DRAINAGE PIPE COMPARISON

Report for Plastics Industry Pipe Association of Australia Limited (PIPA)

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REPORT FOR

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CONTENTS

EXECUTIVE SUMMARY

The collective and urgent need to improve sustainable outcomes in all areas of our lives means assessing the systems and engineered products we rely on each day. As plastic pipes, fittings and systems play a vital role in many industries and are essential for the delivery and function of our everyday services and utilities across Australia, understanding their impact is especially important. The Plastics Industry Pipe Association of Australia (PIPA) has been collaborating with members, industry professionals and global counterparts since 1999 to develop best practice guidelines for the manufacture, installation and use of plastic pipeline systems. Future-focused values help advance the use of plastic pipes and fittings as long-life sustainable infrastructure.

PIPA is committed to providing a more sustainable solution through plastic pipes and fittings by measuring the impact across the whole life cycle, from manufacturing to use and disposal. As an efficient, safe and robust solution, plastic pipes have demonstrated superior sustainability performance and advantages when compared to concrete pipes.

To better understand the advantages of plastic pipes and how they can contribute to a more sustainable future, PIPA engaged Edge Impact to carry out a Life Cycle Assessment (LCA) comparing plastic pipes to concrete pipes. By using third-party published data, our goal is to provide a credible and accessible comparative report for stakeholders to assist them in selecting drainage pipe solutions for their road projects. The scope of this comparative study is cradle-to-installation (module A1-A5) in accordance with General Programme Instructions (GPI) v3.01 for the EPD Australasia System and EN 15804+A2 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.

Drainage plastic pipes of different sizes, such as Polypropylene Corrugated SN8 (375 mm, 600 mm, and 900 mm), Polyethylene Corrugated SN8 (375 mm and 600 mm), Steel Reinforced Concrete (SRC) and Rubber Ring Joint (RRJ) Class 2 & 3 (375 mm, 600 mm, and 900 mm) are included in this study. The declared unit is 1 m of pipe, assuming all pipe materials have the same service life and last the life of the asset (100 years).

The summary of this study are as follows:

- The plastic pipes considered in this study were produced from 100% virgin materials. By comparison, the concrete pipes contained 70% recycled steel[1]. This inclusion of recycled content helped reduce the environmental footprint of concrete pipes. For plastic pipes, a reduction of GWP-Total (Table 6) and EP-Freshwater (Table 7) would be possible if recycled content was used. Plastic pipes are 100% recyclable and, due to their long service life, are still in their first life cycle. Therefore, volume of material available for recycling is low.
- Plastic pipes had lower environmental impact in six of the 13 categories, including global warming potential (GWP), photochemical ozone depletion, marine and terrestrial eutrophication, use of net freshwater (FW) and non-hazardous waste disposed.

1 RCPA concrete pipes reported in their EPD that their steel contains recycled content. The value of recycled content was estimated to be 70% based on average data. However, they have acknowledged that the estimated recycled content may or may not be representative for the steel they receive from their suppliers. RCPA has two suppliers: InfraBuild and an overseas supplier. The InfraBuild EPD doesn't specifically provide the percentage of post-consumer recycled content, but it does show Secondary Materials (SM) of 734 kg per tonne. The estimated recycled content of 70% value was applied across the two steel suppliers.

- Plastic pipes had higher environmental impact in six of the 13 categories, including freshwater eutrophication, abiotic depletion potential (metals and minerals), abiotic depletion potential (fossil resources), ozone depletion potential, hazardous waste disposed, and radioactive waste disposed. Resin production was a primary contributor for these impact categories.
- Plastic pipes and concrete pipes were found to have similar acidification potential values.
- According to the Green Star Buildings Submission Guidelines[2], the weighting factors for GWP and FW are 25% each. The Infrastructure Sustainability Council (ISC) also weighs GWP the highest in its material calculator, with a factor of 47.5%[3]. Plastic pipes had lower environmental impact in both GWP and use of net freshwater categories.
- As the weight of concrete pipes is higher per metre than plastic pipes, the GWP for transporting plastic pipes is lower.

The conclusions of this study are as follows:

- A comparative LCA study for plastic drainage pipes and concrete drainage pipes was successfully carried out for 13 midpoint impact indicators, prioritised by the Building Research Establishment (BRE). As no primary data for concrete pipes are available, comparison for endpoint impact indicators wasn't possible.
- The GWP and FW impact categories are considered most important when using LCA for the built environment in Australia, and plastic pipes have lower impact in both categories compared to concrete pipes.

From this study, PIPA can build communications on the following basis:

- Plastic pipes have demonstrated sustainability performance advantages in the highest priority environmental categories, including GWP and FW.
- The GWP to produce plastic pipes is lower than concrete pipes.
- The GWP per kilometre of transport mode is lower for plastic pipes than concrete pipes.

However, from this study, PIPA can't say the following:

- Plastic pipes have, in general, superior environmental performance over concrete pipes.
- There's less waste generation in the production of plastic pipes compared to concrete pipes.
- There's less depletion of non-renewable resources (fossil fuels and mineral resources) in the production of plastic pipes compared to concrete pipes.
- This study was conducted with the best available third-party technical environmental data and may be challenging to communicate to non-specialist or non-technical audiences and decision-makers. To make a simplified comparison, there's an option to calculate and present aggregated environmental impact (e.g. eco-points). Although both ISC and Green Star have versions of eco-points, they're defined using the old EPD standard (EN 15804 + A1), which isn't yet compatible with EPDs produced using the current standard (EN 15804 + A2).

The comparisons in this report are based on third-party EPD results. The referenced EPDs were developed in accordance with EN 15804+A2 and are aligned with ISO 14040 and ISO 14044. The comparative assertions in this report have not undergone the additional third-party review specified in ISO 14044. Accordingly, the results and interpretations should be regarded as indicative and interpreted with caution. The findings are based on the available data and the assumptions stated in the referenced EPDs.

2 Green Star Buildings Submission Guidelines, Version 1: Revision B, 10 December 2021
3 Infrastructure Sustainability Council (2018), ISv2.0 Materials Calculator Guideline, https://d3n8a8pro7vhmx.cloudfront.net/themes/5a72941f5ee54d4c43000000/attachments/original/1533001335/2018-02-21_ISCA_Materials_Guideline_Version_2.0_Rev_0.pdf?1533001335

1. INTRODUCTION

Plastic pipes play a critical role in many industries, including domestic infrastructure, civil construction, agriculture, mining and gas. They're robust and can have a service life of over 100 years, made from materials engineered to be recycled, safe and reliable.

With a growing number of comparable environmental impact data published for construction products in Australia and internationally, Environmental Product Declarations (EPDs) and other Life Cycle Assessment (LCA) based inventories are the main sources of product-based environmental data. However, there's a general lack of understanding amongst decision-makers on how to use this information in the form of credible and accessible guidelines.

PIPA is working to support Australia's broader community of users who benefit from using plastic pipes. This includes making it easier to access information that helps decision-makers and authorities select drainage pipe solutions for their road projects. Table 1 shows the characteristics of the infrastructure pipes selected for this comparative study.

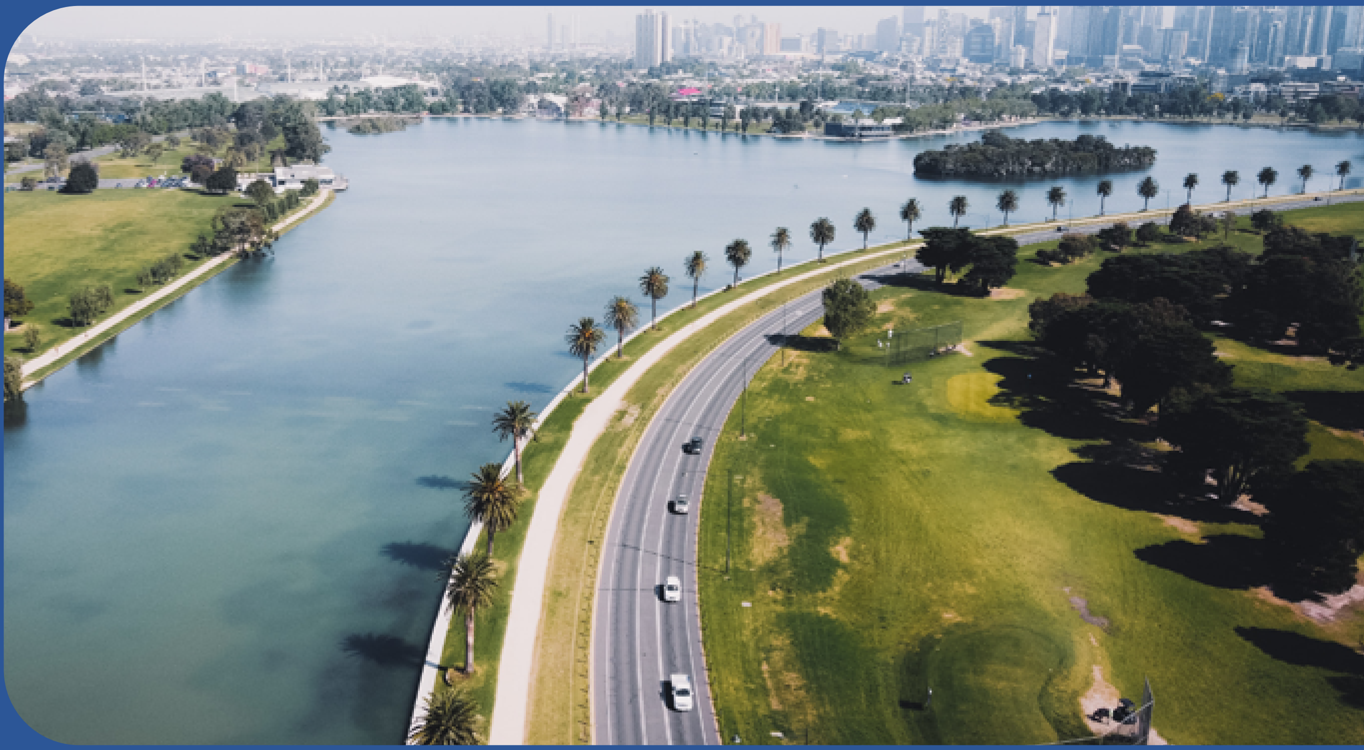

Table 1 – Characteristics of selected pipes for the study

MATERIAL TYPE	DIAMETER	KG/M	INFORMATION SOURCE
Polyethylene (PE) Corrugated SN8	375	7.8	(Vinidex, Environmental Product Declaration Polyethylene Pipes, 2022)
	600	19.16	(Vinidex, Environmental Product Declaration Polyethylene Pipes, 2022)
Polypropylene (PP) Corrugated SN8	375	6.8	(Vinidex, Environmental Product Declaration StormPRO Polypropylene Pipes, 2022)
	600	18.8	(Vinidex, Environmental Product Declaration StormPRO Polypropylene Pipes, 2022)
	900	39.6	(Vinidex, Environmental Product Declaration StormPRO Polypropylene Pipes, 2022)
SRC RRJ Class 2	375	Concrete – 131: Steel – 3.85	(RCPA, SRC Pipes EPD, 2023)[4]
	600	Concrete – 291: Steel – 9.83	(RCPA, SRC Pipes EPD, 2023)
	900	Concrete – 594: Steel – 20.09	(RCPA, SRC Pipes EPD, 2023)
SRC RRJ Class 3	375	Concrete – 131: Steel – 4.27	(RCPA, SRC Pipes EPD, 2023)
	600	Concrete – 290: Steel – 11.97	(RCPA, SRC Pipes EPD, 2023)
	900	Concrete – 712: Steel – 25.21	(RCPA, SRC Pipes EPD, 2023)

4 RCPA: Reinforced Concrete Pipes Australia (Holdings) Pty Ltd

2. GOAL AND SCOPE

PIPA intends to demonstrate the data-driven sustainability performance of plastic pipes. The goal of this study is to develop a comparative life cycle assessment (LCA) based on third-party published data, providing easy access to information for authorities and other key decision-makers when selecting drainage pipe solutions. Furthermore, PIPA aims to demonstrate its leadership and commitment to sustainability through the design and communication of this LCA study. The final audience of this report includes the government, contractors, builders, designers and architects.

The scope of this comparative study includes the cradle-to-installation modules (A1-A5) in accordance with General Programme Instructions (GPI) v3.01 for the Australasia EPD System and EN 15804+A2 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products. The modules are:

The product stage system, which is comprised of:

- A1 – raw material supply
- A2 – transport of raw materials to the manufacturing site
- A3 – manufacturing

Construction, which is comprised of:

- A4 – transport from manufacturing to the construction site
- A5 – construction and installation

The drainage non-pressure pipes and sizes included in this comparison are as follows:

- Polyethylene (PE) Corrugated SN8 Rubber Ring Joint (RRJ) (375 mm and 600 mm)
- Polypropylene (PP) Corrugated SN8 Rubber Ring Joint (RRJ) (375 mm, 600 mm, and 900 mm)
- Steel Reinforced Concrete (SRC) Rubber Ring Joint (RRJ) Class 2 (375 mm, 600 mm, and 900 mm)
- Steel Reinforced Concrete (SRC) Rubber Ring Joint (RRJ) Class 3 (375 mm, 600 mm, and 900 mm)

Based on prioritisation developed by the Building Research Establishment (BRE), the following 13 impact categories were used for the product stage system (A1-A3) comparison of plastic and concrete drainage pipes:

1. Total global warming potential
2. Ozone depletion
3. Acidification
4. Eutrophication – aquatic freshwater
5. Eutrophication – aquatic marine
6. Eutrophication – terrestrial
7. Photochemical ozone formation
8. Abiotic depletion (metals and minerals)
9. Abiotic depletion (fossil resources)
10. Use of net freshwater
11. Hazardous waste
12. Non-hazardous waste
13. Radioactive waste

As the downstream transport environmental impacts weren't included in the EPD for RCPA SRC pipes, they were sourced from the Holcim EPD (Holcim, 2017). However, this version of the Holcim EPD was published as an EN 15804+A1 version, so it wasn't used to compare product stage data. As the indicators of EN 15804+A1 and EN 15804+A2 aren't completely aligned, only GWP was selected for downstream transport comparison.

The calculation of environmental impacts and resource use that apply to the buried installation of plastic and concrete pipes is highly dependent on the specific details relating to a particular pipeline's design. A detailed analysis on installation was carried out based on several construction factors including trench excavation, embedment materials, compaction of embedment materials, pipe lifting equipment, pipe joining, back filling of the trench and transportation of excavated materials.

The endpoint analysis of plastic pipes was performed using primary data supplied by the plastic industry (Appendix A). As no primary data for concrete pipes is available, endpoint analysis of concrete pipes wasn't performed but an analysis can be resourced to the plastic industry if required for future comparisons.

3. DECLARED UNIT AND MEASUREMENT OF COMPARISON

The declared unit is 1 metre of pipe, assuming all pipe materials have the same diameter, the same service life, and last for the life of the asset (100 years). The comparison was performed using information from published EPDs as well as LCA databases such as ecoinvent and AusLCI on SimaPro software platform. The characterisation factors used to analyse background LCA data are consistent with EN 15804+A2 midpoint impact categories.

4. EPD PROCESS DIAGRAM AND BOUNDARIES

Figure 1 and Figure 2 show the entire lifecycle of Vinidex PP pipes LCA and Vinidex PE pipes LCA. The dotted lines in Figure 1 and Figure 2 show the system boundary (A1-A5) of this study. Figure 3 shows the product stage boundary for the RCPA SRC pipes LCA. Figure 3 doesn't show the entire scope used in the study (A1-A5), but it's listed to highlight what the respective EPDs include. The system boundary identifies the aspects inside or beyond the scope and boundary of the study and determines what to measure at the next step.

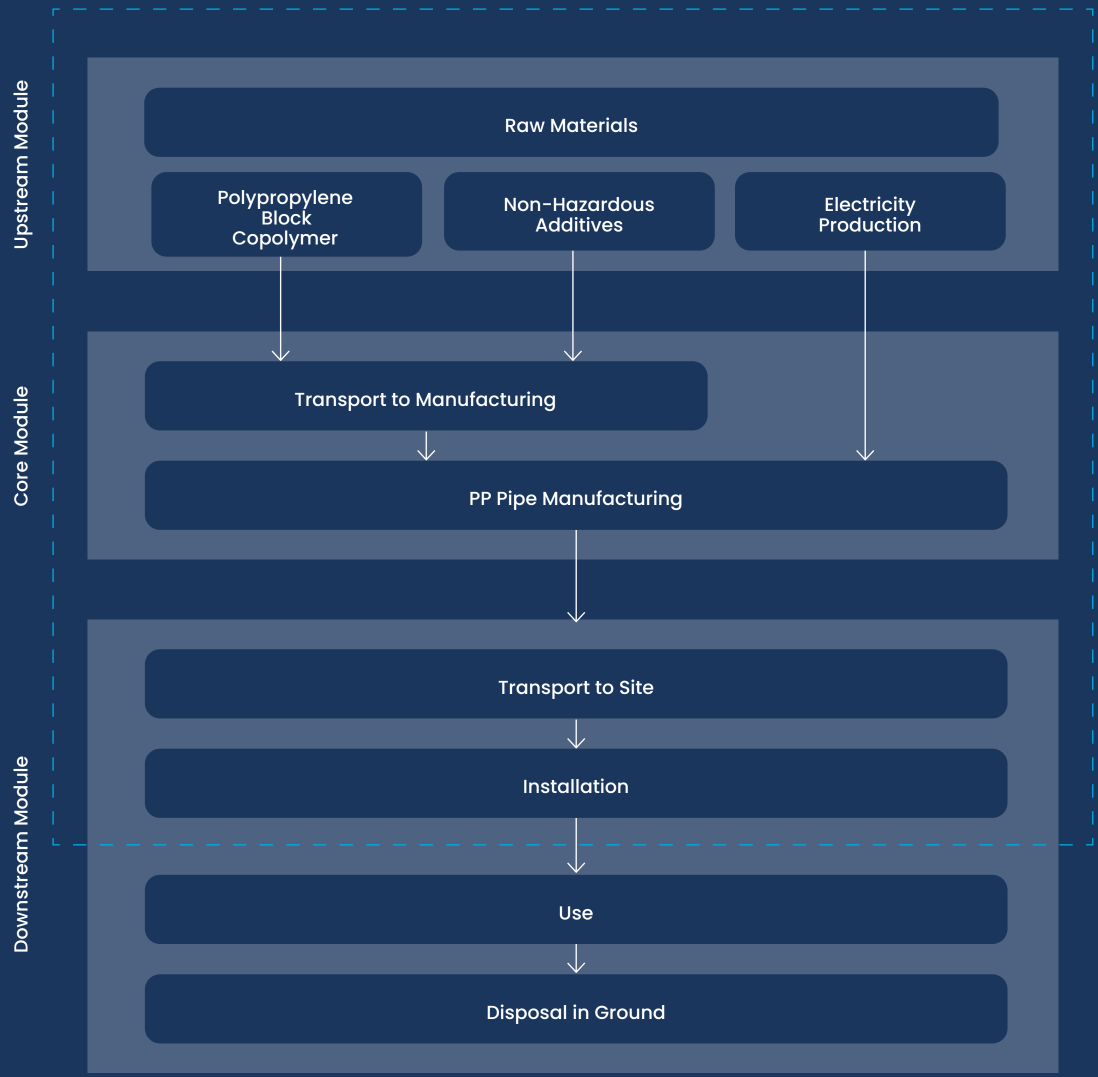

Figure 1 | Product stage system diagram for PP Pipe (Vinidex, Polypropylene pipes EPD, 2022)

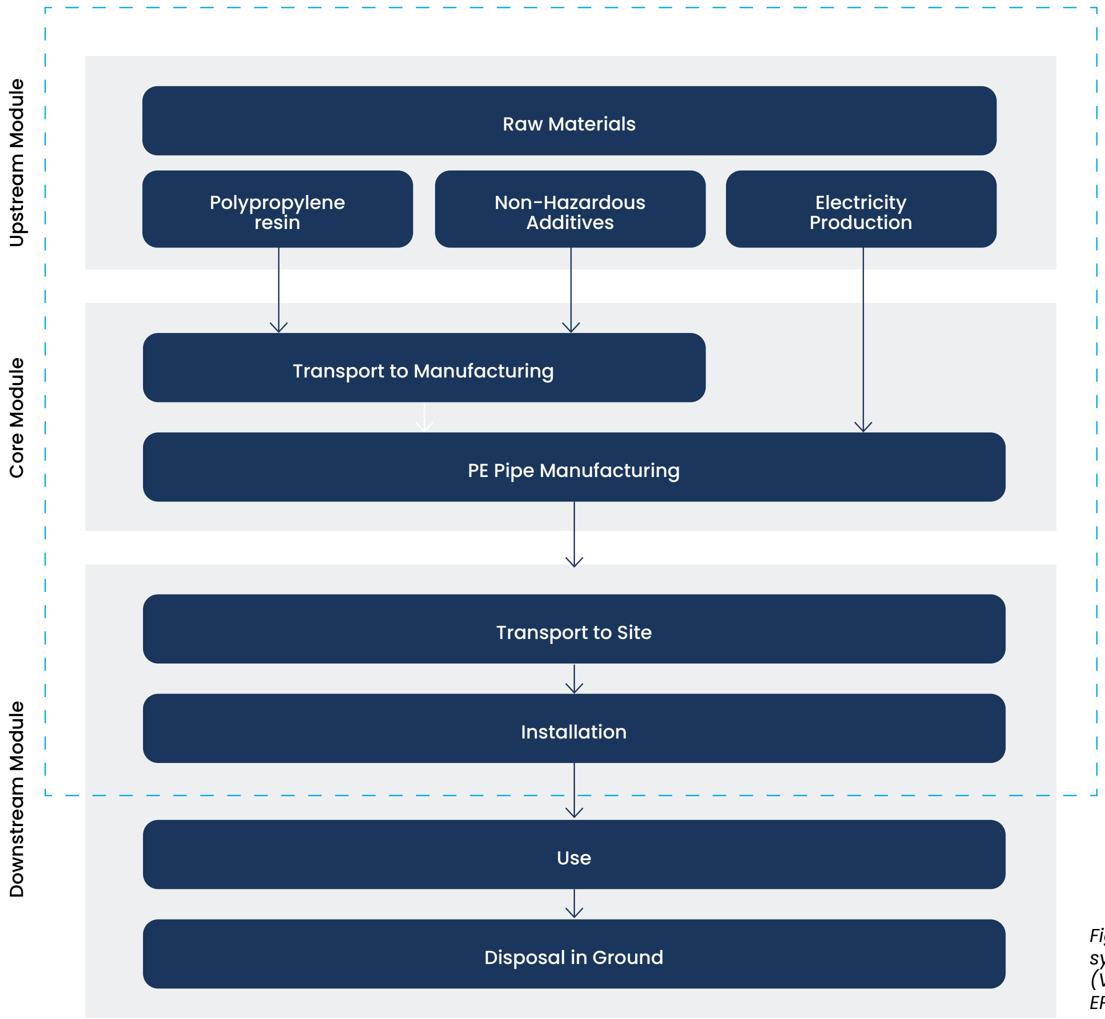

Figure 2 | Product stage system diagram for PE Pipe (Vinidex, Polyethylene Pipes EPD, 2022)

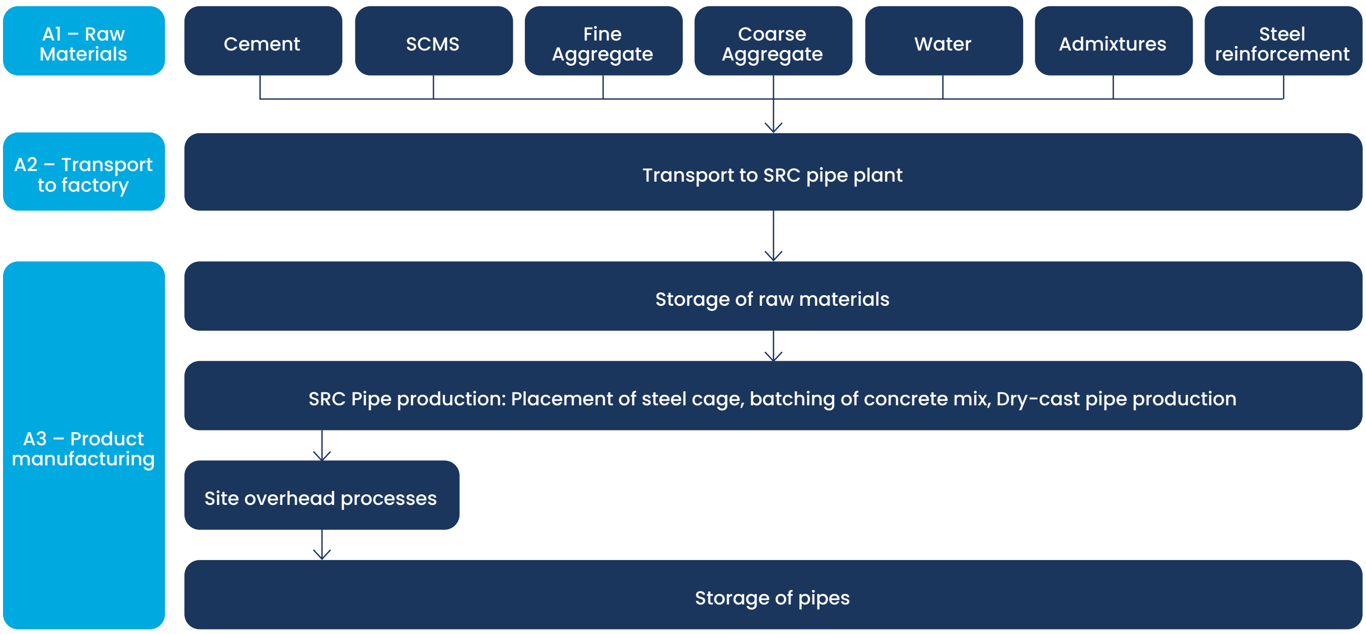

Figure 3 | Product stage system diagram for SRC Pipe (RCPA, SRC Pipes EPD, 2023) [5]

5 RCPA SRC Pipes EPD shows system diagram broader than product stage. In order to keep consistency with plastic pipes, only product stage component is shown here.

5. METHODOLOGY

The impact categories and indicators used in this comparative study are from the EPD standard EN15804+A2. According to a survey comprising 60 responses from expert and non-expert groups, Building Research Establishment (BRE)[6] decided on 13 EPD impacts and indicators to prioritise, shown in the table on the adjacent table.

As the BRE study was based on the EN 15804+A1 standard of EPDs and the latest EPDs are based on the EN 15804+A2 standard, the following 13 indicators (Table 2) were chosen in this comparative study.

6 Abbe, O. and Hamilton, L., 2017. BRE Global Environmental Weighting for Construction Products using Selected Parameters from EN 15804. BRE Global Ltd.: Hertfordshire, UK.

Table 2 – Life cycle impact, resource and waste assessment categories, measurements and methods in accordance with EN 15804+A2

IMPACT CATEGORY	ABBREVIATION	MEASUREMENT UNIT	ASSESSMENT METHOD AND IMPLEMENTATION
Total global warming potential	GWP - Total	kg CO_2 equivalents (GWP100)	Baseline model of 100 years of the IPCC based on IPCC 2013
Acidification potential	AP	mol H^+ eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Eutrophication – aquatic freshwater	EP - freshwater	kg P equivalent	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication – aquatic marine	EP - marine	kg N equivalent	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication – terrestrial	EP – terrestrial	mol N equivalent	Accumulated Exceedance, Seppälä et al. 2006, Posch et al.
Photochemical ozone creation potential	POCP	kg NMVOC equivalents	LOTOS-EUROS, Van Zelm et al., 2008, as applied in ReCiPe
Abiotic depletion potential (metals and minerals)*	ADPE	kg Sb equivalents	CML (v4.1)
Abiotic depletion potential (fossil fuels)*	ADPF	MJ net calorific value	CML (v4.1)
Ozone depletion potential	ODP	kg CFC 11 equivalents	Steady-state ODPs, WMO 2014
Use of net fresh water	FW	m^3	ReCiPe 2016
Hazardous waste disposed	HWD	kg	EDIP 2003 (v1.05)
Non-hazardous waste disposed	NHWD	kg	EDIP 2003 (v1.05)[7]
Radioactive waste disposed/stored[8]	RWD	kg	EDIP 2003 (v1.05)

It should be noted that the results of abiotic depletion potentials (both resource and elements) have a high level of uncertainties. These originate from the uncertainties on the estimation of extractable reserves. In the case of abiotic depletion potential – elements, there are additional uncertainties in the scattered concentrations of elements (L. van Oers; A. de Koning; J.B. Guinée; G. Huppes, 2002).

7 Calculated as sum of Bulk waste and Slags/ash.
**Disclaimer – The results of these environmental impact indicators shall be used with care as the uncertainties on these results are high or as there's limited experience with the indicator.*
8 Radioactive waste is a concern for the countries/regions where electricity is produced from nuclear power plants. This impact category is of low concern in Australia as the radioactive waste values in the LCA of Australian products indicate its presence in overseas supply chain. In the case of polypropylene and polyethylene pipes, nuclear energy-based electricity used in the production of resins is the primary source of radioactive waste. The background Global LCA data, used for resin productions, indicates that nuclear energy-based electricity produced in China, the USA, Canada and Europe are the sources of radioactive waste values of plastic resin productions. However, it should be noted that both PP and PE resins aren't sourced from these countries.

6. PRODUCT INFORMATION

This section presents information related to the products considered for this study. The following tables provide detailed information about the materials used to produce pipes.

