CARBON FOOTPRINT OF OPEN-CUT PIPELINES (NZ CONTEXT)

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1 ABSTRACT

In New Zealand, the central government, local authorities, and various industries have made significant strides in creating, capturing, and reducing their carbon emissions. Auckland Council, a local authority in New Zealand, has set an ambitious goal of reducing greenhouse gas emissions by 50% by 2030. Meanwhile, Watercare, the council-owned organisation responsible for water supply and wastewater treatment in the Auckland Region, aims to reduce their emissions from construction by 40% by 2025, which is a year away. In light of these goals, it may be necessary for local authorities to impose requirements on industries, particularly those involved in asset infrastructure delivery, to begin recording their carbon emissions. However, information on carbon emission baselines, targets, standards, and how to implement them is currently lacking. Additionally, new standards such as PAS2080, which requires carbon management in infrastructure, may exclude contractors or suppliers who are unaware of the standard or not part of the local authorities' value chain.

To address these challenges, my study aimed to develop a practical method or template that contractors can use to capture their carbon footprint for open-cut excavation and installation of stormwater, water, and wastewater pipelines using actual data. The methodology encourages contractors to review their work breakdown structures and identify emission sources. The data gathered can then be used to create the contractor's emission inventory, record their carbon baseline emissions, and plan their emission targets. A procedure or guideline has been created to aid in this process.

Further familiarity with the carbon content/knowledge could push the user (carbon practitioner) to study further and potentially compare their estimated carbon values to calculated values by suppliers or designers on open-cut excavations. By doing so, they could calibrate or inquire about the existing information and, if necessary, recalculate the emissions to make progress in reducing their carbon emissions.

Having access to this information would equip contractors, suppliers, and stakeholders with fundamental knowledge and would help them progress in their journey to reduce their associated carbon footprint.

KEYWORDS

Carbon footprint, Stormwater, Pipelines, Open-cut, ISO 14064, GHG Protocol

2 INTRODUCTION

The world is in a climate crisis. It is increasingly common for news to report about climate change. Entering keywords such as extreme weather in Google alone would reveal an excess of articles relating to extreme weather. Last year, in 2023, New Zealand (NZ) recorded its second warmest year on record (NIWA, 2024). Recent examples of extreme weather events include the Auckland Anniversary floods in late January 2023 and the Hawke's Bay floods resulting from Cyclone Gabrielle in Feb 2023. The question is not whether climate change is real or not. The question is more about when and how often it will affect us. Questions such as the kind of intensity, duration, and damage it may cause should not be taken lightly.

Scientists and nations around the world have mandated policies that aim to mitigate climate change. As a result, government bodies and various organisations that would like to make a difference have taken steps to reduce their climate impact. Auckland Council, a local authority in New Zealand, has set an ambitious goal of reducing greenhouse gas emissions by 50% by 2030, while Watercare in Auckland aims to reduce their emissions from infrastructure by 40% by 2025, which is only a year away at the time of writing this paper. Regardless, the urgency to act and mitigate climate change has not filtered down to grassroots construction.

This paper provides a step-by-step method for contractors to capture the carbon footprint for open-cut excavation via a simple case study of installing a stormwater pipe. The methodology will encourage contractors to define their goals, set a study boundary, review their work breakdown structures, and identify emission sources. The data gathered can then be used to create the contractor's emission inventory, record their carbon baseline emissions, and plan their emission targets. A methodology or guideline has been created to aid in this process. To assist in demonstrating the given methodology, a case study is used consisting of a 100mm diameter PVC pipe, installed 1.3m deep in a 100m open cut excavation in a green fields site (i.e. no existing services, roads, or pavements).

Research undertaken revealed that carbon quantification is complex and is a multidisciplinary practice. To break the complexity, this paper is split into four key sections. Section one (headings 3-6) explains the purpose. It gives the background on climate change, its global and local significance and why everyone must do their part in mitigating its effects. Sections two to four explain three interlinked subjects that when synthesised create a comprehensive carbon inventory. Section two explains the Carbon Accounting (heading 7), three covers the Construction Framework (heading 10) and the fourth section describes Carbon Methodology (heading 11).

3 CLIMATE CHANGE

Understanding the definitions of weather, climate, and the greenhouse effect is essential for grasping the complexities of climate change effectively.

The World Meteorological Organization (WMO) defines **weather** as the state of the atmosphere at a particular time (WMO and OMM, 1966). The Intergovernmental Panel on Climate Change (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 on average is typically 30 years, as defined by the WMO. 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 burning fossil fuels and emitting greenhouse gases (GHG) into the atmosphere. The constant addition of GHG emissions leads to the accumulation of these gases, resulting in climate change. 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 (CO_2), Methane and Nitrous Oxide absorb and trap heat similar to a greenhouse, hence the term **Greenhouse Effect** (Mitchell, 1990, NIWA, 2023). Adding to the concern, some of these gases can endure in the atmosphere for extended periods. Carbon dioxide, for example, can stay in the atmosphere for hundreds to thousands of years. On the other hand, whilst it may not remain as long in the atmosphere, methane can absorb 28 times more energy than carbon dioxide (WRI, 2015).

The amount of GHG emitted into the atmosphere by an individual, building, or organisation is defined simply as their **Carbon Footprint** (Chilana, 2011).

In response to climate change, the United Nations Environmental Programme (UNEP) and the WMO, with the endorsement of the United Nations (UN) General, established the 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 response to climate change (IPCC, 2023). Since then, the IPCC has released six key assessment reports.

