 kg	km	1.538	1.499	1.496	
HGV diesel hybrid	<5,000 kg	km	0.359	0.340	0.332
	5,000- <7,500 kg	km	0.411	0.390	0.380
	7,500- <10,000 kg	km	0.503	0.477	0.465
	10,000- <12,000 kg	km	0.596	0.565	0.551
	12,000- <15,000 kg	km	0.678	0.642	0.627

Appendix 5 Winstone Aggregates

Hunua Quarry

489 Hunua Road, Hunua. Phone 09 273 8785
Open Monday to Friday 5.00am-5.45pm, Saturday 5.00am-12.45pm.



PRODUCT	CODE	Unit	Price \$ per unit	Converted \$ per m ³	Tonnes per m ³
Concrete					
Graded Chip 14-8mm	GC148	tonne			1.44
Graded Chip 22-14mm	GC2214	tonne			1.46
Premium All Passing 7mm	PAP7	tonne			1.60
Drainage					
Drainage 20-7mm	DRAIN207	tonne			1.44
Drainage 25-14mm	DRAIN25	tonne			1.40
Drainage 40mm	DRAIN40	tonne			1.50
Winstone Permeable Basecourse 12mm	WPB12	tonne			1.45
Winstone Permeable Basecourse 7mm	WPB7	tonne			1.45
Drainage 10-7mm	DRAIN10	tonne			1.40
Roading					
General All Passing 100mm	GAP100	tonne			1.60
General All Passing 10mm	GAP10	tonne			1.54
General All Passing 150mm	GAP150	tonne			1.54
General All Passing 7mm	GAP7	tonne			1.54
TNZ All Passing 40mm M/4	TNZ40	tonne			1.63
AT All Passing 20	ATAP20	tonne			1.46
AT All Passing 40	ATAP40	tonne			1.64
AT All Passing 65	ATAP65	tonne			1.54
Sealing Chip					
Grade 3 Sealing Chip	GRADE3	tonne			1.44
Grade 4 Sealing Chip	GRADE4	tonne			1.42
Grade 5 Sealing Chip	GRADE5	tonne			1.40
Grade 6 Sealing Chip	GRADE6	tonne			1.40
Sundry					
Hunua 65mm	HUN65	tonne			1.50
Turf Chip 7-5mm	TURFCHIP75	tonne			1.40

GAP7 Conversion
(tonnes/m³)

Appendix 6 NZIQS Quantity Surveyors Handbook

THE QUANTITY SURVEYOR'S HANDBOOK

5th Edition – Published January 2022
(Revision 5.3)



[Return to contents](#)

LABOUR CONSTANTS – DRAINAGE

		Unit	Tradesman Hours	Labourer Hours
Sewer and Stormwater Drains				
• Constants include laying, jointing and testing, but exclude excavation and backfilling				
Earthenware pipe, with rubber ring joints, diameter				
Sewer	100mm	m	0.50	
	150mm	m	0.70	
	225mm	m	1.00	
Stormwater	100mm	m	0.20	
	150mm	m	0.37	
	225mm	m	0.50	
Bends, junctions	100mm	No	0.25	
	150mm	No	0.25	
	225mm	No	0.50	
PVC pipe, with solvent welded joints, diameter				
Sewer	100mm	m	0.25	
	150mm	m	0.60	
Stormwater	100mm	m	0.20	
	150mm	m	0.35	
Bends, junctions	100mm	No	0.25	
	150mm	No	0.30	
Concrete pipe, with rubber ring joints, diameter				
	100mm	m	0.35	
	150mm	m	0.43	
	225mm	m	0.50	
	300mm	m	0.65	

Appendix 7 Ethics - Information, Consent, and Questionnaire

Appendix 7.1 Ethics Form



31/08/2023

Dear: Kevin Manalo

Re: Low Risk Notification - 4000028061 - Carbon Footprint of Open Cut Pipelines

Thank you for your notification which you have assessed as Low Risk.

Your project has been recorded in our database for inclusion in the Annual Report of the Massey University Human Ethics Committee.

The low risk notification for this project is valid for a maximum of three years.

If situations subsequently occur which cause you to reconsider your ethical analysis, please contact a Research Ethics Administrator.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

A reminder to include the following statement on all public documents:

"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Professor Craig Johnson, Director - Ethics, telephone 06 3569099 ext 85271, email humanethics@massey.ac.nz."

Please note, if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to complete the application form again, answering "yes" to the publication question to provide more information for one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

Professor Craig Johnson
Chair, Human Ethics Chairs' Committee and Director (Research Ethics)

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand T 06 951 6841; 06 95106840
E humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz



Carbon Footprint of Open-Cut Pipelines

Kevin Manalo [Postgraduate Researcher]
Master's Student of Construction | School of Built Environment | Massey University

Dr. Niluka Domingo [Supervisor]
Senior Lecturer in Quantity Surveying | School of Built Environment | Massey University

[Introduction] You are invited to participate in a research project conducted by Kevin Manalo under the supervision of Dr. Niluka Domingo. The research aim is to provide contractors with a carbon emission tool/template for them to learn and create their own Carbon Inventory on the installation of open-cut pipeline excavations.