Recycled plastic wasn't considered in the manufacturing stage, as most plastic pipes are made with thermoplastics. This means they're 100% recyclable and have a service life of 100 years. However, due to their long life, there's a limited amount of suitable recycled material available to use in the manufacturing stage.

The steel, used for the reinforcement of the concrete pipes, was manufactured with significant recycled content as detailed in the EPD (RCPA, SRC Pipes EPD, 2023)[9].

Table 3 | PE pipe feed mix ingredients (Vinidex, Polyethylene Pipes EPD, 2022)

FEED MIX	MASS (%)
PE resin (pre-compounded)	96 – 98
Carbon black	2 – 3
Proprietary additives	0 – 1

Table 4 | PP pipe feed mix ingredients (Vinidex, Polypropylene pipes EPD, 2022)

FEED MIX INGREDIENT	MASS (%)
PP resin	95.8
PP Masterbatch	4.2

9 RCPA concrete pipes reported in their EPD that their steel contains recycled content. The value of recycled content was estimated to be 70% based on average data. However, they have acknowledged that the estimated recycled content may or may not be representative for the steel they receive from their suppliers. RCPA has two suppliers: InfraBuild and an overseas supplier. The InfraBuild EPD doesn't specifically provide the percentage of post-consumer recycled content, but it does show Secondary Materials (SM) of 734 kg per tonne. The estimated recycled content of 70% value was applied across the two steel suppliers.

Table 5 | Material content for concrete pipe (RCPA, SRC Pipes EPD, 2023)

CHEMICAL NAME	MASS (%)
Ready mix concrete	92 – 98
General purpose cement	15 – 22
Fly ash	0 – 6
Coarse aggregates	30 – 45
Natural sand	30 – 45
Water	4 – 7
Admixtures	0 – 0.5
Steel used for reinforcement	2 – 8

7. RESULTS AND INTERPRETATIONS

This section presents the principal findings of the comparative drainage pipes LCA study. The comparison of results in the Product Stage (modules A1-A3) is presented in section 7.1. After discussing product stage indicators, a comparison of all indicators is summarised, and a brief conclusion is drawn. The downstream transportation stage (module A4) is presented in section 7.2, and the installation stage (module A5) is presented in section 7.3.

The EPD results (product stage and downstream transportation) were translated from per kg product/primary ingredients to per metre pipe. This conversion allows us to observe the differences in environmental impacts between plastic pipes and concrete pipes in the application stage. The results for DN 600 pipes are presented here, while the results for DN 375 and DN 900 are presented in the appendices.

7.1. PRODUCT STAGE

7.1.1. Total global warming potential

Global warming potential (GWP) values are used to compare the climate change effects of greenhouse gases (GHG). The GWP values represent how much heat GHG can trap in the atmosphere and contribute to climate change. The GWP indicator includes GHG emissions from three sources:

1. fossil fuels;
2. bio-based resources; and
3. land use change.

The GWP values are calculated as carbon dioxide equivalents (CO_2-eq). Usually, a 100-year gas residence time in the atmosphere is accounted for in the calculation of GWP values.

As can be seen from Figure 4, plastic drainage pipes have a lower carbon footprint compared to concrete drainage pipes.

PE and PP pipes emit 59 and 67 kg CO_2 eq. per metre of pipe, while SRC Class 2 and 3 pipes emit 78 and 82 kg CO_2 eq. per metre of pipe. Assuming in a sub-division there is a requirement for 5 metres of drainage pipe, the product stage carbon footprint of the PE pipe is 295 kg CO_2 eq. By comparison, the product stage carbon footprint is 390 kg CO_2 eq. for the SRC Class 2 pipe.

To give some perspective on these numbers, let's consider driving a car for a shopping trip. According to data available on the National Transport Commission (NTC) website, passenger cars and SUVs emit 146.5 g/km[10]. If a shopper needs to drive their car for a total of 10 kilometres for a trip, the shopper emits 1.47 kg CO_2 eq. If we consider their shopping behaviour, the production of 5 metres of PE pipe is equivalent to 201 shopping trips, and the production of 5 metres of SRC Class 2 pipe is equivalent to 266 shopping trips.

GWP-total comparison DN600

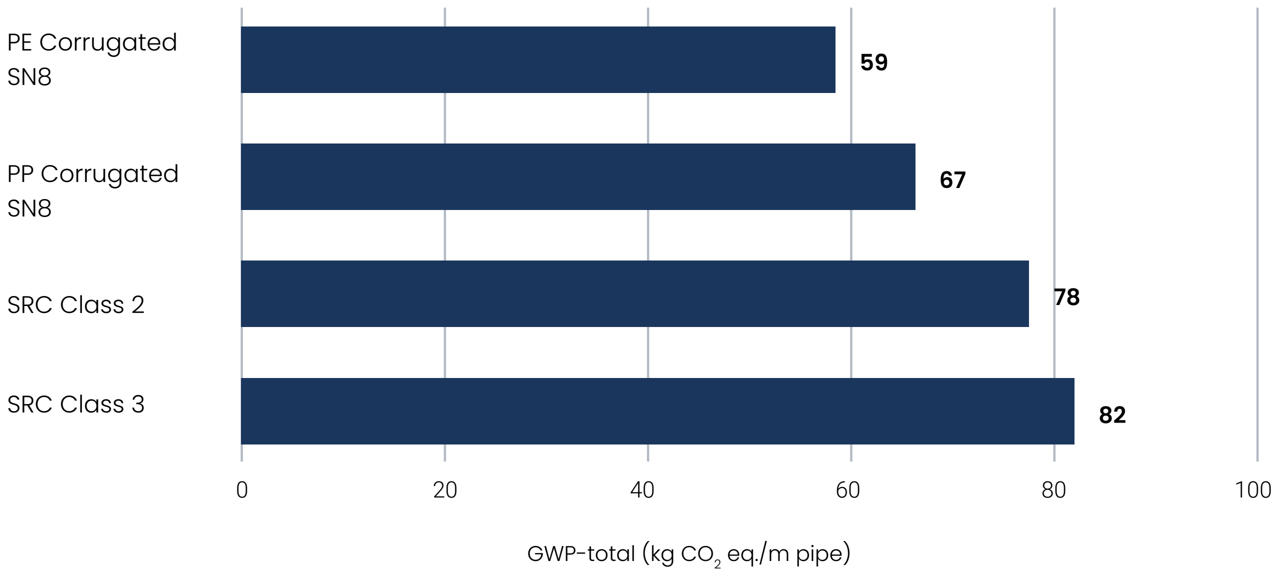

Figure 4: GWP-total comparison of plastic pipes with concrete pipes for the size of DN 600

10 National Transport Commission (2022), Light Vehicle emissions intensity in Australia, https://www.ntc.gov.au/light-vehicle-emissions-intensity-australia#:~:text=Average% 20emissions%20intensity%20in%202021&text=Average%20emissions%20intensity%20for%20passenger,decrease%20from%20the%20previous%20year.

The breakdown of product stage GWP-total values is presented in Figure 5 and Figure 6.
The majority of GWP-total contributions for SRC pipes originate from concrete. It's worth noting that RCPA uses steel with 70% recycled content, which helps to reduce the product stage carbon footprint of steel. For plastic pipes, the majority of contributions originate from resin productions (PP/PE resin). The remaining component includes environmental impacts associated with the production of additives, upstream transport, manufacturing energy and waste.

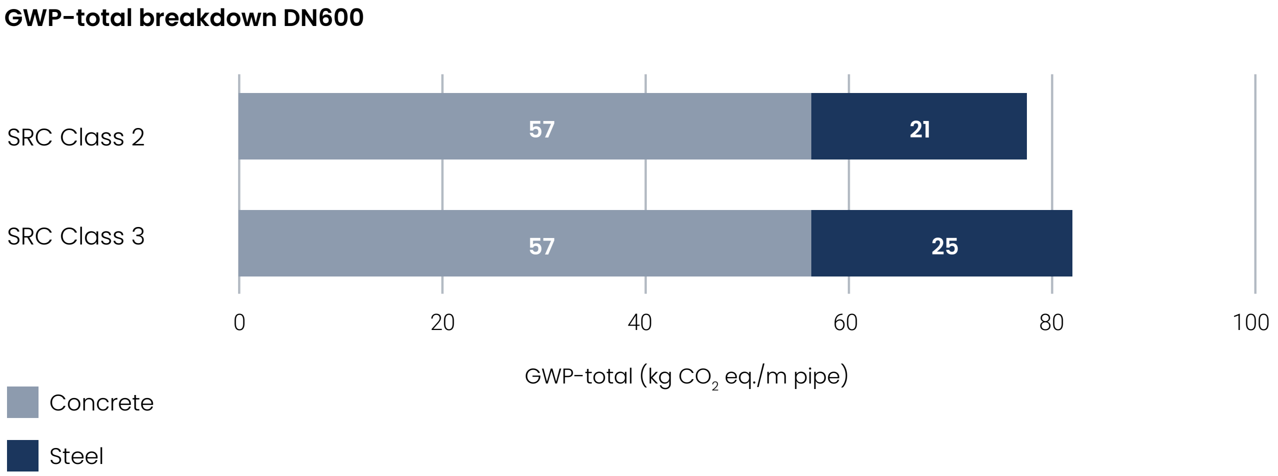

Figure 5: The breakdown of GWP-total of concrete pipes for the size of DN 600

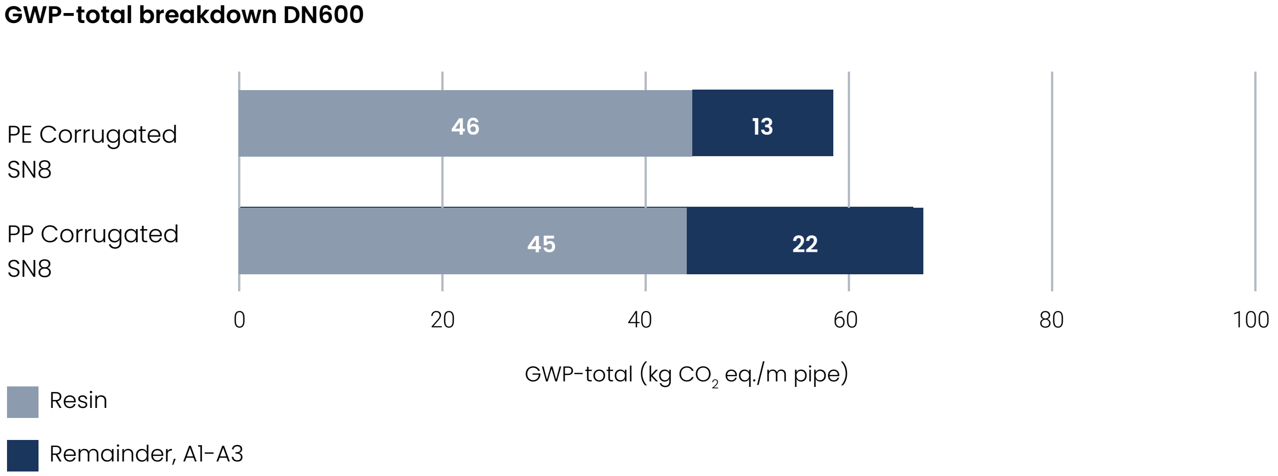

Figure 6: The breakdown of GWP-total of plastic pipes for the size of DN 600

In the case of plastic pipes, no recycled content was accounted for in the EPDs.
Table 6 shows the percentage reduction of GWP-total if recycled content is accounted for.

Table 6: Reduction in GWP-total with the increase in recycled content

RECYCLED CONTENT	% REDUCTION IN GWP-TOTAL (PP PIPES)	% REDUCTION IN GWP-TOTAL (PE PIPES)
10%	5.9	6.9
20%	11.8	13.8
30%	17.7	20.7

7.1.2. Ozone depletion potential (ODP)

The ozone layer sits in the upper atmosphere (the stratosphere) of our planet. Anthropogenic release of chlorinated and brominated chemicals, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons (often termed as ozone depleting substances or ODS) to the atmosphere causes damage to the ozone layer. While the use of many ODS has been restricted or phased out via the establishment of the Montreal Protocol[11], there are existing refrigeration systems and insulation foams that release ODS to the atmosphere. The ozone depletion potential (ODP) indicator measures the release of chlorinated and brominated chemicals equivalent to CFC-11 (trichlorofluoromethane).

Figure 7 shows an ODP comparison of plastic pipes and concrete pipes. The production of plastic pipes has a higher ODP compared to concrete pipes. In 2019, the total Australian ODP-weighted emissions of ODS controlledby the Montreal Protocol accounted for 1.1 kilo tonnes[12]. This equates to 0.04 ODP-weighted emissions per capita in that year. Using these 2019 results as the benchmark, the ODP values of plastic pipes are four orders of magnitude lower than yearly ODP-weighted emissions per capita.

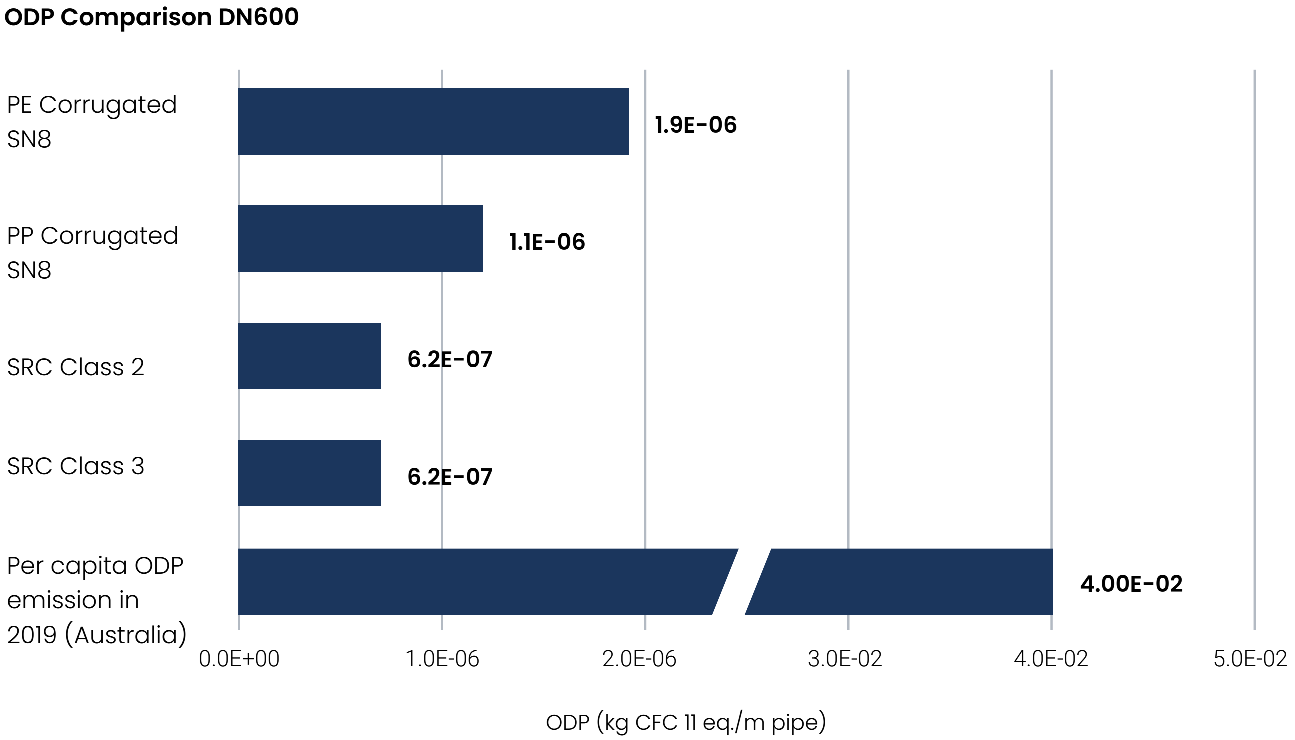

Figure 7: ODP comparison of plastic pipes with concrete pipes for the size of DN 600

11 United Nations Environment Programme (n.d.), The Montreal Protocol, https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol
12 Dunse, B., Derek, N., Fraser, P. and Krummel, P., 2021. Australian and Global Emissions of Ozone Depleting Substances, Report prepared for the Australian Government Department of Agriculture, Water and the Environment. Tech. Rep., CSIRO Oceans and Atmosphere, Melbourne, Australia, iii, 57 pp., https://www. agriculture. gov. au/sites/default/files/documents/australian-global-emissions-ozone-depleting-substances.pdf (last access: 06 Juney 2023).

Figure 8 and Figure 9 show the breakdown of ODP for the product stage of the pipes. For concrete pipes, the ODP originates primarily from the concrete component. For plastic pipes, the majority of ODP originates from the production of resins. Further analysis shows that the electricity used in the production of resins has the highest ODP contribution to resin's ODP impact. While the use of grid electricity in the production of resins is outside of the plastic pipe industry's control, this finding suggests that using renewable energy in the entire sector can support in reducing this environmental impact.

Regarding ODS, it's often difficult to find the root source of its release in the LCA background database. While the Montreal Protocol restricts the production and use of ODS, a few ODS can be produced as a co-product during the manufacture of other important chemicals[13]. It's likely that these leak during the manufacturing process and create an ODP impact on the production chain.

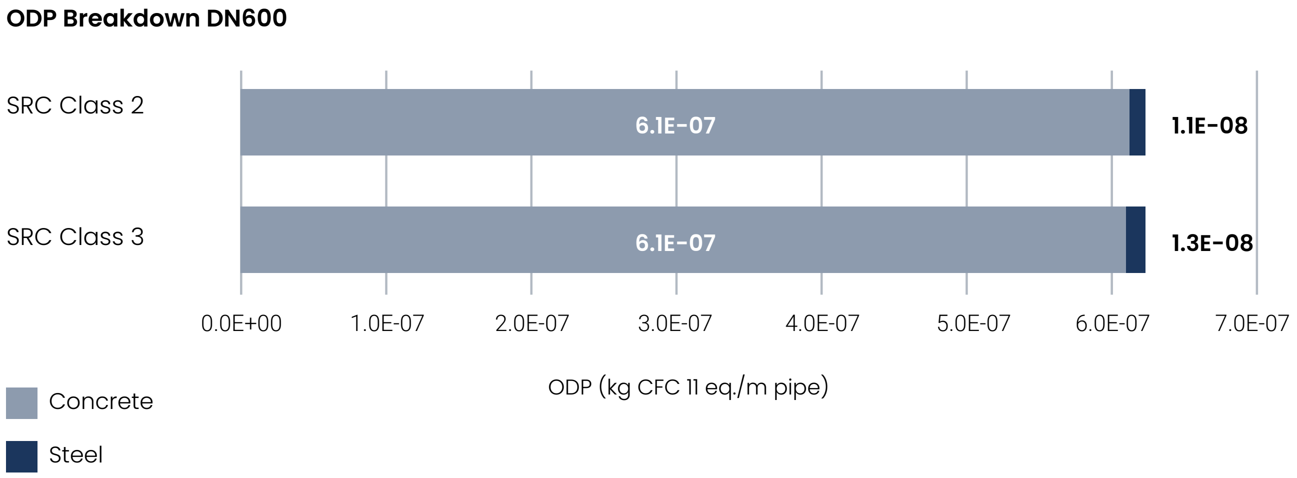

Figure 8: The breakdown of ODP of concrete pipes for the size of DN 600

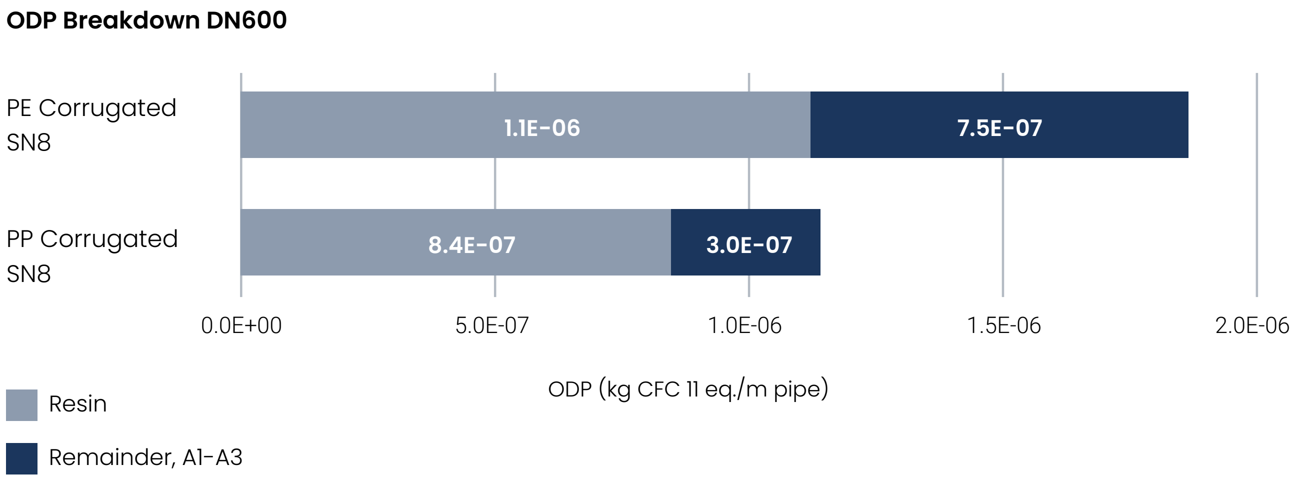

Figure 9: The breakdown of ODP of plastic pipes for the size of DN 600

13 Western, L., Laube, J. (2023), Countries agreed to ban ozone-depleting chemicals in the 1980s – but we found five CFCs increasing to record levels in the atmosphere, https://theconversation.com/countries-agreed-to-ban-ozone-depleting-chemicals-in-the-1980s-but-we-found-five-cfcs-increasing-to-record-levels-in-the-atmosphere-202925

7.1.3. Acidification

The acidification indicator measures the potential acidification of soils and water due to the release of acid gases, including nitrogen oxides and sulphur oxides. The well-known source of these gases' emissions is the combustion of fossil fuels. When these acid gases react with water in the atmosphere, they form an acid that decreases the pH value of rainwater and fog. Depending on the concentration of acid in the rainwater and fog, the damage to ecosystems varies.

The acidification potential of plastic pipes and concrete pipes is similar (Figure 10). Therefore, the findings are inconclusive. Figure 11 and Figure 12 show the breakdown of acidification for the product stage of the pipes. In the case of concrete pipes, the highest acidification potential contribution originates from the production of concrete (Figure 11). For plastic pipes, the production of plastic resins is the primary source of acidification potential (Figure 12).

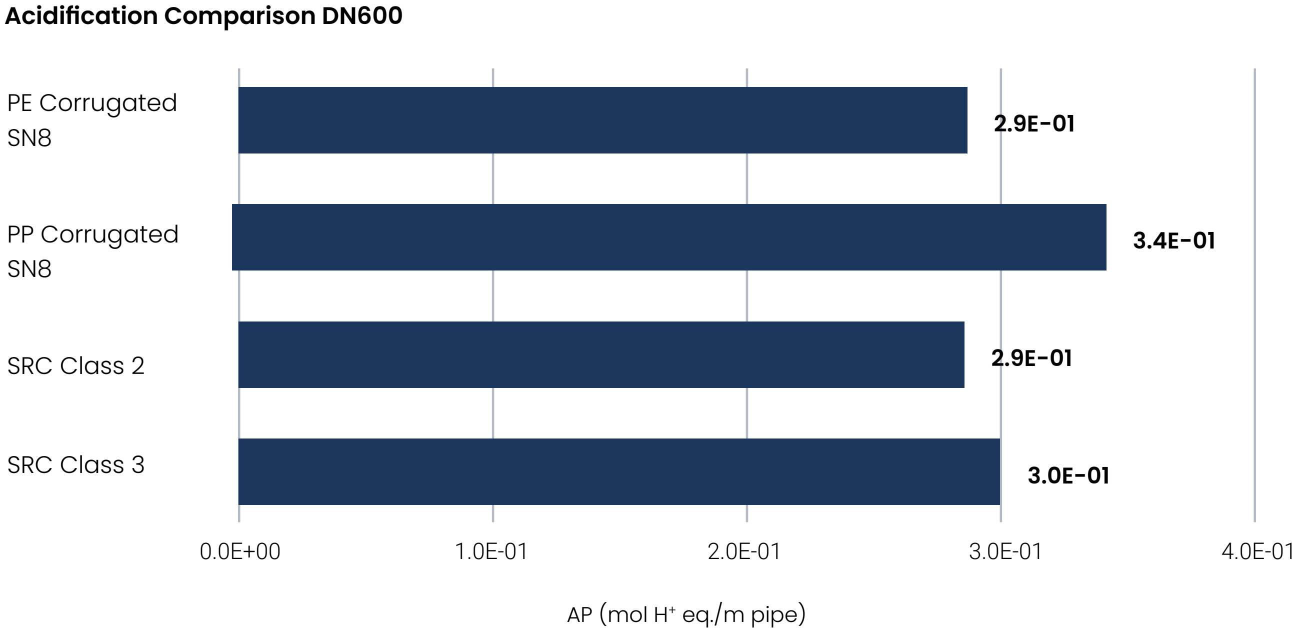

Figure 10: Acidification comparison of plastic pipes with concrete pipes for the size of DN 600

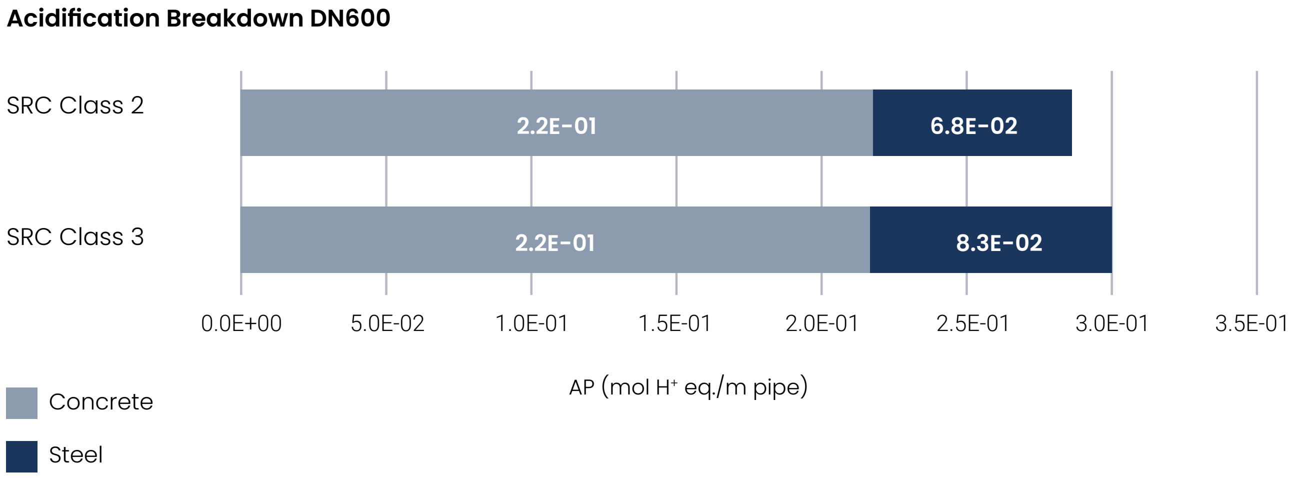

Figure 11: The breakdown of acidification of concrete pipes for the size of DN 600

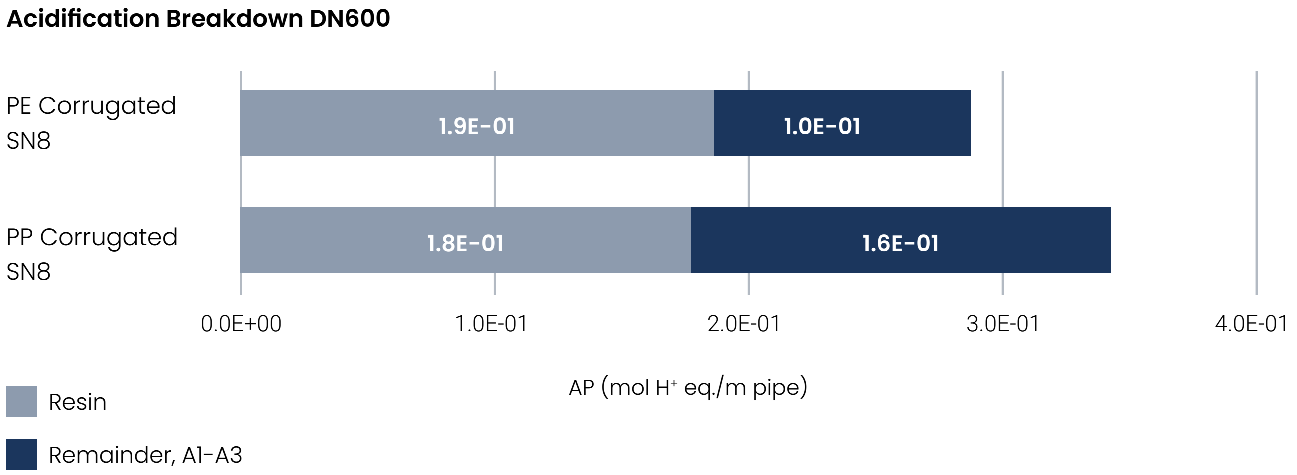

Figure 12: The breakdown of acidification of plastic pipes for the size of DN 600

7.1.4. Eutrophication – aquatic freshwater

The discharge of plant nutrients, such as nitrates and phosphates, into freshwater bodies impacts the ecosystem. The nutrient enrichment in water bodies leads to excessive growth of algae, resulting in a reduction of oxygen within the water. This makes it difficult for aquatic organisms to survive. Species that survive only in low-nutrient environments in water can die due to eutrophication. Common sources of nitrates and phosphates include the production of nitrogen oxides from the combustion of fossil fuels and biomass, and the use of nitrogen and phosphorous based fertilisers in agricultural lands.