There are two important IPCC reports to keep in mind. The first is The Second Assessment Report which was a pivotal document in adopting the Kyoto Protocol in 1997. One of the key successes of this Protocol lies in the ongoing collaborative efforts of nations worldwide, which continue to safeguard the ozone layer. The second document to keep in mind is The Fifth Assessment Report which unequivocally confirmed (without a doubt) that anthropogenic activities (human-induced) are changing our planet. The fifth report also introduced the four representative concentration pathways scenarios (RCP 2.6, 4.5,6.0 and 8.5). These are scenarios which show four different climate futures predicting potentially catastrophic temperature increases. It is this report, 10 years after the Kyoto Protocol, which was used as the basis for the Paris Agreement in 2015. 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 to agree and limit the global temperature rise of the world below 2°C above preindustrial levels and limiting the temperature increase to 1.5°C. Each nation responded and acted out their contribution by committing and putting effort through nationally determined contributions and reporting regularly on their emissions and implementations.

4 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 accounted for 36% of global energy use and 39% of energy related CO_2 emissions (Operational Carbon). Also in their report, 28% of the annual building CO2 emission comes from material use (Embodied Carbon).

The MBIE (2020) explains that in the life cycle of a building emission is put into two groups.

- Operation 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.

As the focus of the author's research was on construction of pipe infrastructure related to stormwater, water, and wastewater, it was found that emission data specifically in this sector was scarce because predominantly construction infrastructure is embedded in building and construction emissions. However, research from Thacker et al. (2021), expanded and included construction infrastructure. Their report showed construction infrastructure contributed to 79% of total GHGs, with 5% of the emissions attributed to the Water Sector, refer Figure 1. 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, refer Figure 2.

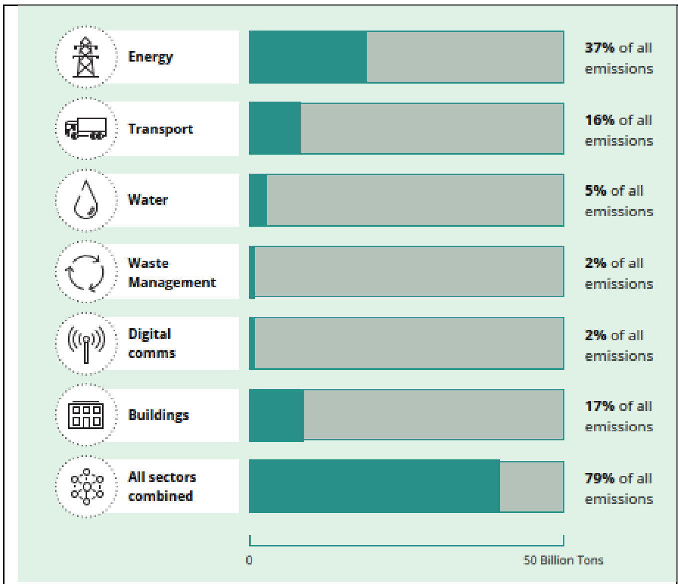


Figure 1: Infrastructure Sector Contribution to the total GHG emissions (IBRD, 2010)

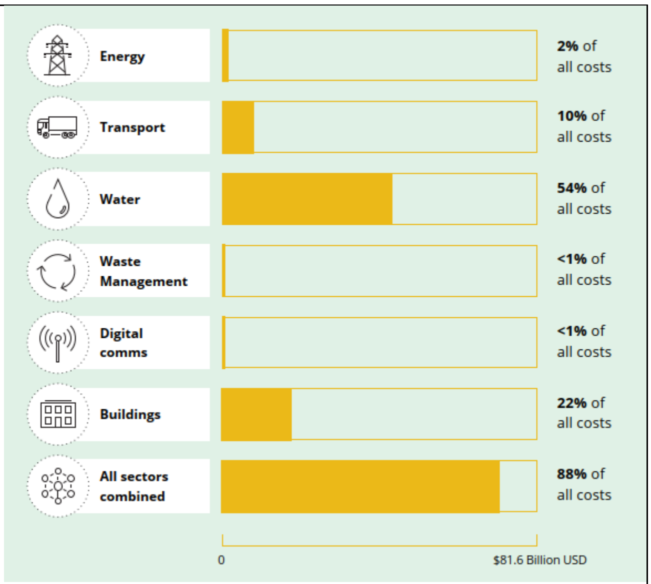


Figure 2: Infrastructure Sector Share of Global Climate Adaptation Cost (IBRD, 2010)

5 NEW ZEALAND'S GROSS AND NET EMISSIONS

From NZ's GHG 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. Their records show a net emission of 55.7 $MtCO_2e$. Figure 3 below shows NZ's 2030 and 2050 net zero targets, excluding biogenic methane. It can be seen that NZ's emissions have been stable in the last 20 recent years. It is neither increasing nor decreasing dramatically and is generally plateaued. If in the last 30 years, NZ as a nation could not decrease its emissions, how is NZ supposed to meet its net emissions goal of lowering its net emissions to zero by 2050? Drastic change is needed.

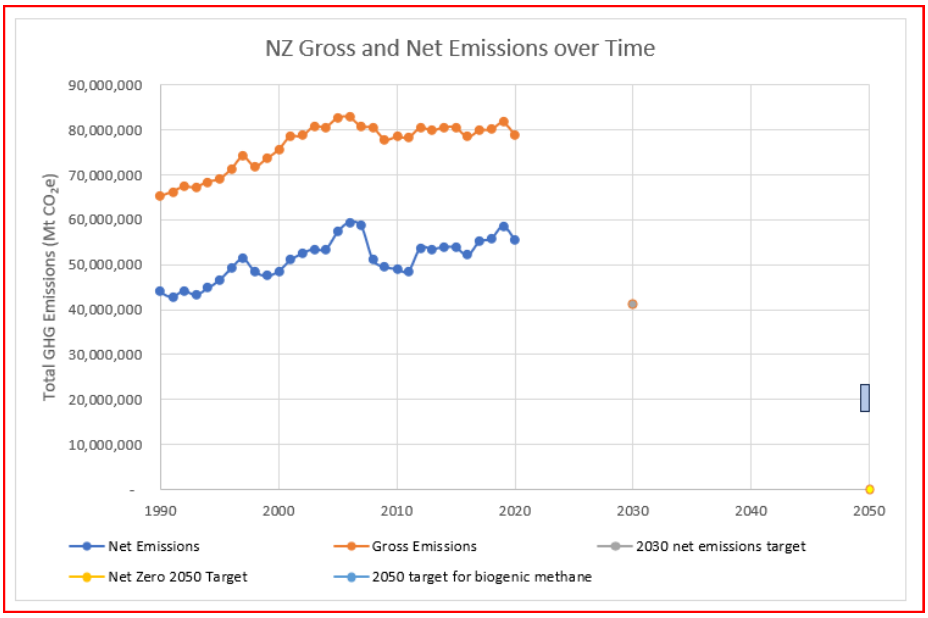


Figure 3: NZ Gross and Net Emissions over Time, sourced from StatsNZ (2022)

