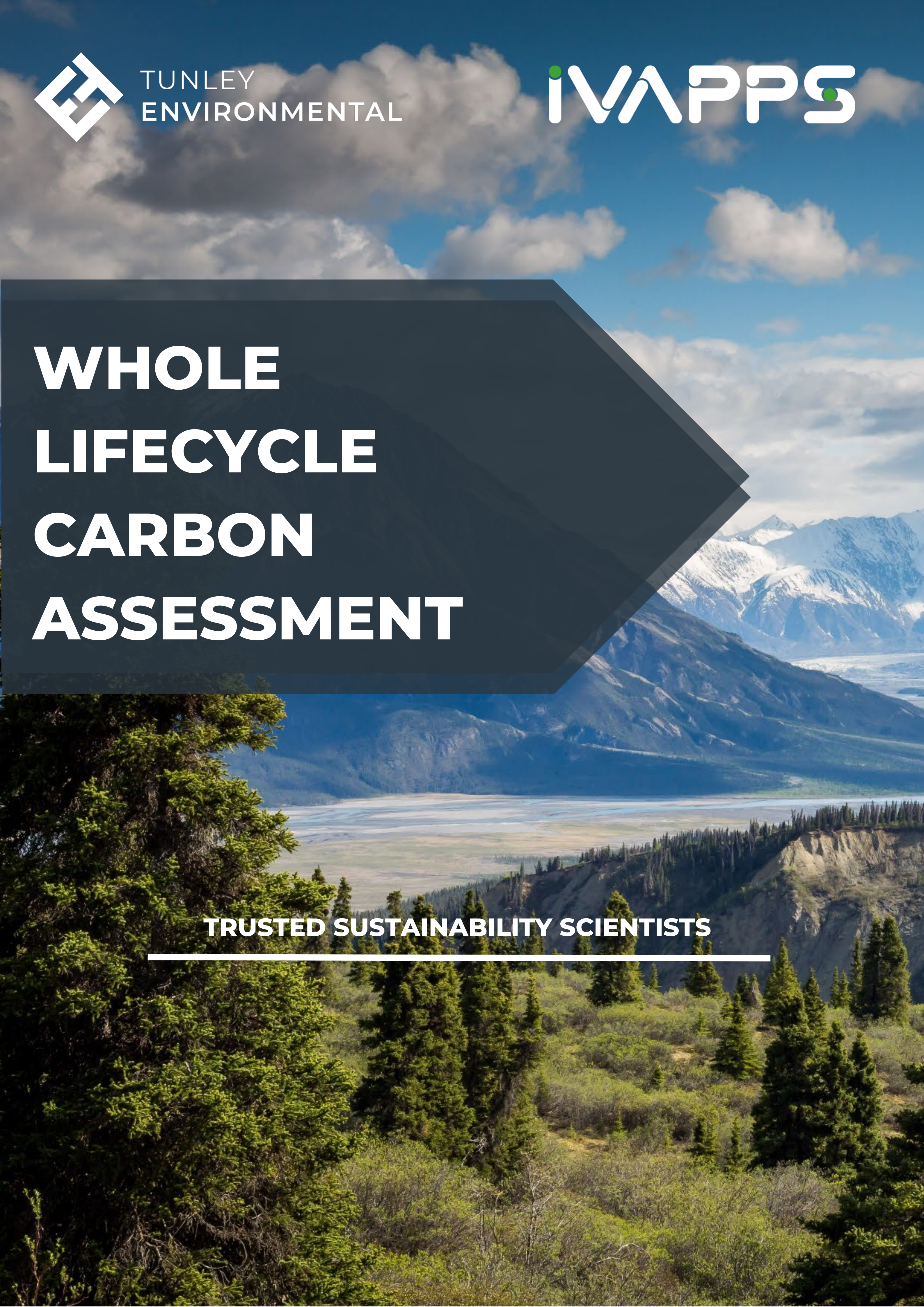
TUNLEY ENVIRONMENTAL

IVAPPS

WHOLE LIFECYCLE CARBON ASSESSMENT



TRUSTED SUSTAINABILITY SCIENTISTS

TUNLEY ENVIRONMENTAL

Contents

LIST OF FIGURES

List of Tables

APPROVAL

Author:	Nathan Wood MChem MRSC
Position:	Carbon Reduction Scientist
Written Date:	3rd April 2023
Approved by:	Dr Aaron Yeardley AMIChemE
Position:	Senior Carbon Reduction Scientist
Approved Date:	4th April 2023
Reference:	LCA-iVapps-01
Revision:	A

Revision History:	Change Description:	Changed by:	Date:	Approved by:	Date:
B					
C					
D					
E					
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The greenhouse gas emissions from completing this analysis were 2.90 $kgCO_2e$.

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NOMENCLATURE

Nomenclature	Description
GHG	Greenhouse Gases, gases that trap heat in our atmosphere. GHG include Carbon dioxide, methane, nitrous oxides and fluorinated gases.
Embodied Carbon	The total GHG emissions generated to produce a product; It includes those from extraction, manufacture, processing, transportation and assembly in every component.
Life-Cycle Carbon Analysis (LCA)	The compilation and evaluation of the inputs, outputs and the potential carbon impacts of a product system throughout its life cycle.
Zero Carbon	The absence of GHG emissions
Net Zero Carbon (NZC)	The sum effect of combining actions to reduce GHG emissions with actions to off-set them.
Carbon Off-setting	A reduction in emissions of GHG to compensate for unavoidable emissions.
Global Warming Potential (GWP)	The heat adsorbed by any GHG as a multiple of the equivalent in carbon dioxide.
IPCC	The Intergovernmental Panel on Climate Change. It provides regular scientific assessment on climate change to policy makers.
AR5	The fifth assessment report of the IPCC. The most recent assessment report is 2014.
tCO_2e	Notation for tonnes of carbon dioxide equivalent emissions.
$kgCO_2e$	Notation for kilograms of carbon dioxide equivalent emissions.

STANDARD

This report has been prepared in accordance with BS EN ISO 14067:2018 Greenhouse gases - Carbon footprint of products - requirements and guidelines for quantification, Part 6 Methodology for quantification of the CFP and partial CFP. Following a manner consistent with International Standards on Life-Cycle Analysis (LCA) (ISO 14040 and ISO 14044).

Carbon equivalent data conversions have been calculated in accordance with greenhouse gas reporting: 2021 published by the UK Government Department for Business, Energy and Industrial Strategy and the UK Department for Environmental Food and Rural Affairs (DEFRA).

Additionally, The Inventory of Carbon and Energy (ICE) or peer-reviewed literature sources have provided carbon equivalent data conversions for complex materials.

Global Warming Potentials are stated in IPCC Sixth Assessment Report, 2021 (AR6).

Executive Summary

A comprehensive Life-Cycle Carbon Analysis (LCA) was conducted to compare the iVapps Products, including Portal + Valve Cartridge NP (with and without Data Logger) and Portal + SMART Cartridge NP, with a Standard Gate Valve (with and without Data Logger) and Data Logger commonly used in the water industry. The assessment was performed in accordance with BS EN ISO 14067:2018 with a manner consistent with the International Standards on Life-Cycle Analysis (LCA) (ISO 14040 and ISO 14044). During the 100-year LCA analysis period, two scenarios were evaluated for the iVapps products. The best-case scenario involves swapping the Portal directly from a Standard Gate Valve that has already been installed and has reached the end of its lifespan, as well a reduced frequency of refurbishment for the SMART Cartridge NP.

The embodied carbon was quantified (Figure 1) for the iVapps product and compared with their reference (comparison) products. The Portal + Valve Cartridge NP and Portal + SMART Cartridge NP were found to have a larger embodied carbon than their references products. To reduce the embodied carbon, the implementation of guidelines concerning material selection and minimisation is recommended. This may encompass employing recycled materials or those with a low carbon footprint, and restricting material usage to amounts essential for maintaining safe and durable product performance.

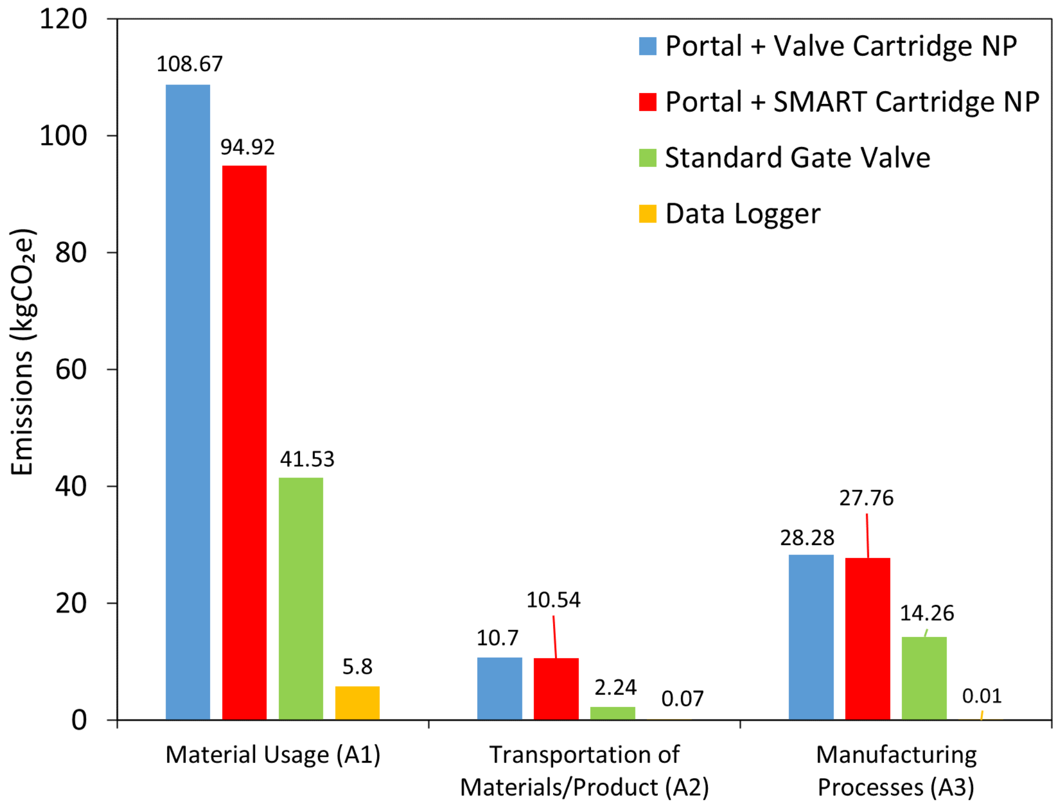


Figure 1. Embodied carbon results for the Portal + Valve Cartridge NP, Portal + SMART cartridge NP compared to the comparison products at each stage (A1-A3)

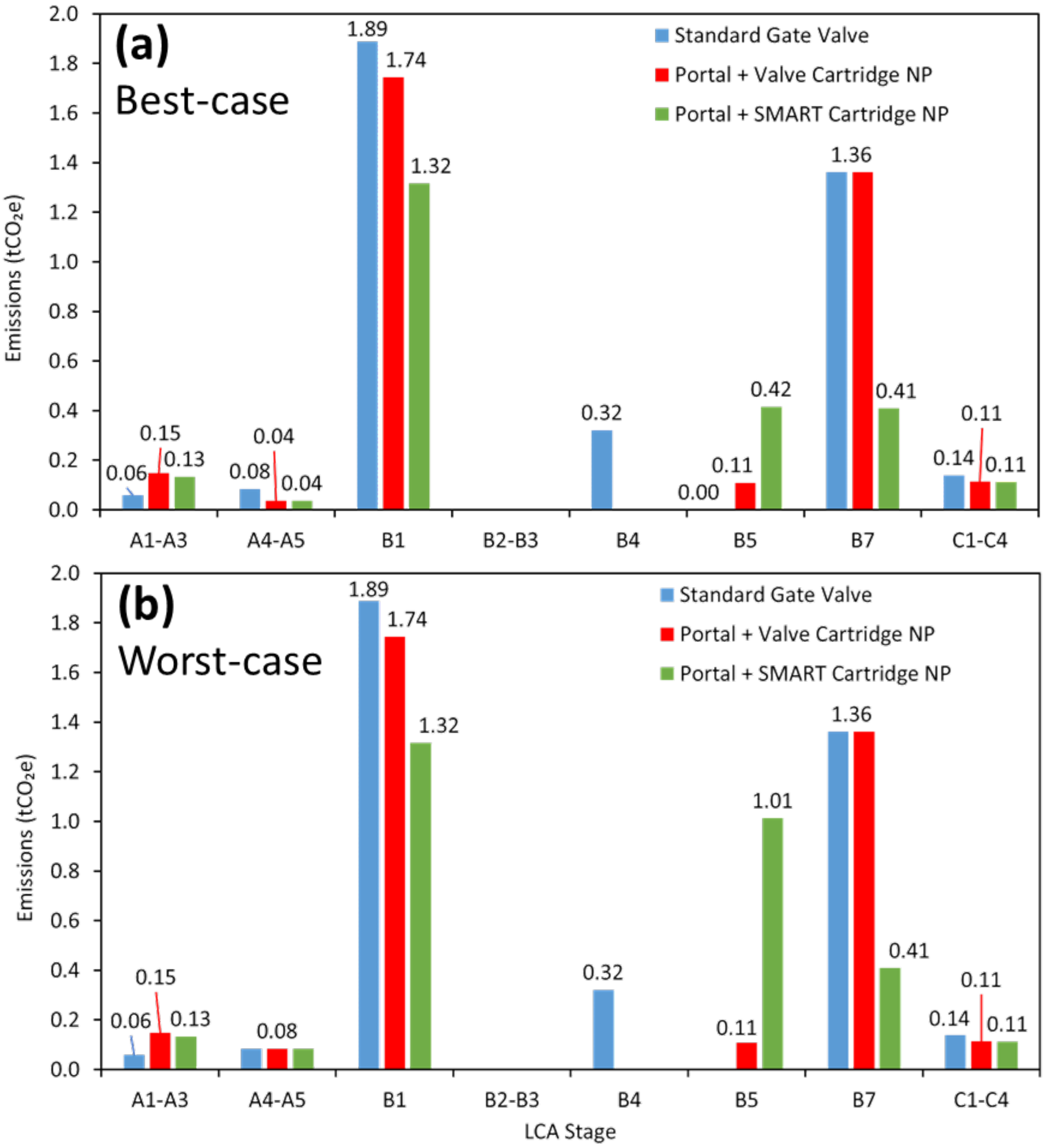


Figure 2. Calculated Carbon Life Cycle footprint for the Portal + Valve Cartridge NP, Portal + SMART cartridge NP compared to the Standard Gate Valve at each stage (A1-C4) for the best-case (a) and worst-case (b) scenarios.