Figure 13 compares the freshwater eutrophication of plastic pipes and concrete pipes. As demonstrated, plastic pipes generate two orders of magnitude higher freshwater eutrophication compared to concrete pipes. The breakdown of freshwater eutrophication for concrete pipes is given in Figure 14, showing most freshwater eutrophication comes from steel. In plastic pipes, most of the freshwater eutrophication originates from the production of plastic resins. The results suggest that the use of fossil fuels is much higher in plastic pipes than in concrete pipes.

According to EF 3.0 normalisation software package (November 2019)[14], the freshwater eutrophication per capita (global average) per year is 1.607 kg P eq. Freshwater eutrophication values of plastic pipes three orders of magnitude lower than that of yearly freshwater eutrophication per capita.

EP-Freshwater Comparison DN600

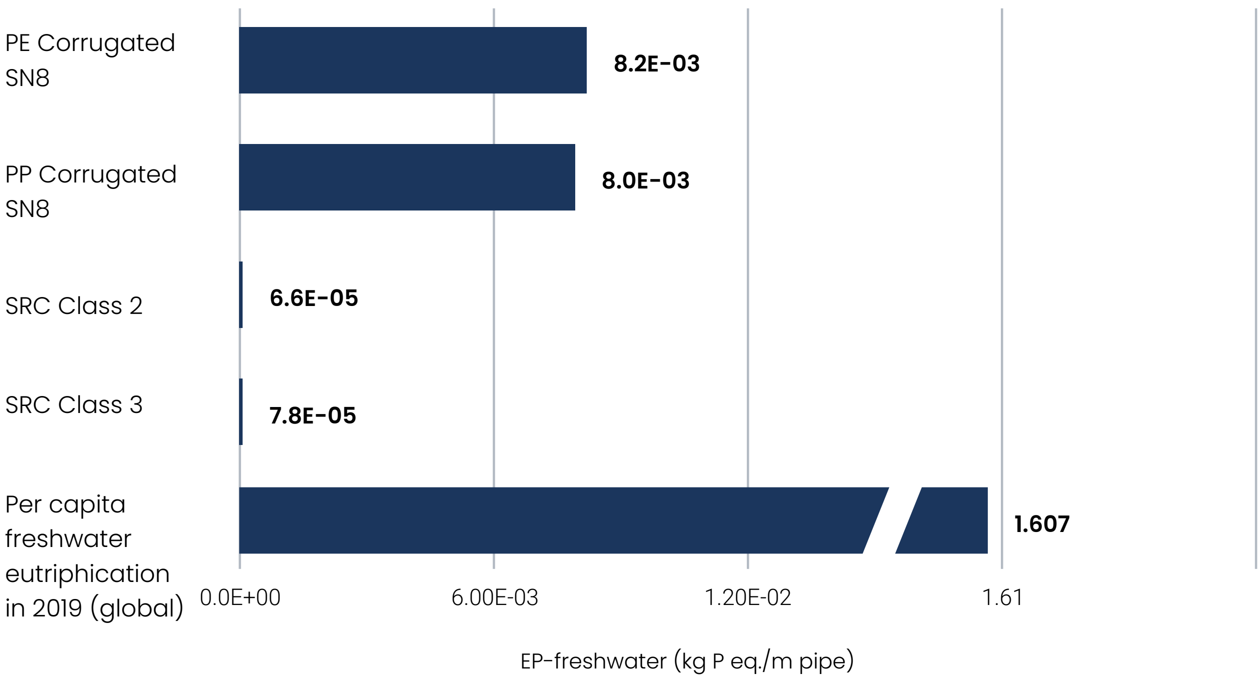

Figure 13: Eutrophication (aquatic freshwater) comparison of plastic pipes with concrete pipes for the size of DN 600

14 European Platform on LCA (2019), EF 3.0 normalisation values, https://eplca.jrc.ec.europa.eu/LCDN/EF_archive.xhtml

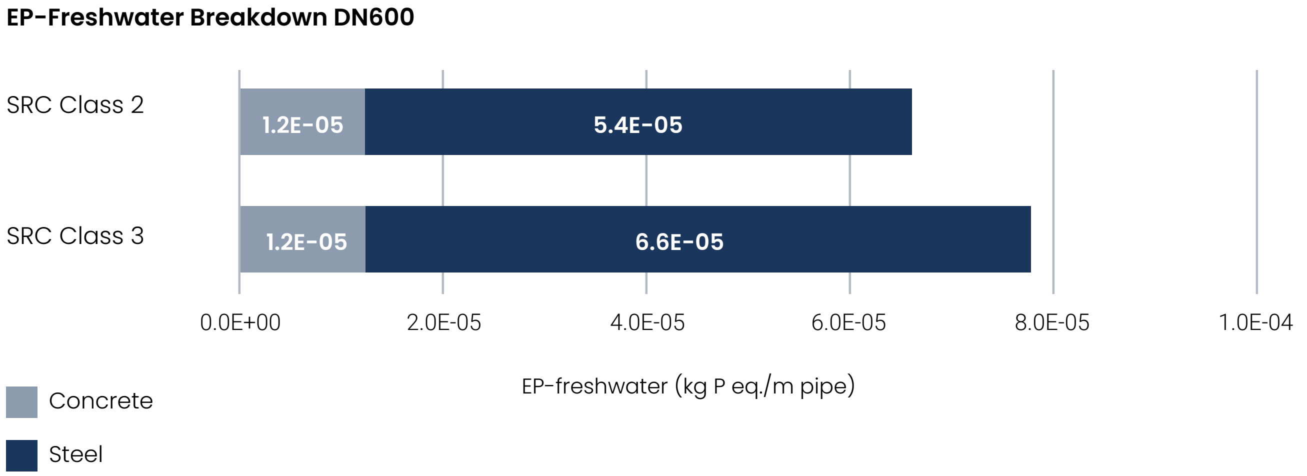

Figure 14: The breakdown of eutrophication (aquatic freshwater) of concrete pipes for the size of DN 600

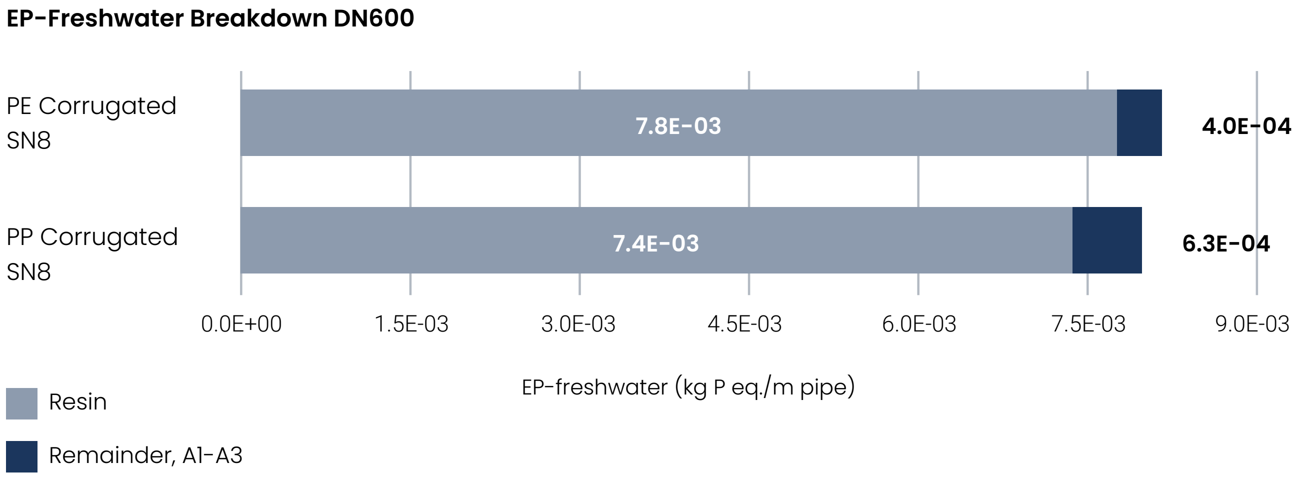

Figure 15: The breakdown of eutrophication (aquatic freshwater) of plastic pipes for the size of DN 600

The use of recycled content in plastic pipe production can reduce freshwater eutrophication values. However, the EPDs didn't account for recycled content. Table 7 shows the percentage reduction of freshwater eutrophication if recycled content is accounted for.

Table 7: Reduction in EP-freshwater with the increase in recycled content

RECYCLED CONTENT	% REDUCTION IN EP-FRESHWATER (PP PIPES)	% REDUCTION IN EP-FRESHWATER (PE PIPES)
10%	9.2	9.5
20%	18.4	19.0
30%	27.6	28.5

7.1.5. Eutrophication – aquatic marine

The runoff and leaching of nitrates and phosphates from soil to riverine or marine systems, alongside atmospheric deposition, increases nutrient levels in marine waters. The phytoplankton growth and the anoxia developed due to marine eutrophication cause disturbances to marine ecosystems. These effects are noticeable in many coastal regions of the world, including most parts of the Gulf of Finland, the Gulf of Riga, the Baltic Proper and south-western parts of the Baltic Sea[15].

The marine eutrophication of plastic pipes is lower than that of concrete pipes (Figure 16). The breakdown of marine eutrophication is given in Figure 17 and Figure 18. As seen in Figure 17, the production of concrete causes significant marine eutrophication.

According to the EF 3.0 normalisation software package (November 2019)[16], the marine eutrophication per capita (global average) per year is 19.54 kg N eq. Therefore, the marine eutrophication values of plastic pipes are three orders of magnitude lower than the yearly marine eutrophication per capita.

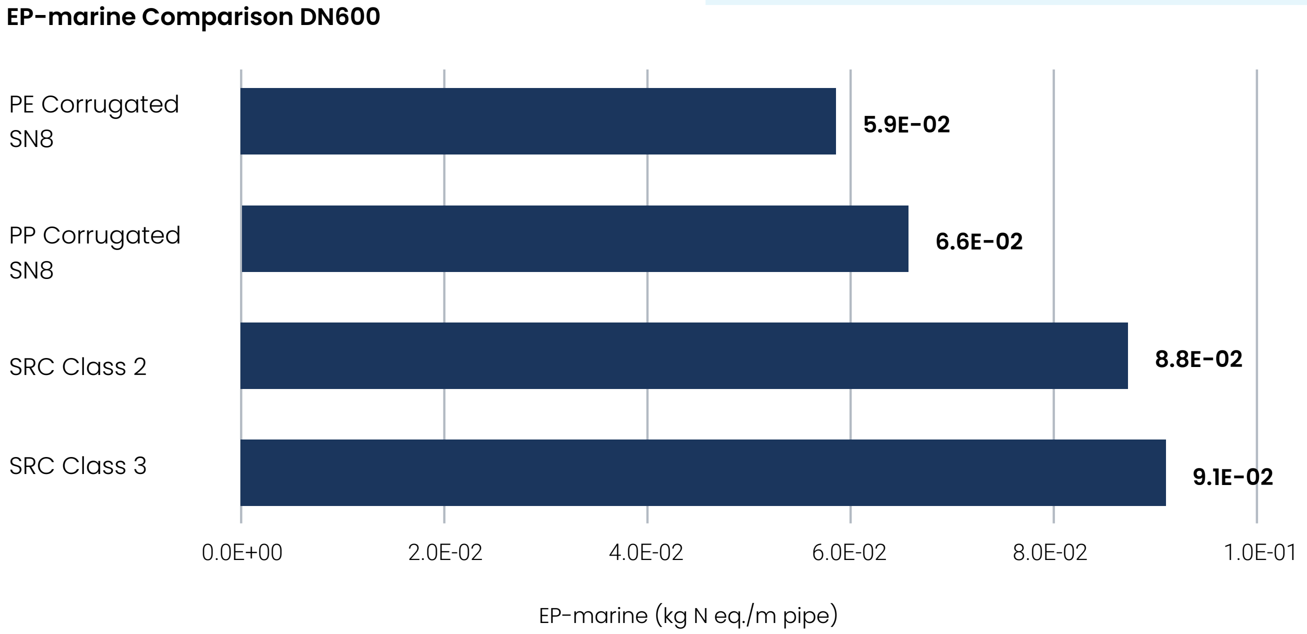

Figure 16: Eutrophication (aquatic marine) comparison of plastic pipes with concrete pipes for the size of DN 600

15 Coastal Wiki (E2018) Eutrophication in coastal environments, https://www.coastalwiki.org/introduced/Eutrophication_in_coastal_environments#:~:text=Causes %20of%20eutrophication,-Anthropogenic%20nutrient%20enrichment&text=Atmospheric%20deposition%20in%20the%20sea,areas%20 without%20much%20human%20activities.
16 European Platform on LCA (2019), EF 3.0 normalisation values, https://eplca.jrc.ec.europa.eu/LCDN/EF_archive.xhtml

EP-marine Breakdown DN600

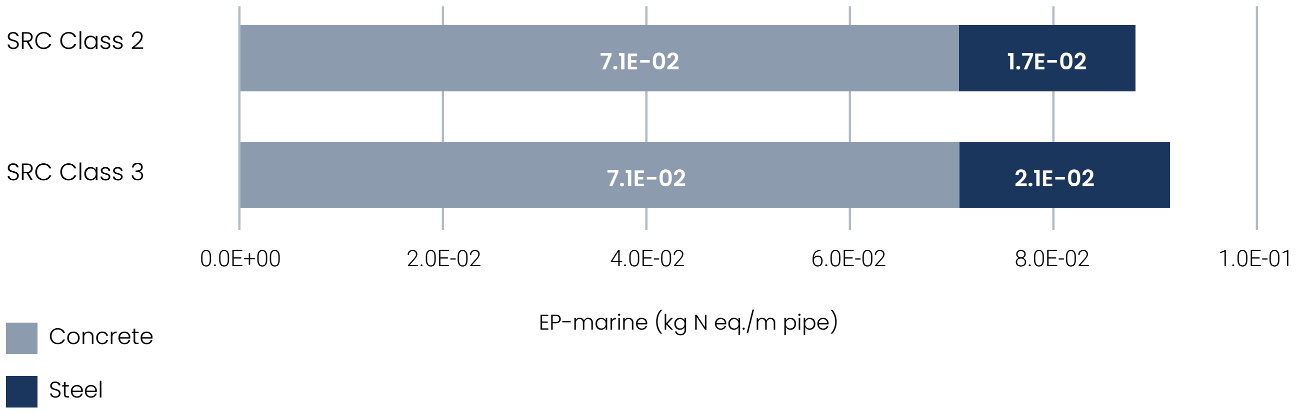

Figure 17: The breakdown of eutrophication (aquatic marine) of concrete pipes for the size of DN 600

EP-marine Breakdown DN600

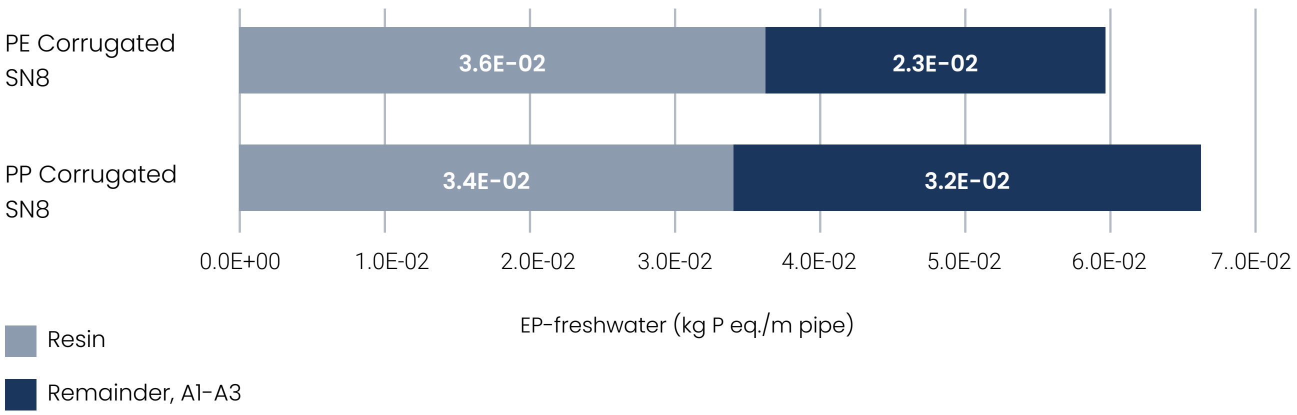

Figure 18: The breakdown of eutrophication (aquatic marine) of plastic pipes for the size of DN 600

7.1.6. Eutrophication – terrestrial

This indicator measures the eutrophication of terrestrial ecosystems due to airborne nitrogen deposition. The airborne nitrogen oxides and ammonia emissions originating from air pollution can lead to airborne nitrogen deposition in ecosystems. Excessive atmospheric nitrogen loads can result in the increased growth of species, including in sensitive terrestrial ecosystems such as grassland. Consequently, the habitat structure and function can be impacted[17].

The terrestrial eutrophication trend is similar to marine eutrophication. As shown in Figure 19, plastic pipes have lower terrestrial eutrophication compared to concrete pipes.

The breakdown of terrestrial eutrophication shows that the production of concrete causes a significant amount (Figure 20 and Figure 21).

According to EF 3.0 normalisation software package (November 2019)[18], the terrestrial eutrophication per capita (global average) per year is 175.74 mol N eq. Benchmarking against plastic pipes, the terrestrial eutrophication values of plastic pipes are three orders of magnitude lower than that of yearly terrestrial eutrophication per capita.

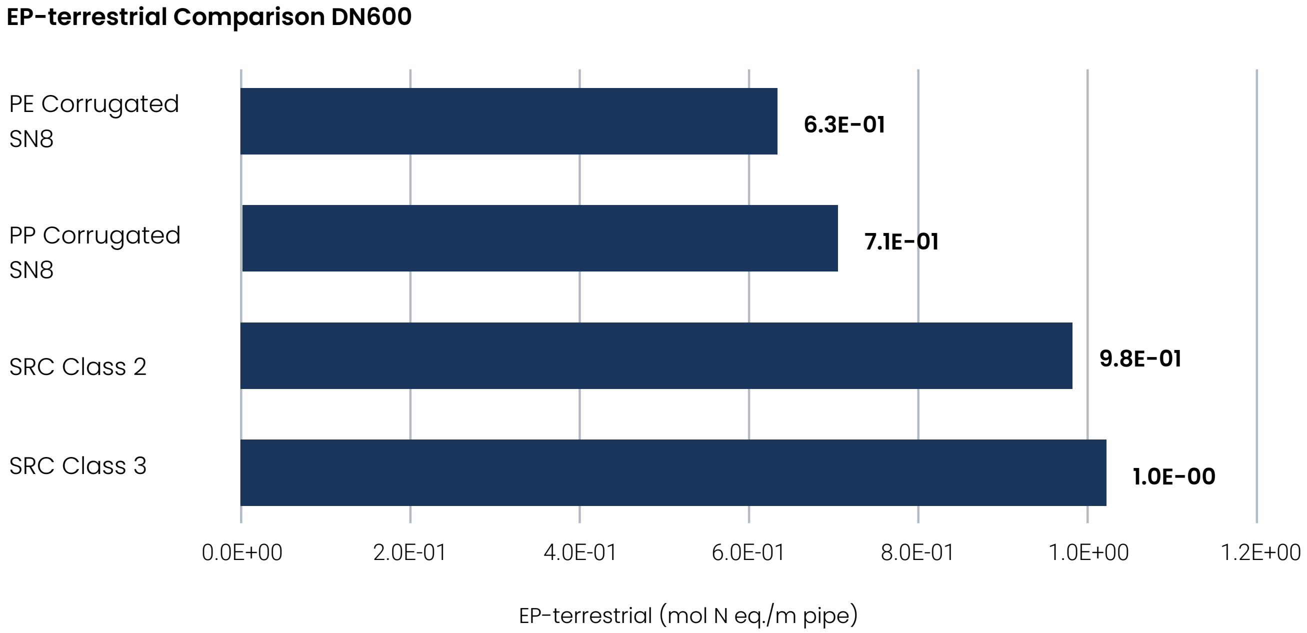

Figure 19: Eutrophication (terrestrial) comparison of plastic pipes with concrete pipes for the size of DN 600

17 European Environment Agency (2021) Eutrophication of terrestrial ecosystems due to air pollution, https://www.eea.europa.eu/airs/2018/natural-capital/eutrophication-of-terrestrial-ecosystems
18 European Platform on LCA (2019), EF 3.0 normalisation values, https://eplca.jrc.ec.europa.eu/LCDN/EF_archive.xhtml l

EP-terrestrial Breakdown DN600

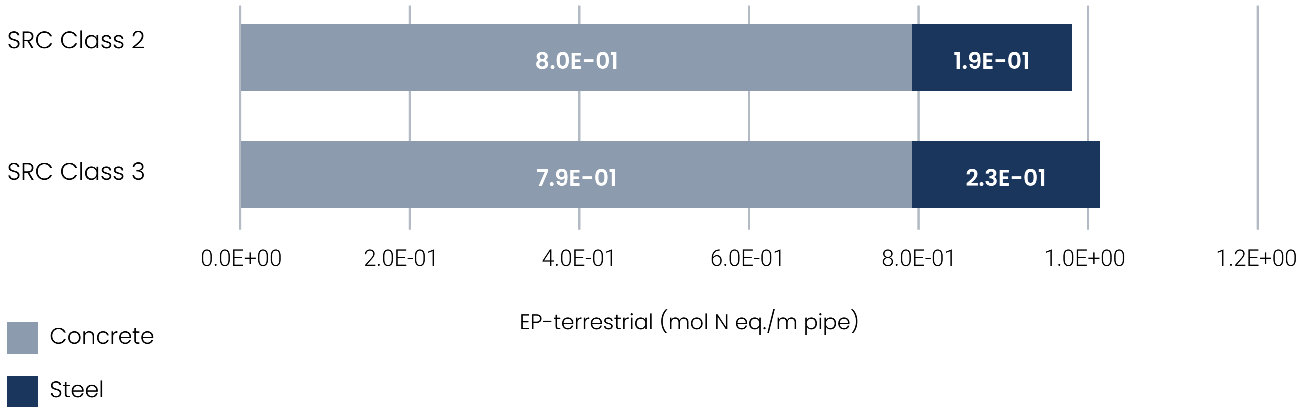

Figure 20: The breakdown of eutrophication (terrestrial) of concrete pipes for the size of DN 600

EP-terrestrial Breakdown DN600

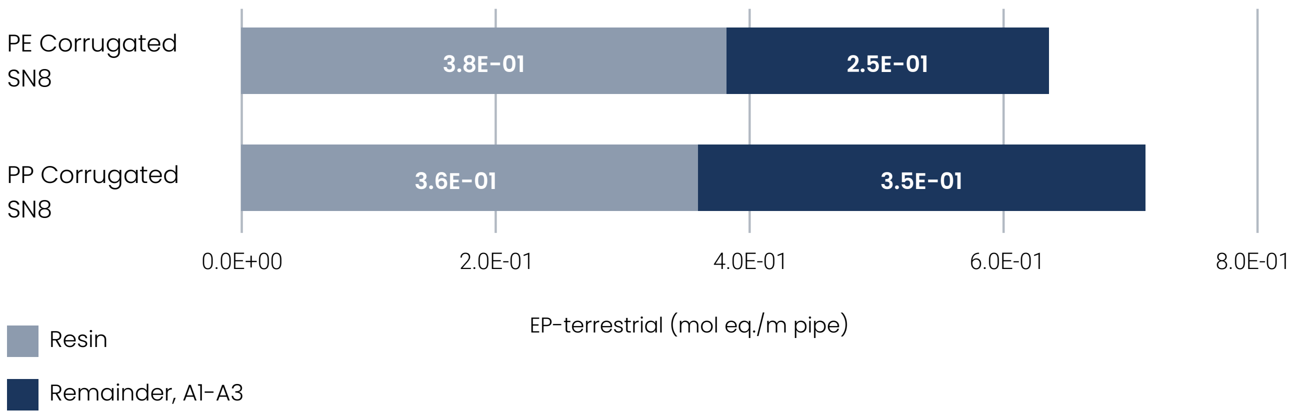

Figure 21: The breakdown of eutrophication (terrestrial) of plastic pipes for the size of DN 600

7.1.7. Photochemical ozone formation potential (POCP)

This indicator measures undesired ozone formation in the lower atmosphere (troposphere). While stratospheric ozone protects us against ultraviolet (UV) light, tropospheric ozone formation impacts our ecosystem, including crop damage and the development of respiratory issues such as asthma.

In the presence of sunlight, ozone can be created in the troposphere where chemicals such as nitrogen oxides (NOx) and volatile organic compounds (VOCs) are present. This indicator is often referred to as 'summer smog'. Chemical factories usually produce NOx and VOCs by burning fossil fuels[19].

In addition, energy production from biofuels, fossil fuels and biomass also produce NOx and VOCs.

Figure 22 shows a comparison of photochemical ozone formation between plastic and concrete pipes. Photochemical ozone formation by plastic pipes is lower compared to concrete pipes. In the case of concrete pipes, the production of concrete is primarily responsible for the photochemical ozone formation (Figure 23). In plastic pipes, the source is primarily plastic resins (Figure 24).

19 Environmental Protection Agency (2024) Sources of Hydrocarbon and NOx Emissions in New England, https://www3.epa.gov/region1/airquality/piechart.html

POCP Comparison DN600

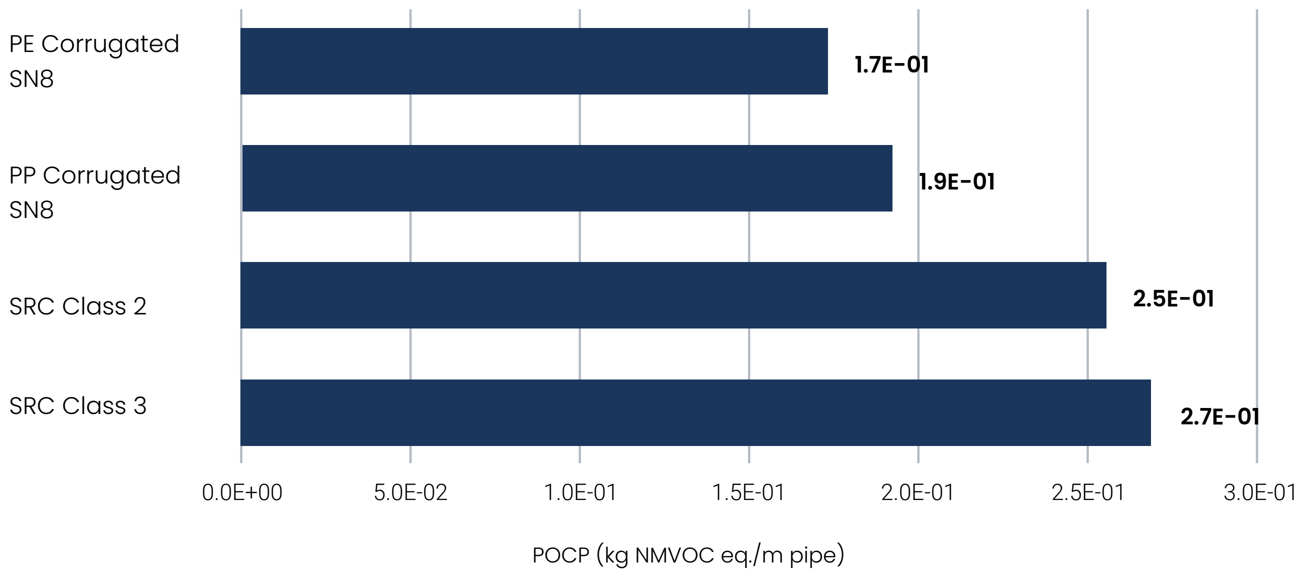

Figure 22: Photochemical ozone formation comparison of plastic pipes with concrete pipes for the size of DN 600

POCP Breakdown DN600

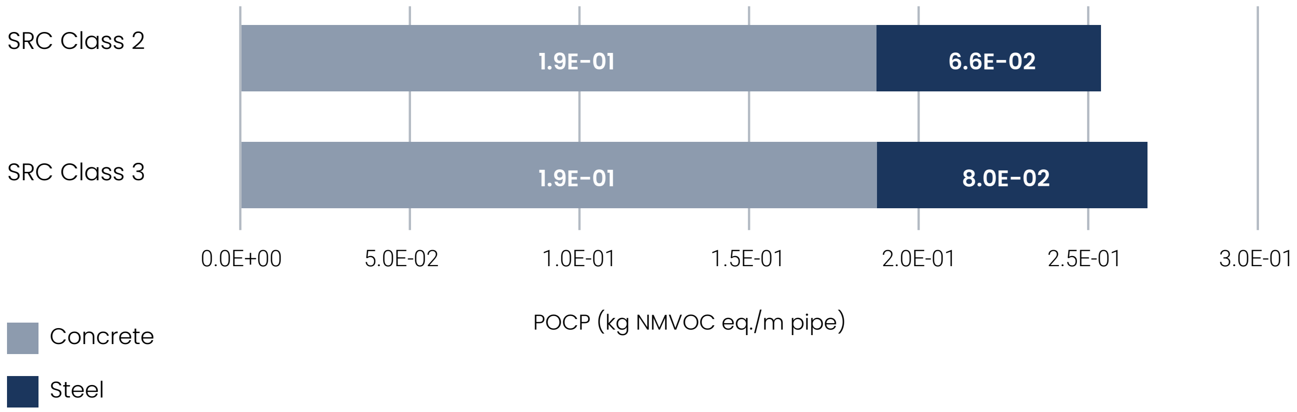

Figure 23: The breakdown of photochemical ozone formation of concrete pipes for the size of DN 600

POCP Breakdown DN600

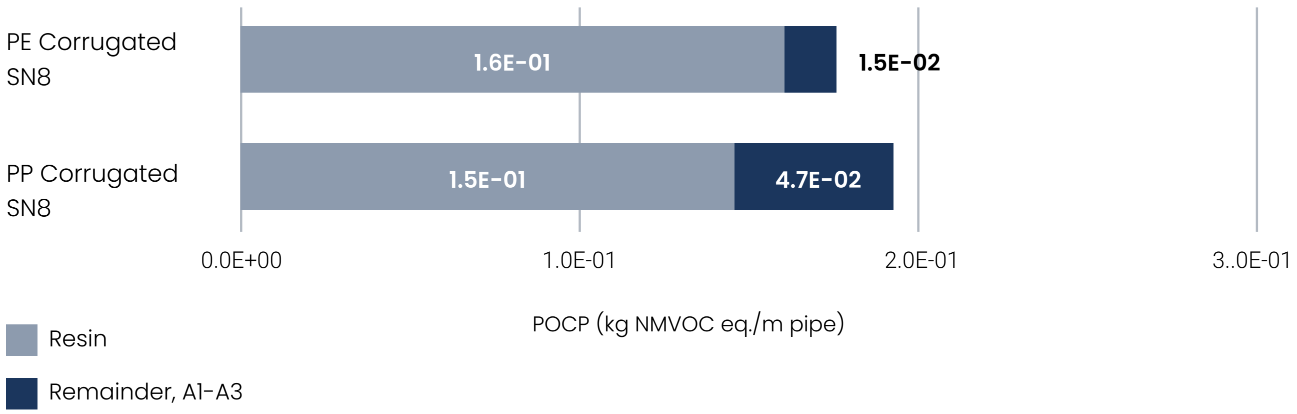

Figure 24: The breakdown of photochemical ozone formation of plastic pipes for the size of DN 600

7.1.8. Abiotic depletion potential (metals and minerals)

Our planet has a finite storage of abiotic materials such as aggregates, metal ores and minerals. Due to the continual extraction of these materials, they'll become unavailable for use by future generations. The abiotic depletion potential (metals and minerals) indicator measures the extraction of these abiotic materials and addresses their scarcity.