6 NEW ZEALAND'S EMISSION BY SECTOR

The MfE prepares a snapshot of emissions by sector. When looking at emissions by sector, the MfE 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 4. The information prepared by MfE is important because it helps investors, policy, and decision makers to make decisions. For example, in September 2023. The central government confirmed its investment of $140m to NZ Steel in their installation of an electric furnace (Gray, 2023). It is estimated that the furnace could reduce 800,000 tonnes of carbon emissions annually and reduce NZ's emissions by 1% (MBIE, 2023b).

Finding specific construction data related to pipework infrastructure is difficult as it is combined with Manufacturing. To find data, the MfE has spreadsheets available, however, the reader will have to extract the data as it is embedded within other sectors. An easier way to find specific pipework emission data is sourcing the data from local councils or service authorities like Watercare. This is a missed opportunity. As mentioned earlier, water accounts for the highest adaptation cost. Should central government want to invest in pipeline related infrastructure and see its carbon impacts, construction emissions must be separated from manufacturing emissions.

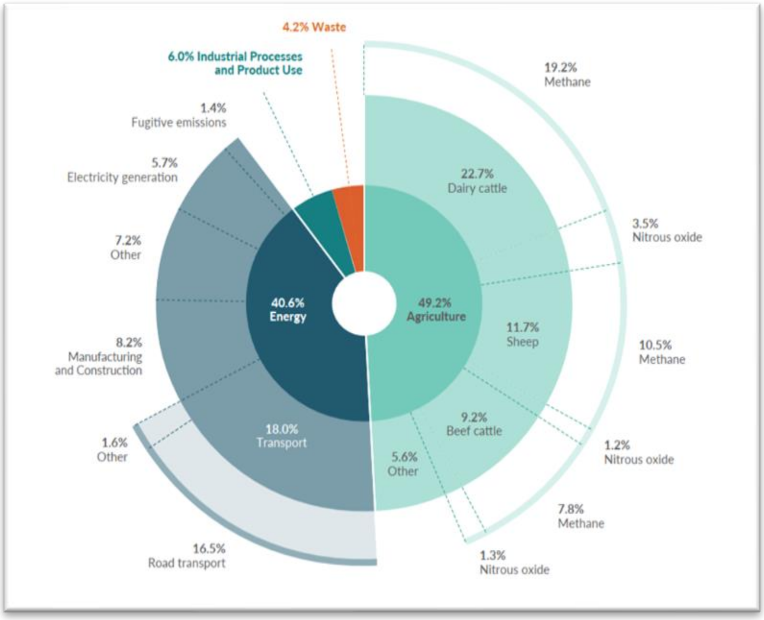


Figure 4: MfE NZ GHG Gas Inventory Snapshot 2021

It is noted that NZ was one of the first countries to adopt the Kyoto Protocol (UNFCC, 1997). Since then, NZ has made great strides in using renewable energy. In 2022 NZ sourced 87% of its electricity from renewable sources (MBIE, 2023a). So, it should not be a surprise that Agriculture has the highest emission by sector at 49% rather than energy (which has transport, construction, electricity generation etc). NZ can be bold and courageous like the 90's when it adopted the Kyoto Protocol. It can be a world leader again by its commitment to the Paris Agreement and start tackling other sectors which are uncomfortable and not easy. Tackling the massive sector of Agriculture (49.2%) for example. The central government may struggle to tackle this sector as it is one of NZ main industries (dairy industry). Currently, the coalition government (National, Act and NZ First) is doing the reverse. Rather than decreasing emissions on transport (18%), they are increasing it more by building 15 new roads of national significance (Brown, 2024) and axing public transport projects such as Auckland light rail and KiwiRail's Inter-island Resilient Connection project (iReX) (Bishop, 2024). The USEPA (2023) explains that automobiles (typical passenger vehicle) using petrol produces GHG's such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and small traces of hydrofluorocarbons (HFC). The same could be said for heavy duty natural gas, hybrid and conventional diesel on road trucks during freight transport (Quiros et al., 2017). Burning fossil fuels produces GHG's and without a strong mandatory policy to reduce GHG gases, there is little incentive for the industry to change.

7 CARBON QUANTIFICATION AND ACCOUNTING

The GHG Protocol written by the World Resources Institute (2004) mentions, "What gets measured, gets managed". Accounting for GHG emissions can help identify hot spots and create reduction opportunities.

Based on the literature, the simplest accounting method to use is the embodied calculation method, refer equation 1 to 3 below. There are two parts. The first part is identifying and quantifying the emission source. The second part is multiplying the quantified emission source to an emission factor. The emission factor is a factor that amounts to the GHG emitted (World Resources Institute, 2004). The emission factor is typically a GHG gas that has been defined in today's atmosphere and compared with an equal quantity of CO_2. This is where the term Carbon Dioxide Equivalent or CO_2e comes from.

There are two common sources to find emission factors. The first source is from a Carbon Database. The second source is from suppliers with an Environmental Product Data Sheet (EPD). An EPD is a third party verified document communicating its environmental impact and may follow standards such as the ISO 14025 standard.