[Participant Inclusion] Any individual with experience and knowledge in open-cut excavation its work breakdown and its quantification are welcome to participate.

[Procedure] If you choose to participate, you will be given a 10-15 min presentation on the carbon emission tool on the installation of open-cut excavation. You will then be requested to:

1. Questionnaire: Complete a Questionnaire about your experience with the carbon tool.
2. (Optional - if Questionnaire is not possible) Structured Interview: Participate in an interview session where you will be asked questions about your experience with the carbon tool, the interview may be conducted in person, or through video conferencing.



[Confidentiality] All information collected during this research will be strictly confidential. Your participation will be assigned a unique identifier, and your personal details will not be disclosed in any publications or presentations. Only the research team (Kevin Manalo and Dr. Niluka) will have access to the collected data.

[Voluntary Participation] Your participation in this research is entirely voluntary. You have the right to withdraw from the study at any point without providing a reason and without any negative consequences.

[Data Usage] The information you provide will be used solely for this research project. Data collected may be used in academic publications, presentations, or reports; however, no personally identifiable information will be included.

[Potential Risks and Benefits] There are no anticipated risks associated with participating in this research. The benefits include learning about carbon accounting and its standards (GHG Protocol and ISO 14064) and contributing to the improvement of the carbon tools in the installation of open-cut pipelines, which could potentially lead to improvements in the 3 waters industry.

[Contact Information] If you have any questions or concerns about this research, you may contact the researcher – Kevin Manalo, at kevinmanalo@gmail.com or through +64 027 590 5021, and the supervisors – Dr. Niluka Domingo, at N.D.Domingo@massey.ac.nz.

Thank you for your time.

"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Professor Craig Johnson, Director - Ethics, telephone 06 3569099 ext 85271, email humanethics@massey.ac.nz."



Carbon Footprint of Open-Cut Pipelines
PARTICIPANT CONSENT FORM – INDIVIDUAL

I have read the information sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I wish/do not wish to have data placed in an official archive.

I agree to participate in this study under the conditions set out in the information sheet.

Full Name: _____

Signature: _____

Date: _____

Appendix 7.4 Open-Cut Carbon Emission Tool Improvement Questionnaire



Open Cut Carbon Emission Tool Improvement Questionnaire

Background

The objectives of the carbon emission tool are to achieve the following:

- Simplify the carbon methodology for Contractors to understand
- Identify areas where carbon emissions could be mitigated or reduced.
- Present emission to the relevant stakeholders
- Provide a basic understanding of carbon emission.

By participating in this questionnaire, your response is helping us improve the carbon emission tool for other users to begin their carbon journey. Please take a few minutes to answer the following questions and thank you for your participation.

Please circle the appropriate number to show your level of agreement with each of the following:	Beginner	Improver	Intermediate	Advance	Expert
1. On a scale of 1 to 5 what was your understanding of Carbon <u>before</u> the presentation	1	2	3	4	5
2. On a scale of 1 to 5 what was your understanding of Carbon <u>after</u> the presentation	1	2	3	4	5



Please circle the appropriate number to show your level of agreement with each of the following:	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
3. The carbon emission tool has been useful in helping me understand about carbon accounting	1	2	3	4	5
4. The tool has assisted me in understanding the need to capture a good work breakdown structure to identify emission sources.	1	2	3	4	5
5. The carbon emission tool has assisted me in understanding what emission sources I need to measure.	1	2	3	4	5
6. The tool has helped me understand about Emission Factors.	1	2	3	4	5
7. The tool has assisted me in identifying what emissions I can reduce.	1	2	3	4	5



User Functionality

1. What features in the carbon tool that you find valuable?

2. Keeping in mind that there are several inputs required to generate the overall emissions. Are there additional inputs or outputs that you would like to see or added to assist in the learning process?



3. Are there any inputs or variables that are not clear or missing that you would like to see or add?

4. Do you have additional feedback or comments you would like to add?

5. Would you use the Carbon Tool Template?

Yes

No

Other



Personal Particulars

Your background information:

1. Your working experience years in construction field:

- 1-5 years 6-10 years 11-15 years 16-20 years over 20 years

2. Your working experience years in design-build field:

- 1-5 years 6-10 years 11-15 years 16-20 years over 20 years

3. Your organizations:

- Research institution Government State-owned company Private company Others

4. Types of DB project you got involved:

- | | | |
|--|--|---|
| <input type="checkbox"/> Building project | <input type="checkbox"/> Civil project | <input type="checkbox"/> Chemical project |
| <input type="checkbox"/> Metallurgic project | <input type="checkbox"/> Electronic project | <input type="checkbox"/> Petrochemical projects |
| <input type="checkbox"/> Building Material project | <input type="checkbox"/> Environmental engineering project | <input type="checkbox"/> Others |