The abiotic depletion of materials is much higher for plastic pipes when compared to concrete pipes (Figure 25). The production of plastic resins is a major contributor to the abiotic depletion of materials for plastic pipes (Figure 27). The detailed analysis shows that the construction of chemical factories for the production is primarily responsible as this requires chemical cement, aggregate and metals. Compared to concrete pipes, the production of steel is the main contributor to the abiotic depletion of materials.

While there's a high level of uncertainty in the results of abiotic depletion potentials (metals and minerals), the significant difference between concrete and plastic pipes indicates that the relative difference isn't expected to change.

ADP - metals and minerals comparison DN600

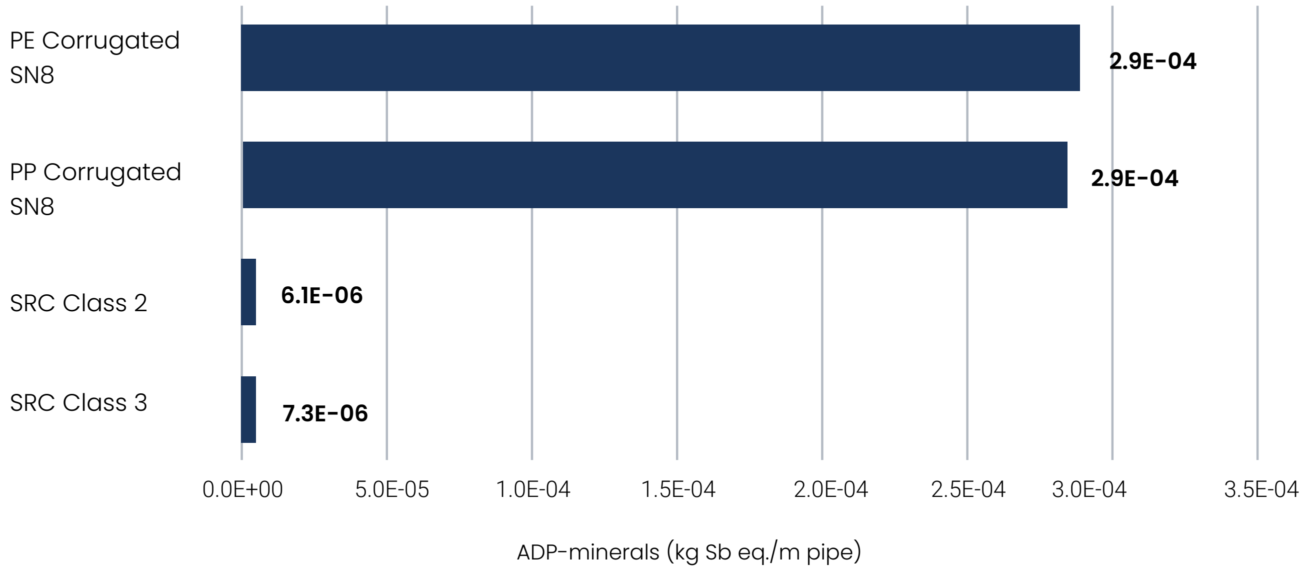

Figure 25: Abiotic depletion potential (metals and minerals) comparison of plastic pipes with concrete pipes for the size of DN 600

ADP - metals and minerals breakdown DN600

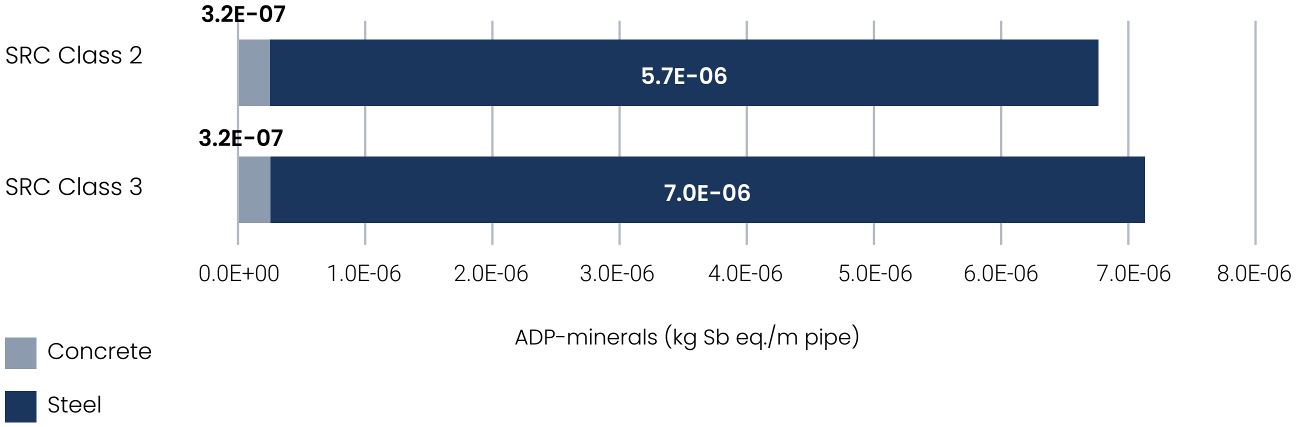

Figure 26: The breakdown of abiotic depletion potential (metals and minerals) of concrete pipes for the size of DN 600

ADP - metals and minerals breakdown DN600

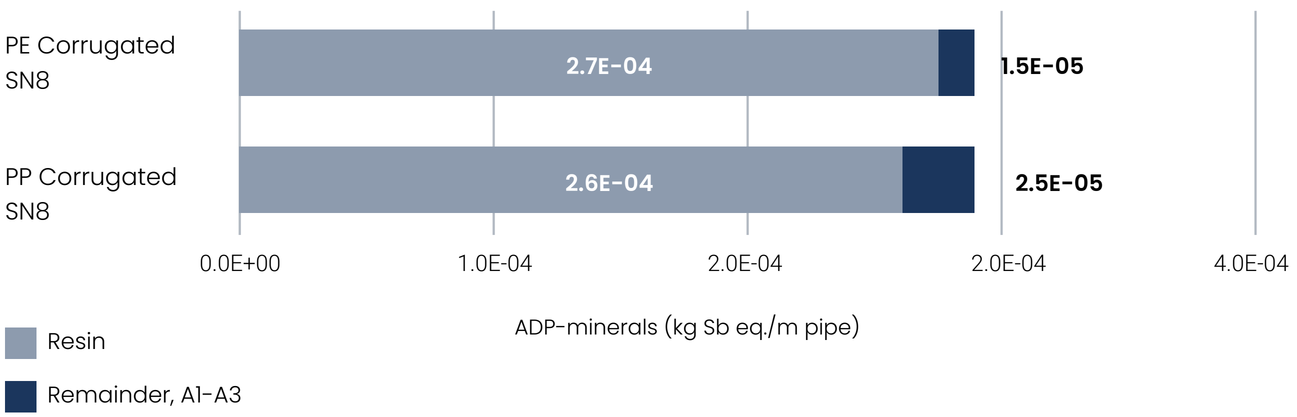

Figure 27: The breakdown of abiotic depletion potential (metals and minerals) of plastic pipes for the size of DN 600

7.1.9. Abiotic depletion potential (fossil resources)

Fossil fuels are raw materials used to manufacture commodities like plastics and synthetic rubber. Although renewable energy is emerging, we still rely on fossil fuels in the energy sector. The continual use of fossil fuels, which are finite resources, makes them unavailable for future generations. The indicator abiotic depletion potential (fossil resources) or ADP-fossil measures the extraction of fossil resources and addresses the scarcity of them.

Figure 28 shows that the abiotic depletion potential for fossil resources is higher for plastic pipes than concrete pipes. Figure 29 and Figure 30 show the breakdown of ADP-fossil for the product stage of the pipes.

In the case of plastic pipes, the production of resins are primary contributors to abiotic potentials for fossil resources (Figure 30). A deeper analysis shows that the production of monomers, such as ethylene in the case of polyethylene, consumes significant abiotic fossil resources. In the case of concrete pipes, the production of both concrete and steel requires noticeable abiotic fossil resources (Figure 29).

Similar to abiotic depletion potentials (metals and minerals), while there's a high level of uncertainties in the results of abiotic depletion potentials (fossil resources), the significant difference between concrete and plastic pipes indicates that the relative difference isn't expected to be changed.

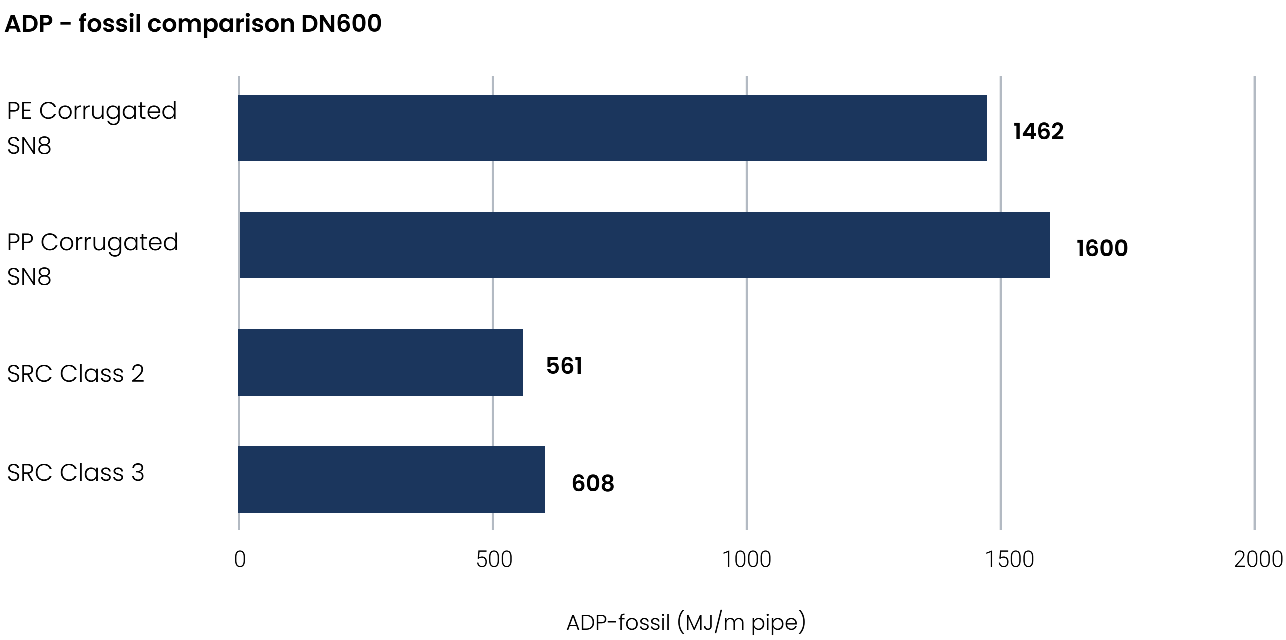

Figure 28: Abiotic depletion potential (fossil resources) comparison of plastic pipes with concrete pipes for the size of DN 600

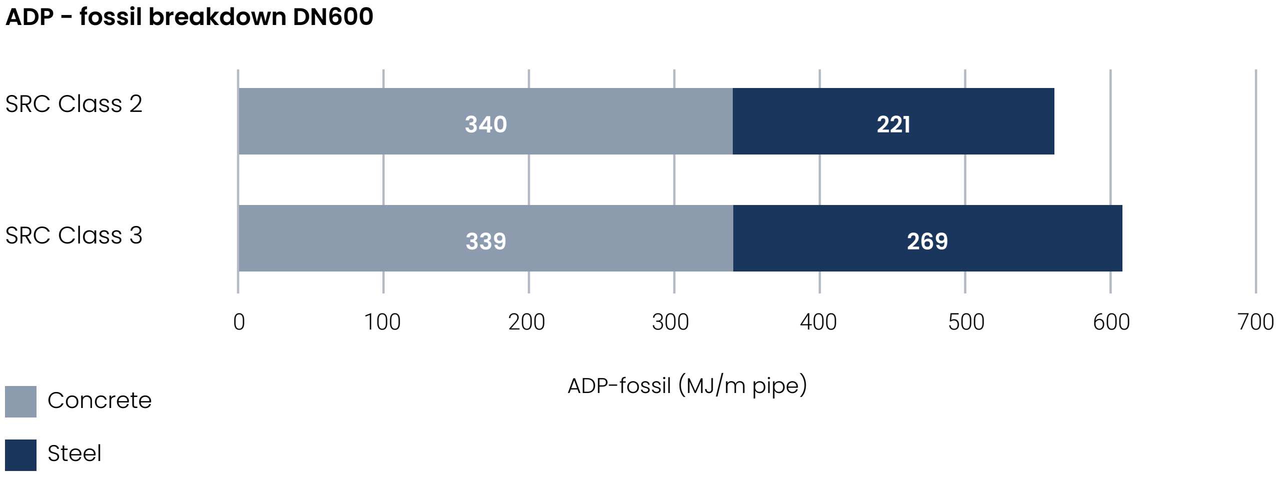

Figure 29: The breakdown of abiotic depletion potential (fossil resources) of concrete pipes for the size of DN 600

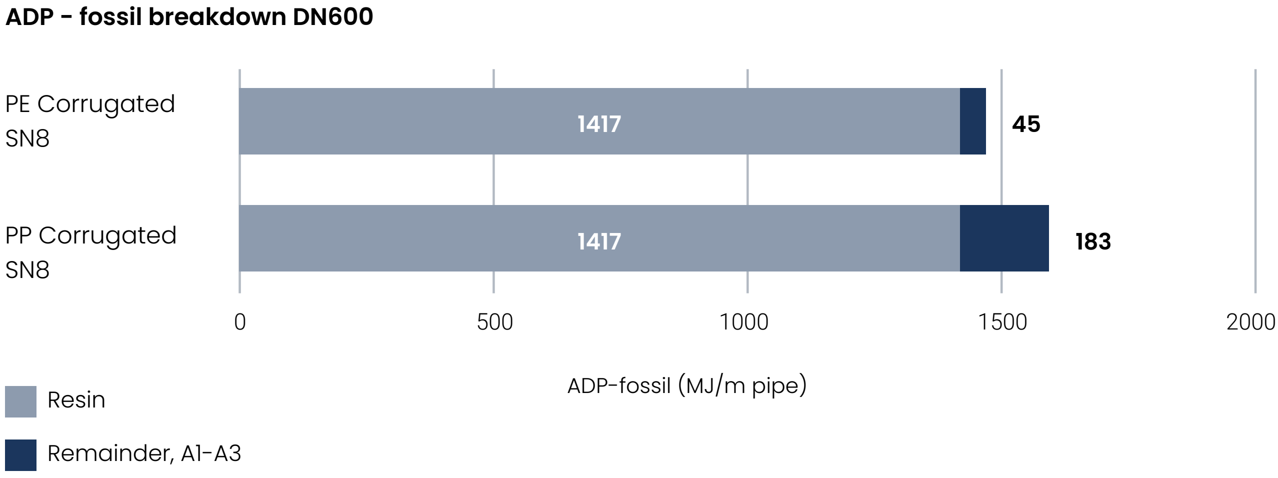

Figure 30: The breakdown of abiotic depletion potential (fossil resources) of plastic pipes for the size of DN 600

7.1.10. Use of net freshwater

This indicator models the reduction of freshwater availability to ecosystems. The removal of water from water bodies such as rivers, lakes, reservoirs and aquifers can disrupt ecosystems. Water withdrawn from these sources may be evaporated, transformed into products or transferred to other watersheds or seas.

The production of concrete pipes uses nearly double the amount of net freshwater compared to the production of plastic pipes (Figure 31). The breakdown shows that the production of concrete requires significant freshwater (Figure 32). In plastic pipes, the production of plastic resins requires noticeable freshwater (Figure 33).

FW comparison DN600

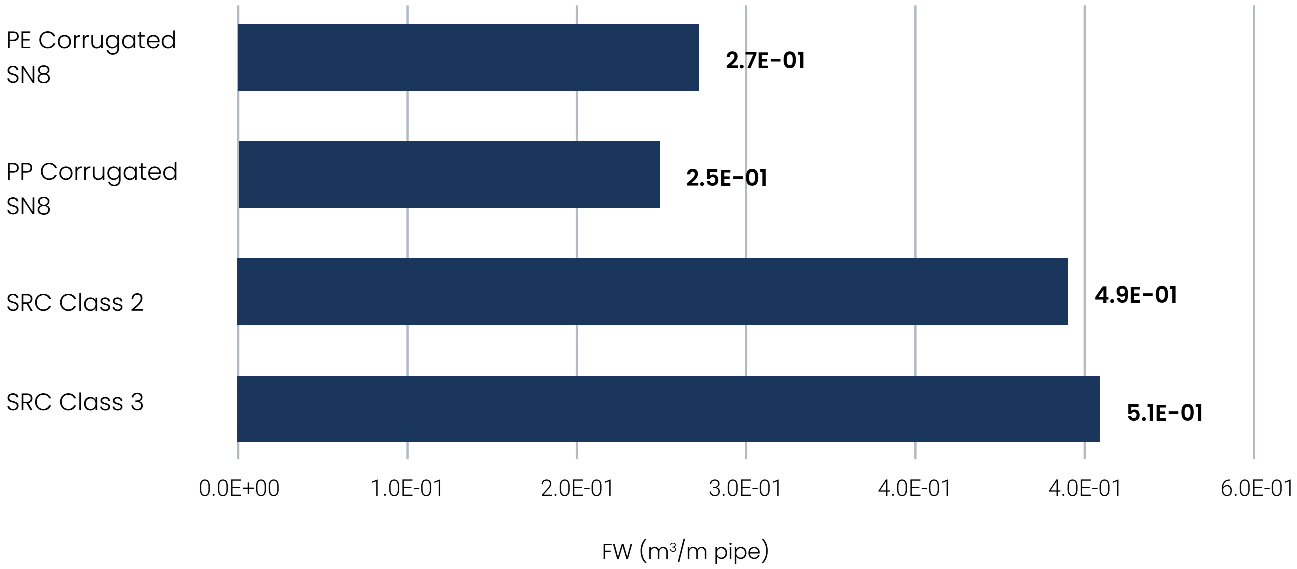

Figure 31: Use of net freshwater comparison of plastic pipes with concrete pipes for the size of DN 600

FW breakdown DN600

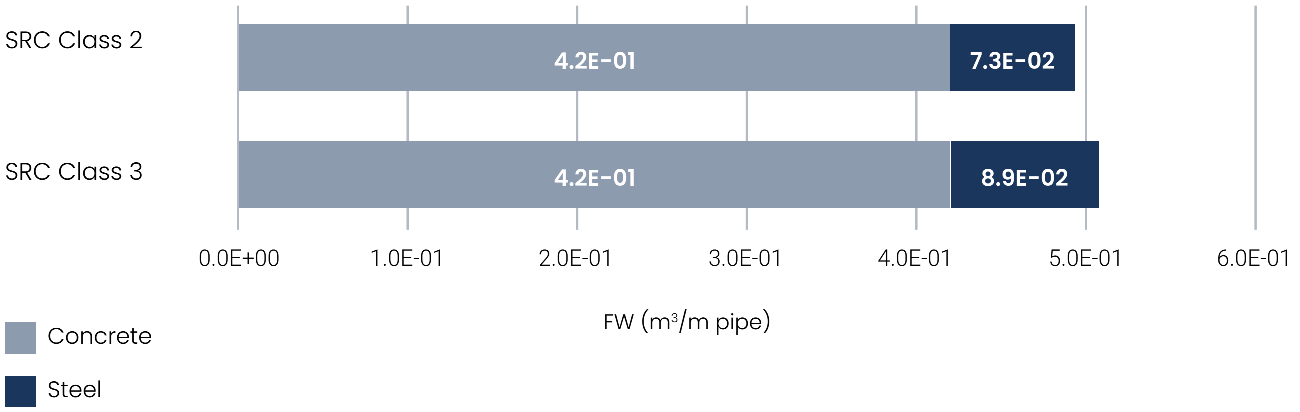

Figure 32: The breakdown of use of net freshwater of concrete pipes for the size of DN 600

FW breakdown DN600

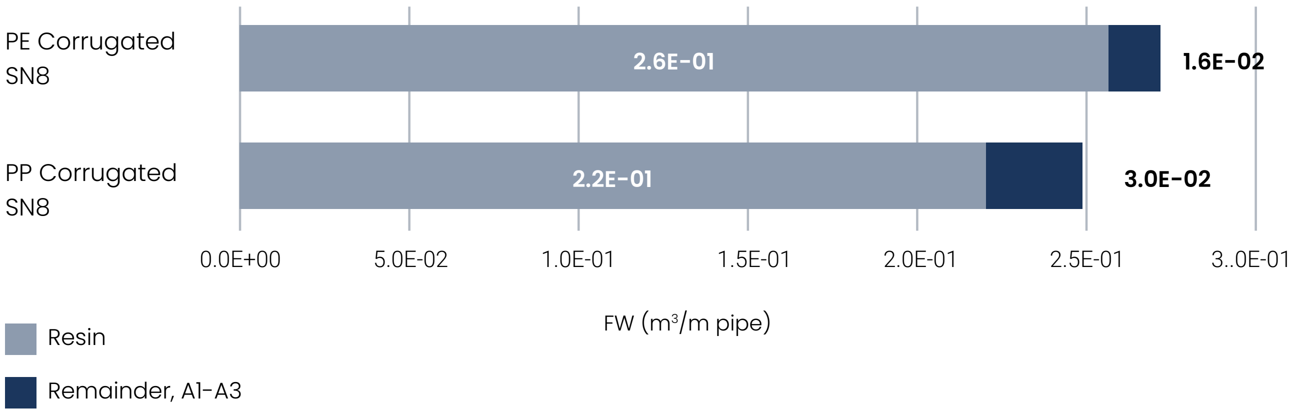

Figure 33: The breakdown of use of net freshwater of plastic pipes for the size of DN 600

7.1.11. Hazardous waste disposed

Hazardous waste can cause serious harm to ecosystems, and the waste generated in the production of a product requires special treatment. The value of the indicator hazardous waste disposed (HWD) represents the amount of hazardous waste that needs to be disposed of. However, the method of disposal depends on the local guidelines. For example, the European Union follows a waste framework directive[20]. In Australia, every state and territory has its own waste disposal guidelines. In New South Wales, the EPA provides waste disposal guidelines[21].

Figure 34 shows that the HWD values to produce plastic pipes are significantly higher than those of concrete pipes.

The breakdowns of HWD for the product stage of the pipes are presented in Figure 35 and Figure 36. The production of plastic resins, as well as products from those resins, generates significant hazardous wastes, as evident in Figure 36.

In contrast, there's nearly no noticeable hazardous waste produced in the production of concrete. However, steel production leads to noticeable production of hazardous wastes as presented in Figure 35. Hazardous waste generated in the production of plastic resins include spent catalyst, solvent (e.g., hexane) and other chemicals .

HWD comparison DN600

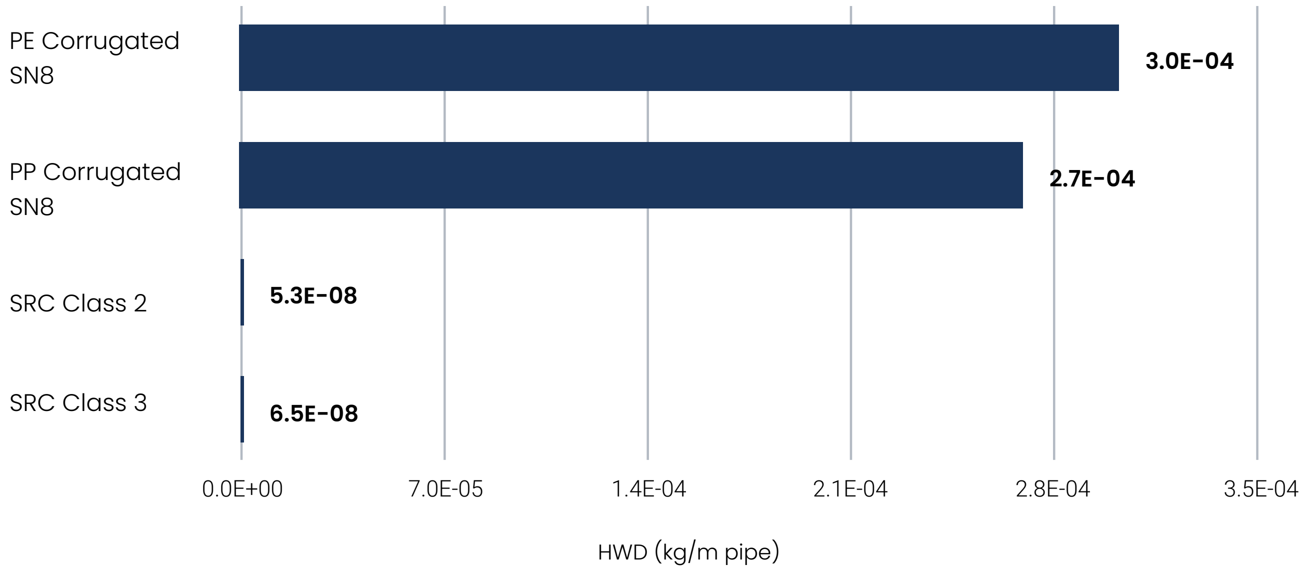

Figure 34: Hazardous waste disposed comparison of plastic pipes with concrete pipes for the size of DN 600

20 European Commission (2023), Waste Framework Directive, https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

21 NSW Environment Protection Authority (2021), Waste classification guidelines, https://www.epa.nsw.gov.au/your-environment/waste/classifying-waste/waste-classification-guidelines

HWD breakdown DN600

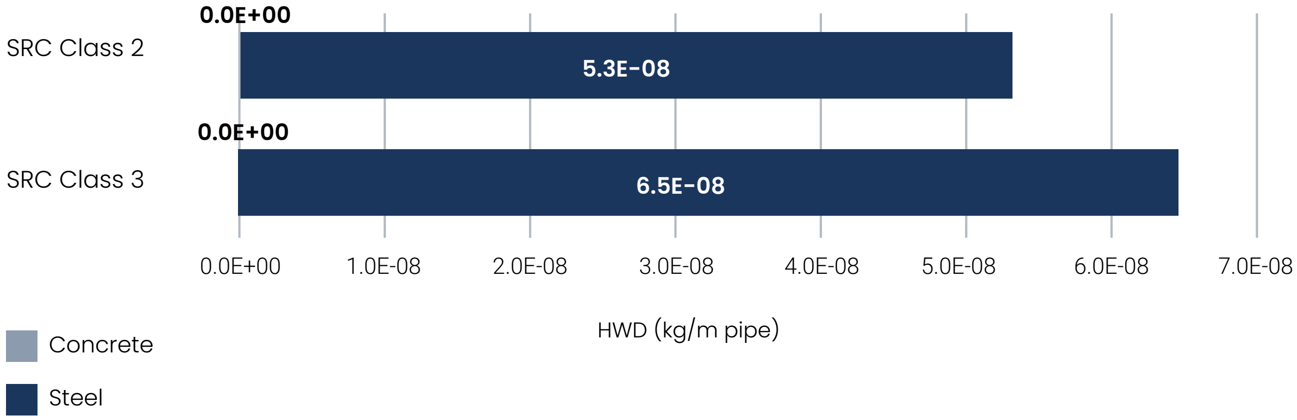

Figure 35: The breakdown of hazardous waste disposed of concrete pipes for the size of DN 600

FW breakdown DN600

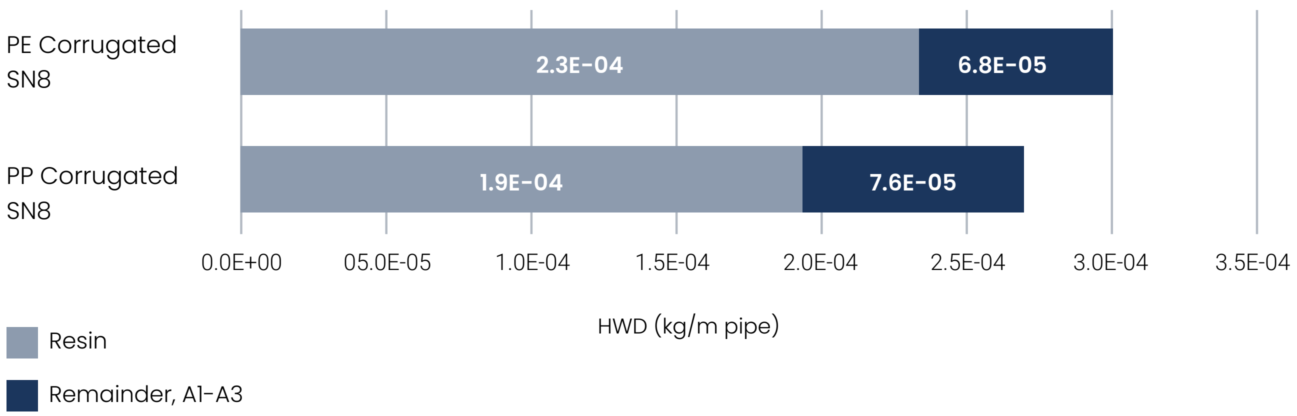

Figure 36: The breakdown of hazardous waste disposed of plastic pipes for the size of DN 600

7.1.12. Non-hazardous waste disposed

The non-hazardous waste disposed (NHWD) indicator measures the quantity of non-hazardous waste produced and disposed of during the manufacture of a product.