When looking at emission factors via databases the following researchers Chilana (2011), Chilana et al. (2016), Khan and Tee (2015), Nandyala et al. (2019) used the Inventory of Carbon and Energy (ICE) database. Alsadi and

Matthews (2020) used e-calc software, and Ariaratnam and Sihabuddin (2009) created their own using the Environmental Protection Agency (EPA)/ United States Environmental Protection Agency (USEPA) and the Clean Air Act. This method is difficult as the user may have to pay to access the tools. To add to the complexity, the ICE database specifies embodied energy and embodied carbon. Research by Elhag (2015) in particular, cautions against using the ICE database and warns users to check its data quality and representativeness. Elhag records considerable differences in values recorded in various databases with some varying up to 40% for some products.

Research by Pandey et al. (2011) recommended the use of region specific emission factors as this was recommended by the IPCC and the GHG Protocol. Again, these emission factors are verified to its operation and geographical context. Hence, based on the research direct EPD's from suppliers are used in this research study.

The calculation method using Emission Factors is calculated from the formula below. *Table* 1 below is shown as an example.

$$E = Q \times F \ (Equation\ 1)$$

Where:

E	=	*emissions from the emission source in kg CO_2e*
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.

Table 1: Example calculation of an activity with its emission factor

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_2e/litre*	=	*12.3 kg CO_2e*

In this paper, equation 1 is manipulated to calculate different fuel consumption rates, refer equations 2 and 3 below. This hybrid equation gives a guide on how to calculate plant or equipment if the total fuel consumption is unknown.

Inspired by research from Kim et al. (2012) who used a three step carbon calculation in their research, the following steps can be followed. The first step is the estimated number of hours that the plant or machinery is used. The second step is choosing the fuel consumption rate and the last step local emission factors such as the factors given by the MfE are used.

The hybrid equation is defined as follows:

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

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*

$$Energy_i^j = H_i^j \times C_i = hour\ \times \frac{litre}{hour}\ (Equation\ 2\ - Stage\ 2)$$

Where:

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

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

Where:

E = *emissions from the emission source in kg CO_2e*

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*

As evident from the calculations, the calculation cannot be made without the activity data or emission source, along with their corresponding emission factors. This underscores the importance of understanding the construction methodology. Furthermore, familiarity with the various stages or life cycle of the construction works can help establish boundaries regarding what to measure and what not measure.

8 LIFE CYCLE ASSESSMENT APPROACH & STUDY BOUNDARY

In construction of pipeline infrastructure, a contractor may only want to construct the pipeline (embodied carbon) and hand over the assets to the client. The client on the other hand throughout the course of the life of the pipeline will operate and maintain the asset (mix of embodied and operation carbon). Knowing which boundary or stage would limit the activities that need to be quantified. The Life Cyle Approach (LCA) looks at the beginning, from raw materials to the end of their lifetime to disposal. The BS EN 15804:2012 is a good visual representation of the LCA Approach, which the ISO 14040 series standards provide principles and guidelines for the LCA methodology. Combining the life cycle for a pipeline from fabrication to installation, operation, and disposal with the LCA diagram based on BS EN 15804, you get the figure as shown in Figure 5. *Important note for the reader*, *BS EN 15804 is only used as a visual reference for the user to grasp the concept of study boundaries*. The scope of this paper is from A1 to A5 (Product Stage to Construction Stage) or Cradle to Practical Completion.