Both the Portal + Valve Cartridge NP and Portal + SMART cartridge exhibit lower carbon footprints during the use (B1) and end-of-life (C1-C4) stages and possess a lower overall carbon footprint over their lifetime compared to the Standard Gate Valve. The Portal + SMART Cartridge NP provides significant operational water-loss emissions savings (B7). Furthermore, the Standard Gate Valve needs replacement every 35-40 years, adding 0.32 tCO_2e to its carbon footprint. In the best-case scenario, the implementation emissions (A4-A5) for both Portal systems are lower than in the worst-case scenario due to the lack of excavation needed when replacing an existing Standard Gate Valve. The Portal + SMART Cartridge NP also shows lower refurbishment emissions (B5) in the best-case scenario, attributed to longer component lifespans and less frequent refurbishment requirements. Further details and comparisons can be found within the discussion section.

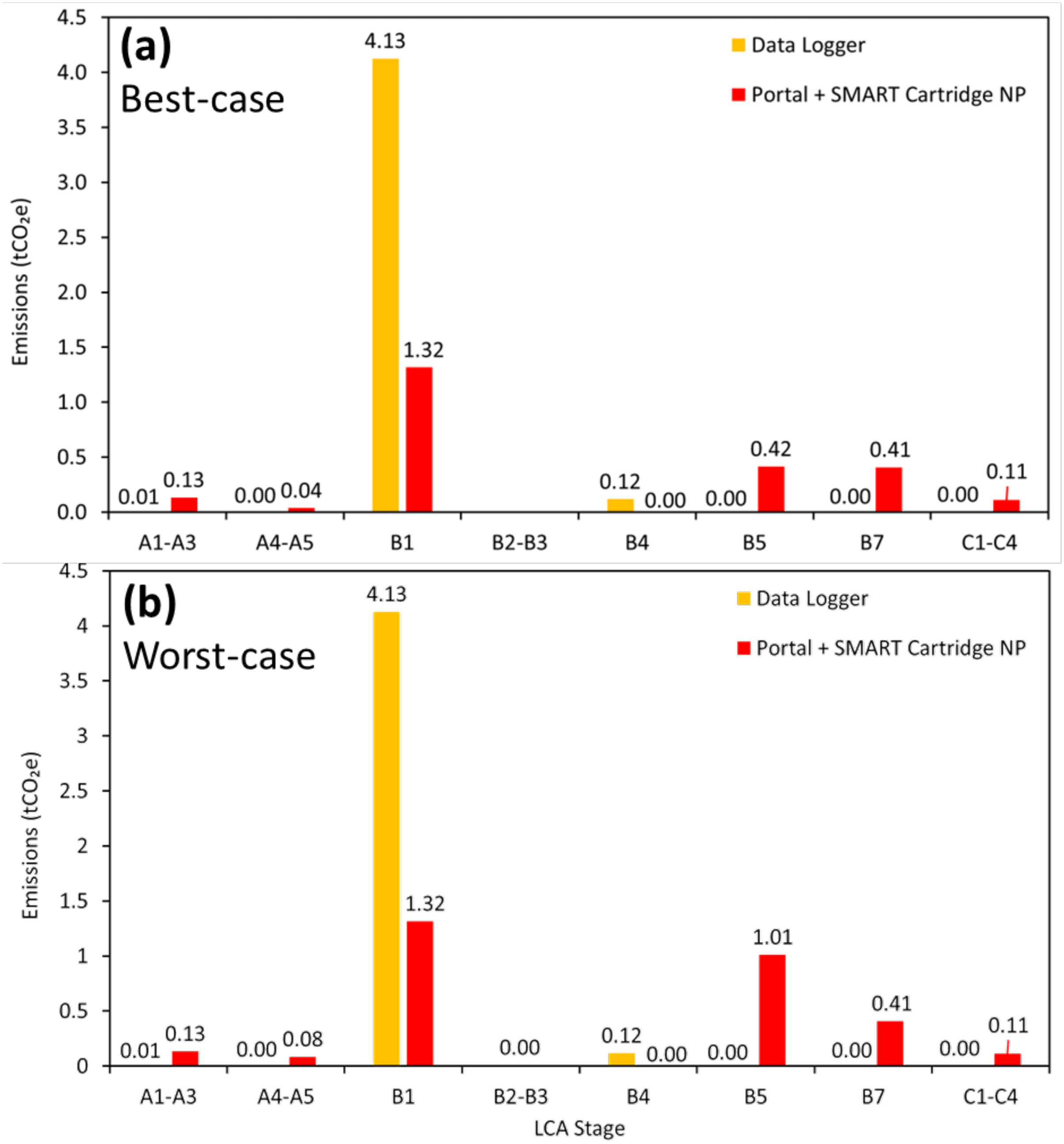


Figure 3. Calculated Carbon Life Cycle footprint for the Portal + SMART cartridge NP compared to the Data Logger at each stage (A1-C4) for the best-case (a) and worst-case (b) scenarios.

The Portal + SMART Cartridge NP demonstrates significantly lower emissions in the use stage (B1) compared to the Data Logger. This is attributed to the Data Logger requiring travel for implementation and readings, while the Portal + SMART Cartridge NP stays in place, providing real-time telemetry data after installation without additional travel for readings until refurbishment is needed.

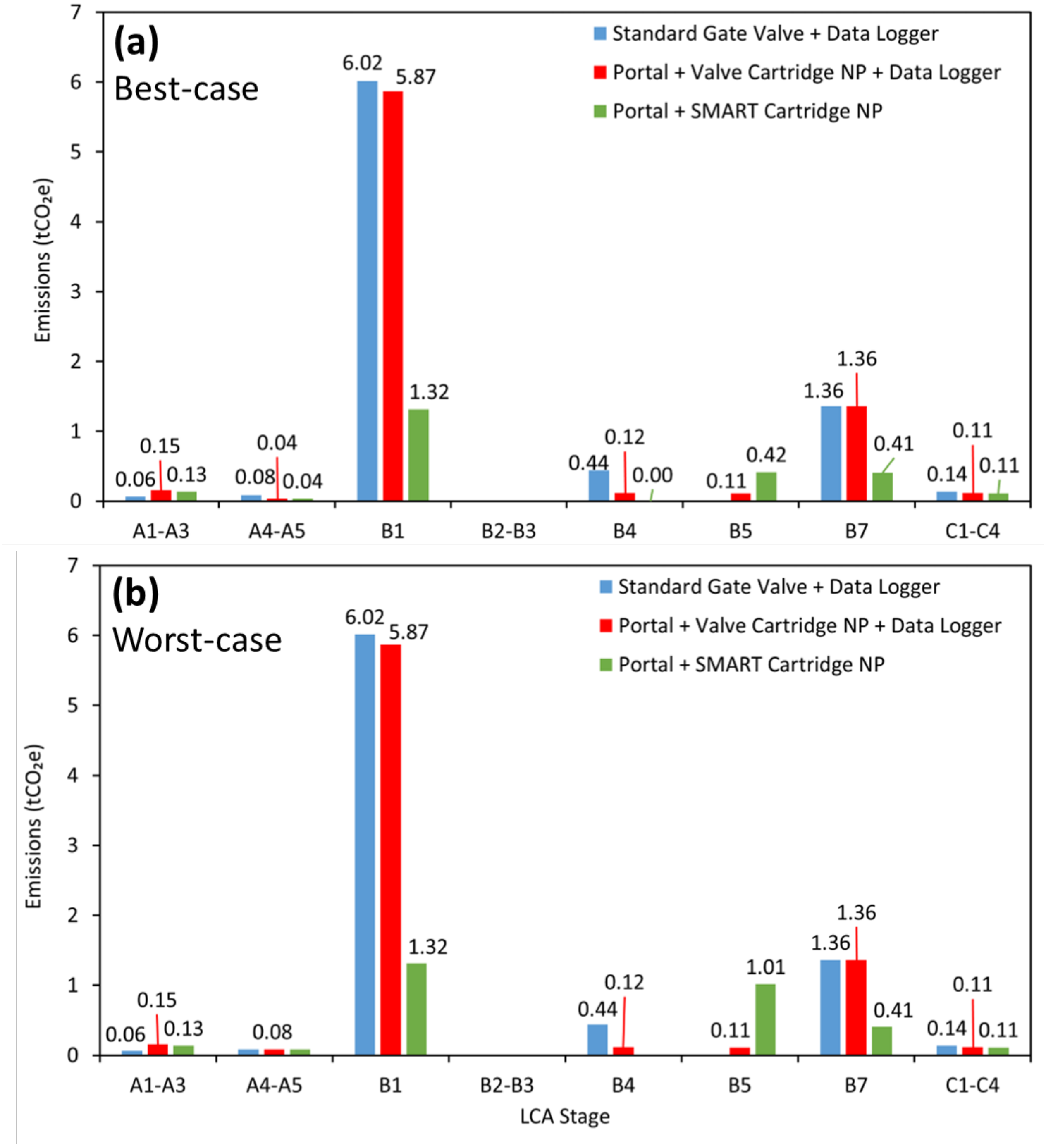


Figure 4. Calculated Carbon Life Cycle footprint for the Portal + Valve Cartridge NP + Data Logger, Portal + SMART cartridge NP compared to the Standard Gate Valve + Data Logger at each stage (A1-C4) for the best-case (a) and worst-case (b) scenarios.

The use of a Data Logger with a Standard Gate Valve results in a higher carbon footprint during the use stage (B1) compared to the Portal + Valve Cartridge NP. The Portal + SMART Cartridge NP exhibits significantly lower emissions during the use stage (B1) compared to both other combinations, highlighting the carbon benefits of adopting the Portal + SMART Cartridge NP over traditional valve systems and Data Loggers.

Introduction

iVapps has engaged Tunley Environmental to undertake a comprehensive whole Life-Cycle Carbon Life-Cycle Carbon Analysis (LCA) of their products, encompassing the carbon emissions associated with the manufacture (embodied carbon), implementation, use, and end-of-life stages (A1 – C4, as illustrated below). The primary objective of this report is to present the emissions data for each life-cycle stage (A1 – C4) and to conduct a comparative LCA of iVapps Ltd's products: "Portal + Valve Cartridge NP" and "Portal + SMART Cartridge NP," in comparison to a "Standard Gate Valve" and "Data Logger" typically employed in the water industry. The assessment was carried out following a manner consistent with the International Standards on Life-Cycle Carbon Analysis (ISO 14040 and ISO 14044).

Embodied Carbon Stage			Construction		Use Stage							End-of-Life Stage			
Raw Materials	Transport	Manufacturing	Transport to Site	Installation	Use/Application	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	Deconstruction	Transport	Waste Processing	Disposal
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4

Figure 5 illustrates the iVapps product line, which includes the Portal as the main component for implementing the Non-Pressured Valve (Valve cartridge NP) and the SMART cartridge (SMART Cartridge NP). Tunley Environmental has quantified the embodied carbon of each product and their combination. The assessment utilised a Life-Cycle Carbon Analysis methodology to evaluate the carbon impact of the Portal in conjunction with the Valve Cartridge NP and the SMART Cartridge NP. We also considered a scenario involving the use of a data logger with the Portal and Valve Cartridge NP combination. This allowed for a like-for-like comparison of the use stage (B1) with a Standard Gate Valve with/without a data logger. We considered two scenarios: a worst-case scenario, in which the components of the SMART cartridge are refurbished and replaced more frequently than in the best-case scenario (Table A3). Furthermore, the best-case scenario assumes that the iVapps products can be implemented without the need for excavation work, such as replacing an existing valve within a manhole.