The value of NHWD represents the amount of non-hazardous waste that needs to be disposed of. However, the method of disposal depends on local guidelines. For example, the European Union follows a waste framework directive[22]. In Australia, every state and territory has its own waste disposal guidelines. In New South Wales, the EPA provides waste disposal guidelines[23].

Apart from Class 3 SRC pipes, the non-hazardous waste production during the manufacture of plastic pipes and concrete pipes is similar (Figure 37). Figure 38 and Figure 39 show the breakdown of NHWD for the product stage of the pipes. In the case of concrete pipes, the highest non-hazardous waste production originates from the production of steel (Figure 38). For plastic pipes, the production of plastic resins is the primary source of non-hazardous waste production (Figure 39). Non-hazardous waste generated in plastic resin production includes used containers, paper bags, wooden pallets, anthracite, used ion-exchange resins and cooling tower packing (Abbasi & Kamalan, 2018).

NHWD comparison DN600

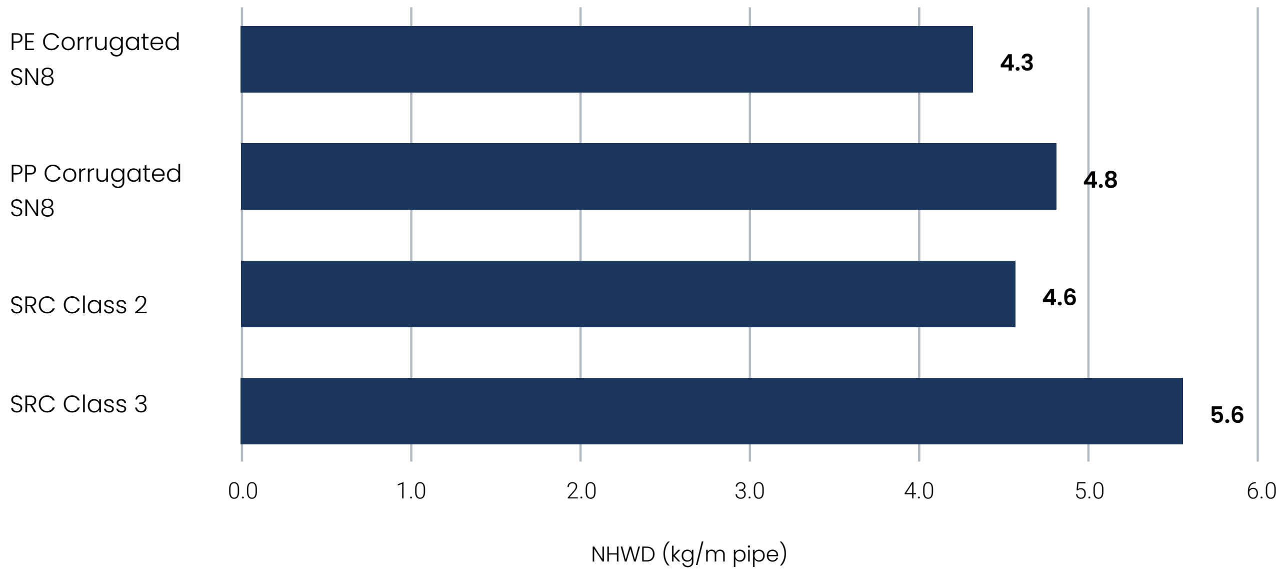

Figure 37: Non-hazardous waste disposed comparison of plastic pipes with concrete pipes for the size of DN 600

22 European Commission (2023), Waste Framework Directive, https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

23 NSW Environment Protection Authority (2021), Waste classification guidelines, https://www.epa.nsw.gov.au/your-environment/waste/classifying-waste/waste-classification-guidelines

NHWD breakdown DN600

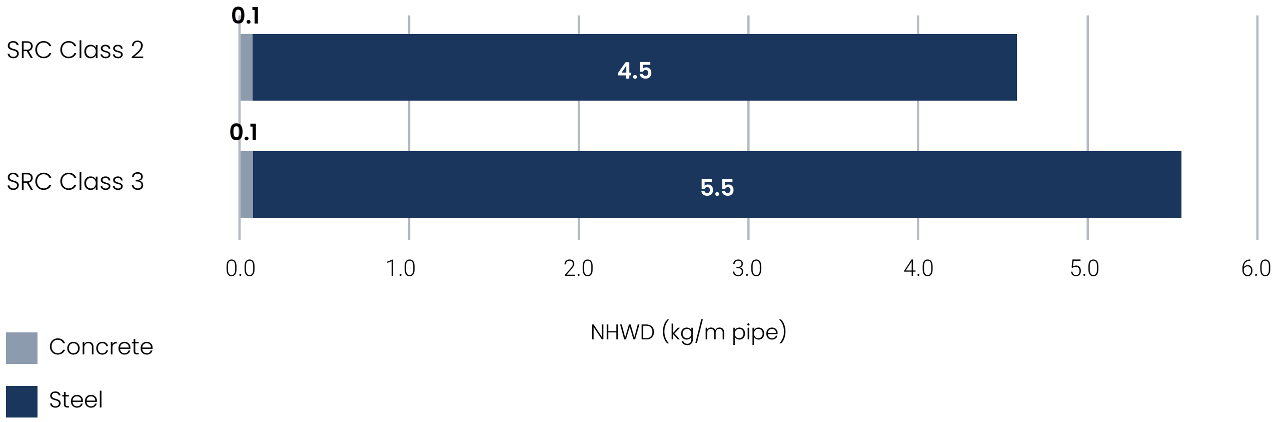

Figure 38: The breakdown of non-hazardous waste disposed of concrete pipes for the size of DN 600

NHWD breakdown DN600

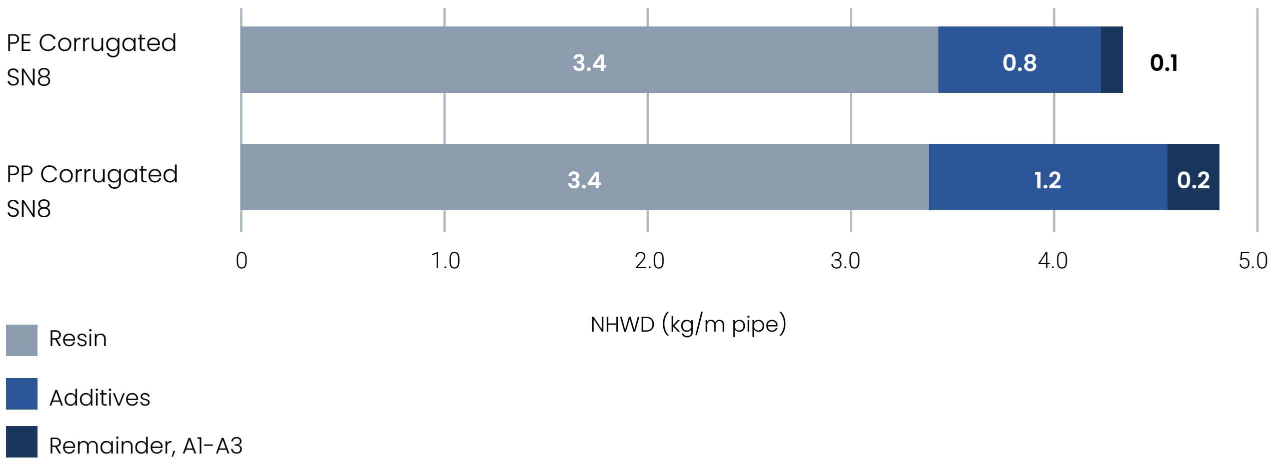

Figure 39: The breakdown of non-hazardous waste disposed of plastic pipes for the size of DN 600

7.1.13. Radioactive waste disposed

Radiation poisoning by radioactive materials can cause serious damage to ecosystems. One major source of radioactive waste is nuclear power plants. The spent fuel from nuclear power plants can be highly radioactive requiring more than a few thousand years of safe storage. The 'radioactive waste disposed' (RWD) indicator measures the quantity of radioactive waste produced and disposed of during the manufacture of a product.

This impact category is of lower concern in Australia as the radioactive waste values indicate its presence in the overseas supply chain. In the case of polypropylene and polyethylene pipes, nuclear energy-based electricity used to produce resins is the primary source of radioactive waste. The background LCA data used for resin productions indicates that nuclear energy-based electricity produced in China, the USA, Canada and Europe are the sources of radioactive waste values of plastic resin productions.

Figure 40 shows that the radioactive waste generated during the production of PP pipes and SRC Class 3 pipes is similar. While SRC Class 2 pipes generate the lowest radioactive waste, PE pipes generate the highest.

The breakdowns of RWD for the product stage of the pipes are presented in Figure 41 and Figure 42. In the case of concrete pipes, there's no noticeable radioactive waste produced during the production of concrete (Figure 41). However, the production of steel generates noticeable radioactive waste. In the case of plastic pipes, the production of plastic resins generates significant radioactive waste (Figure 42). The remainder (A1-A3) component of PE pipe includes the production of carbon black, pipe manufacturing energy and waste. Most radioactive waste in this remainder (A1-A3) component comes from the production of carbon black.

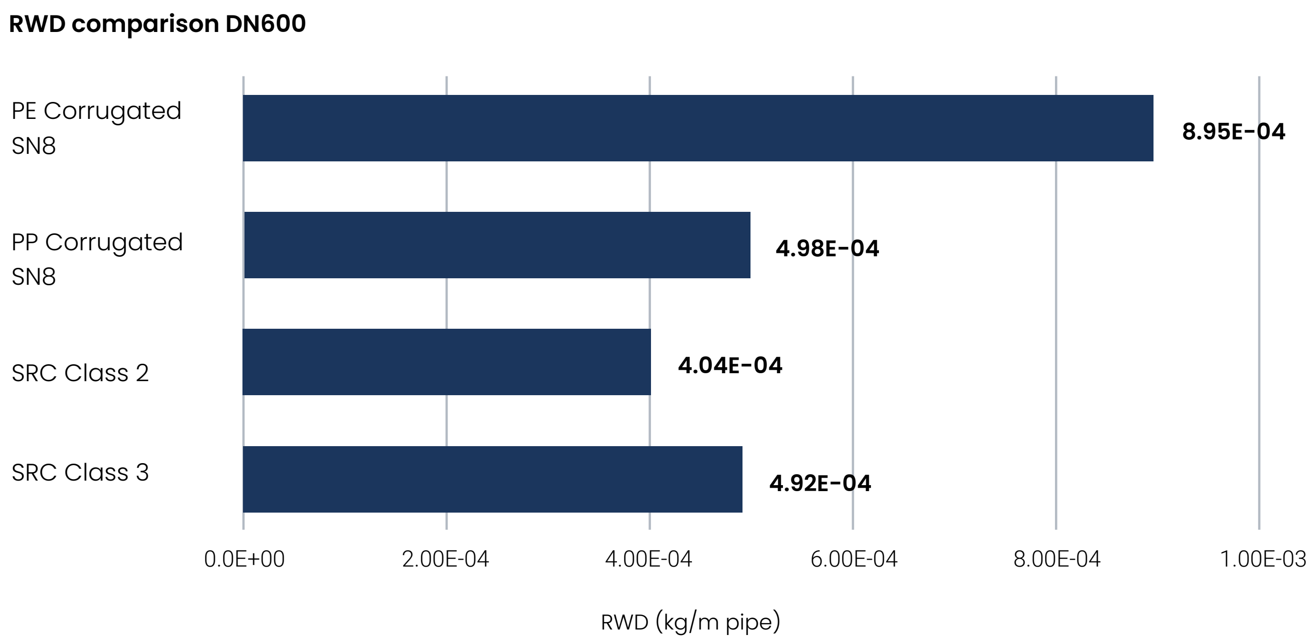

Figure 40: Radioactive waste disposed comparison of plastic pipes with concrete pipes for the size of DN 600

RWD breakdown DN600

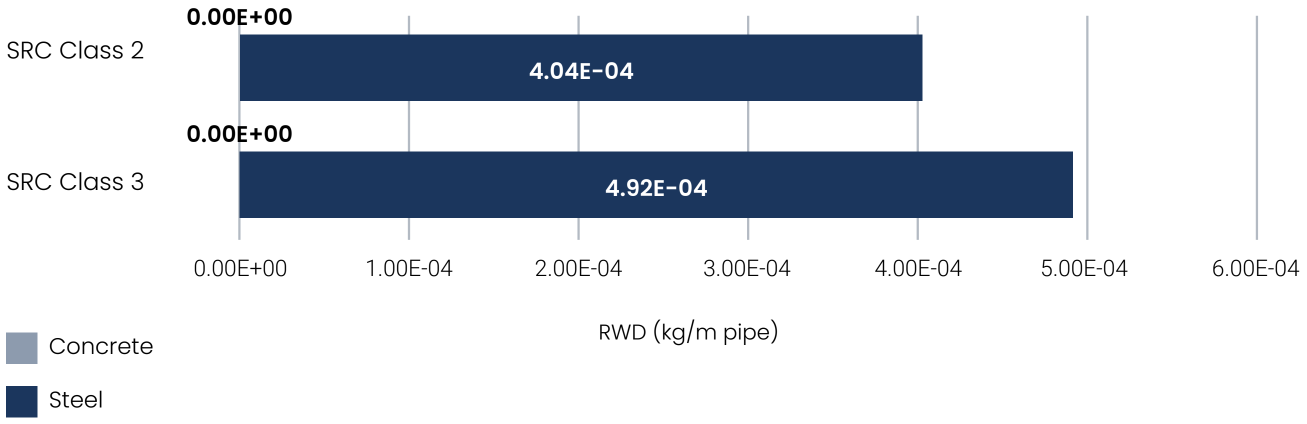

Figure 41: The breakdown of radioactive waste disposed of concrete pipes for the size of DN 600

RWD breakdown DN600

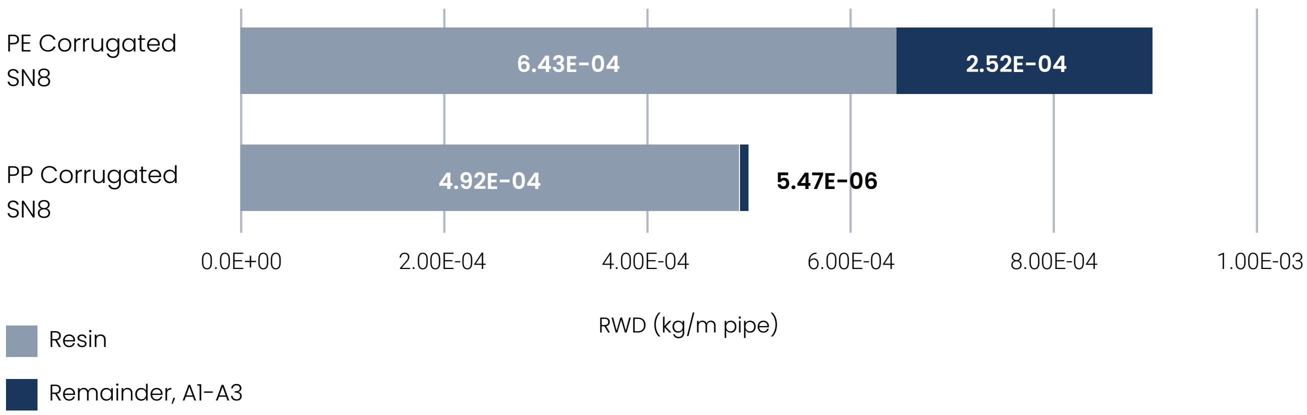

Figure 42: The breakdown of radioactive waste disposed of plastic pipes for the size of DN 600

7.1.14. Summarised comparison of all indicators reported

The results presented between sections 7.1.1 and 7.1.13 are summarised in Table 8. As evident in this table, both plastic pipes and concrete pipes perform well across several indicators.

In the case of radioactive waste, the performance of both types of pipes becomes almost similar for DN 900 (Appendix C). This is due to the relatively high steel requirement for DN 900 compared to DN 375 and DN 600.

Table 8: Comparison of midpoint selected indicators for plastic and concrete pipes for DN 600

IMPACT CATEGORY	ABBREVIATION	PLASTIC PIPES	CONCRETE PIPES
Total global warming potential	GWP - Total	↑	↓
Acidification potential	AP	—	—
Eutrophication – aquatic freshwater	EP - freshwater	↓	↑
Eutrophication – aquatic marine	EP - marine	↑	↓
Eutrophication – terrestrial	EP – terrestrial	↑	↓
Photochemical ozone creation potential	POCP	↑	↓
Abiotic depletion potential (elements)	ADPE	↓	↑
Abiotic depletion potential (fossil fuels)	ADPF	↓	↑
Ozone depletion potential	ODP	↓	↑
Use of net fresh water	FW	↑	↓
Hazardous waste disposed	HWD	↓	↑
Non-hazardous waste disposed	NHWD	↑	↓
Radioactive waste disposed/stored	RWD	↓	↑

↑ **performing better** ↓ **performing worse** — **inconclusive**

The comparison presented in Table 8 shows that plastic pipes are performing well in both GWP and FW environmental impact categories. According to the Green Star Buildings Submission Guidelines[24], the weighting factor[25] is 25% for both GWP and FW. The Infrastructure Sustainability Council (ISC) uses weighting for their material calculator, with a weighting factor of 47.5% for GWP[26]. The ISC material calculator doesn't include a FW indicator. The comparison shows that plastic pipes have a demonstrable advantage in the environmental categories of highest priority.

The BRE assessment[27] also concluded that GWP and FW parameters convey the topmost environmental concerns. BRE's weighting factors for GWP and FW are 24.1 and 15.2, respectively. They additionally noted that the ranking of leading issues has not changed since its previous assessment in 2008.

24 Green Star Buildings Submission Guidelines, Version 1: Revision B, 10 December 2021

25 Normalisation and weighting are often used in comparative LCA to get a single environmental performance score. When the environmental impact values of a product are normalised with annual impacts caused by one citizen, the mathematical process is known as normalisation. The normalised values are then weighted to get a single environmental impact score. The weighting factors are determined based on the importance of environmental indicators. The EPD results weren't transformed to single score in this report. This is because the EN 15804 + A2 complaint EPDs results aren't available for normalisation and weighting.

26 Infrastructure Sustainability Council (2018), ISv2.0 Materials Calculator Guideline, https://d3n8a8pro7vhmx.cloudfront.net/themes/5a72941f5ee54d4c43000000/attachments/original/1533001335/2018-02-21_ISCA_Materials_Guideline_Version_2.0_Rev_0.pdf?1533001335

27 Abbe, O. and Hamilton, L., 2017. BRE Global Environmental Weighting for Construction Products using Selected Parameters from EN 15804. BRE Global Ltd.: Hertfordshire, UK.

7.2. DOWNSTREAM TRANSPORT (MODULE A4)

Downstream transport refers to product distribution and transportation from the manufacturing plant to the building site. A few factors can affect the results of downstream transport, including the weight of the product, transport load, transport type and the distance. As evident in Table 1, the weight of concrete pipe per metre is much higher than that of plastic pipes. So, plastic pipes are expected to have less environmental impact when it comes to downstream transport.

As the downstream transport environmental impacts weren't included in the EPD for RCPA SRC pipes, they were sourced from the Holcim EPD (Holcim, 2017). This version of the Holcim EPD was published with the EN 15804+A1 version of EPD, so it wasn't used to compare product stage data. As the indicators of EN 15804+A1 and EN 15804+A2 aren't completely aligned, only GWP was selected for downstream transport comparison.

Table 9 shows GWP comparison for the downstream transport of DN 600 pipes. The EPD for Vinidex PE pipes presents an average downstream transport environmental footprint for PE pipes for various uses, including agriculture, industrial and gas applications.

As this report is focused on drainage pipes only, the downstream transport environmental footprint of PP pipes is representative of both PP and PE pipes. The environmental impact of PP and PE pipes in Table 9 is the downstream transport environmental footprint for PP pipes as documented in the EPD for Vinidex PP pipes.

In the case of concrete pipes, there are two sets of A4 values in the Holcim EPD (Holcim, 2017): 1) A4 value for spun pipes produced in NSW/VIC/SA/WA/TAS and 2) A4 value for spun pipes produced in QLD/NT. The average GWP value of two data sets was used in the calculation and presented in Table 9. The QLD/NT A4 GWP value is lower than that of NSW/VIC/SA/WA/TAS (3.15 vs 3.55 kg CO_2 eq./tonne of pipe), lowering the overall A4 value. Also, Holcim A4 GWP value is based on their product weightage per metre and distribution patterns and may not be representative of RCPA pipes or concrete pipes produced by other companies.

The downstream GWP value is low compared to product stage GWP. As presented in the appendices, a similar trend of results has been found for 375 mm and 900 mm pipes. Concrete pipe class 3 has significant higher impacts on GWP.

Table 9 | Environmental impacts of module A4 for 600 mm pipes (concrete pipe data is from (Holcim, 2017)

INDICATOR	RESULTS PER 1M OF 600MM PIPE		
	PP/PE	**Class 2**	**Class 3**
GWP	6.4	8.7	15.8

7.3. INSTALLATION (MODULE A5) – IMPACT OF BEDDING MATERIAL ON OVERALL IMPACT

This section of the report provides information for the impact of the use of different bedding materials in Module A5. The calculation of environmental impacts and resource use that apply to the buried installation of flexible and rigid (concrete) pipes is highly dependent on the specific details relating to a particular pipeline's design.

Variables include pipe diameters, length of the pipeline, terrain, geology, environmental conditions, trench depth, specified fill and embedment materials and the resulting installation techniques employed by the installing contractor. Given the significant number of variables, attempts to define an 'average' or 'typical' pipeline installation for the purpose of calculating environmental and resource impacts will be highly inaccurate. Additionally, it would be potentially misleading for the resulting numbers to be applied across a range of pipe diameters and buried pipeline installations and used for comparisons.

Uniform guidance on the correct design and installation of polypropylene and polyethylene non-pressure drainage pipes is provided in AS/NZS 2566.2 Buried flexible pipelines - Installation. Similar guidance covering the installation of concrete drainage pipes is provided in AS/NZS 3725 Design for Installation of Buried Concrete Pipes.

Both standards cover trench excavation and design, definition of fill and embedment zones and their respective compaction requirements and field testing of the installed pipeline. Installation design is also dependent on other factors including location, construction and traffic loadings and minimum design requirements specified by Infrastructure Agencies such as Road Authorities. In all cases, the diameter of the installed pipe significantly influences installation design, which directly influences environmental impacts associated with buried pipeline construction.

LCA modelling of one assumed scenario shows the relative contribution of key construction factors in the chart below. In many cases, the specifier and constructor can influence these factors and the overall environmental impact of pipe installation. For example, in the modelled scenario, the embedment material is assumed to be crushed rock. However, embedment materials with lower environmental impacts could be selected, as discussed below.

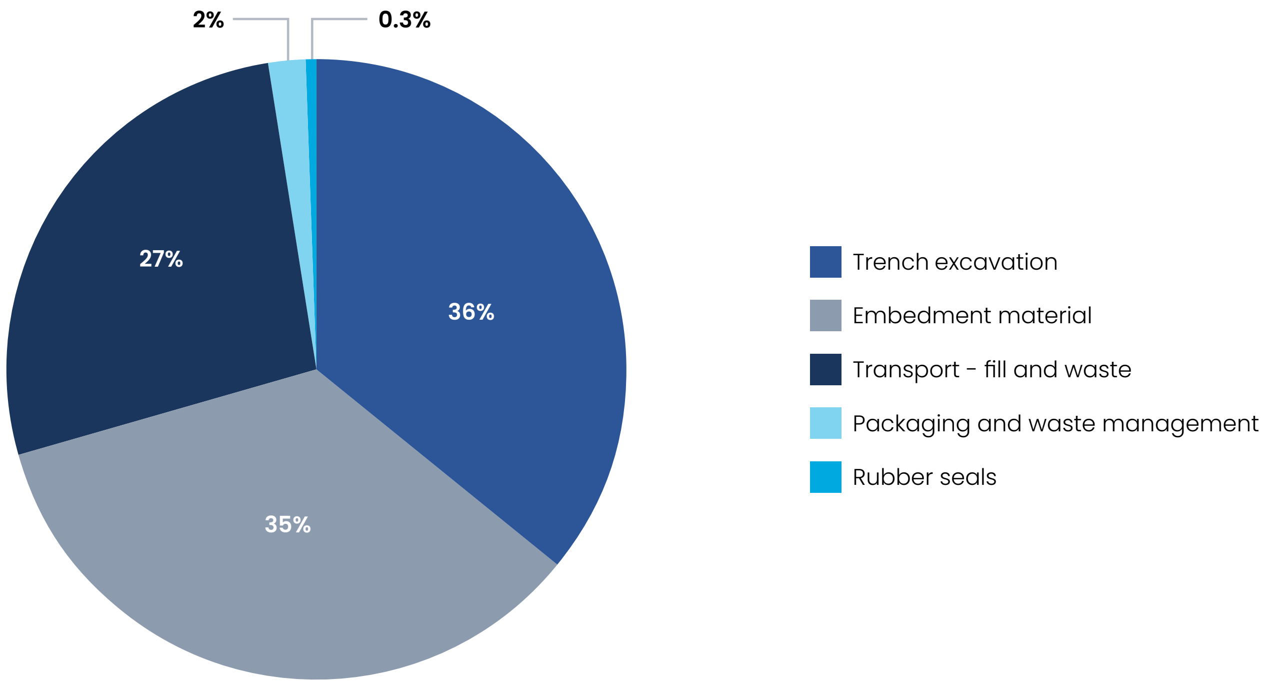

Figure 43 I Relative contribution of construction factors to Global Warming Potential (kg m^3/lineal m eq.)[28]

28 Embedment material: crushed rock was assumed; trench excavation: diesel used in excavator (12-20 tonne) at a rate of 20 litre/h; Transport – fill and waste: a transport distance of 50 km was assumed.

Many factors must be considered to gain a true picture of environmental impacts and resource use. Given that most of these factors are in the control of pipeline designers, infrastructure agencies and installing contractors, the A5 installation model will not be covered, other than to outline the installation processes and highlight those factors that influence environmental and resource impacts.

As expected, there are some differences when it comes to designing and installing buried flexible pipes compared to rigid pipes. Some of these are seen in the recommended trench dimensions and the type and amount of fill material required around the pipe.

A more detailed summary of the construction factors influencing environmental impacts are outlined below:

i. Trench excavation

Trench excavation, in particular diesel consumption by trenching excavators, governs most of the environmental and resource burden for the installation phase. It's strongly correlated to the size of the trench and the type and configuration of the excavator used. Additionally, various factors affect the efficiency of the excavator and speed of the excavation, including excavator bucket volume, bucket fill rate, cycle time, swing angle, type of excavated ground, site environment and weather conditions. Equipment choice and operational efficiency are under the control of the trenching contractor.

There are some differences when comparing the minimum trench dimensions specified in AS/NZS 2566.2 and AS/NZS 3752. For example, corrugated PP pipes require slightly larger trenches than concrete pipes in most cases (refer to Table 9). These differences tend to be less for small-diameter pipes but become more significant for larger diameters and are primarily related to the trench. However, some infrastructure authorities, such as VicRoads and Queensland Department of Main Roads, specify trench dimensions and embedment zones larger than the AS/NZS 3752 minimum, resulting in excavation volumes greater than those for corrugated SN8 PP / PE pipes (refer to Table 10 for comparison with QDTMR).