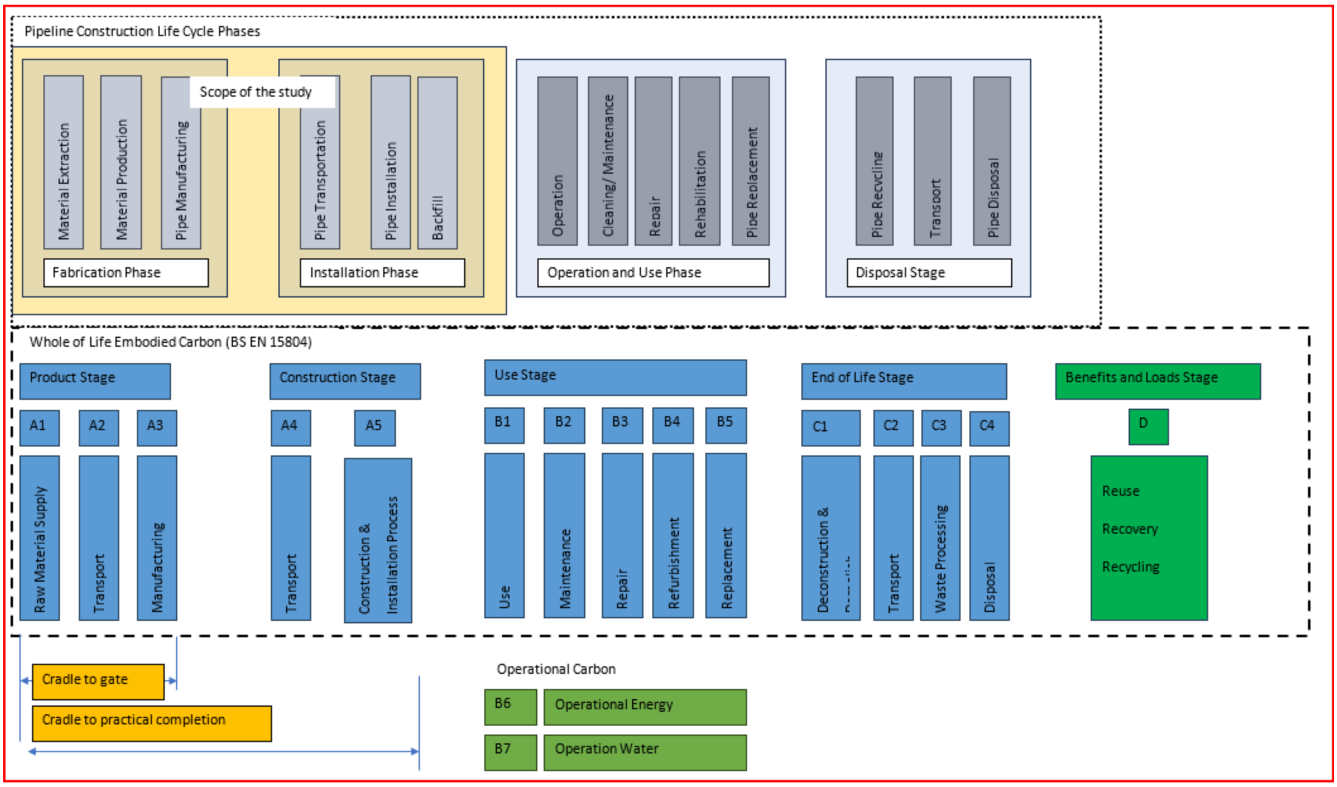


Figure 5: Pipeline Construction Life Cycle Phases

9 WORK BREAKDOWN STRUCTURE

Following the identification of the study boundary. The next step is to do a work breakdown structure (WBS) as shown in Figure 6. Apart from the visual clarity of the breakdown of work, the WBS assists the user in identifying emission sources and resources used.

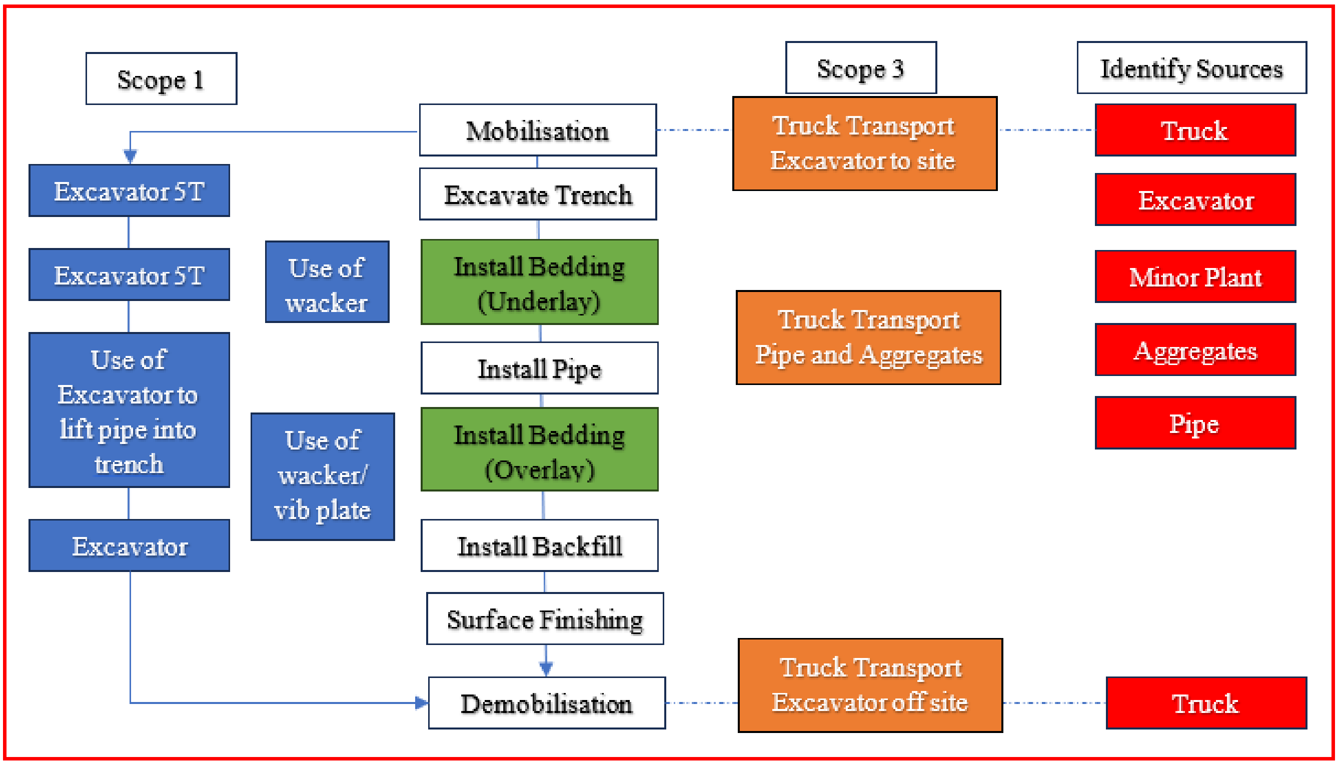


Figure 6: Pipeline Work Breakdown Structure

10 CARBON FRAMEWORK

In carbon measurement, researchers employ various carbon frameworks as systematic methods to assess, calculate and track their carbon emissions. The procedure that directs the steps of a user from start to finish is the carbon framework. The challenge facing new users or practitioners is the multitude of standards available when they begin researching Carbon Frameworks or standards.

Some of the carbon frameworks found from literature are: GHG Protocol, ISO 14064-1:2015, PAS2050, 2006 IPCC Guidelines, Carbon Trust UK, ISO14025 and ISO 14067, UK's BRE Environmental Profile Methodology, BE EN 15804 and ISO 14040/44, EPA non-road model.

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). Other researchers such as Alsadi and Matthews (2020), Chilana et al. (2016), Khan and Tee (2015) used the LCA framework. They did not mention what LCA standard they used for their respective research, but it could have been similar to PAS 2050, ISO 14040/44 or the British Standard BS EN 15804. Although the LCA framework is a thorough framework (cradle to grave). There is no need for the user or contractor to do a full LCA stock take when their scope of works could be from product stage to Construction Stage (cradle to practical completion). ISO 14025 is for suppliers, ISO 14067 is suited for products, and while the Carbon Trust and the 2006 IPCC guidelines are relevant, these standards are almost 20 years old. Research from Pandey et al. (2011) recommended the use of the GHG Protocol.

In New Zealand, the MfE recommends using either the GHG Protocol or ISO 14064 as carbon frameworks to create a carbon inventory. 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 foot printing" (Weidema et al., 2008).