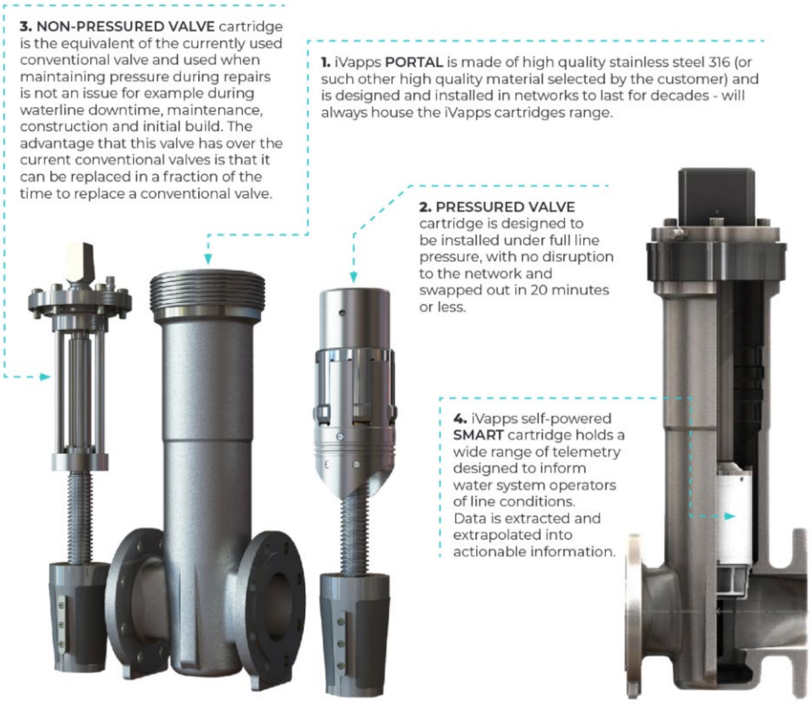


Figure 5. Illustration of iVapps products. [https://ivappstech.com/the-ivapps-solution/]

Methodology

A comprehensive whole Life-Cycle Carbon Analysis (LCA) of the iVapps products was conducted. This encompassed the carbon emissions associated with the manufacture (embodied carbon), implementation, use, and end-of-life stages (A1 – C4, as illustrated in Figure 6). The stage B6 was excluded as there are no operational electricity requirements.

Two scenarios were considered over a 100-year timescale, a best-case and a worst-case for the iVapps products. In the worst-case scenario the components of the SMART cartridge are refurbished and replaced more frequently than in the best-case scenario (Table A3). Furthermore, the best-case scenario assumes that the iVapps products can be implemented without the need for excavation work, such as replacing an existing valve within a manhole. Further details of the assumptions and life cycle indicators applied can be found within “Appendix A - Assumptions and Data Sources”, whereas the key data inputs can be found in “Appendix B - Data Inputs”.

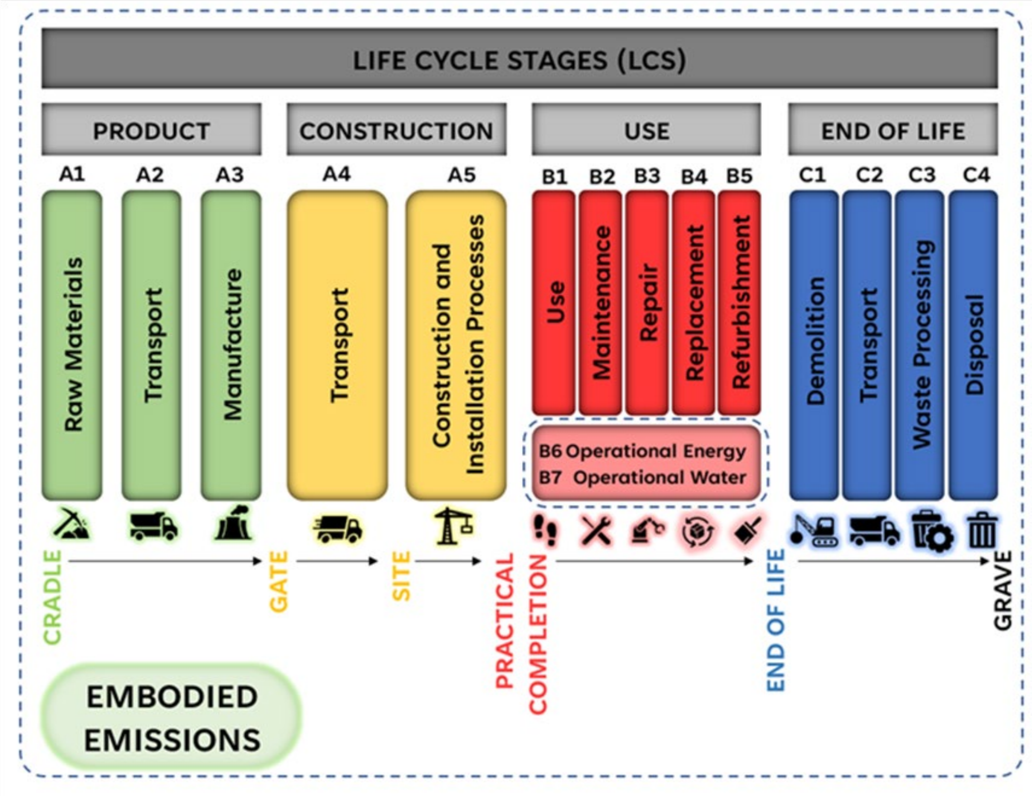


Figure 6. Illustration of the life cycle stages within a Life-Cycle Carbon Analysis.

The scope of the analysis which has been agreed with iVapps includes the life cycle stages stated within Table 1 below:

Table 1: Summary of the life cycle stages included in the LCA

Life cycle stage	Life cycle stage module	Summary scope description
Before use stage	A1-A3 Product Stage	The extraction, processing and manufacturing of all materials required for the permanent assets. This includes all of the carbon emissions from manufacturing, including primary and secondary manufacturing stages as well as any transport emission between these stages. This also includes transport from country or site of manufacturing to iVapps.
	A4 Transport to site	The transportation of the iVapps products to the site where it will be constructed and implemented. This includes all of the equipment required for implementation at the site of construction.
	A5 Construction and Implementation Stage	Emissions associated with construction activities.
Use stage	B1 Use stage	The emissions linked to product usage throughout the 100-year investigation period encompass various factors such as transportation to and from the implementation site for surveying with data loggers, the lifecycle of the data logger, pipe repair, or replacement within the specific section of pipe associated with the installed product.
	B2 Maintenance and B3 Repair	The emissions linked to maintenance and repair are estimated to constitute 2% of the product's embodied carbon, aligning with established guidelines for infrastructure
	B4 Replacement	Emissions associated to the replacement of any product with a design life of less than 100 years (e.g., Standard Gate Valve) including: Cradle to gate emissions associated with the products. Transportation emissions associated with transporting bulk materials and products. Emissions associated with the transportation of products and equipment to and from site. Emissions associated with construction and implementation activities.
	B5 Refurbishment	Emissions associated to the refurbishment the iVapps products, this includes: Cradle to gate emissions associated to replacement parts Transportation emissions associated with transporting bulk materials and products. Emissions associated with the transportation of products and equipment to and from site.
	B7 Operational Water	The emissions stemming from water loss in a section of pipe influenced by the product. This includes both the emissions associated with the water production and water treatment. It is assumed to occur once every 10 years over the 100-year investigation period. There are two scenarios in which water loss can occur: Major pipe failure, 14.4 m3 of water loss per hour for 24 hours. Replacement of pipe is needed (B1). Minor pipe failure, 0.254 L of water loss per hour for 12 hours. Pipe is fixed through implementation of pipe collar (B1)
End of life stage	C1-C4 End of life stage	End of life emissions associated with landfill or recycling of products.

6.1 Inclusions and exclusions

The analysis accounted for all materials utilised in the manufacturing of the Standard Gate Valve, iVapps products, and the data logger + probe. Emissions linked to the production processes were quantified and incorporated, as well as transportation emissions from both within and outside their respective countries of origin.

The definitive list of materials used within the LCA can be found below:

- Iron, Stainless Steel
- Brass
- Aluminium
- EPDM
- Polyurethane
- Polyoxymethylene
- NBR
- Polyamide
- Epoxy
- PTFE
- Electrical Cabling
- Printed Circuit Board
- Battery - Li-ion
- Copper
- Polycarbonate
- Sm_2Co_{17}
- SSIC ceramic

6.3 Scope, Boundaries, Limitation and Assumptions

The assessment boundary considers a 100 year lifetime of a section of pipeline in which the valves are responsible for isolating.

The embodied carbon of the Standard Gate Valve was determined using technical data for a 4" diameter pipe gate valve, which conforms to the water industry standard. The valve was assumed to be manufactured in Saudi Arabia and includes emissions from transportation to the UK. The expected lifespan of 35-40 years was obtained from the EPA publication EPA 816-R-03-016 (September 2003)

The embodied carbon of the data logger and probe was calculated using technical data for a standard data logger and probe utilised in the water industry. The assumed origin of manufacture for both components is the United States, and their embodied carbon includes emissions from transportation to the UK. Discussions with water industry experts were used to determine a 5-year lifespan for the data logger and probe.

The analysis assumes that the section of the pipe related to the product will encounter a failure every 10 years. Based on this assumption, it is estimated that the Portal + Standard Cartridge NP (Table A1) and Standard Gate Valve will experience 10 significant pipe failures during the 100-year study period, whereas the Portal + SMART Cartridge NP will only encounter 3 major pipe failures. For the Portal + SMART Cartridge NP, the remaining failures are expected to be minor pipe failures that can be remedied using a collar, rather than requiring pipe replacement as is the case for significant pipe failures.

The analysis assumes that all transportation to and from the implementation site will occur within a 100 km radius, representing local travel. Annual use of the data logger in conjunction with the Portal + Standard Cartridge NP and Standard Gate Valve will involve two vans. It is further assumed that electric vans will be used 30% of the time, while diesel vans will be used 70% of the time, to reflect the current trend of utility companies transitioning to electric vehicles.
The best-case and worst-case scenarios involve varying timeframes for refurbishment and part replacement in the iVapps products. Furthermore, the best-case scenario assumes that the iVapps products can be implemented without the need for excavation work, such as replacing an existing valve within a manhole A comprehensive list of assumptions and limitations can be found in "Appendix A - Assumptions and Data Sources"

Results

7.1 Embodied Carbon

The embodied carbon (A1-A3, Figure 6) was calculated for several items, including the "Portal," "Valve Cartridge NP," "SMART Cartridge NP," and their combinations with the portal, "Portal + Valve Cartridge NP" and "Portal + SMART Cartridge NP." The embodied carbon was also determined for the comparison products, "Standard Gate Valve" and "Data Logger". Table 2 provides a summary of the total embodied carbon for the iVapps products and their respective combinations compared to the comparison products.

Table 2: Calculated embodied carbon of the iVapps products and their respective combinations compared to the comparison products. Reported in $kgCO_2e$.

Product Name	Embodied Carbon (A1-A3, $kgCO_2e$)
iVapps Products	
Valve Cartridge NP	56.08
SMART Cartridge NP	41.72
Portal + Valve Cartridge NP	147.66
Portal + SMART Cartridge NP	133.22
Comparison Products	
Standard Gate Valve	58.02
Data Logger	5.88

The embodied carbon of iVapps cartridges, namely "Valve Cartridge NP" and "SMART Cartridge NP," is lower than that of the industry-standard "Standard Gate Valve." However, when considering the implementation of these cartridges in infrastructure, in combination with the portal as "Portal + Valve Cartridge NP" and "Portal + SMART Cartridge NP" their embodied carbon increases to 147.66 and 133.22 $kgCO_2e$, respectively (Table 2). This is significantly higher than that of the "Standard Gate Valve" (58.02 $kgCO_2e$), by a factor of approximately 2.55 and 2.29, respectively.

Figure S1, presented in Appendix C - Supporting Information, illustrates the embodied carbon for each stage (A1-A3) of the “Valve Cartridge NP” and “SMART Cartridge NP”. This section will solely on the complete iVapps products, "Portal + Valve Cartridge NP" and "Portal + SMART Cartridge NP," as compared to the reference products "Standard Gate Valve" and "Data Logger.

Figure 7 outlines a comparative analysis of the embodied carbon stages (A1-A3) for iVapps products with regards to their reference counterparts. In the material use component (A1) the iVapps products exhibit a higher footprint than the reference products, with the Data Logger demonstrating the smallest impact. To mitigate this, the implementation of guidelines concerning material selection and minimisation is recommended. This may encompass employing recycled materials or those with a low carbon footprint, and restricting material usage to amounts essential for maintaining safe and durable product performance.