Table 9 | Environmental impacts of module A4 for 600 mm pipes (concrete pipe data is from (Holcim, 2017)

DIAMETER	225	300	375	450	525	600	750	900
VOLUME DIFFERENCE VS. CONCRETE (M^3/LINEAL M)	-0.08[29]	0.13	0.12	0.5	0.6	0.6	0.6	0.78

Table 11 – Trench excavation volume differences corrugated SN8 PP/PE vs. Concrete pipe for depth of cover = 1 m as per QLD Department of Main Roads Drawing No: 1359 Culverts[30]

DIAMETER	300	375	450	525	600	750	900
VOLUME DIFFERENCE VS. CONCRETE (M^3/ LINEAL M)	-0.51	-0.54	-0.17	-0.17	-0.18	-0.93	-0.75

29 Negative value indicates lower volume trench for corrugated PP pipe
30 Queensland Government Department of Main Roads Drawing No:1359 Culverts: Installation, Bedding and Filling/Backfilling Against/Over Culverts

ii. Type of fill and embedment materials

- The type of fill and embedment materials are nominated by the pipeline designer, infrastructure owner or installer and depends on the pipe application. LCA modelling shows that the use of screened and quarried virgin aggregate material (gravel) results in a higher environmental impact than other materials like natural sand, recycled glass sand, crusher dust and concrete recycled into aggregate. The impact of different embedment materials is shown in Figure 44.

Global warming potential (kg m³/lineal m eq) per m³ of embedment material

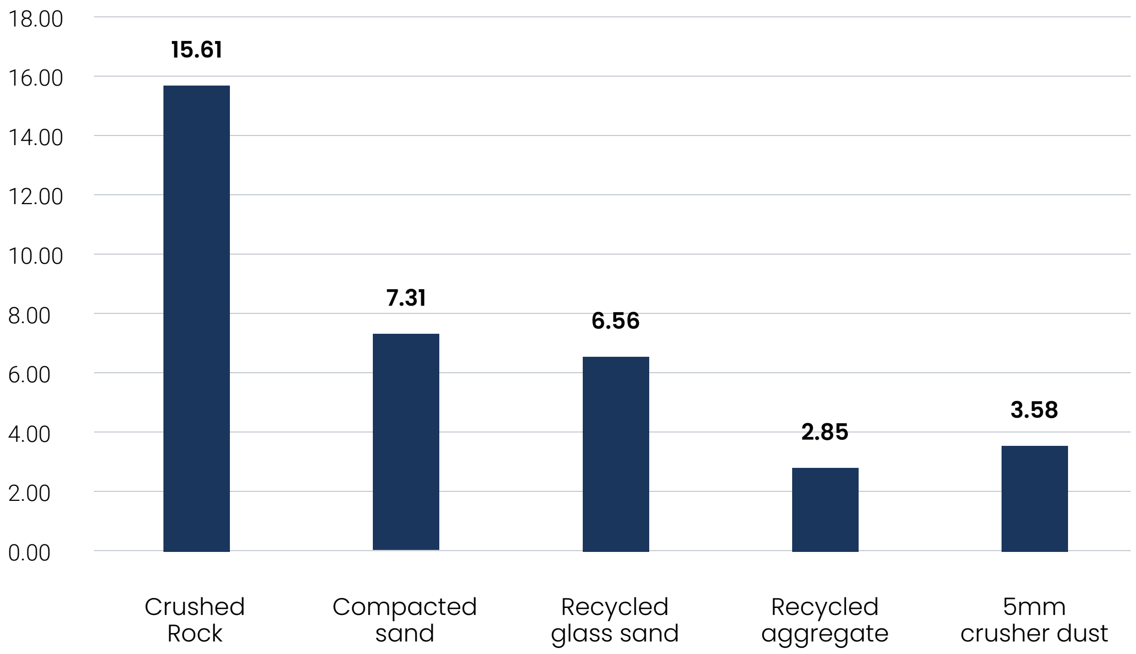

Figure 44 | Global Warming Potential per m³ of embedment material

- Transportation of fill materials to be imported to the site and excavated material from the site that can't be used in the embedment zone will impact carbon footprint and energy consumption.
- The use of equipment for backfilling and compaction also contributes to the total environmental impact. Backfilling is achieved either by using machinery or done manually. Compaction of embedment material is achieved using powered portable compacting machines, such as surface plate vibrators, or by manual means like hand tampers. Where single size aggregate is used, the required compaction may be achieved during material dumping.

Materials that are required to be imported to site impact carbon footprint and energy consumption. In the case of PP corrugated pipes and other flexible pipes, imported compacted embedment material of a specified type must be at least 150mm over the top of the pipe. On the other hand, concrete doesn't require imported fill material above the spring line (mid-point) of the pipe. Imported embedment material volumes for corrugated SN8 PP pipe and concrete pipes for different bedding support types are shown in Figure 13 below. In all cases, corrugated PP pipes require a larger volume of imported embedment material due to the fundamental design differences between buried flexible pipelines and rigid pipelines.

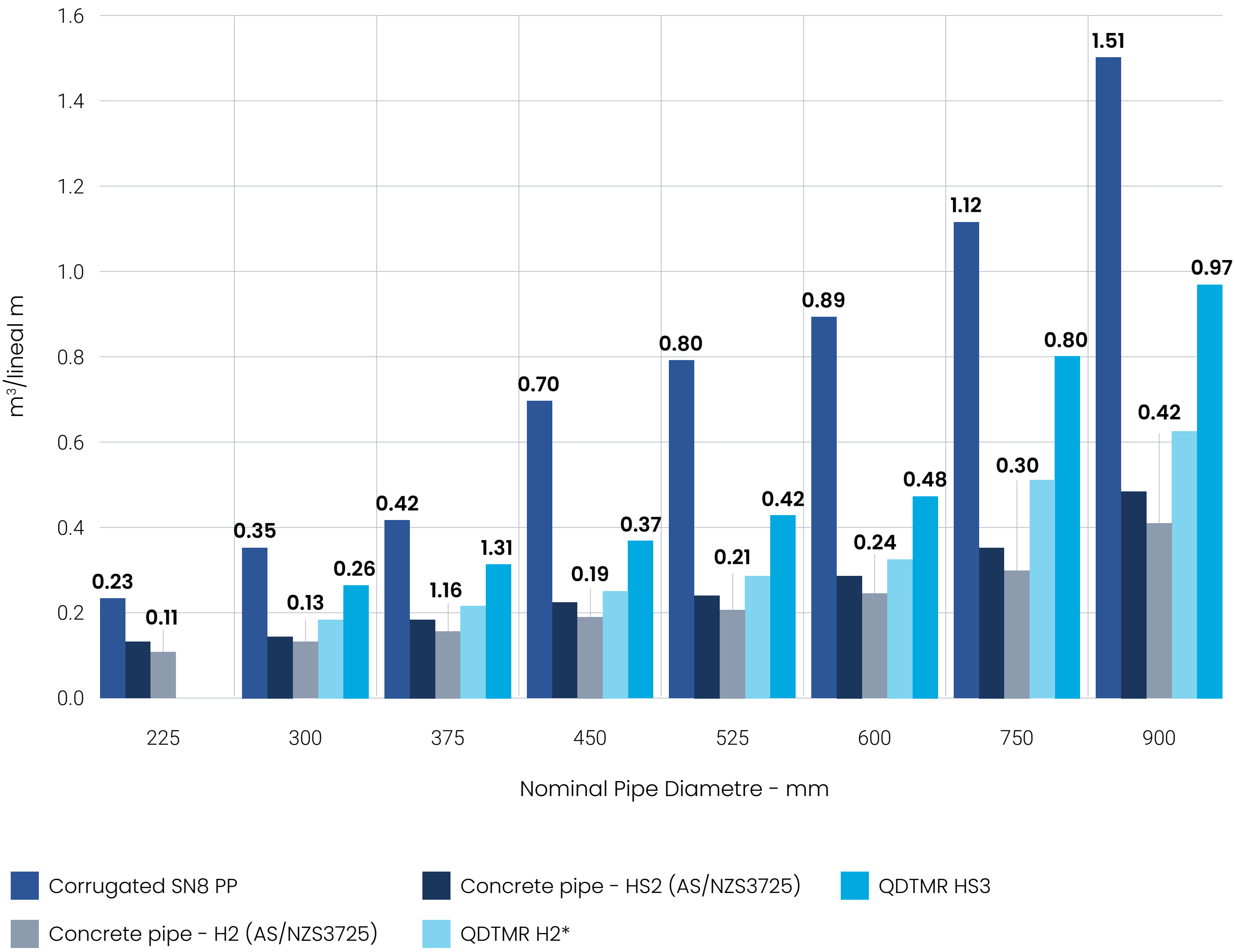

Figure 45 | Specific compacted fill embedment zone m3/lineal m of installed pipe vs. Diameter - Corrugated PP vs. RCP (H2, HS2 & HS3 bedding support)

* https://www.tmr.qld.gov.au/_/media/busind/techstdpubs/specifications-and-drawings/standard-drawings-roads/roadworks-drainage-culverts-and-geotechnical/sd1359.pdf?sc_lang=en&hash=C3495A3F5B198DBD8C6B485C43F20A96

iii. Pipe lifting equipment

Small-diameter corrugated PP pipes, such as DN225, DN300 and DN375, are light enough to be lifted into the trench by hand. However, this is dependent on trench depth. Larger diameter corrugated PP pipes require mechanical lifting equipment, and in most cases, an excavator is used.

Mechanical lifting equipment is required for DN225 and above steel reinforced concrete pipes. The use of mechanical equipment results in environmental and resource impacts due to diesel consumption.

As concrete pipes typically have shorter effective lengths, typically around 2.44 metres versus corrugated PP pipe at approximately 6 metres, more mechanical lifts are required for concrete pipe in comparison to corrugated PP/PE pipes. See Table 11. This also applies to other pipe lifting operations, such as truck loading and unloading, where the number of lifts is determined by the number of pipes crated together in a single pack. For corrugated PP/PE pipes, this ranges from 8 to 1 depending on diameter. Steel reinforced concrete pipes are usually handled individually.

Table 12 – Mechanical lifts required for concrete pipe versus corrugated PP/PE pipes

PIPE TYPE	MECHANICAL LIFTS PER 100 M INSTALLED	MANUAL LIFTS (TWO PERSON)
Concrete pipe SRCP (DN225 – 900)	41	N/A
PP/PE Corrugated SN8 pipe (DN450-900)	17	N/A
PP Corrugated SN8 pipe (DN225-375)	0	17

IV. Pipe joining

Both corrugated PP pipes and concrete pipes use rubber ring joints. Jointing requires the application of lubricant to reduce jointing forces. Corrugated PP pipes are often light enough to be joined using hand tools, such as a crowbar and timber bridging piece to protect the pipe. For concrete pipes, both mechanical and manual assistance is required to join.

V. Back filling of the trench

Manual or the use of the appropriate mechanical equipment.

VI. Compaction of embedment material

This can be achieved by using powered portable compacting machines such as surface plate vibrators or manual means, like using hand tampers. Where the single size aggregate is used, the required compaction may be achieved during material dumping.

VII. Transportation of excavated material

Excavated material from the site that can't be used in the embedment zone must be disposed of. This is more significant in the case of corrugated PP pipe installations, due to a larger zone of specified embedment material that's required (refer to Figure 45).

In summary, the relative impacts of the A5 installation module are highly dependent on the specific details and design of a particular installation, so it's not meaningful to attempt a quantitative comparison. Many factors are comparable, such as the provision of a trench. However, some factors that show differences between concrete and corrugated flexible pipes are worth noting. Corrugated PP and PE pipes require more embedment material than concrete pipes and disposal of more surplus spoil. The installation of concrete pipes requires more mechanical handling equipment to unload and move pipes on site and assist with jointing. This results in higher diesel consumption for concrete pipes.

8. CONCLUSIONS

This report compares plastic drainage pipes of two materials (PP and PE) with SRC pipes of two classes (Class 2 and 3). The data for this comparison was primarily sourced from published EPDs (Vinidex PP and PE pipes EPDs and RCPA SRC pipes EPD).

Thirteen impact indicators from the EPD results were compared, and these were selected based on prioritisation developed by the BRE study. They include climate change, ozone depletion, acidification, eutrophication (aquatic freshwater), eutrophication (aquatic marine), eutrophication (terrestrial), photochemical ozone formation, abiotic depletion (metals and minerals), abiotic depletion (fossil resources), use of net freshwater, hazardous waste, non-hazardous waste and radioactive waste. However, although radioactive waste is a concern in Europe due to its numerous nuclear power plants, this impact category may be of lower concern in Australia.

The summary of this study is as follows:

- Plastic pipes considered in this study were produced from 100% virgin materials. The concrete pipes contained 70% recycled steel[31]. The inclusion of recycled content in the concrete pipes helped in reducing their environmental footprint. A reduction of GWP-Total (Table 6) and EP-Freshwater (Table 7) is possible if plastic pipes also used recycled content.
- Out of 13 impact categories compared, plastic pipes had lower environmental impact in six categories, including global warming potential (GWP), photochemical ozone depletion, eutrophication - marine, eutrophication - terrestrial, use of net freshwater (FW) and non-hazardous waste disposed.
- Plastic pipes had higher environmental impact in six categories, including eutrophication - freshwater, abiotic depletion potential (metals and minerals), abiotic depletion potential (fossil resources), ozone depletion potential, hazardous waste disposed and radioactive waste disposed.
- Acidification potential values of plastic pipes and concrete pipes were found to be similar.
- According to the Green Star Buildings Submission Guidelines, the weighting factors are 25% for GWP and FW. The Infrastructure Sustainability Council (ISC) also weights GWP the highest in their material calculator, with a weighting factor of 47.5% for GWP. Plastic pipes had less environmental impact than concrete pipes in both GWP and use of net freshwater categories.
- As the weights of concrete pipes per meter are higher compared to those of plastic pipes, the GWP for plastic pipes transport is lower than that of concrete pipes.

The conclusions of this study are as follows:

- Comparative LCA study for plastic drainage pipes and concrete drainage pipes was successfully carried out for 13 midpoint impact indicators, prioritised by BRE. As no primary data for concrete pipes is available, comparison for endpoint impact indicators weren't possible.

31 RCPA concrete pipes reported in their EPD that their steel contains recycled content. The value of recycled content was estimated to be 70% based on average data. However, they have acknowledged that the estimated recycled content may or may not be representative for the steel they receive from their suppliers. RCPA has two suppliers: InfraBuild and an overseas supplier. The InfraBuild EPD doesn't specifically provide the percentage of post-consumer recycled content, but it does show Secondary Materials (SM) of 734 kg per tonne. The estimated recycled content of 70% value was applied across the two steel suppliers.

- Both the GWP and FW impact categories can be considered of highest importance when using LCA for the built environment in Australia, and plastic pipes have lower impact compared with concrete pipes in both categories.
- The radioactive waste generated during the production of PP pipes and concrete pipes is similar. PE pipes generate slightly higher radioactive waste compared to PP pipes. This impact category is of low concern in Australia as the radioactive waste values in the LCA of Australian products indicate its presence in the overseas supply chain. In the case of polypropylene and polyethylene pipes, nuclear energy-based electricity used in the production of resins is the primary source of radioactive waste. The background Global LCA data used for resin productions indicates that nuclear energy-based electricity produced in China, the USA, Canada and Europe are the sources of radioactive waste values of plastic resin production. However, it should be noted that neither PP nor PE resins are sourced from these countries.

From this study, PIPA can build communications on the following basis:

- Plastic pipes have demonstrated sustainability performance advantages in the highest priority environmental categories, including GWP and FW.
- The GWP to produce plastic pipes is lower compared to concrete pipes.
- The GWP per kilometre of transport mode is lower for plastic pipes compared to concrete pipes.

However, from this study, PIPA can't say the following:

- Plastic pipes have, in general, superior environmental performance over concrete pipes.
- There's less waste generation in the production of plastic pipes compared to concrete pipes.
- There's less depletion of non-renewable resources (fossil fuels and mineral resources) in the production of plastic pipes compared to concrete pipes.

This study was conducted based on the best available third-party technical environmental data. Therefore, the comparison may be challenging to communicate to non-specialist and technical audiences and decision makers. To make a simplified comparison, there's an option to calculate and present aggregated environmental impact (e.g. eco-points). However, although both ISC and Green Star have versions of eco-points, both are defined using the old EPD standard (EN 15804 + A1), which isn't yet compatible with EPDs produced using the current standard (EN 15804 + A2).

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APPENDIX A: ENDPOINT ANALYSIS FOR PLASTIC PIPES

The endpoint analysis of plastic pipes was performed using the ReCiPe 2016 impact assessment method. EPD results, compared in the main part of this report, are known as midpoint indicators. Midpoint indicators are used to calculate endpoint results. The endpoint analysis focuses on three areas of protection: human health, ecosystem quality and resource scarcity (Table 12).

Table 13: ReCiPe 2016 Endpoint method – Life Cycle Impact, Resource and Waste Assessment Categories, Measurements and Methods

DAMAGE CATEGORY	ABBREVIATION	DESCRIPTION	UNIT
Human health	HH	Disability-adjusted loss of life years	DALY [32]
Ecosystems	ED	Loss of species during a year	Species.yr[33]
Resources	RA	Increased cost	USD2013[34]

There are 18 midpoint impact indicators that focus on single environmental problems, such as GHG emissions or acidification. Meanwhile, three endpoint indicators trace the damage pathways from each midpoint impact category to broaden the impact categories and simplify the interpretation of the results. ReCiPe's endpoint method is an efficient tool to compare products when multiple indicators are integrated into three categories.

32 The damage to human health estimates the years lost to premature death and expresses the reduced quality of life due to illness. The DALY unit is used to quantify the burden of human disease resulting from environmental pollution and attribute it to the life cycle of the product.
33 The Species.yr unit is used to quantify the damage to ecosystems that represents the local species loss integrated over time (species year).
34 The USD2013 unit is used to quantify the increased cost due to increasing resource extraction.

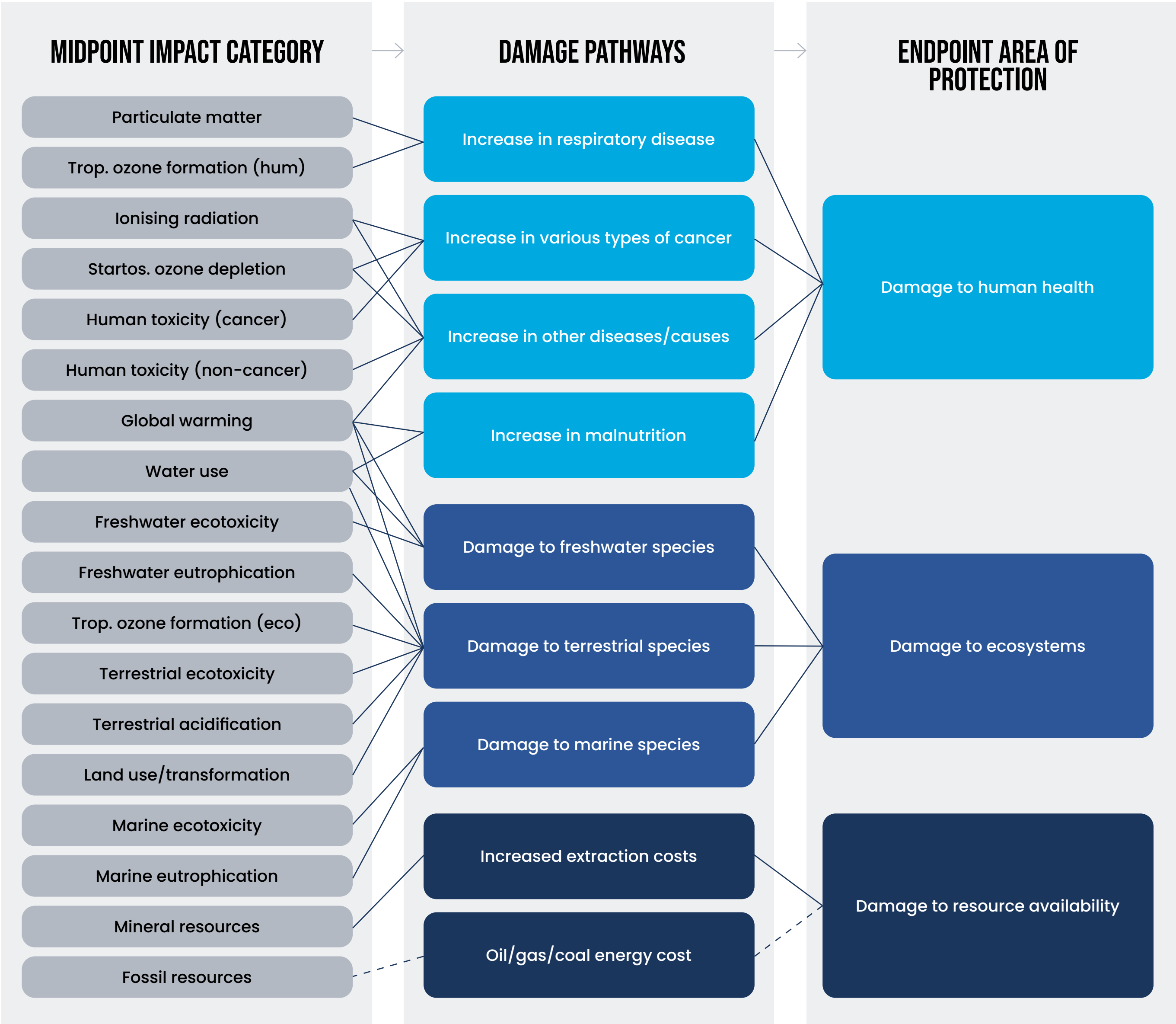

Figure 46 | ReCiPe environmental impact categories

Table 14 and Table 15 provide information about environmental impacts in accordance with the ReCiPe method for plastic pipes in DN 375 mm and 600mm. In DN 375mm, PE pipe has a higher impact than PP pipe in all assessed categories. However, in DN 600 mm, PP pipe has slightly higher results in all indicators.

Table 14 | Environmental impacts for plastic pipes in DN375 mm

DAMAGE CATEGORY	UNIT	PE	PP
Human health	DALY	4.81E-05	4.64E-05
Ecosystems	species.yr	1.19E-07	1.13E-07
Resources	USD2013	5.31E+00	4.85E+00

Table 15 | Environmental impacts for plastic pipes in DN600 mm

DAMAGE CATEGORY	UNIT	PE	PP
Human health	DALY	1.18E-04	1.28E-04
Ecosystems	species.yr	2.93E-07	3.12E-07
Resources	USD2013	1.30E+01	1.34E+01

Table 16 and Table 17 provide information about the contribution of different components to the total impact of the product stage. As the tables show, plastic resin accounts for the highest contribution in all impact categories, followed by energy for pipe production. Plastic resin also has a significant impact on resource scarcity (>91%) in both types of plastic pipes. For PP pipe, material transportation (A2) has a higher proportion than PE pipe, which means the distance for material transportation of PP pipe is longer than PE pipe.

Table 16 | Contribution of different component to environmental impacts of PE pipe

DAMAGE CATEGORY	PE RESIN	CARBON BLACK	CHEMICAL	ENERGY	TRANSPORT	PACKAGING
Human health	69.8%	1.8%	1.4%	22.1%	4.6%	0.1%
Ecosystems	61.1%	1.3%	2.8%	26.9%	6.7%	1.2%
Resources	94.7%	2.9%	0.1%	1.3%	0.9%	0.1%

Table 17 | Contribution of different component to environmental impacts of PP pipe

DAMAGE CATEGORY	PP RESIN	CHEMICAL	ENERGY	TRANSPORT	PACKAGING
Human health	60.0%	2.6%	21.1%	16.0%	0.2%
Ecosystems	54.3%	2.4%	24.2%	17.7%	1.4%
Resources	91.5%	4.0%	2.4%	2.1%	0.0%

APPENDIX B: ENVIRONMENTAL IMPACTS OF DN 375 PIPES

This section presents the comparative results for DN 375 pipes. This section covers the comparison of product stage results followed by a comparison of downstream transportation results for DN 375 pipes. The purpose of this section is to demonstrate that the reduction of diameter doesn't alter conclusions drawn from DN 600 pipe comparisons.

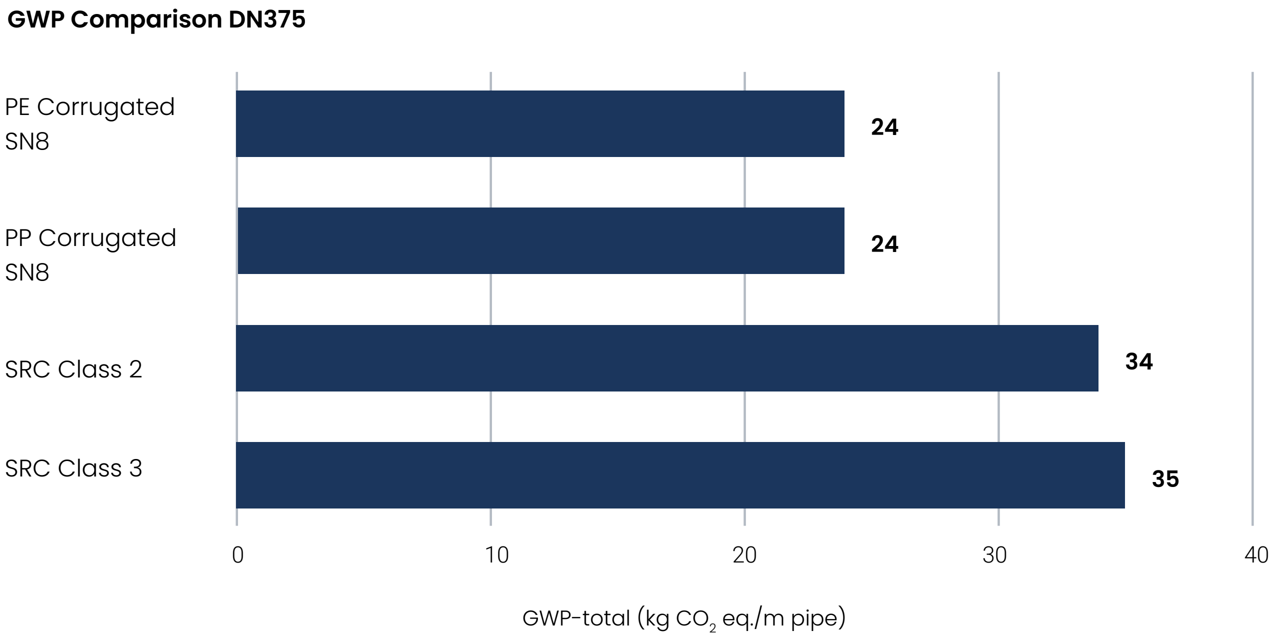

Figure 47: GWP-total comparison of plastic pipes with concrete pipes for the size of DN 375

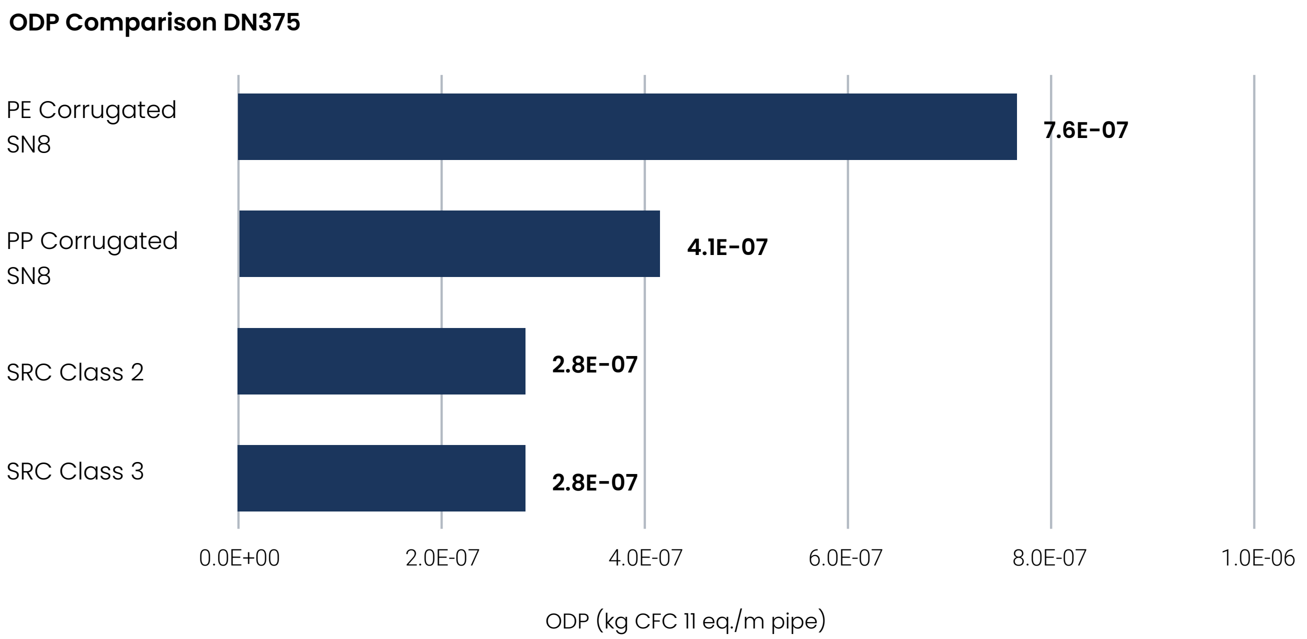

Figure 48: ODP comparison of plastic pipes with concrete pipes for the size of DN 375