The GHG Protocol classifies emissions into two simple emission types: Scope 1 - direct emission and Scope 2 and 3 indirect emissions. Table 2 below defines the different scopes.

Table 2: GHG Protocol scope definition and examples

Emission Type	Scope	Definition	Example
Direct Emissions	1	Emissions that are owned or controlled by the company	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

The ISO 14064 standard has similar principles and guidelines to the GHG Protocol. However, the standard expands Scope 3 Indirect emissions into four more categories. The additional four categories are good because they give scope 3 more depth and define other emission categories that could be measured and reduced.

Table 3: ISO 14064 emission categories

GHG Protocol Scope	ISO 14064 Category	Description
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)

The GHG Protocol Scope 3 even goes deeper (refer Table 4) and expands Scope 3 into 15 additional 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 the Scope 3 emissions from its value chain, it may face difficulties if their subcontractors do not know how to or do not want to record or track their emissions.

Table 4 below shows the varying scope and complexity from GHG Protocol, ISO 14064 and GHG Protocol Scope 3. The table is important because it shows how the GHG emissions are reported by scope. In its most basic level, the GHG Protocol is the best and easiest way to learn and is good for new users who want to start on their carbon journey. Once the user is familiar with the concepts, they can move on to ISO 14064 and GHG Protocol Scope 3.

Table 4: GHG Protocol, ISO 14064 and GHG Protocol Scope 3 scope boundaries

GHG Protocol

Scope 1	*Direct GHG Emissions and Removals - Fuel*
Scope 2	*Indirect GHG emissions from imported energy*
Scope 3	*Indirect GHG emissions (Optional)*

ISO 14064

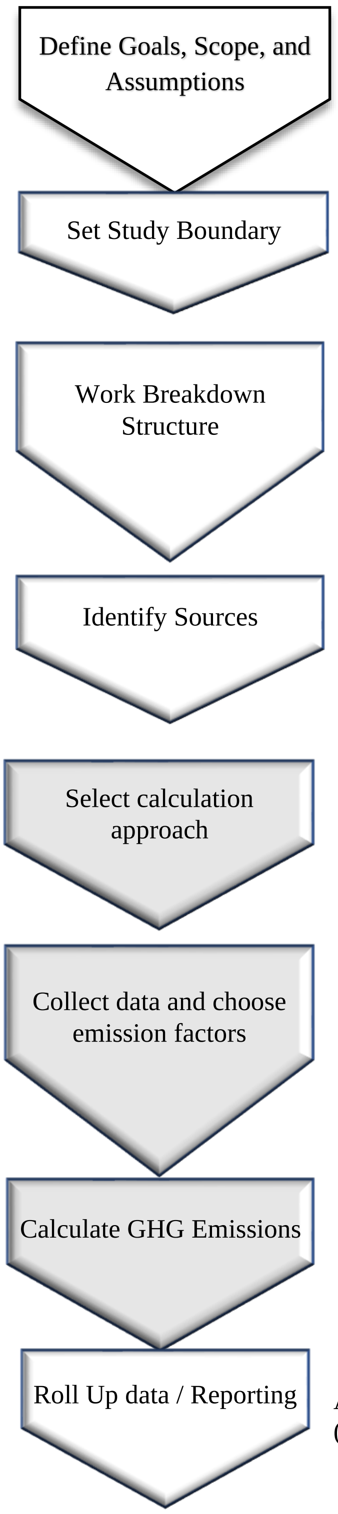
Scope 1	*C1*	*Direct GHG Emissions and Removals - Fuel*
Scope 2	*C2*	*Indirect GHG emissions from imported energy*
Scope 3	*C3*	*Indirect GHG emissions from Transportation* *- Freight Transport* *- Employee Commute*
	C4	*Indirect GHG emissions from products an organisation uses* *- Materials and waste*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

GHG Protocol – with Scope 3 categories

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*

11 METHODOLOGY

Based on a pragmatic approach, research from literature, data collection findings, the multiple standards compiled, assessed, and reviewed, the methodology below gives a step-by-step guide or procedure to follow to create a carbon emissions inventory from a pipeline installed via open-cut excavation.



The goal is to create a carbon inventory by quantifying all emission sources in an open-cut excavation. Check design standards.

The study boundary is from cradle-to-practical completion A1-A5 construction stage, refer to Figure 5. Create construction methodology. What resources need to be purchased (Cradle to gate)? What items need to be transported, constructed, and installed (to practical completion)?

Thorough work breakdown of the open-cut excavation to reveal emission sources and materials/resources used, refer Figure 6: Pipeline Work Breakdown Structure.

Sources to be quantified.

- Materials procured – pipes and aggregates
- Transportation of materials, plant, and labour
- Plant – use of heavy machinery

The embodied calculation approach is used, refer section 7.

NZ databases and local emission factors will be used if possible (use of EPD's).

Allocate emission sources and allocate to emission categories and calculate.

All activities are quantified, calculated, reported, and given to the required stakeholder (Scope 1, 2 and 3)

IMPORTANT NOTE: To demonstrate the effectiveness of the given methodology a *simple case study* is used. *For this paper, a 100m open cut excavation is used on a green fields site (no existing services, no roads, no pavements). The pipe is 100mm diameter PVC pipe and installed 1.3m deep.* Standards used for Stormwater are in accordance with Auckland Council Stormwater Code of Practice SW02 version 3, non-carriageway, while Water and Wastewater is in accordance with Watercare (Water DW02 and Wastewater DW01) grass area.

12 RESULTS

Due to brevity and conciseness requirements for this paper, only key calculations are shown to demonstrate the methodology and concepts discussed in this paper.

12.1 EXCAVATION AND BEDDING CALCULATIONS

Table 5 below shows detailed calculations for excavation and bedding.