The transportation phase (A2) reveals a larger carbon footprint for the iVapps products in comparison to the reference items. Reduction of this impact can be achieved through the localisation of manufacturing processes or the procurement of raw materials from proximate countries, thereby diminishing the transportation distance to assembly and production sites.

Moreover, the manufacturing process stage (A3) also indicates a greater carbon footprint for iVapps products. This can be attenuated through investments in novel manufacturing technologies and/or utilising renewable energy sources to power production facilities.

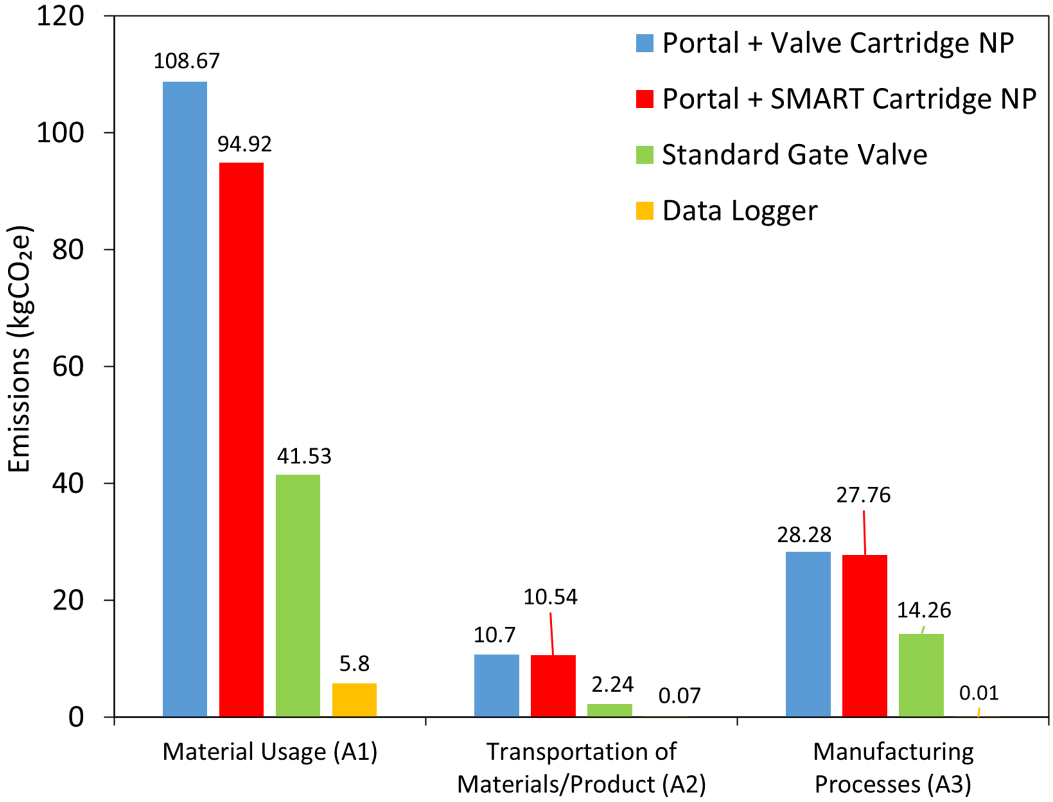


Figure 7. Embodied carbon results for the Portal + Valve Cartridge NP, Portal + SMART cartridge NP compared to the comparison products at each stage (A1-A3)

Figure 8 offers an in-depth analysis of the individual material contributions to the embodied carbon stages (A1-A3) for iVapps products, alongside their reference equivalents. Concurrently, Figure S2, located in Appendix C - Supporting Information, depicts the material contributions to the embodied carbon for the "Valve Cartridge NP" and "SMART Cartridge NP" components. Ductile iron emerges as the most significant contributor to the embodied carbon of the iVapps products, originating from the emissions linked to the Portal. This is succeeded by the stainless steel components, with the Standard Gate Valve exhibiting the same pattern. In the case of the Portal + Valve Cartridge NP, EPDM ranks as the third largest contributor, whereas miscellaneous materials, inclusive of electronics, assume this position for the Portal + SMART NP. The miscellaneous components encompass the magnetic coupling and an assortment of electronic components, such as sensors, wires, and circuit boards.

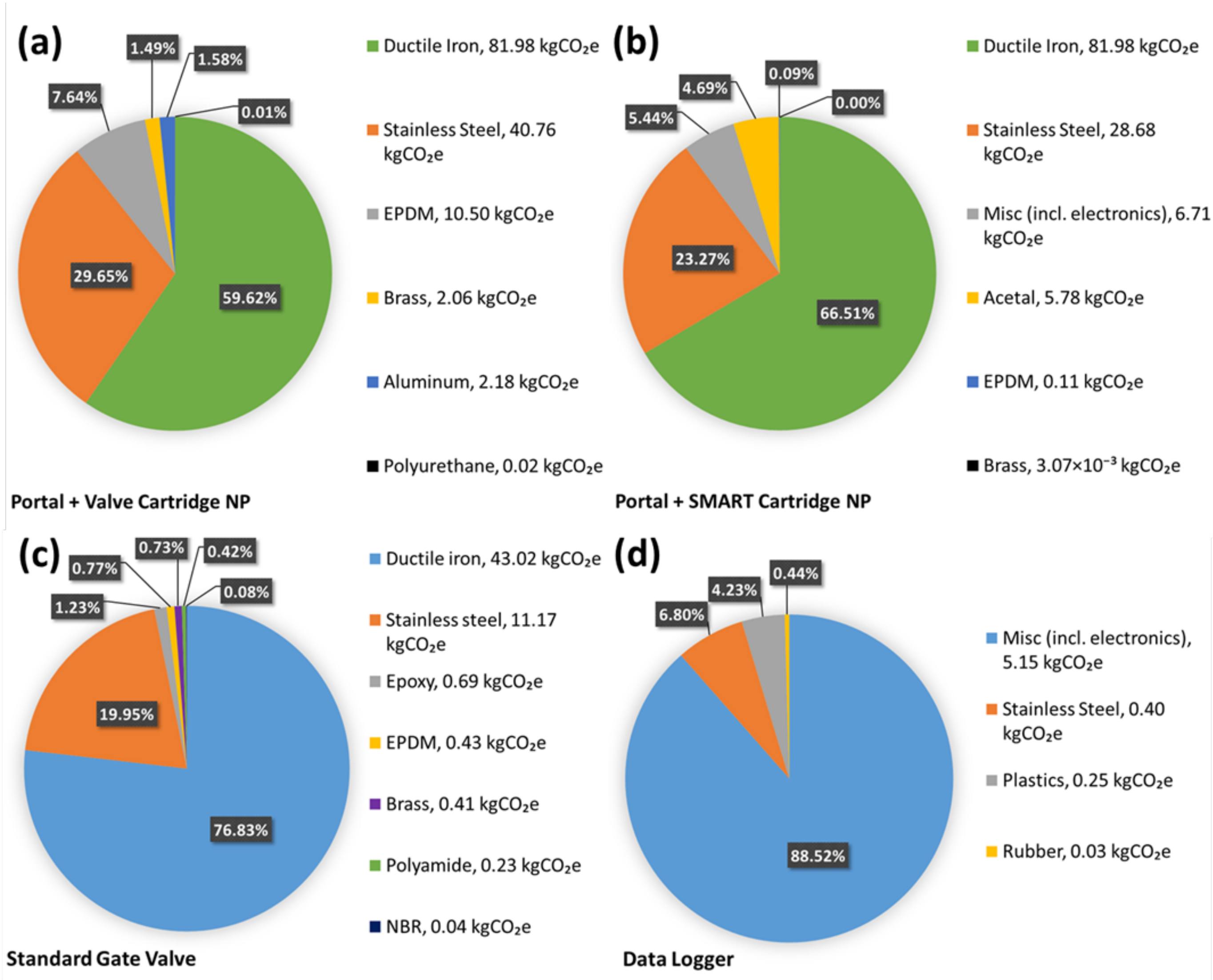


Figure 8. Breakdown of the material component emissions for the embodied carbon (A1-A3) of the Portal + Valve Cartridge NP (a), Portal + SMART cartridge NP (b), Standard Gate Valve (c) and Data Logger (d)

7.2 Carbon Life Cycle Analysis

The Carbon Life Cycle Analysis (A1-C4 excluding B6, Figure 6) was calculated for the iVapps cartridges used in conjunction with the portal "Portal + Valve Cartridge NP" and "Portal + SMART Cartridge NP". The Carbon Life Cycle Analysis was also determined for the comparison products, "Standard Gate Valve" and "Data Logger". The combination of "Portal + Valve Cartridge NP + Data Logger" and "Standard Gate Valve + Data Logger" are also considered. In this assessment two scenarios were considered over a 100-year timescale, a best-case and a worst-case for the iVapps products. Details of the assumptions and life cycle indicators applied can be found within the methodology and "Appendix A - Assumptions and Data Sources", whereas the key data inputs can be found in "Appendix B - Data Inputs". The full tabulated results over each stage (module) of the lifecycle can be found with Tables A4 – A5.

Table 3 provides a summary of the total carbon footprint for the iVapps products and their respective combinations over both scenarios compared to the comparison products over the 100-year study period.

Table 3: Calculated Carbon Life Cycle footprint of the iVapps products and their respective combinations compared to the comparison products. Reported in tCO_2e.

Product Name	Carbon Life Cycle Footprint (A1-C4, tCO_2e)
Comparison Products	
Standard Gate Valve	3.83
Data Logger	4.25
Standard Gate Valve + Data Logger	8.10
iVapps Products	
Best-case Scenario:	
Portal + Valve Cartridge NP	3.51
Portal + SMART Cartridge NP	2.42
Portal + Valve Cartridge NP + Data Logger	7.76
Worst-case Scenario:	
Portal + Valve Cartridge NP	3.56
Portal + Smart Cartridge NP	3.07
Portal NP + Valve Cartridge NP + Data Logger	7.81

In both the best-case and worst-case scenario, the Portal + Valve Cartridge NP shows a carbon benefit of 0.32 tCO2e and 0.27 tCO_2e, respectively, when compared to the Standard Gate Valve. Over a network of pipes under the control of 100 valves this has the potential of reducing emissions by a significant 32 tCO_2e over a 100 year period. When inclusive of the Data Logger the Portal + Valve Cartridge NP also shows significant carbon savings of 0.34 tCO2e and 0.29 tCO2e when compared to the Standard Gate Valve, respectively. The Portal + SMART Cartridge NP shows the lowest carbon footprint over the 100-year study period compared to the other study products across both scenarios. In the best-case scenario the carbon footprint of the Portal + SMART Cartridge NP is 2.42 tCO_2e, whilst the worst-case scenario shows a footprint of 3.07 tCO_2e.

Figure 9 provides a breakdown on the carbon footprint of the Portal + Valve Cartridge NP and Portal + SMART Cartridge NP compared to the Standard Gate Valve over each life cycle stage module for the best-case (a) and worst-case (b) scenarios. Across both scenarios the use stage (B1) and end-of-life stages (C1-C4) are lower for the Portal + Valve Cartridge NP and Portal + SMART Cartridge NP in comparison to the Standard Gate Valve. The Portal + SMART Cartridge NP offers significant savings in operational water-loss associated emissions (B7) compared to the Portal + Valve Cartridge NP and Standard Gate Valve. The Standard Gate Valve requires replacement every 35-40 years, meaning that is replaced 2 times within the 100 assessment period, contributing 0.32 tCO_2e to the carbon footprint. A direct comparison between the Portal + Valve Cartridge NP and Standard Gate Valve is highlighted in Figure S3 of the appendix.

For the best case scenario Figure 9(a) emissions associated with the implementation (A4-A5) of the Portal + Valve Cartridge NP and Portal + SMART Cartridge NP are lower than that in the worst-case

(Figure 9(b)). This is attributed to the fact that the portals can be replaced without the need for excavation, as they are swapped from a Standard Gate Valve that has reached the end of its lifespan and has already been installed. Significant reductions in emissions associated with the refurbishment stage (B5) are observed for the Portal + SMART Cartridge NP compared to the worst-case scenario (Figure 9(b)). his can be attributed to the longer lifespan of components and less frequent need for refurbishment considered in this scenario. A detailed breakdown of the percentage contribution to the carbon footprint for each life-cycle stage, as well as their corresponding scenarios, can be found in the appendix, Figures S4-S6.