5. What is your role? (Quantity Surveyor, Estimator, Project Manager)

Appendix 8 Questionnaire Combined Raw Data

No Code	1	2	3	4	5	Added Value							Functionality					
						1	2	3	4	5	6	7	1	2	3	4	5	6
	Working Experience Construction Field	Working Experience Ind design and build Field	Your Organisation	Types of Design and Build Project	What is your role?	On a scale of 1 to 5, what was your understanding of Carbon before the presentation?	On a scale of 1 to 5, what was your understanding of Carbon after the presentation?	The carbon emission tool has been useful in helping me understand carbon accounting	The tool has assisted me in understanding the need to capture a work breakdown structure to understand to identify emissions	The carbon emission tool has assisted me in understanding what emission sources I need to measure.	The tool has helped me understand Emission Factors	The tool has assisted me in identifying what emissions I can reduce	Features in the carbon tool that you find valuable?	Special outputs they would like to see	Any outputs not clear or missing that they would like to see	Any additional feedback	Would you use the carbon tool	Other
1	11-15 years	11-15 years	Private Company	Civil Project	Project Manager	3	3	4	4	4	4	4	EPD	-	-	-	Yes	
2	11-15 years	1-5 years	Private Company	Civil Project	General Manager	4	4	4	4	4	4	4	WBS & Emission Sources	How to evaluate at a site level rather than a discrete portion of works	-	We would be keen to have access to the tool if available	Yes	
3	11-15 years	11-15 years	Private Company	Civil Project	Project Manager	3	4	5	5	5	5	5	Capturing Information Display of Information Breakdown of carbon emissions per item	-	-	-	Yes	Very good presentation, thanks for presenting to us
4	6-10 years	1-5 years	Private Company	Building Project	Business Manager	2	3	4	4	5	4	4	Scope 1-3 How to report correctly	Example activity inputting data into the calculator	-	Very knowledgeable Instructor	Yes	
5	1-5 years	1-5 years	Private Company	Civil Project	Administrator Assistant	4	5	4	5	4	4	4	Capturing Scope 3 Specific Documents Needed for Recording 3 waters future	More of a breakdown of specific vehicles plant, electrical production method	-	Ask what we already understand	Yes	
6	11-15 years	11-15 years	Private Company	Civil Project	Company Director Accountant	2	3	4	4	4	4	4	More knowledge around the Scope 3 aspect to calculate emissions	-	-	Very good explanation for someone starting on their carbon emission journey	Yes	
7	6-10 years	6-10 years	Private Company	Civil Project	Director/Project Engineer	2	3	5	5	5	5	4	Simplicity understanding the 3 reporting structures	Low hanging fruit what are some easy wins?	-	-	Yes	Thanks
8	6-10 years	6-10 years	Private Company	Civil Project	Quantity Surveyor	1	3	5	5	5	5	4	Clear to show where the emissions come from and gives a source where you can best target reduction	-	-	-	Yes	

9	6-10 years	1-5 years	Private Company	Civil Project	Quantity Surveyor	2	4	4	4	4	4	3	The standards that you can measure against	How to capture all carbon used as a whole (by Month) then spread to each job	-	-	Yes
10	Over 20 years	Over 20 years	Private Company	Civil Project	Estimator	1	3	5	4	5	4	5	Based on actual on-site operations	Tool seeing to cover most things	-	Can see this is going to be more important going forward	Yes
11	1-5 years	1-5 years	Private Company	Civil Project	Bid Writer	2	3	4	5	5	4	4	The Why, why we need to track carbon	-	-	-	Yes
12	11-15 years	11-15 years	Private Company	Civil Project	Estimator	3	4	4	4	3	3	2	The why, introduction to carbon	-	-	-	Yes
13	1-5 years	1-5 years	Private Company	Civil Project	Administrator	2	3	4	4	4	5	3	Helpful step-by-step tool which has helped me to understand the mission and end goal	No, I think what is already there is fine	-	-	Yes
14	Over 20 years	1-5 years	Private Company	Civil Project	Environmental Manager	2	3	4	4	4	5	4	I've been working with Toitu over the last few months, but this presentation (tool) has simplified the whole process	No, I think there are enough inputs	highlight misinformation from social media Provide a summary of the pros and cons of so individuals can choose the right solution for them	Breakdown, GHG, Climate, presentation is good	Yes
15	16-20 years	1-5 years	Private Company	Civil Project	Continued Improvement Advisor	3	3	4	4	4	4	4	Finding EPD	more information on plant drilling vs open-cut	-	Go into more examples	Yes
16	Over 20 years	Over 20 years	Private Company	Civil Project	CEO/Director	3	4	4	4	4	4	4	Ability to baseline clarity of method	training	I think this would become clearer by going through some examples	Key is to understand what it will take to get real cut through with the industry	Yes
17	16-20 years	6-10 years	Private Company	Civil Project	Estimator	3	4	4	4	4	4	3	Calculation & carbon output	-	-	-	Yes
18	1-5 years	1-5 years	Private Company	Civil Project	Sustainability and Operations	4	4	5	5	3	4	5	The simple ability to visualise emissions data in a structure and clear format that allows for ease of use and training functionality	A discussion on EPD/ emissions factor selection and comparison of variables of variables between good /bad data.	-	Fantastic presentation, welcome further opportunities in this space	Yes