Table 5: 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 (m3)	**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	1.540	1.540	1.540
Compaction factor	1.600	1.600	1.600
GAP7 mass (tonnes)	22.071	70.119	80.468
Truck 6 wheeler (9T payload)	9	9	9
No of trips (*Tonnes/9T payload)	3	8	9

12.2 DIRECT EMISSIONS

Table 6 below shows the calculations for Scope 1 or direct emission calculations. Keep in mind each contractor will have their own machine and have different efficiencies and productivities. The easiest way to get data for a contractor is to use day sheets. Throughout the day the contractor can record how long they took to excavate, install bedding, pipe, and backfill. They can also record the amount of fuel they used throughout the day.

Table 6: Direct Emission Calculations

Description		**Unit**	**Stormwater**	**Water**	**Wastewater**
Total installation hours (includes excavation, pipe install, bedding compaction)		hr	29.81	49.33	49.96
No of staff		No#	2	2	2
Efficiency		%	50	50	50
Total Hours		hr	14.90	24.66	24.98
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* *Ministry for the Environment (2022)	kg CO_2e/ L	2.69	2.69	2.69
	Total Emissions	**kg CO_2e**	**465**	**770**	**780**
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* *Ministry for the Environment (2022)	kg CO_2e/ L	2.46	2.46	2.46
	Total Emissions	**kg CO_2e**	**26**	**42**	**43**
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* *Ministry for the Environment (2022)	kg CO_2e/ L	2.46	2.46	2.46
	Total Emissions	**kg CO_2e**	**37**	**61**	**61**
Overall Summary	**Descriptions**	**Unit**	**Stormwater**	**Water**	**Wastewater**
Excavator	Total Emissions	kg CO_2e	**465**	**770**	**780**
Small Plant – Wacker	Total Emissions	kg CO_2e	**26**	**42**	**43**
Small Plant – Vib Plate	Total Emissions	kg CO_2e	**37**	**61**	**61**

12.3 INDIRECT EMISSIONS

Table 7 below calculates the Scope 3 or indirect emissions.

Table 7: Indirect Emission Calculations

Indirect GHG Emission	Description	Unit	Stormwater	Water	Wastewater
Material GAP7	GAP 7* *refer Table 5	Tonne	22.1	70.1	80.5
	Emission Factor* *Winstone Aggregates (2022)	kg CO_2e/ t	3.59	3.59	3.59
	Total Emissions	**kg CO_2e**	**79**	**252**	**289**
Material Pipe	Pipe length	m	100	100	100
	Emission Factor* RXP New Zealand (2022)	kg CO_2e/ m	5.18	6.37	5.18
	Total Emissions	**kg CO_2e**	**518**	**637**	**518**
Truck Mobilisation (Excavator to site) *Cycle distance - 40km from yard to supplier yard - 40km yard to site - return	Total Cycle distance*	km	160	160	160
	No of trips	trips	1	1	1
	Total distance	km	160	160	160
	Emission Factor* *Ministry for the Environment (2022) HGV 7,500<10,000kg	kg CO_2e/ L	0.624	0.624	0.624
	Total Emissions	**kg CO_2e**	**100**	**100**	**100**
Transport Aggregate GAP7	Total Cycle distance*	km	160	160	160
	No of trips	trips	3	8	9
	Total distance	km	480	1,280	1,440
	Emission Factor	kg CO2e/ L	0.624	0.624	0.624
	Total Emissions	**kg CO_2e**	**300**	**799**	**899**
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*	kg CO2e/ L	0.624	0.624	0.624
	Total Emissions	**kg CO_2e**	**100**	**100**	**100**
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	kg CO2e/ L	0.624	0.624	0.624
	Total Emissions	**kg CO_2e**	**100**	**100**	**100**
Employee Commuting * 40km home to site *40km site to home	No of staff	Staff	**3**	**3**	**3**
	Total distance	km	**80**	**80**	**80**
	Installation time* refer Table 6	hours	15	25	25
	Workday = 7 hours	days	**3**	**4**	**4**
	Total distance* *No of staff x total distance x workday	km	720	960	960
	Emission Factor*Ministry for the Environment (2022)	kg CO_2e/ km	0.317	0.317	0.317
	Total Emissions	**kg CO_2e**	**228**	**304**	**304**

12.4 SUMMARY OF EMISSIONS

Table 8 below shows the emissions categories and summarized to the different standards.

Table 8: 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_2e)	Water (kg CO_2e)	Wastewater (kg CO_2e)
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

Life Cycle			**GHG Protocol Standard**	**ISO 14064**		**GHG Protocol – Scope 3**		**Three Waters**		
Stage	**Number**	**Description**	**Scopes**	**Category**	**Description**	**Category**	**Description**	**Stormwater** (kg CO_2e)	**Water** (kg CO_2e)	**Wastewater** (kg CO_2e)
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

12.5 EMISSION REPORTING

Figure 7 to Figure 9 shows the final emissions graphed and categorised to its particular standard.