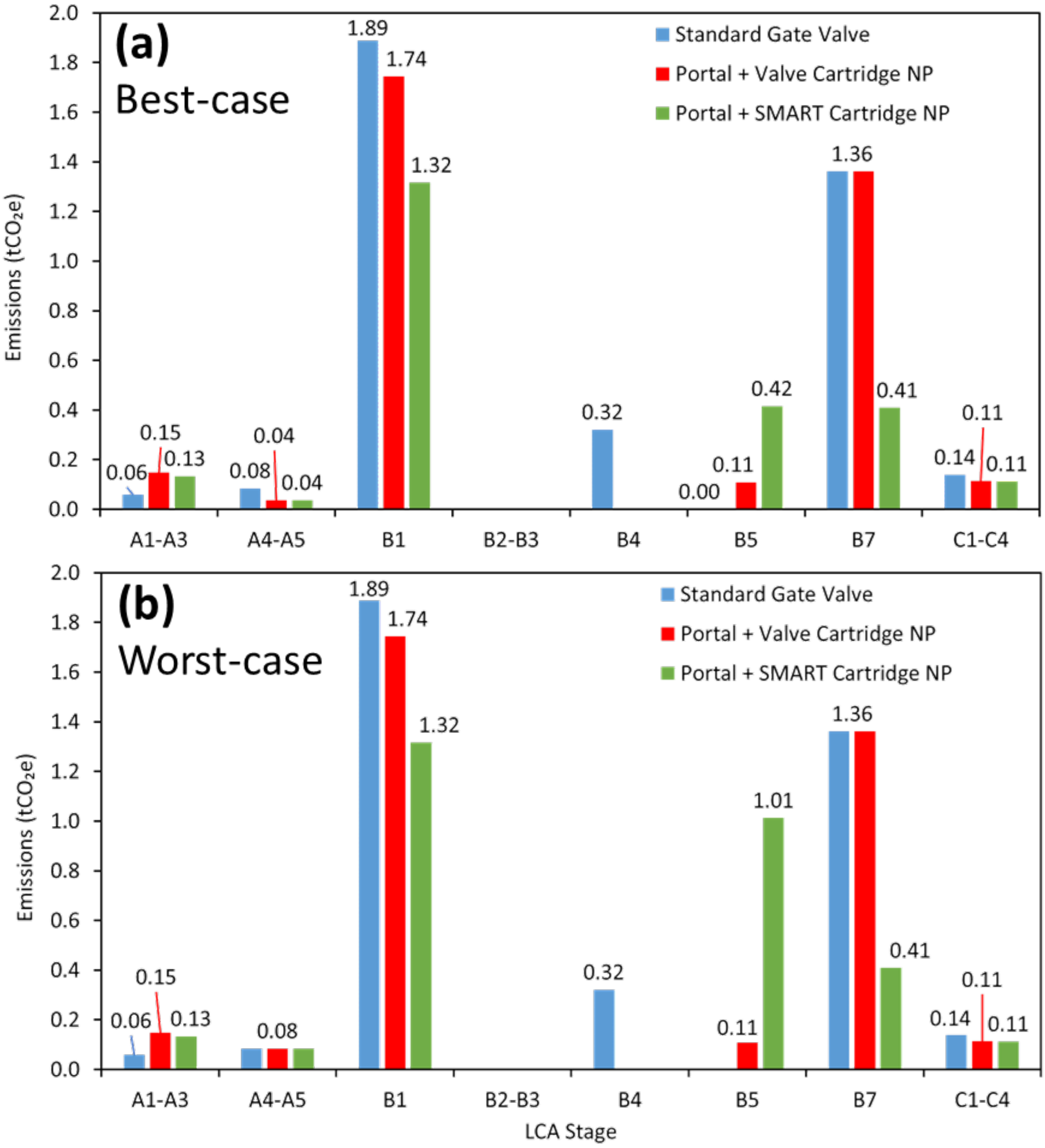


Figure 9. Calculated Carbon Life Cycle footprint for the Portal + Valve Cartridge NP, Portal + SMART cartridge NP compared to the Standard Gate Valve at each stage (A1-C4) for the best-case (a) and worst-case (b) scenarios.

The Portal + SMART Cartridge NP, which offers telemetry data on the status of pipe networks, should be directly compared to a Data Logger as they provide a similar role within the water industry. Therefore,

Figure 10 has been provided. In the use stage (B1), the Portal + SMART Cartridge NP exhibits notably lower emissions when compared to the Data Logger. This is because the Data Logger necessitates travel to implement and take readings, while the Portal + SMART Cartridge NP can remain in place until refurbishment is required to provide real-time telemetry of readings after being installed in a network of pipes.

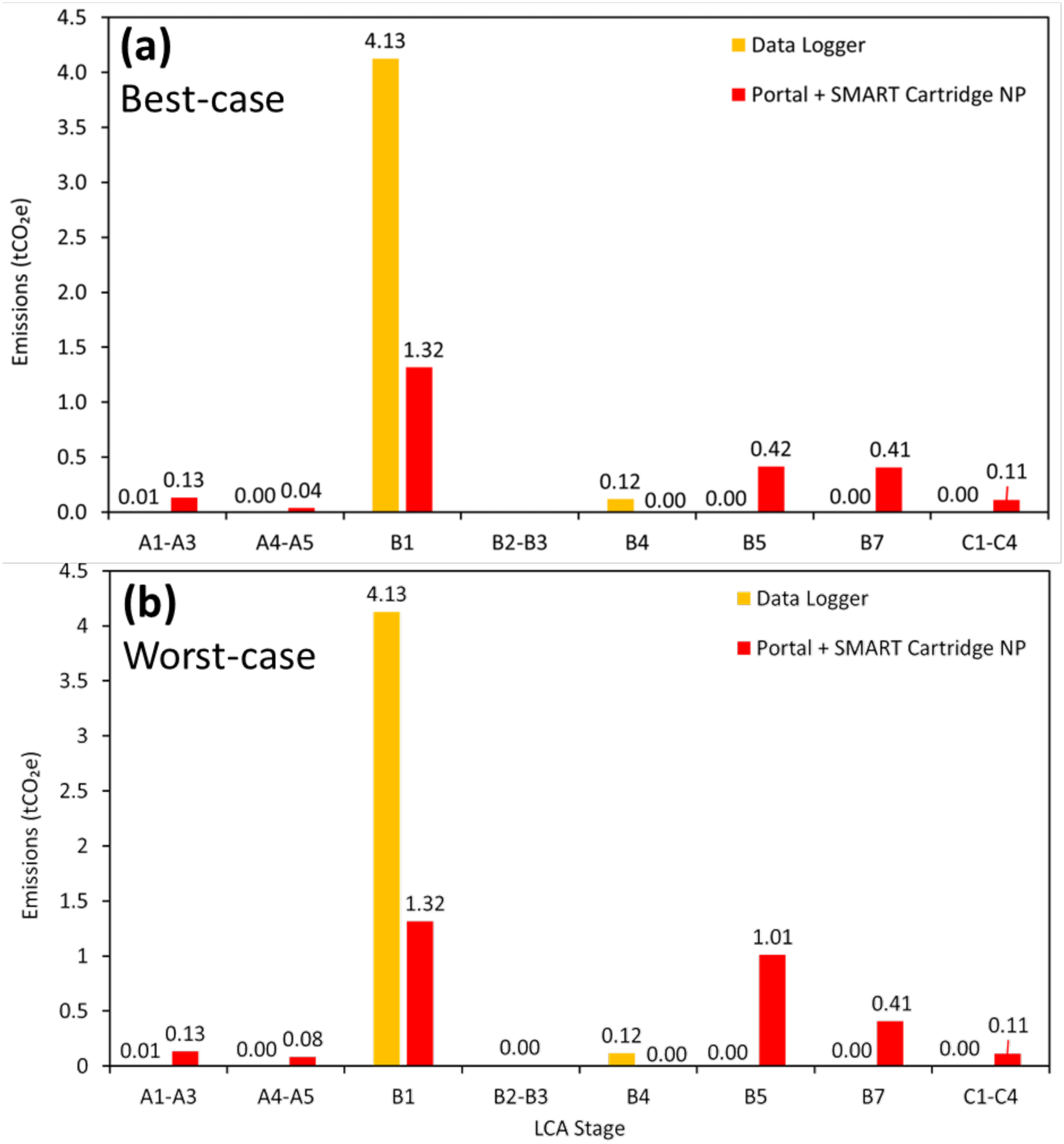


Figure 10. Calculated Carbon Life Cycle footprint for the Portal + SMART cartridge NP compared to the Data Logger at each stage (A1-C4) for the best-case (a) and worst-case (b) scenarios.

The water industry frequently uses Data Loggers to perform readings on pipe networks influenced by valves, which offers valuable insights into the pipes' condition and is regularly conducted. As a result, we have included Figure 11, which compares products, including Portal + SMART Cartridge NP and Portal + Valve Cartridge NP + Data Logger, to a Standard Gate Valve + Data Logger.

The use of a Data Logger with a Standard Gate Valve results in a larger carbon footprint during the use stage (B1) when compared to the Portal + Valve Cartridge NP. Furthermore, the emissions associated with the Portal + SMART Cartridge NP are significantly lower during the use stage (B1) when compared to both the Portal + Valve Cartridge NP and Standard Gate Valve + Data Logger. This underscores the carbon benefits of implementing the Portal + SMART Cartridge NP instead of using traditional valve systems and Data Loggers. With the implementation of the Portal + SMART Cartridge NP, there is no need for teams to travel to a site to take readings, thus reducing the emissions associated with travel.

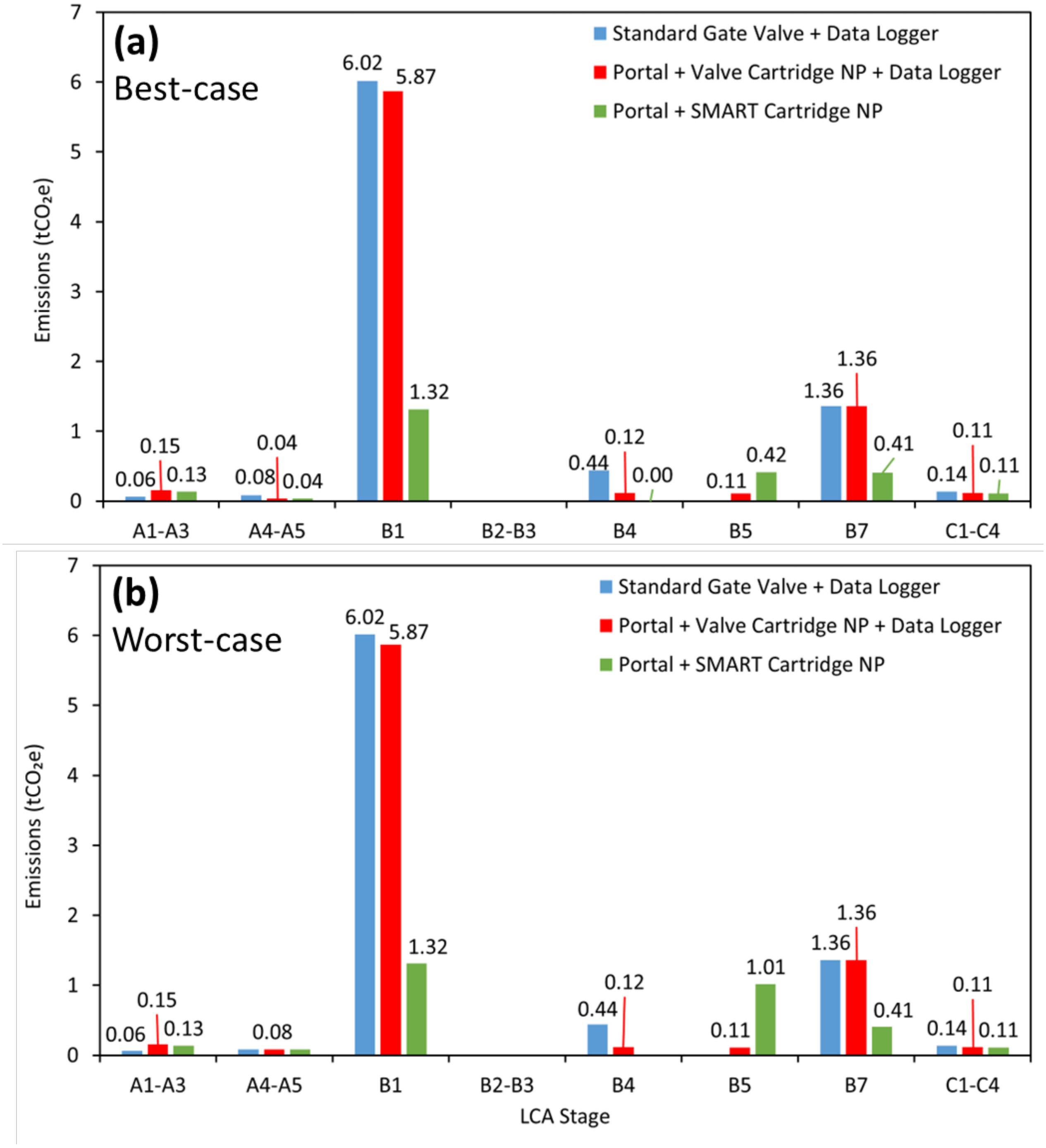


Figure 11. Calculated Carbon Life Cycle footprint for the Portal + Valve Cartridge NP + Data Logger, Portal + SMART cartridge NP compared to the Standard Gate Valve + Data Logger at each stage (A1-C4) for the best-case (a) and worst-case (b) scenarios.