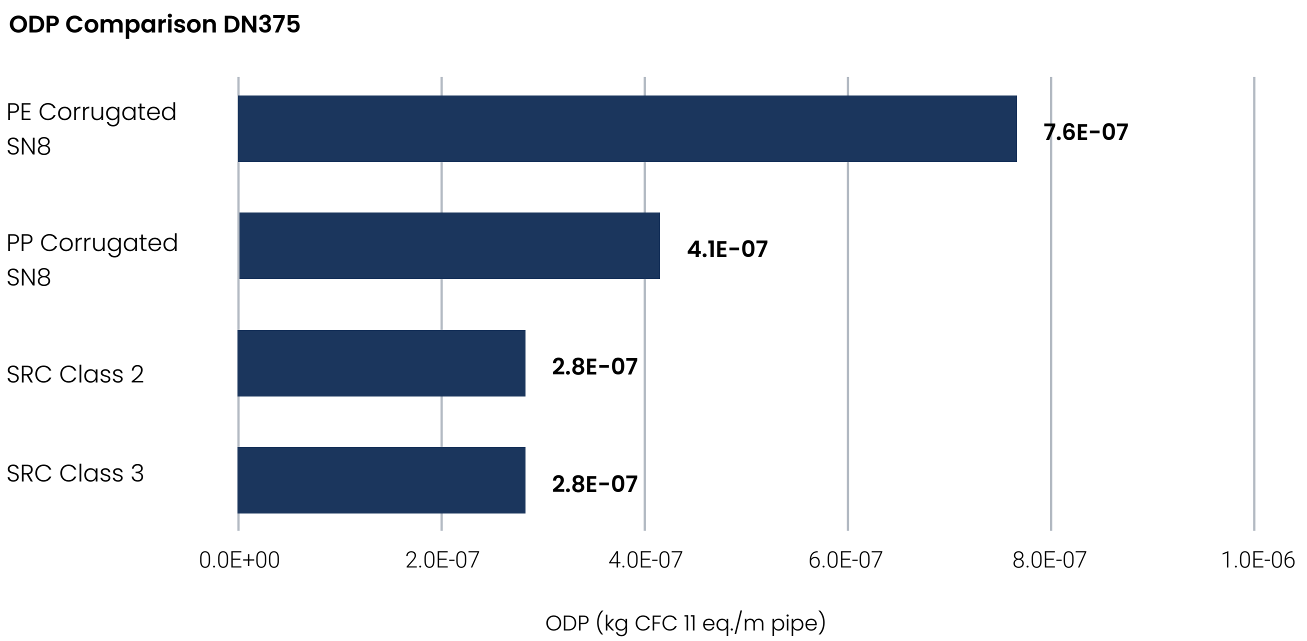
ODP Comparison DN375
PE Corrugated SN8
PP Corrugated SN8
SRC Class 2
SRC Class 3
7.6E-07
4.1E-07
2.8E-07
2.8E-07
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
ODP (kg CFC 11 eq./m pipe)

Figure 48: ODP comparison of plastic pipes with concrete pipes for the size of DN 375

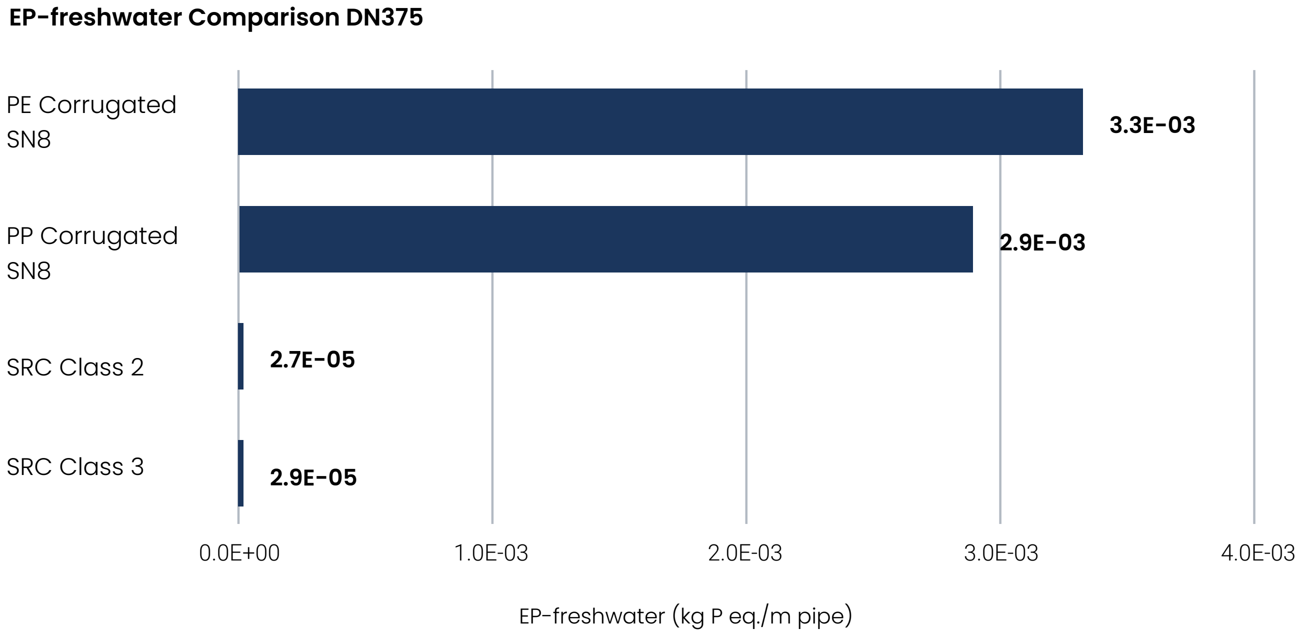

Figure 50: Eutrophication (aquatic freshwater) comparison of plastic pipes with concrete pipes for the size of DN 375

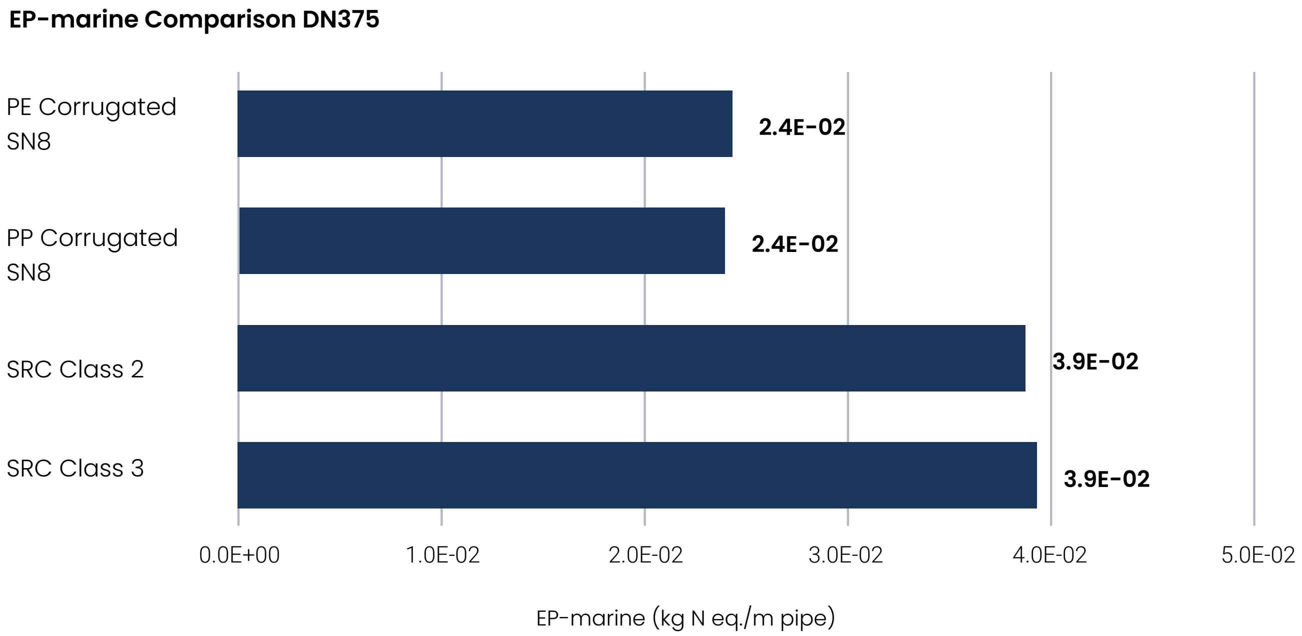

Figure 51: Eutrophication (aquatic marine) comparison of plastic pipes with concrete pipes for the size of DN 375

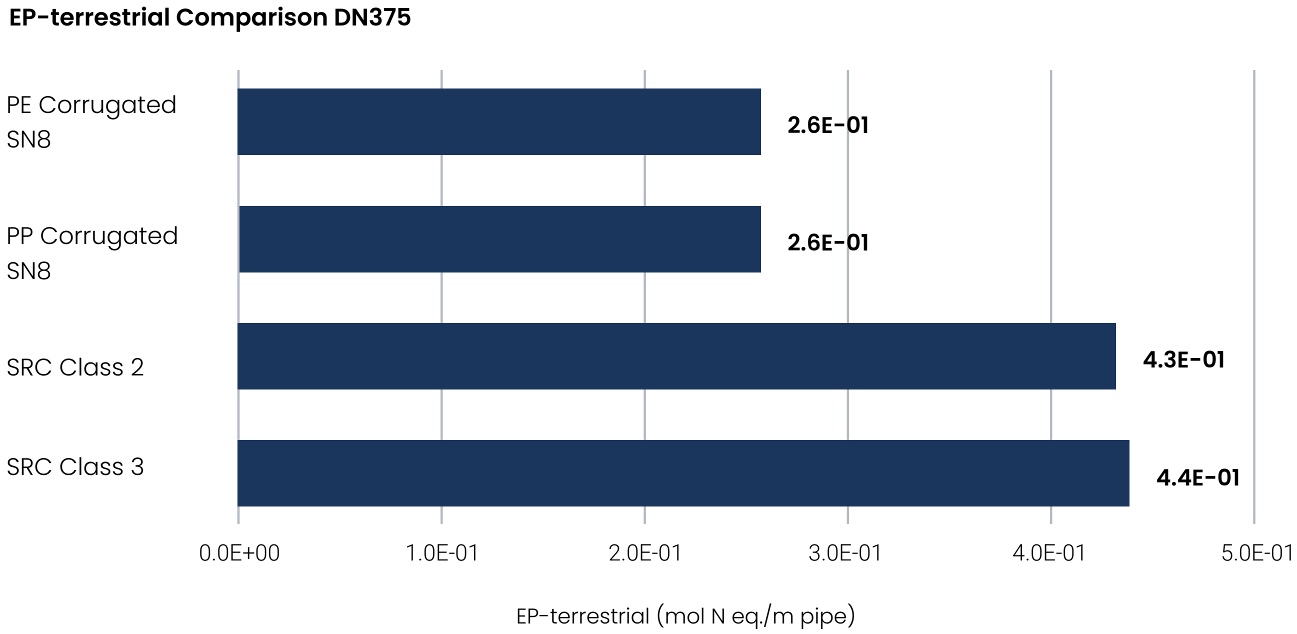

Figure 52: Eutrophication (terrestrial) comparison of plastic pipes with concrete pipes for the size of DN 375

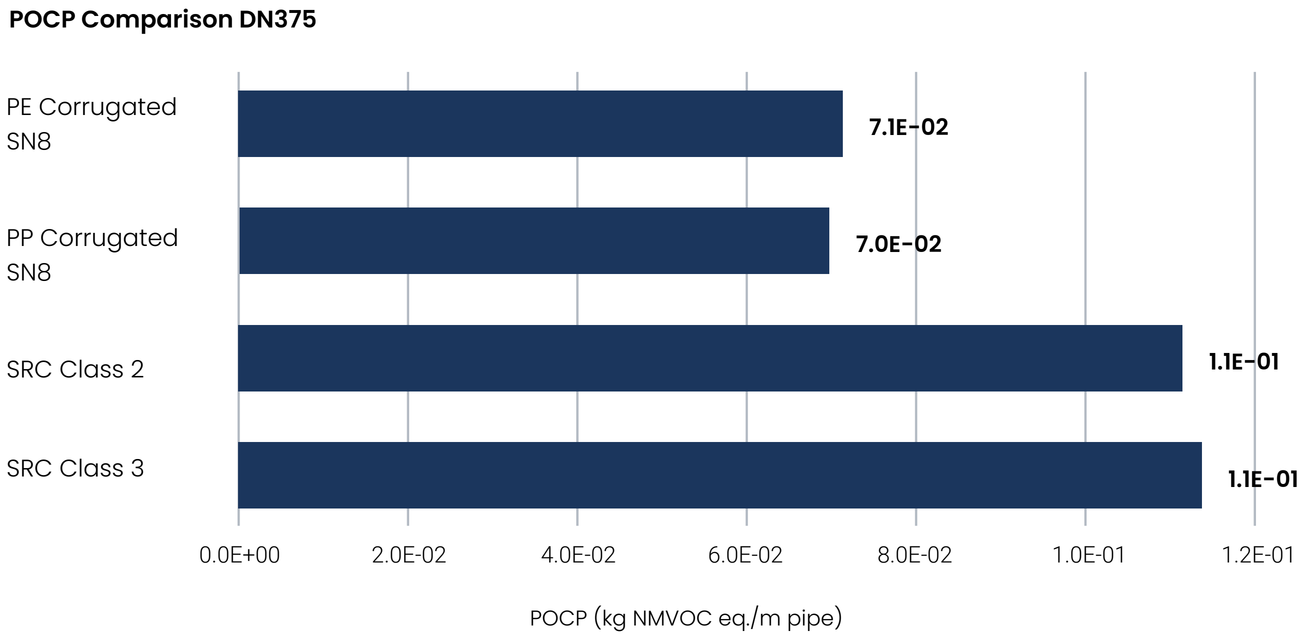

Figure 53: Photochemical ozone formation comparison of plastic pipes with concrete pipes for the size of DN 375

ADP-minerals Comparison DN375

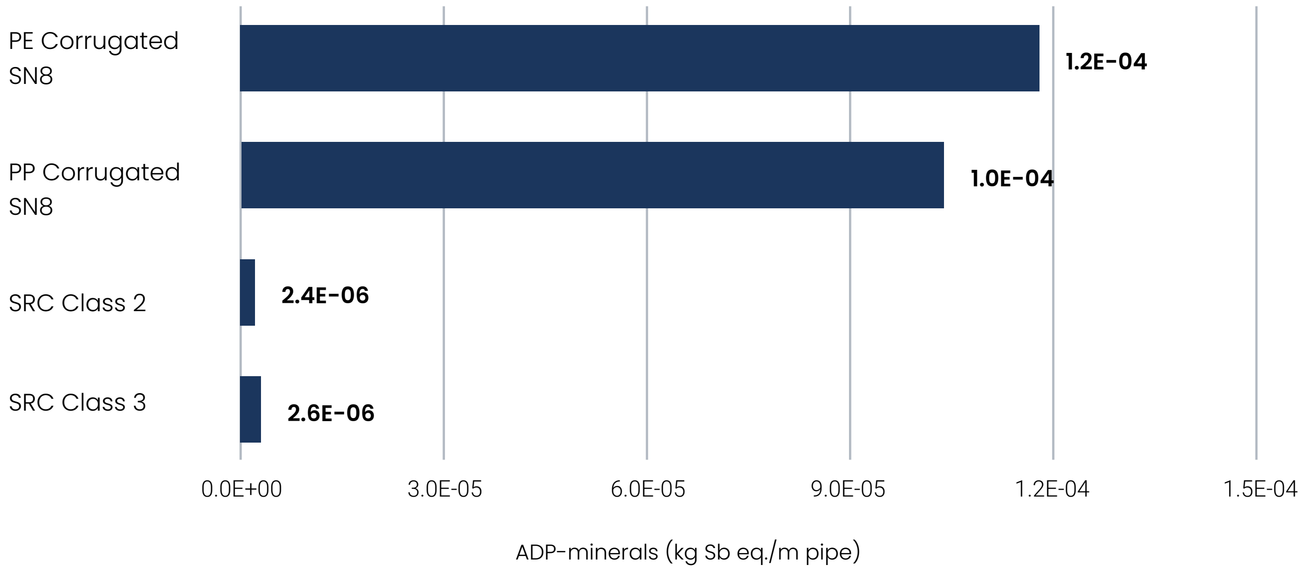

Figure 54: Abiotic depletion potential (metals and minerals) comparison of plastic pipes with concrete pipes for the size of DN 375

ADP-fossil Comparison DN375

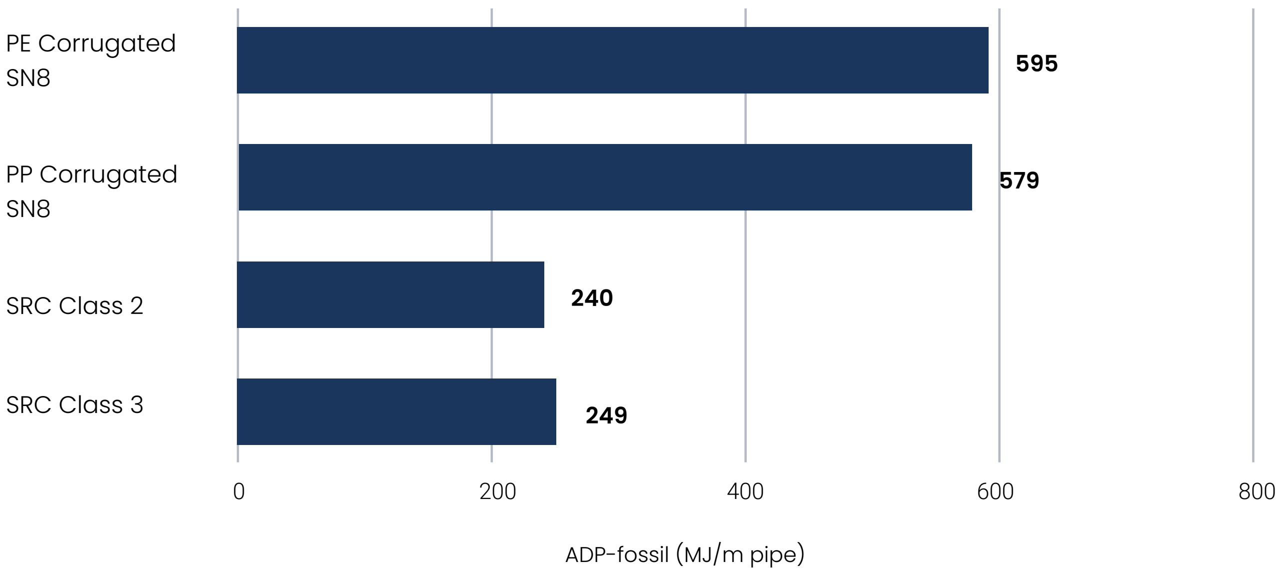

Figure 55: Abiotic depletion potential (fossil resources) comparison of plastic pipes with concrete pipes for the size of DN 375

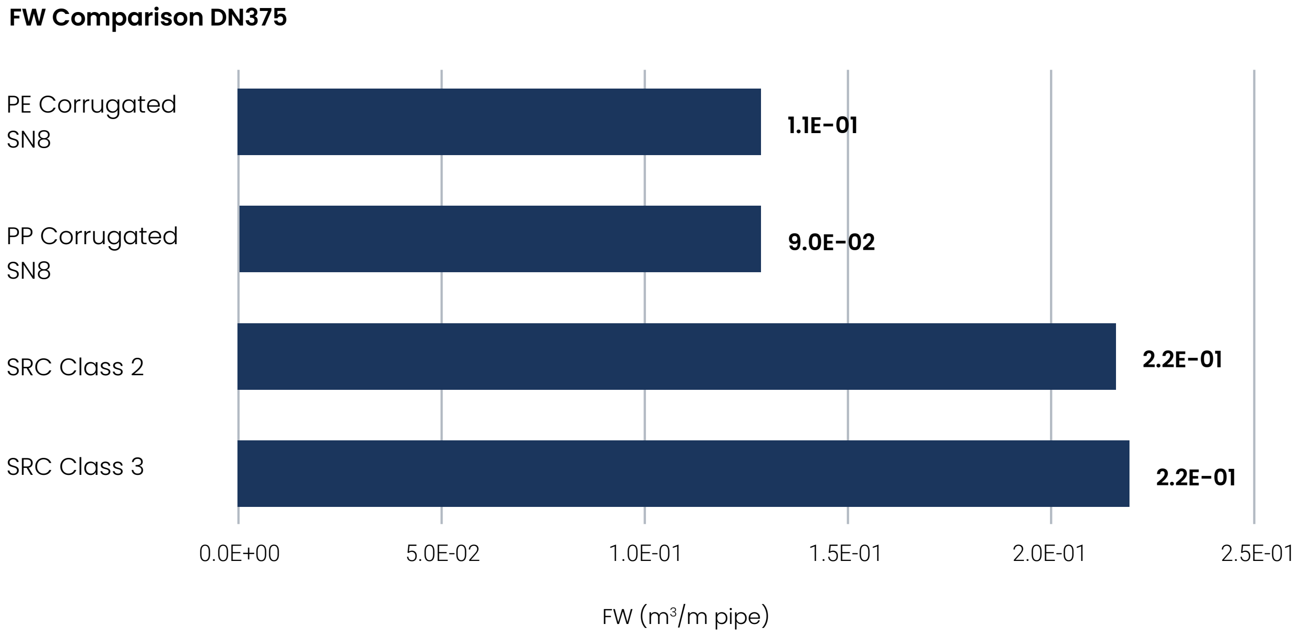

Figure 56: Use of net freshwater comparison of plastic pipes with concrete pipes for the size of DN 375

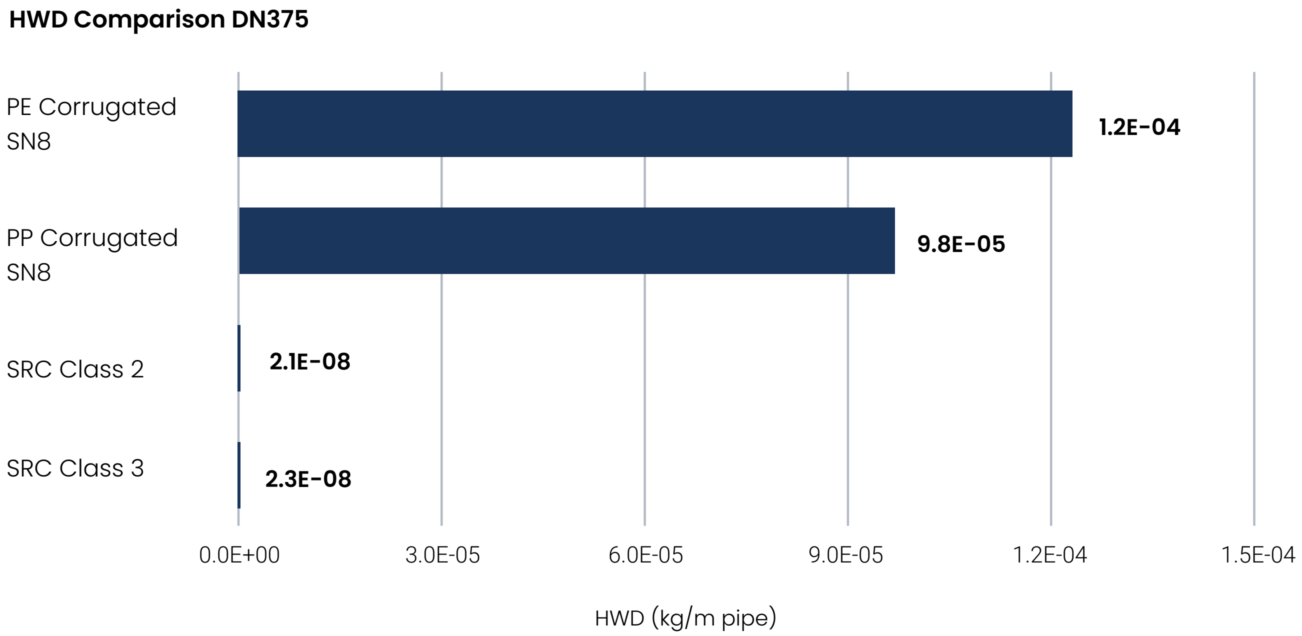

Figure 57: Hazardous waste disposed comparison of plastic pipes with concrete pipes for the size of DN 375

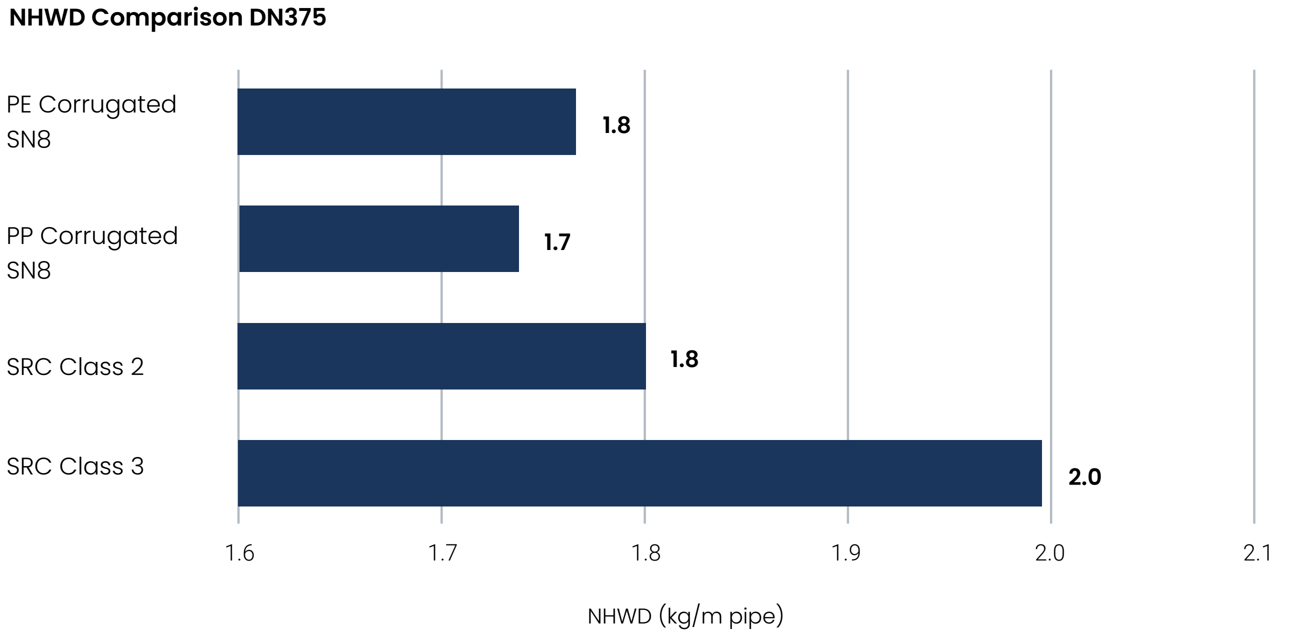

Figure 58: Non-hazardous waste disposed comparison of plastic pipes with concrete pipes for the size of DN 375

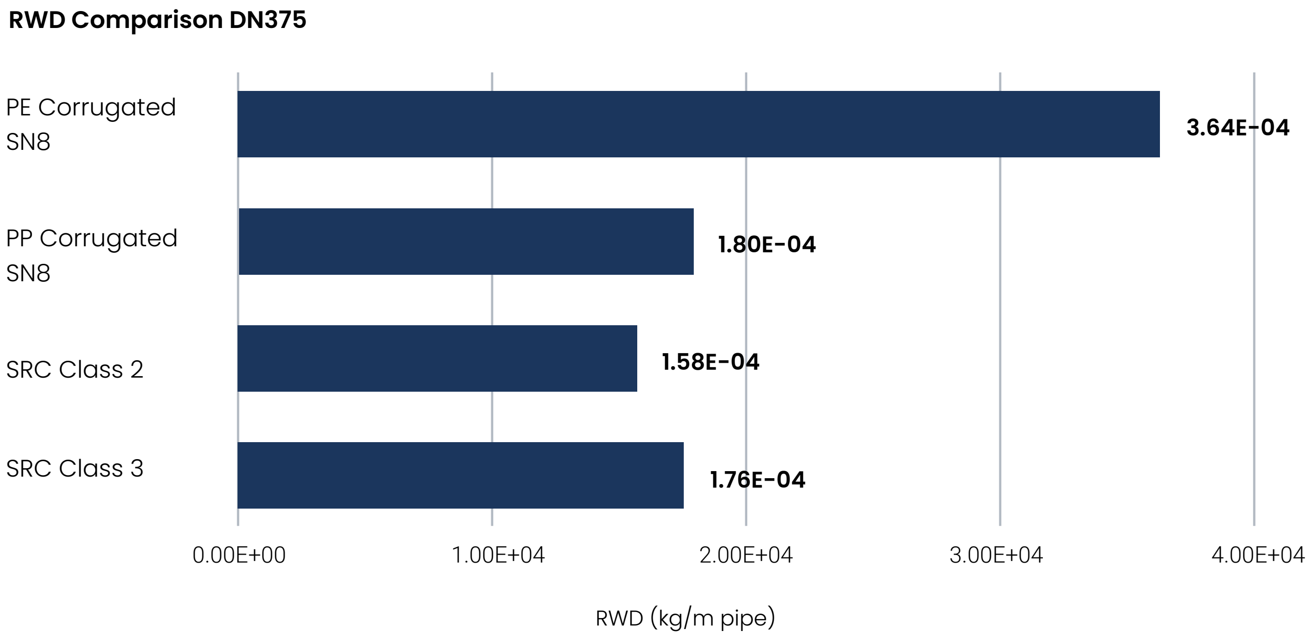

Figure 59: Radioactive waste disposed comparison of plastic pipes with concrete pipes for the size of DN 375

Table 18 | Environmental impacts of module A4 for 375 mm pipes

INDICATOR	RESULTS PER 1M OF 375MM PIPE		
	PP/PE[35]	Class 2	Class 3
GWP	2.3	4.4	7.1

35The EPD for Vinidex PE pipes presents average downstream transport environmental footprint for PE pipes of various applications including agriculture, industrial and gas applications. As this report is focused on drainage pipe only, the downstream transport environmental footprint of PP pipe is considered to be representative for both PP and PE pipes. The environmental impact of PP and PE pipes in Table 9 is the downstream transport environmental footprint for PP pipes as documented in Vinidex PP pipes EPD.