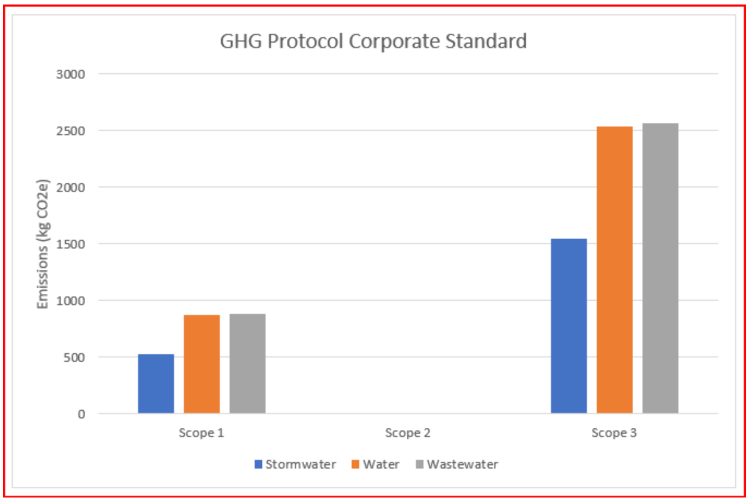


Figure 7: Carbon Footprint values shown in GHG Protocol

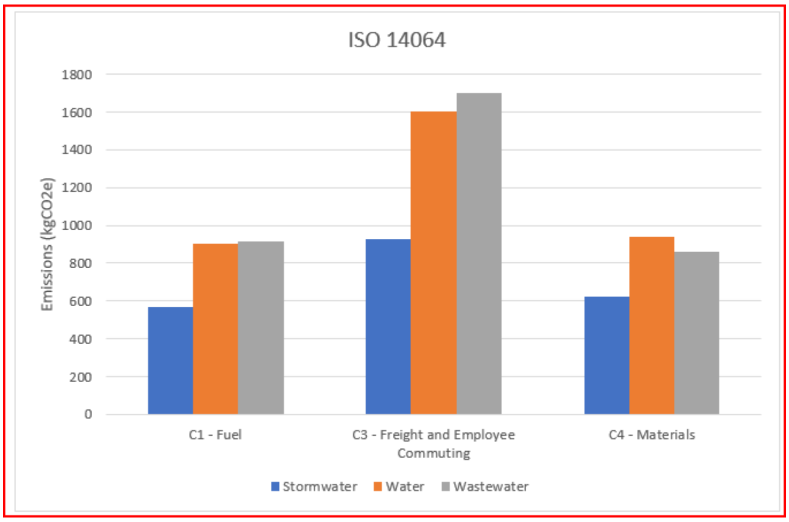


Figure 8: Carbon Footprint values shown in ISO 14064

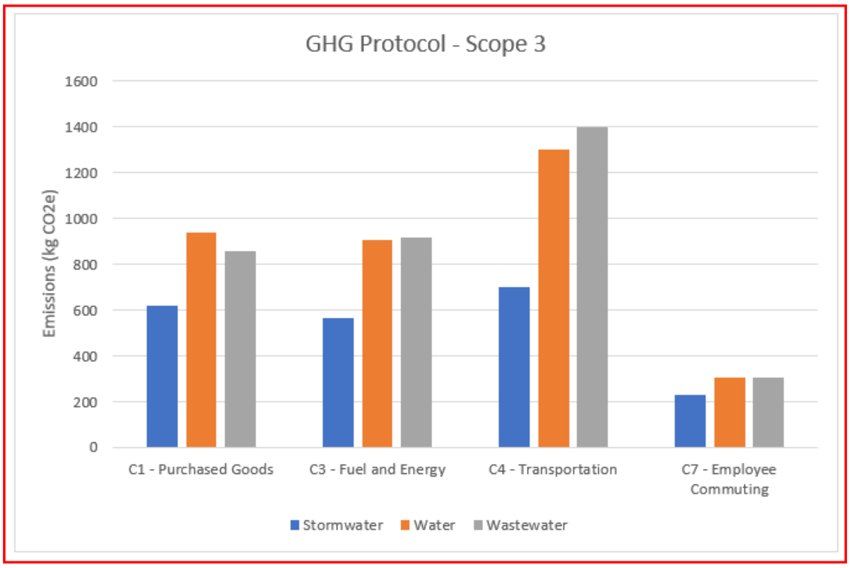


Figure 9: Carbon Footprint values shown using the GHG Protocol - Scope 3

13 DISCUSSIONS AND CONCLUSIONS

The paper aimed to provide a practical method for contractors to use for them to capture the carbon footprint for open cut excavation and installation of stormwater, water, and wastewater pipelines. In this paper, climate change was described in section 3 and NZ's GHG position is described in sections 5 & 6. These sections were written to give background and give a purpose as to why we need to measure our carbon footprint.

As creating a carbon inventory is complex and is a multi-disciplinary practice, users need to grasp three interlinking key concepts in order to acquire the necessary knowledge and proficiency for their carbon journey. The first is the carbon theory, quantification, and accounting (section 7), the second is the life cycle and work breakdown of the construction works (section 8 &9) and the procedure which guides the steps is the carbon framework (section 10). The final method or guideline for the user to follow is written in section 11. To demonstrate the effectiveness of the method, a case study scenario of a 100m open cut excavation is used on a green fields site (no existing services, no roads, no pavements), involving a 100mm diameter PVC pipe installed 1.3m deep. The calculations and results are shown in section 12.

Depending on the experience of the user, while they are still learning they may want to start with the GHG protocol. As they progress with experience, they can expand their knowledge to ISO 14064, to eventually learn the complexities of GHG protocol scope 3. For example, on a construction site the contractors do not own the construction assets they are building and are only constructors. Emissions on site are scope 3 indirect emission for the client. As more and more clients who independently want to reduce their emissions, eventually contractors will need to understand advanced standards such as the GHG Protocol Scope 3.

The knowledge written in this paper gives a new user a summary on why, how and what they need to do to quantify the carbon footprint in open cut excavations. It is practical and they can use the example as a template for them to learn and build on it.

14 RECOMMENDATIONS

Cost of Upskilling - Regardless of the knowledge which can be obtained from reading this paper, users will need to upskill and educate themselves on these key concepts and standards: Stages of the life cycle assessment, Carbon Emissions Scope 1,2 and 3, ISO 14064 categories 1 to 6, GHG Protocol – Scope 3, Emissions factors, and EPD's.

Embedding Carbon Management in Construction Projects – Should the need arise when clients mandate the compulsory need for carbon reporting, the contractor can embed carbon management procedures during pre-contract, ongoing construction tracking and at the end at claim time. During pre-contract activities there is an opportunity to identify and capture emission sources. Typically, a quantity surveyor or an estimator can start allocating emission factors to emission sources right from tender. During construction, a site engineer can collect data on emission sources such as recording fuel consumption rates, truck logbooks, GPS tracking and packing list of materials and quantities. While at the end of the month during payment claims, a project manager or a quantity surveyor can compile the quantified and calculated emissions values and report it to the client.

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 factors.

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