Conclusions and Recommendations

The Portal + Valve Cartridge NP and Portal + SMART cartridge NP have a larger embodied carbon than the Standard Gate Valve. To reduce the embodied carbon, the implementation of guidelines concerning material selection and minimisation is recommended. This may encompass employing recycled materials or those with a low carbon footprint, and restricting material usage to amounts essential for maintaining safe and durable product performance.

During the 100-year LCA analysis period, two scenarios were evaluated for the iVapps products. The best-case scenario involves swapping the Portal directly from a Standard Gate Valve that has already been installed and has reached the end of its lifespan, as well a reduced frequency of refurbishment for the SMART Cartridge NP. In both scenarios, the Portal + Valve Cartridge NP and Portal + SMART Cartridge NP demonstrated a lower carbon footprint when compared to the Standard Gate Valve, even when a Data Logger was also considered. Additionally, the comparison between the Portal + SMART Cartridge NP and Data Logger demonstrated a significantly smaller carbon footprint during the use stage (B1) for the Portal + SMART Cartridge NP, emphasising the carbon advantages of using the Portal + SMART Cartridge NP instead of traditional valve systems and Data Loggers.

Tunley Environmental was provided with supplier analysis data by iVapps, which evaluated six water utility companies using a scale rating system ranging from 1 to 10, where 10 denotes a high level of importance. The analysis revealed that Carbon Neutrality (Net Zero) received a score of 59 out of 60 on the importance scale, as cumulated across all six water utility companies that were surveyed. The parameter “Renewable Energy” also ranked 50 out of 60, both whilst “Sustainable Water Solution” and “Reducing Leakage” ranked 47 out of 60. Tunley Environmental has assessed iVapps products to be a valuable in addressing all of the aforementioned parameters.

The SMART Cartridge is designed to be self-powered, thus eliminating the requirement for a mains power supply that is frequently sourced from a non-renewable energy grid. In contrast, the Valve Cartridge does not require power to operate and has a significantly larger expected lifetime compared to the Standard Gate Valve inclusive of refurbishment, removing any emissions associated with the implementation of a new valve. When comparing the Standard Gate Valve used in conjunction with a Data Logger, the SMART Cartridge offers several advantages. The telemetry data provided by the SMART Cartridge negates the necessity for utility teams to physically visit a site to install a data logger and conduct network assessments. Additionally, the lifespan of the SMART Cartridge far exceeds that of a Data Logger. These factors, in combination, can result in carbon emissions savings of up to 4.25 tCO_2e over a 100-year period per system. Moreover, the telemetry offered by the SMART Cartridge enhances assessment capabilities by enabling real-time detection of potential pipeline issues, thereby reducing the likelihood of catastrophic pipe failures, reducing water loss and its associated carbon footprint, and allowing for the optimal allocation of water utility team resources.

Over a water network implemented with iVapps products, the carbon savings would be significant over a 100 year study period. Assuming a hypothetical scenario where 50 Portal + Valve Cartridge NP are combined with Portal + SMART cartridge NP, the total carbon footprint over the 100-year period would range between 296.83 tCO_2e (best-case scenario) to 331.48 tCO_2e (worst-case scenario). By contrast, implementing 50 Standard Gate valve + Data Logger or 100 Standard Gate valve + Data Logger would result in significantly higher emissions of 405.11 tCO_2e and 810.22 tCO_2e, respectively. Even in the worst-case scenario considering 50 Portal + Valve Cartridge NP being combined with 50 Portal + SMART cartridge NP, compared to the use of 50 Standard Gate valve + Data Logger, a reduction in carbon emissions of 73.63 tCO_2e would still be achieved, whilst in the best-case scenario, the reduction would be 108.28 tCO_2e. Consequently, incorporating iVapps products in water utility networks provides a substantial advantage in facilitating water utility companies' transition towards Carbon Neutrality (Net Zero).

Appendix A - Assumptions and Data Sources

Assumptions, and life cycle indicators applied to and / or used to inform this LCA is listed in the tables below. These sources and common assumptions have been previously agreed with iVapps.

Table A1: Assumptions, and life cycle indicators applied to and / or used to inform this LCA across both the best-case and worst-case scenarios.

Data point	Unit	Description	Life-Cycle Stage(s)	Why used?	Source/Justification
Emission Factor	kgCO2e/kg	Virgin EPDM emission factor	A1-A3	To calculate stage A1-A3 for Standard Gate Valve, Valve Cartridge NP and SMART Cartridge NP	EPDM Material with Sustainable Content, D. ARSLAN & A. HELDIC, Department of Industrial and Material Science, CHALMERS UNIVERSITY OF TECHNOLOGY, 2021
Emission Factor	kgCO2e/kg	Polyoxymethylene (POM) emission factor	A1-A3	To calculate stage A1-A3 for Data Logger, Valve Cartridge NP and SMART Cartridge NP	IAEG dataset/ Base Impacts
Emission Factor	kgCO2e/m	Electrical cable emission factor	A1-A3	To calculate stage A1-A3 for SMART Cartridge NP and Data Logger	IAEG dataset/ Base Impacts
Emission Factor	kgCO2e/m2	Printed circuit board emission factor	A1-A3	To calculate stage A1-A3 for SMART Cartridge NP and Data Logger	IAEG dataset/ Base Impacts
Emission Factor	kgCO2e/kg	Lithium ion battery emission factor	A1-A3	To calculate stage A1-A3 for SMART Cartridge NP and Data Logger	Defining a zero-carbon building including embodied energy of materials, Parkin, A. (Author). 20 Nov 2019
Emission Factor	kgCO2e/kg	Sm2Co17 emission factor	A1-A3	To calculate stage A1-A3 for SMART Cartridge NP	Browning, C., et al. (2016). Life Cycle Assessment of Rare Earth Production from Monazite. In: , et al. REWAS 2016. Springer, Cham. https://doi.org/10.1007/978-3-319-48768-7_12
Emission Factor	kgCO2e/kg	Silicon Carbide (SSiC) emission factor	A1-A3	To calculate stage A1-A3 for SMART Cartridge NP	GHG Inventory for South Africa: 2000 – 2010, Department of Environmental Affairs (DEA). Silicon metal emission factor

Data point	Unit	Description	Life-Cycle Stage(s)	Why used?	Source/Justification
					was used as this will be close to carbide
Emission Factor	kgCO2e/kg	HDPE pipe emission factor	B1	To calculate impact of pipe replacement	Cowle, Matt & Samaras, Vasilios & Rauen, William. (2013). A COMPARATIVE ANALYSIS OF THE CARBON FOOTPRINT OF LARGE DIAMETER CONCRETE AND HDPE PIPES.
Emission Factor	kgCO2e/kg	NBR rubber emission factor	A1-A3	To calculate stage A1-A3 for Standard Gate Valve	Greenhouse Gas Index for Products in 39 Industrial Sectors: Synthetic Rubber, Brian P. Flannery and Jan W. Mares, Working Paper 22-16 M23, September 2022
Emission Factor	kgCO2e/kg	Fluoroelastomers emission factor	A1-A3	To calculate stage A1-A3 for Data Logger	Estimating the Impact of Using Recycled PTFE on CO2 Emissions, Poszmik, HS Kim, J Choo – Shamrock Technologies Inc PTFE emission factor was used, as this is similar to fluoroelastomers
Emission Factor	kgCO2e/kg	Epoxy emission factor	A1-A3	To calculate stage A1-A3 for Standard Gate Valve	DACOMAT project: LCA database of environmental impacts to inform material selection process, Callum Hill, Andrew Norton, JCH Industrial Ecology Ltd
Emission Factor	kgCO2e/t	Emission factor for iron casting process in China	A1-A3	To calculate stage A1-A3 for Portal NP and Standard Gate Valve	Rapport nr 2016-008, Climate impact of metal-casting, Martin Wänerholm, Swerea SWECAST AB
Emission Factor	kgCO2e/kg	Emission factors for stainless steel machining process	A1-A3	To calculate stage A1-A3 for Standard Gate Valve, Data logger, Valve Cartridge NP and SMART Cartridge NP	IAEG dataset/ Base Impacts
Emission Factor	kgCO2e/kg	Emission factor for brass machining process	A1-A3	To calculate stage A1-A3 for Standard Gate Valve, Data	IAEG dataset/ Base Impacts

Data point	Unit	Description	Life-Cycle Stage(s)	Why used?	Source/Justification
				logger, Valve Cartridge NP and SMART Cartridge NP	
Emission Factor	kgCO2e/kg	Emission factor for aluminium machining process	A1-A3	To calculate stage A1-A3 for Valve Cartridge NP	IAEG dataset/ Base Impacts
Weight	kg	Weights of components in Data Logger and Standard Gate Valve	A1-A3	To calculate stage A1-A3 for Standard Gate Valve and Data Logger	Weights and components were obtained from tech sheets for standard products used within the water industry. Where weights were unavailable, they were estimated from product knowledge
100.00	km	Distance of raw material/components to manufacturing site when distance was unknown, including return using a HGV	A1-A3	To include transport emissions without excessive requirement for data gathering (A1-A3)	Assumption that transport of raw material/components to site is the same distance for all raw material/components with unknown distance to ensure comparability
100.00	km	Distance from manufacturing site to port, including return using an HGV	A1-A3	To include transport emissions without excessive requirement for data gathering (A1-A3)	Assumption that transport of components to a port is the same distance for all components to ensure comparability
100.00	km	Distance from port to storage site, including return using an HGV	A1-A3	To include transport emissions without excessive requirement for data gathering (A1-A3)	Assumption that transport of components from the port is the same distance for all components to ensure comparability
21599.88	km	Distance from port in China to UK port, for container ship	A1-A3	To include transport emissions without excessive requirement for data gathering (A1-A3)	Assumption that transport of components from China via ship is the same for all components from China to ensure comparability
352.00	km	Distance from UK manufacturing site to storage, including return using a HGV	A1-A3	To include transport emissions without excessive requirement for data gathering (A1-A3)	Assumption that transport of components/products to storage is the same distance for all to ensure comparability

Data point	Unit	Description	Life-Cycle Stage(s)	Why used?	Source/Justification
6995.00	km	Distance from port in Saudi Arabia to UK port, for container ship	A1-A3	To include transport emissions without excessive requirement for data gathering (A1-A3)	Assumption that transport of components from Saudi Arabia via ship is the same for all components from China to ensure comparability
5844.91	km	Distance from port in USA to UK port, for container ship	A1-A3	To include transport emissions without excessive requirement for data gathering (A1-A3)	Assumption that transport of components from USA via ship is the same for all components from China to ensure comparability
348723.00	km	Total length of water mains in England and Wales	B7	To allow Tunley to calculate water loss per km of pipe per year in England and Wales	Data is provided by reports on Water.org.uk and discoverwater.co.uk
3172.48	m^3 km^{-1} $year^{-1}$	m^3 of "non-revenue" water lost per year per km of pipe	B7	To allow Tunley to calculate a normalised water loss per km of pipe per year in England and Wales	Data is provided by reports on Water.org.uk and discoverwater.co.uk
0.00025	m^3 m^{-1} $hour^{-1}$	m^3 of normalised "non-revenue" water lost per hour per m of pipe	B7	This allows Tunley Environmental to estimate the flow rate of water lost per m of pipe with a minor leak	Assume 20% is stolen, 5% accountancy issues, 5% other issues
60.00	L^3 m^{-1} $minute^{-1}$	m^3 of water lost per minute per m of pipe when burst	B7	This allows Tunley Environmental to estimate the water lost per m of pipe with a major leak	Provided by pressure information of water from utility companies
3.75	L $hour^{-1}$	Litres of diesel used per hour for Excavation and Backfilling operations	A5	This allows Tunley Environmental to calculate the emissions associated with fixing pipes (B1) and implementation of products (A5)	Valve was calculated from fuel use in a typical van when idling per hour and technical specifications of an excavator
100.00	km	Distance from water utility depot to site and back using diesel or electric van (30% electric, 70% diesel)	A4,B1,B4,B5,C2	To include transport emissions without excessive requirement for data gathering	Assumption the same distance for operations to ensure comparability between products
2.00	number	Number of vans used to travel to fit a valve, repair/replace pipes or	A4,B1,B4,B5,C2	To include transport emissions without excessive	Assumption based on discussion with water industry expert