APPENDIX C: ENVIRONMENTAL IMPACTS OF DN 900 PIPES

This section presents the comparative results for DN 900 pipes. This section covers the comparison of product stage results followed by a comparison of downstream transportation results for DN 900 pipes. The purpose of this section is to identify how the increase in pipe diameters impacts the results. It was found that the conclusions drawn for DN 600 pipes were similar to DN 900 pipes except for the radioactive waste disposed indicator. For DN 600 pipes, plastic pipes performed better in this indicator compared to concrete pipes. By comparison, the results are inclusive for DN 900 pipes.

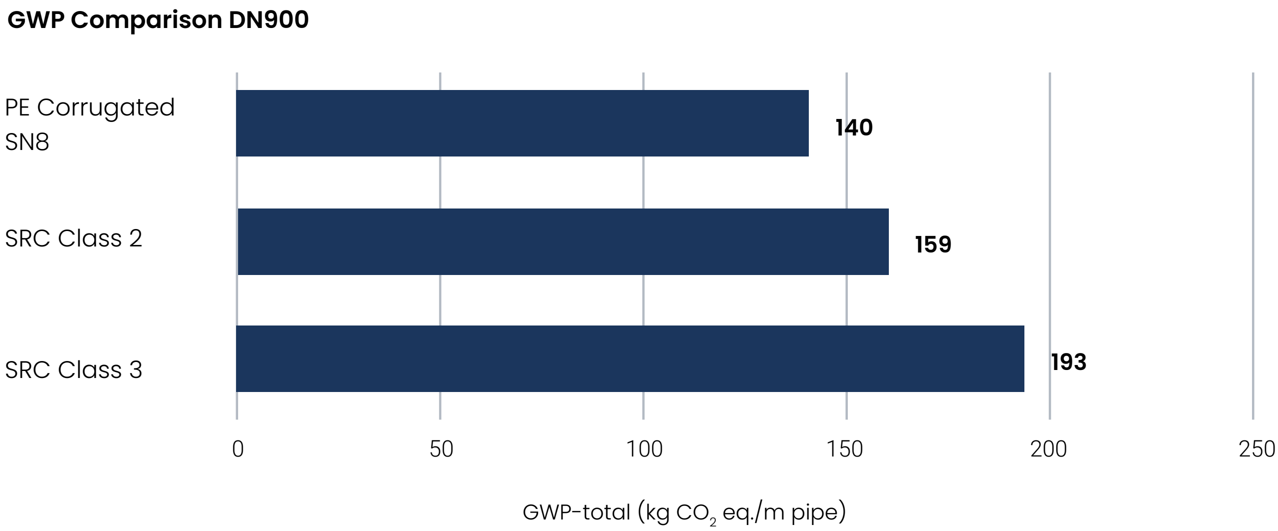

Figure 60: GWP-total comparison of plastic pipes with concrete pipes for the size of DN 900

ODP Comparison DN900

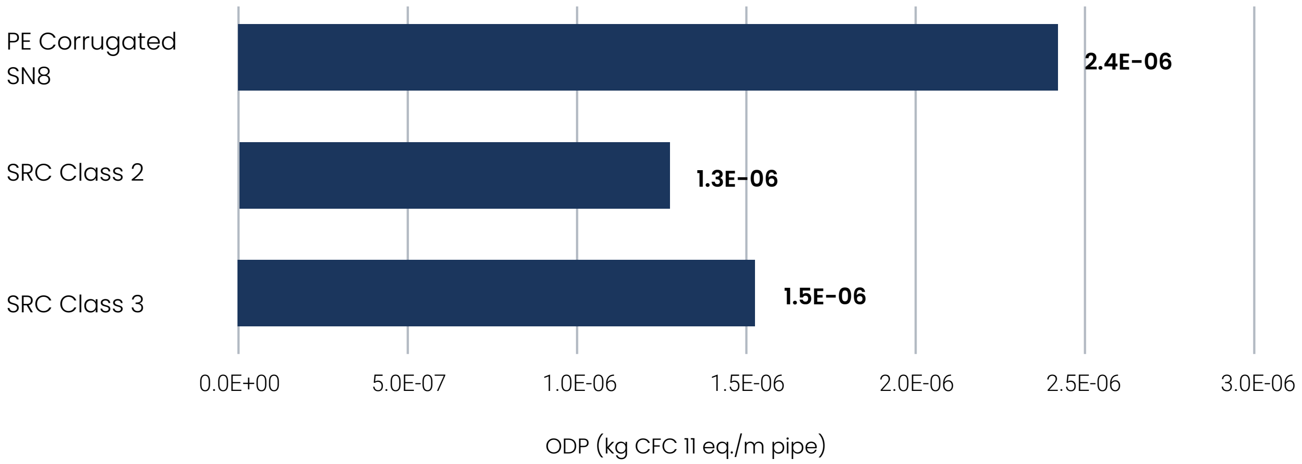

Figure 61: ODP comparison of plastic pipes with concrete pipes for the size of DN 900

Acidification Comparison DN900

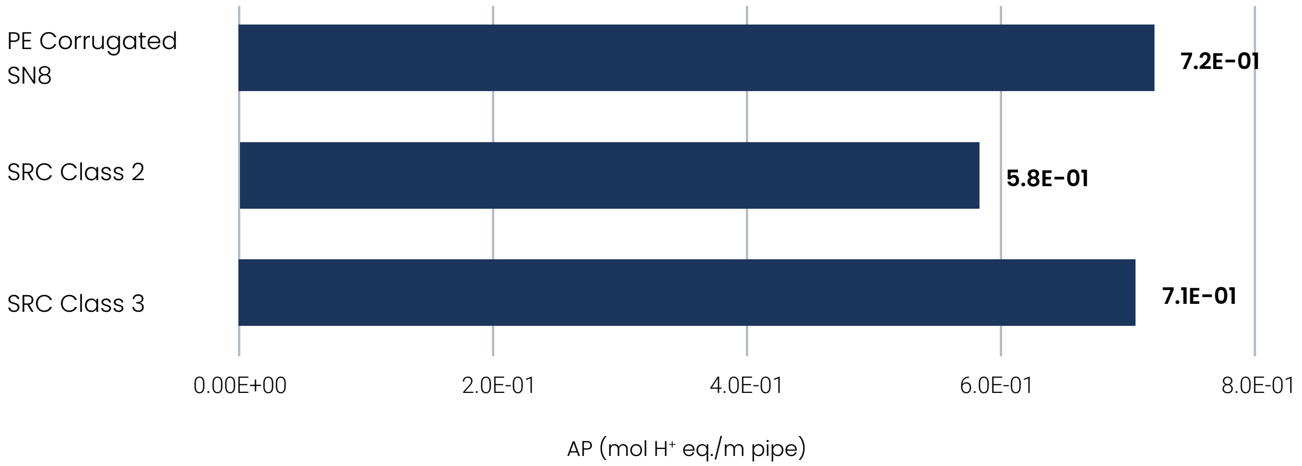

Figure 62: Acidification comparison of plastic pipes with concrete pipes for the size of DN 900

EP-freshwater Comparison DN900

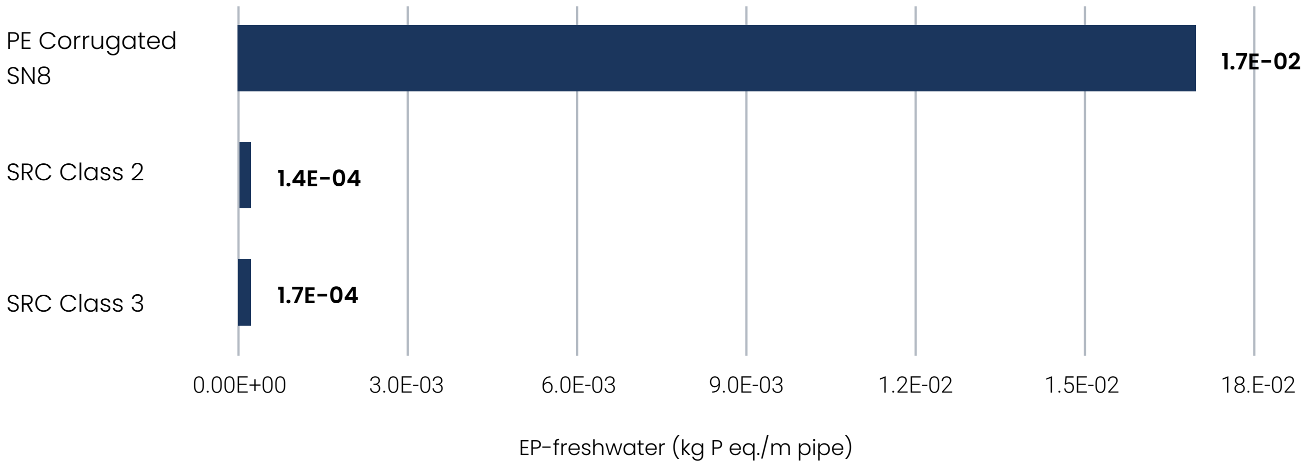

Figure 63: Eutrophication (aquatic freshwater) comparison of plastic pipes with concrete pipes for the size of DN 900

EP-marine Comparison DN900

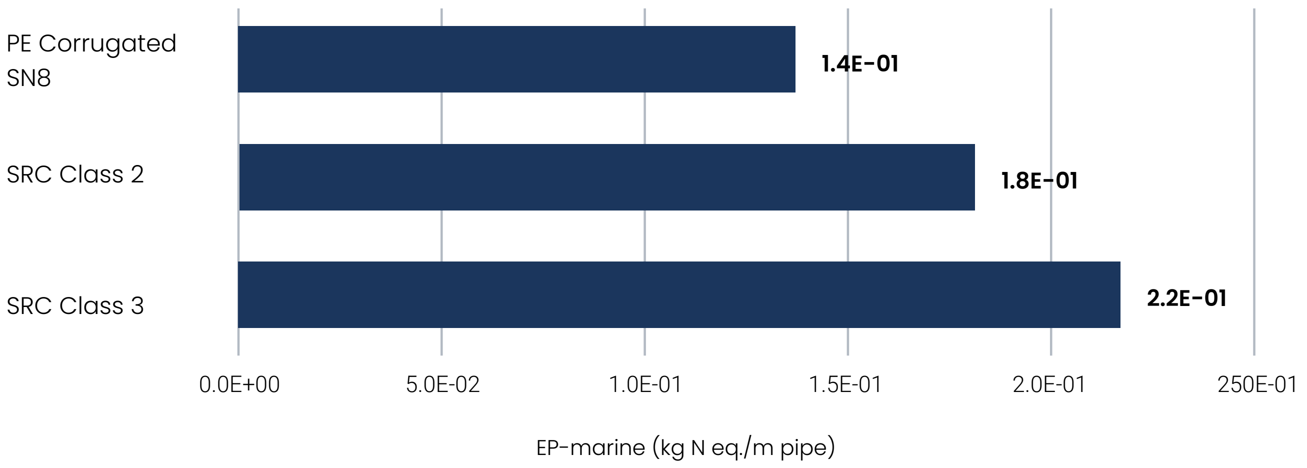

Figure 64: Eutrophication (aquatic marine) comparison of plastic pipes with concrete pipes for the size of DN 900

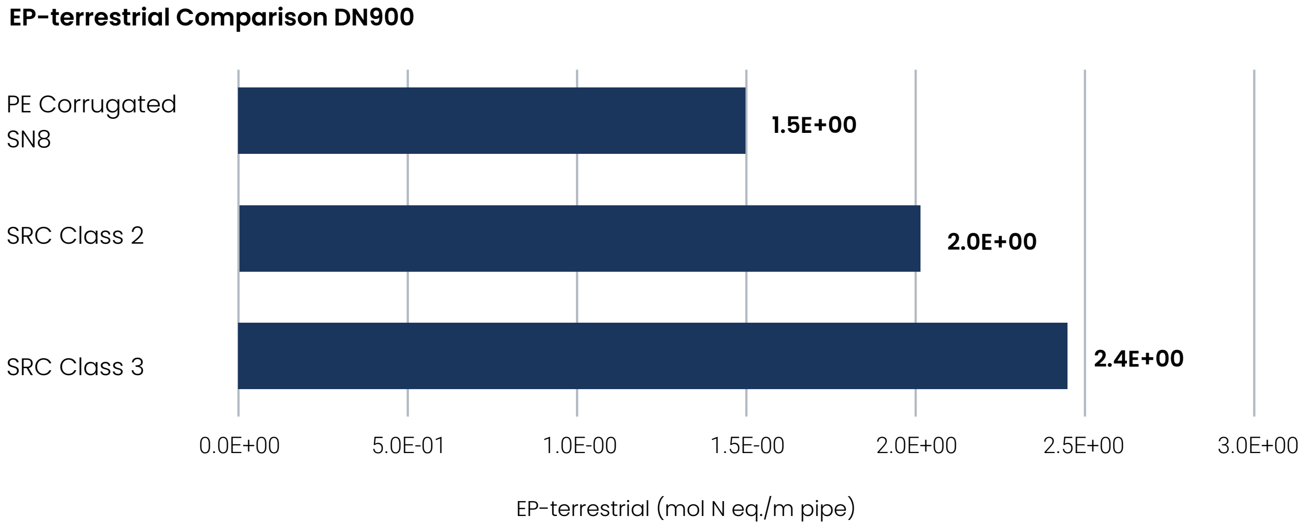

Figure 65: Eutrophication (terrestrial) comparison of plastic pipes with concrete pipes for the size of DN 900

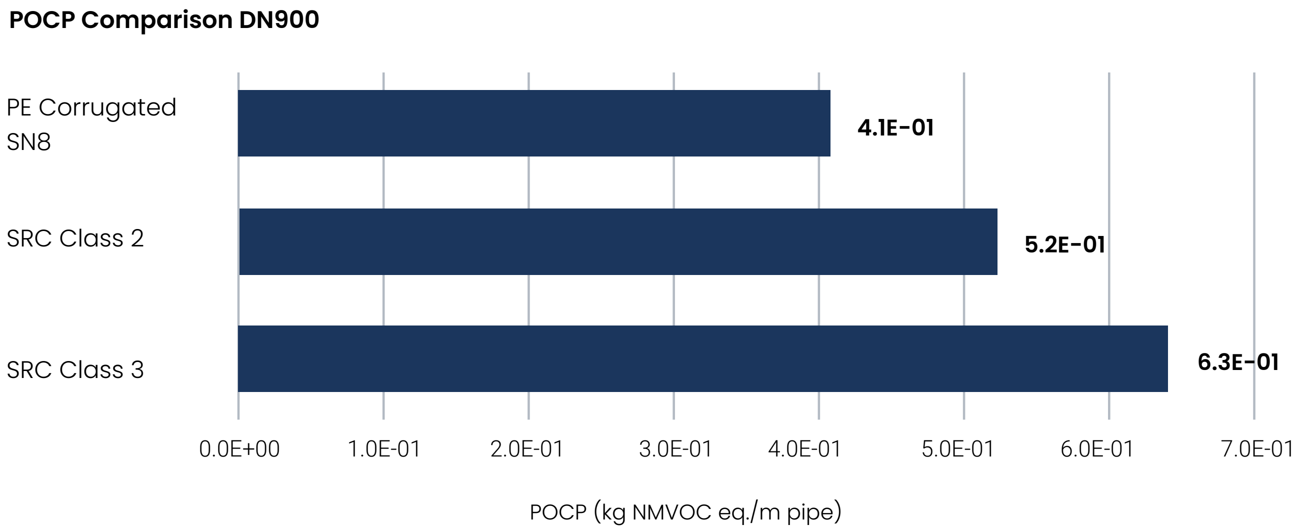

Figure 66: Photochemical ozone formation comparison of plastic pipes with concrete pipes for the size of DN 900

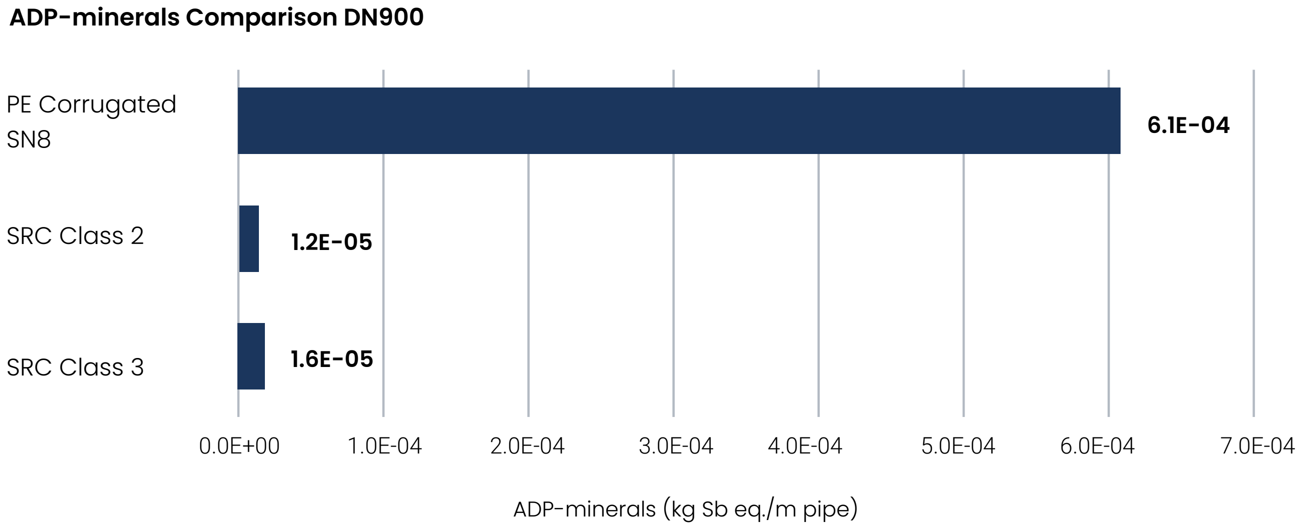

Figure 67: Abiotic depletion potential (metals and minerals) comparison of plastic pipes with concrete pipes for the size of DN 900

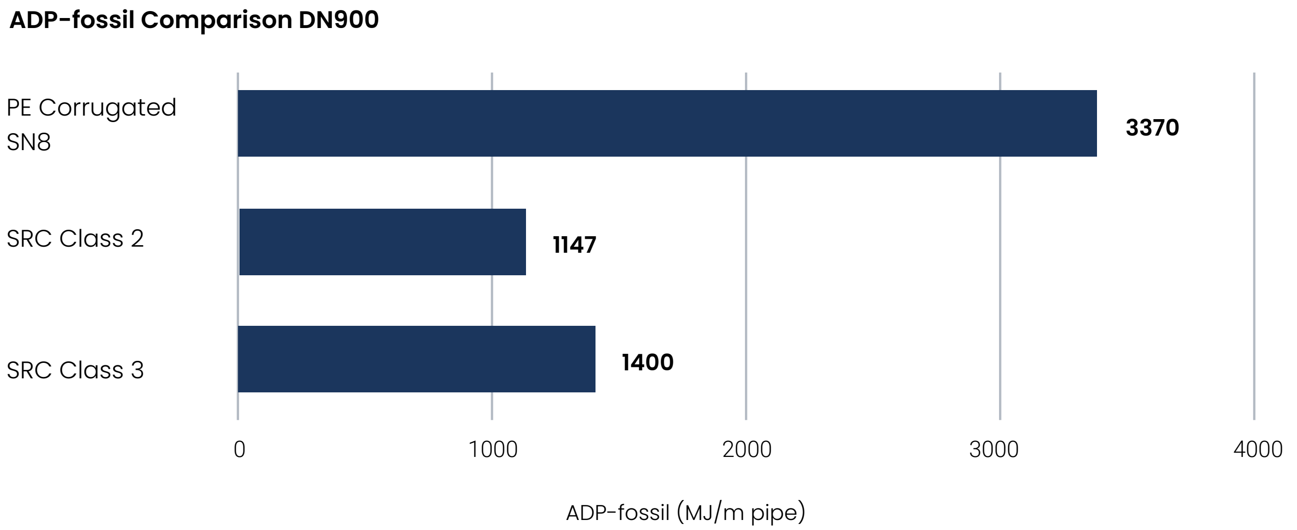

Figure 68: Abiotic depletion potential (fossil resources) comparison of plastic pipes with concrete pipes for the size of DN 900

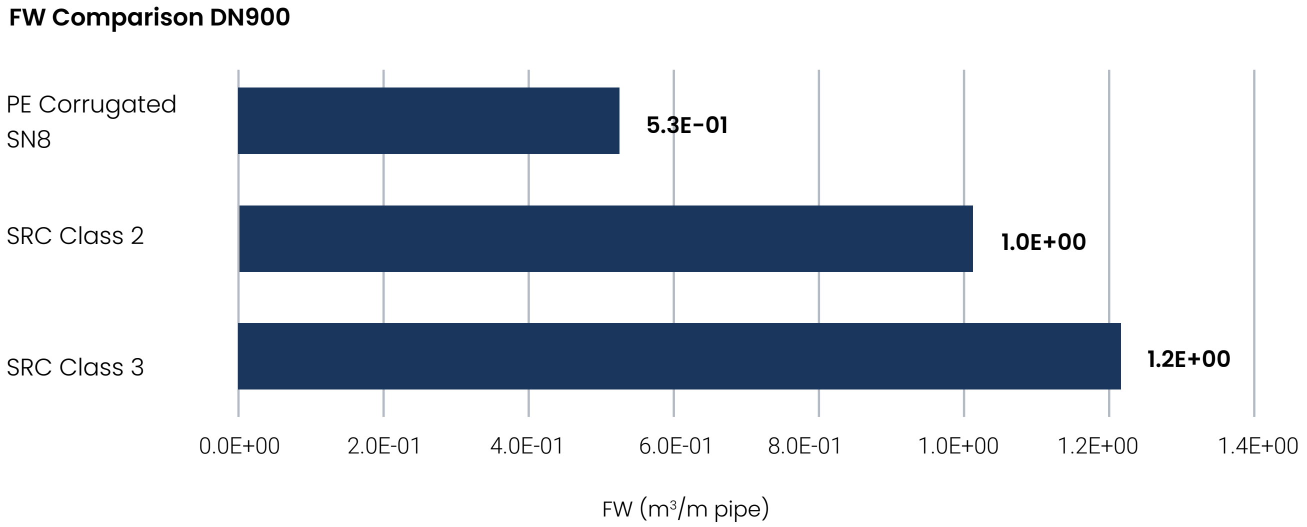

Figure 69: Use of net freshwater comparison of plastic pipes with concrete pipes for the size of DN 900

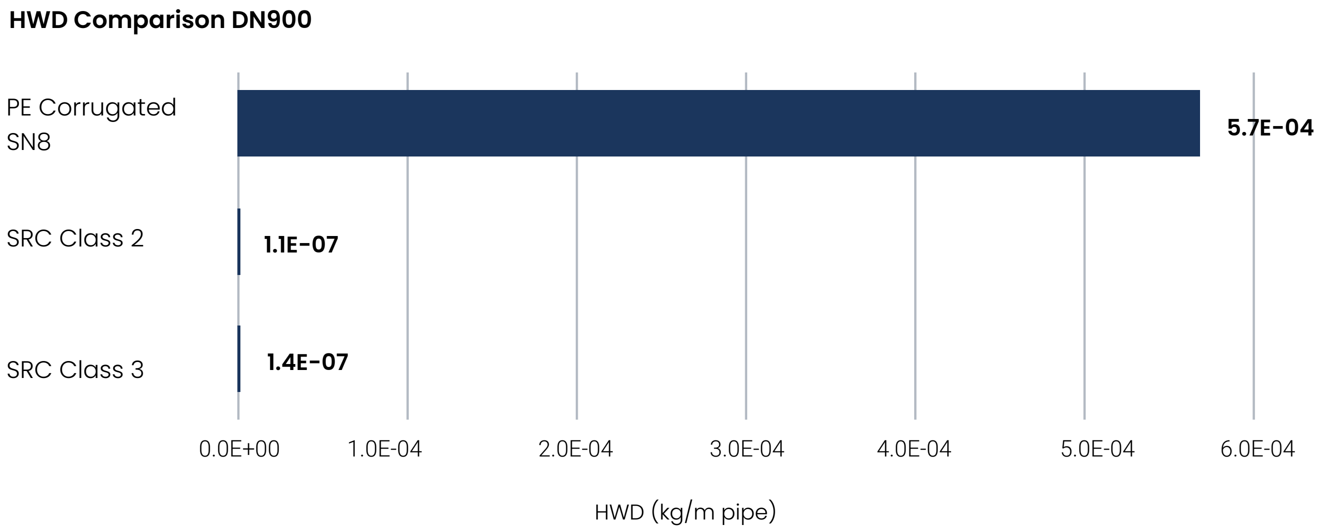

Figure 70: Hazardous waste disposed comparison of plastic pipes with concrete pipes for the size of DN 900

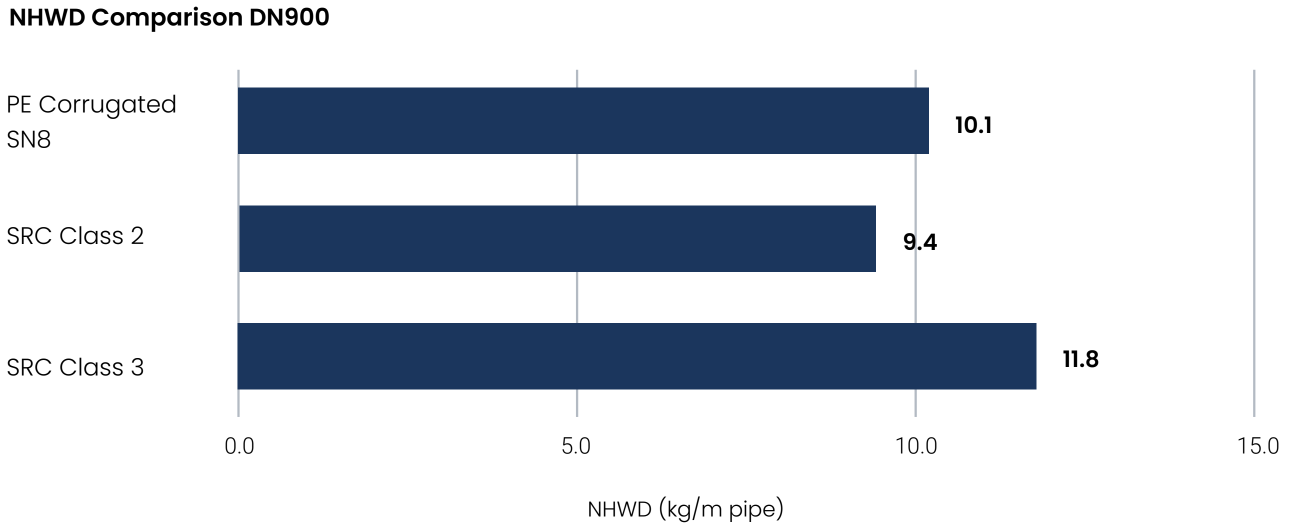

Figure 71: Non-hazardous waste disposed comparison of plastic pipes with concrete pipes for the size of DN 900

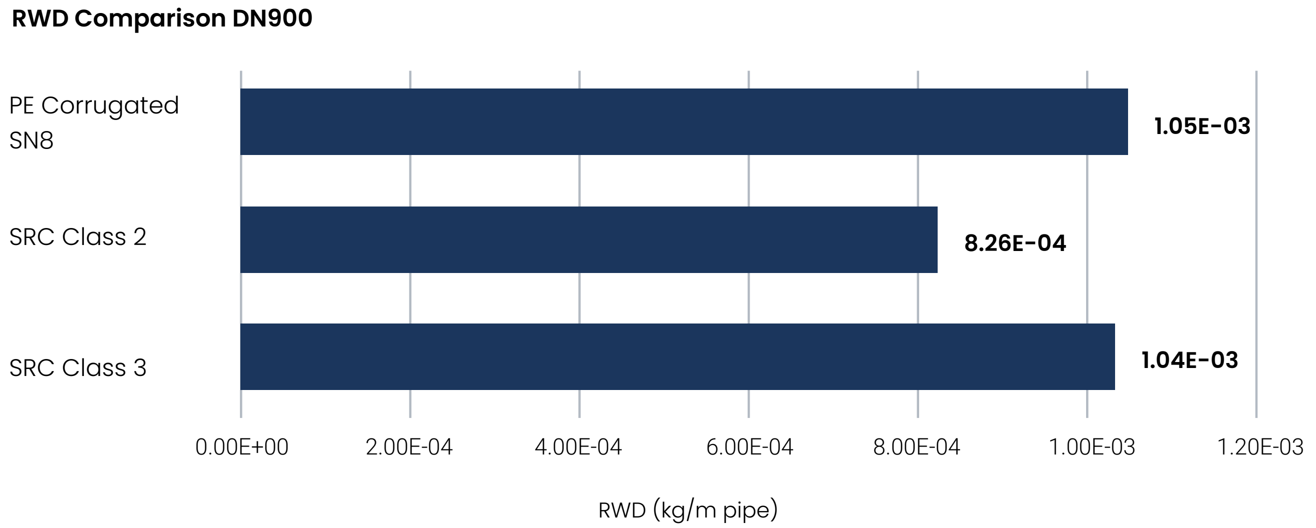

Figure 72: Radioactive waste disposed comparison of plastic pipes with concrete pipes for the size of DN 900

Table 19 | Environmental impacts of module A4 for 900 mm pipes

INDICATOR	RESULTS PER 1M OF 900MM PIPE		
	PP	**Class 2**	**Class 3**
GWP	13.4	19.4	32.1

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