Data point	Unit	Description	Life-Cycle Stage(s)	Why used?	Source/Justification
		conduct maintenance/repair on a Standard Gate Valve Including using the Data logger		requirement for data gathering	
1.00	number	Number of vans used to travel conduct maintenance/repair on an iVapps valve	B5	To include transport emissions without excessive requirement for data gathering	Provided by iVapps
100.00	km	Distance to and from water utility depot / site to iVapps for refurbishment of cartridge or swap out of cartridge	B5	To include transport emissions without excessive requirement for data gathering	Provided by iVapps
24.00	hour	Time taken from catastrophic failure of pipe to complete pipe replacement	B1,B7	To include water loss emissions without excessive requirement for data gathering	Discussed with water industry expert and iVapps
12.00	hour	Time taken from small failure of pipe to repair with iVapps solution	B1,B7	To include water loss emissions without excessive requirement for data gathering	Discussed with water industry expert and iVapps
10.00	frequency	Occurrence of major failure in a lifetime for Standard Gate Valve and Valve Cartridge NP	B1,B7	To include water loss emissions without excessive requirement for data gathering	Discussed with water industry expert and iVapps
3.00	frequency	Occurrence of major failure in a lifetime for SMART Cartridge NP	B1,B7	To include water loss emissions without excessive requirement for data gathering	Discussed with water industry expert and iVapps
7.00	frequency	Occurrence of minor failure in a lifetime for SMART Cartridge NP	B1,B7	To include water loss emissions without excessive requirement for data gathering	Discussed with water industry expert and iVapps
2.00	%	Emissions of embodied carbon to account for B2/B3, Maintenance/Repair	B2,B3	To account for any emissions associated with maintenance and repair	In line with specific guidelines for infrastructure
10.00	%	Percentage of wasted journeys over the 100 year time period to perform	B1	To account for the instances where access to the manhole/valve is hindered	Discussed with water industry expert and iVapps

Data point	Unit	Description	Life-Cycle Stage(s)	Why used?	Source/Justification
		repairs or Data Logger activities on the Standard Gate Valve		e.g., blocked manhole, cars parked.	
6.00	%	Percentage of wasted journeys over the 100 year time period to perform repairs or Data Logger activities on the Portal + Valve Cartridge	B1	To account for the instances where access to the manhole/valve is hindered e.g., blocked manhole, cars parked.	Discussed with iVapps

Table A2: Assumptions, and life cycle indicators applied to and / or used to inform this LCA across both the best-case and worst-case scenarios

Data point	Unit	Description	Life-Cylce Stage(s)	Why used?	Source/Justification
Best-Case Scenario:					
20	Frequency	Frequency of refurbishment of SMART Cartridge NP over 100 year timeframe	B1,B5	To account for refurbishment of SMART Cartridge NP over lifetime	Refurbishment schedule provided by iVapps
6	Frequency	Frequency of refurbishment of Valve Cartridge NP over 100 year timeframe	B1,B5	To account for refurbishment of Valve Cartridge NP over lifetime	Refurbishment schedule provided by iVapps
1.28	factor	Factor multiplied of embodied carbon emissions for refurbishment of SMART Cartridge NP over lifetime	B5	To account for refurbishment of SMART Cartridge NP over lifetime	Refurbishment schedule provided by iVapps
0.13	factor	Factor multiplied of embodied carbon emissions for refurbishment of Valve Cartridge NP over lifetime	B5	To account for refurbishment of Valve Cartridge NP over lifetime	Refurbishment schedule provided by iVapps
Worst-Case Scenario:					
50	Frequency	Frequency of refurbishment of SMART Cartridge NP over 100 year timeframe	B1,B5	To account for refurbishment of SMART Cartridge NP over lifetime	Refurbishment schedule provided by iVapps
6	Frequency	Frequency of refurbishment of Valve Cartridge NP over 100 year timeframe	B1,B5	To account for refurbishment of Valve	Refurbishment schedule provided by iVapps

				Cartridge NP over lifetime	
2.60	factor	Factor multiplied of embodied carbon emissions for refurbishment of SMART Cartridge NP over lifetime	B5	To account for refurbishment of SMART Cartridge NP over lifetime	Refurbishment schedule provided by iVapps
0.13	factor	Factor multiplied of embodied carbon emissions for refurbishment of Valve Cartridge NP over lifetime	B5	To account for refurbishment of Valve Cartridge NP over lifetime	Refurbishment schedule provided by iVapps

Appendix B - Data Inputs

Data inputs for materials and products are listed below.

Table A3: Data inputs for materials and products for the items considered within this LCA.

Product	Design component	Material	Specification	Quantity	Product life span / maintenance cycles
Both Scenarios:					
Portal NP	Portal body	Ductile Iron		27.05 kg	100 yeas, in line with pipe
Valve Cartridge NP	All expt. O-rings	Stainless steel, Brass, EPDM, Polyurethane, Aluminium	-	12.87 kg	100 yeas, in line with pipe
Valve Cartridge NP	O-rings	EPDM	-	-	15 years

SMART Cartridge NP	All expt. O-rings, plastics, screws and electronics	Stainless steel, Brass, EPDM, Plastics,	-	8.47 kg	100 yeas, in line with pipe
SMART Cartridge NP	O-rings	EPDM	-	-	15 years
Standard Gate Valve	All	Ductile Iron, Stainless steel, Brass, Rubber, Epoxy, Plastics	-	17 kg	35 years
Data Logger	All	Electronics, Stainless steel, Plastics, Rubber	-	0.63 kg	5 years
Best-case Scenario:					
SMART Cartridge NP	Plastics	Plastics	-	-	20 years
SMART Cartridge NP	Plastics	Electronics	-	-	8 years - sensors replaced or recalibrated, screws replaced if worn
Worst-case Scenario:					
SMART Cartridge NP	Plastics	Plastics	-	-	10 years
SMART Cartridge NP	Plastics	Electronics	-	-	4 years - sensors replaced or recalibrated, screws replaced if worn

Appendix C – Supporting Information

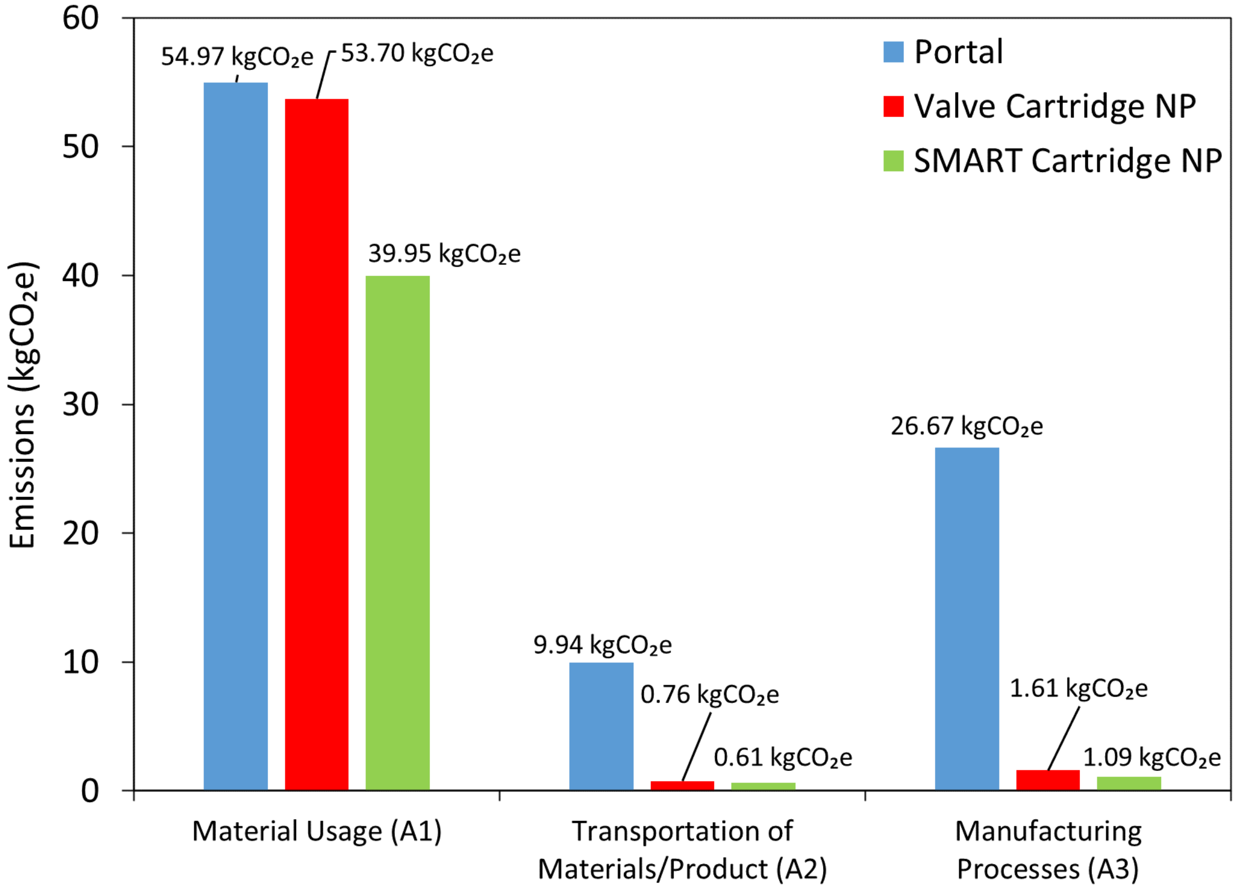


Figure S1. Embodied carbon results for the iVapps Portal, Valve Cartridge NP and SMART cartridge NP at each stage of A1-A3

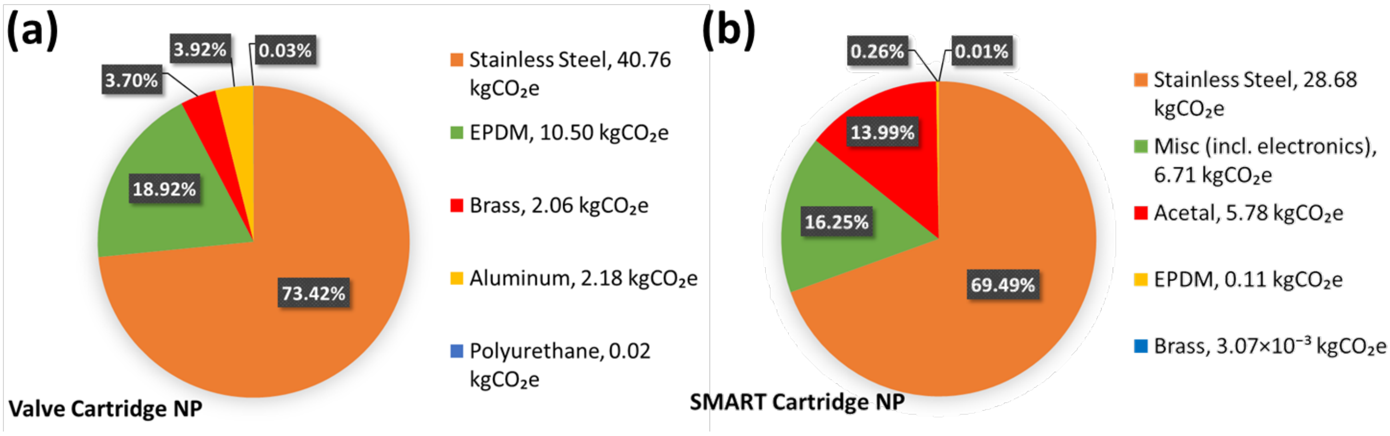


Figure S2. Breakdown of the material component emissions for the embodied carbon (A1-A3) of the Valve Cartridge NP (a) and SMART cartridge NP (b).

Table A4: Total carbon footprint (tCO_2e) by life cycle stage module for comparison products and their combinations

	A1-A3	A4-A5	B1	B2-B3	B4	B5	B7	C1-C4	A1-C4	A1-C4
Product	Embodied Carbon ($kgCO_2e$)	Implementation ($kgCO_2e$)	Use/Application ($kgCO_2e$)	Maintenance/Repair ($kgCO_2e$)	Replacement ($kgCO_2e$)	Refurbishment ($kgCO_2e$)	Water Loss ($kgCO_2e$)	End-of-life ($kgCO_2e$)	Total ($kgCO_2e$)	Total (tCO_2e)
Gate valve	58.02	84.11	1,888.15	1.28	320.73	0.00	1,360.97	113.01	3,826.27	3.83
Data Logger	5.88	0.00	4,126.91	0.00	117.55	0.00	0.00	0.11	4,250.44	4.25
Gate valve + Data Logger	63.90	84.11	6,015.06	1.28	438.27	0.00	1,360.97	138.61	8,102.20	8.10

Table A6: Total carbon footprint (tCO_2e) by life cycle stage module for iVapps products and their combinations

Product	A1-A3 Embodied Carbon ($kgCO_2e$)	A4-A5 Implementation ($kgCO_2e$)	B1 Use/Application ($kgCO_2e$)	B2-B3 Maintenance/Repair ($kgCO_2e$)	B4 Replacement ($kgCO_2e$)	B5 Refurbishment ($kgCO_2e$)	B7 Water Loss ($kgCO_2e$)	C1-C4 End-of-life ($kgCO_2e$)	A1-C4 Total ($kgCO_2e$)	A1-C4 Total (tCO_2e)
Worst-case Scenario										
Portal + Valve Cartridge NP	147.66	84.11	1,743.54	3.07	0.00	109.03	1,360.97	113.01	3,561.40	3.56
Portal + SMART Cartridge NP	133.22	84.11	1,315.59	2.66	0.00	1,012.40	408.30	111.98	3,068.27	3.07
Portal + Valve Cartridge NP + Data Logger	153.53	84.11	5,870.45	3.07	117.55	109.03	1,360.97	113.12	7,811.84	7.81
Best-case Scenario										
Portal + Valve Cartridge NP	147.66	36.15	1,743.54	3.07	0.00	109.03	1,360.97	113.01	3,513.44	3.51
Portal + Smart Cartridge NP	133.22	36.15	1,315.59	2.66	0.00	415.15	408.30	111.98	2,423.07	2.42

Product	A1-A3 Embodied Carbon ($kgCO_2e$)	A4-A5 Implementation ($kgCO_2e$)	B1 Use/Application ($kgCO_2e$)	B2-B3 Maintenance/Repair ($kgCO_2e$)	B4 Replacement ($kgCO_2e$)	B5 Refurbishment ($kgCO_2e$)	B7 Water Loss ($kgCO_2e$)	C1-C4 End-of-life ($kgCO_2e$)	A1-C4 Total ($kgCO_2e$)	A1-C4 Total (tCO_2e)
Portal NP + Valve Cartridge NP + Data Logger	153.53	36.15	5,870.45	3.07	117.55	109.03	1,360.97	113.12	7,763.88	7.76

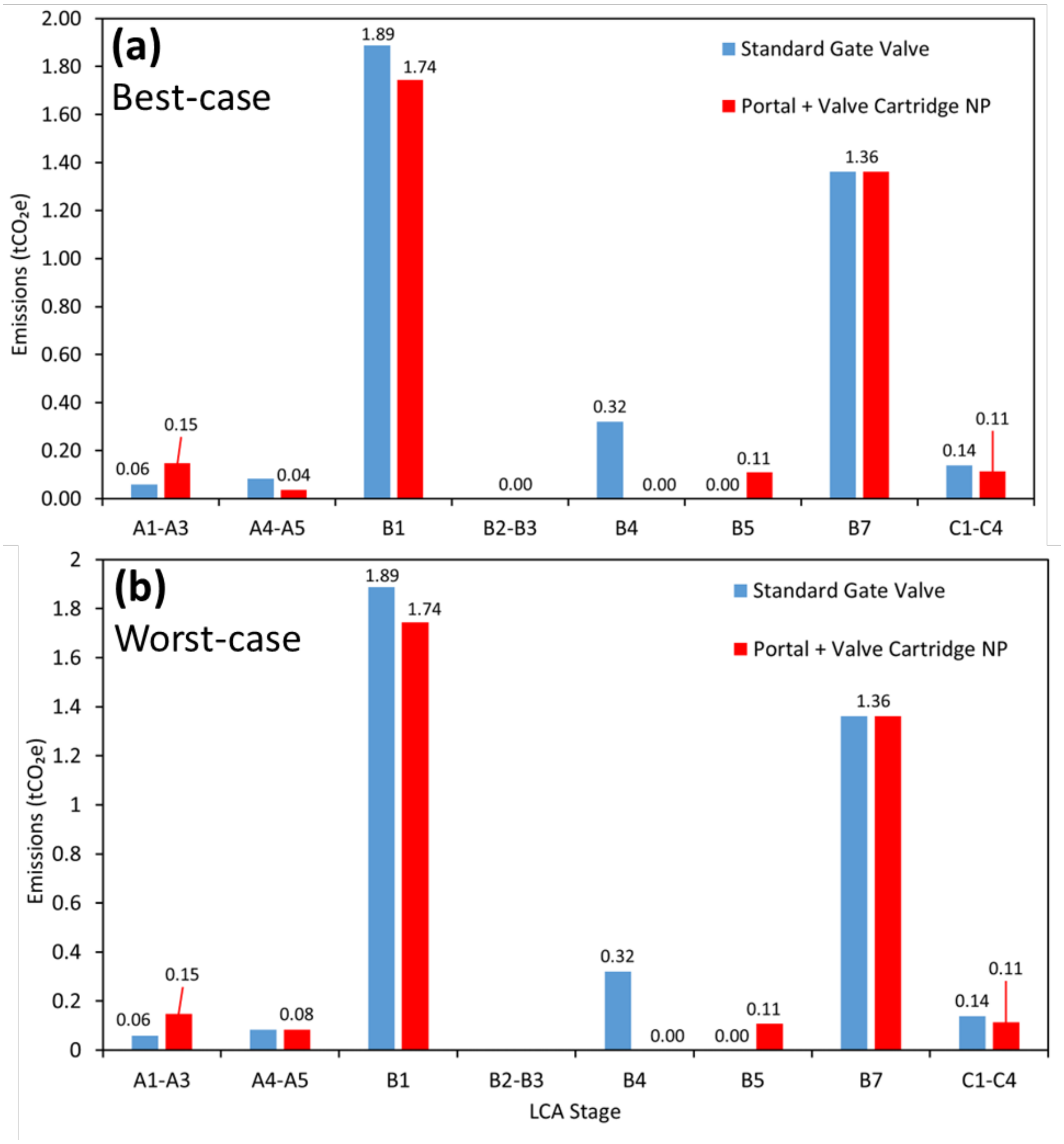
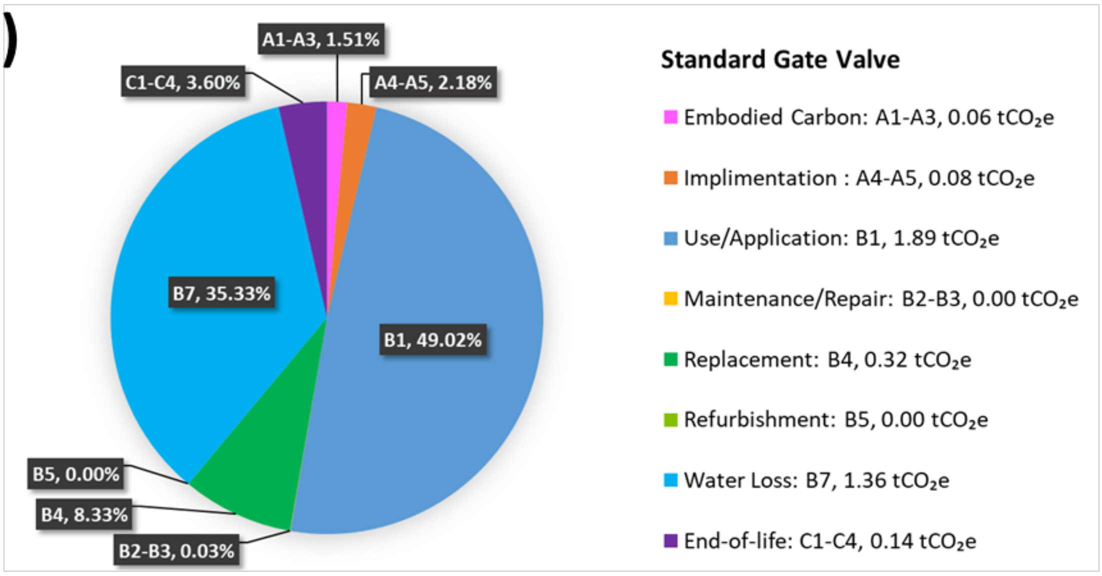
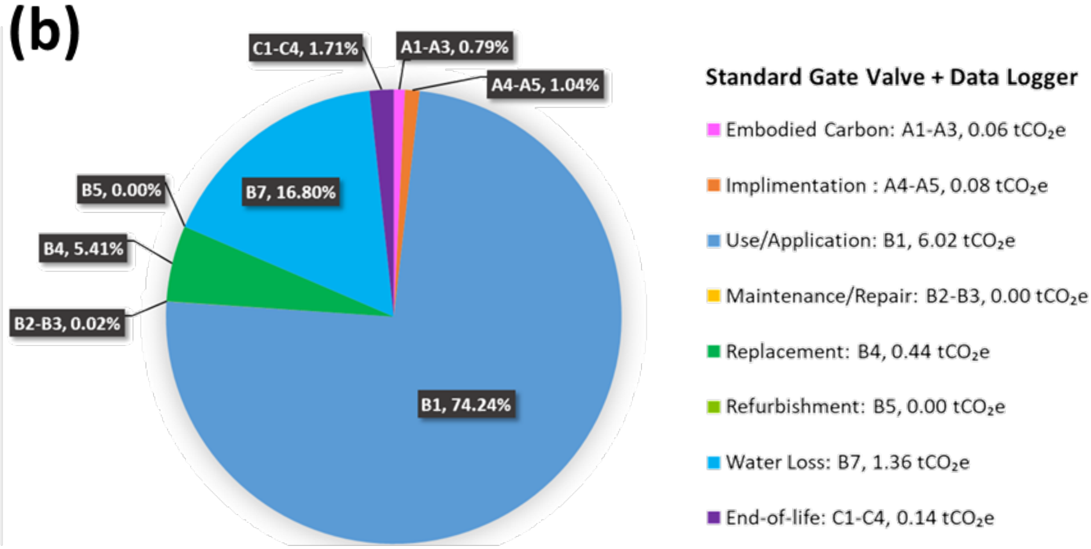


Figure S3. Calculated Carbon Life Cycle footprint for the Portal + Valve Cartridge NP compared to the Standard Gate Valve at each stage (A1-C4) for the best-case (a) and worst-case (b) scenarios.

(a)


A1-A3, 1.51%
A4-A5, 2.18%
C1-C4, 3.60%
B7, 35.33%
B1, 49.02%
B5, 0.00%
B4, 8.33%
B2-B3, 0.03%
Standard Gate Valve
Embodied Carbon: A1-A3, 0.06 tCO₂e
Implimentation : A4-A5, 0.08 tCO₂e
Use/Application: B1, 1.89 tCO₂e
Maintenance/Repair: B2-B3, 0.00 tCO₂e
Replacement: B4, 0.32 tCO₂e
Refurbishment: B5, 0.00 tCO₂e
Water Loss: B7, 1.36 tCO₂e
End-of-life: C1-C4, 0.14 tCO₂e

(b)


C1-C4, 1.71%
A1-A3, 0.79%
A4-A5, 1.04%
B5, 0.00%
B7, 16.80%
B4, 5.41%
B2-B3, 0.02%
B1, 74.24%
Standard Gate Valve + Data Logger
Embodied Carbon: A1-A3, 0.06 tCO₂e
Implimentation : A4-A5, 0.08 tCO₂e
Use/Application: B1, 6.02 tCO₂e
Maintenance/Repair: B2-B3, 0.00 tCO₂e
Replacement: B4, 0.44 tCO₂e
Refurbishment: B5, 0.00 tCO₂e
Water Loss: B7, 1.36 tCO₂e
End-of-life: C1-C4, 0.14 tCO₂e

(c)

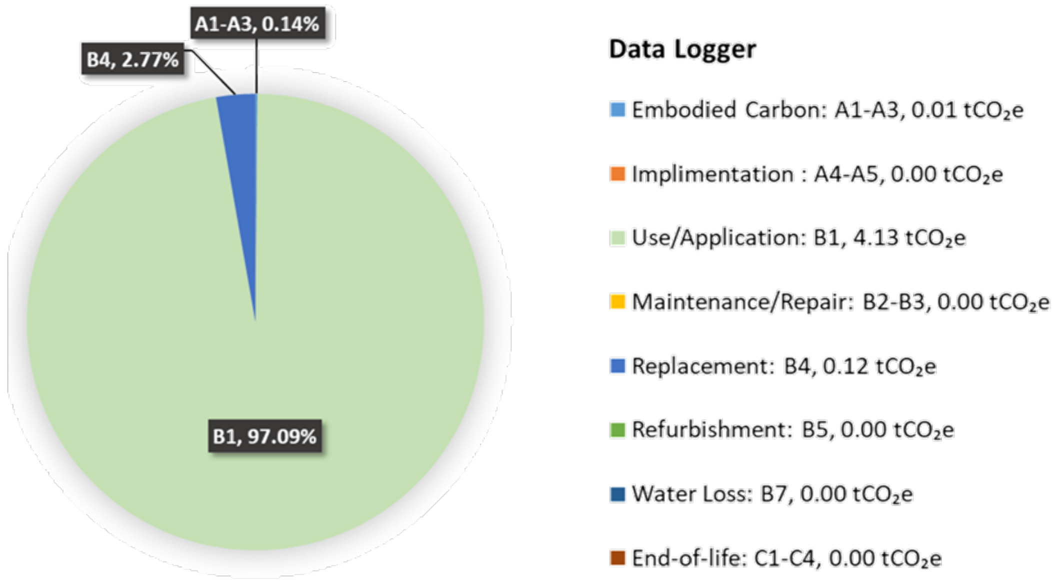

A1-A3, 0.14%
B4, 2.77%
B1, 97.09%
Data Logger
Embodied Carbon: A1-A3, 0.01 tCO₂e
Implimentation : A4-A5, 0.00 tCO₂e
Use/Application: B1, 4.13 tCO₂e
Maintenance/Repair: B2-B3, 0.00 tCO₂e
Replacement: B4, 0.12 tCO₂e
Refurbishment: B5, 0.00 tCO₂e
Water Loss: B7, 0.00 tCO₂e
End-of-life: C1-C4, 0.00 tCO₂e

Figure S4. Detailed breakdowns of the percentage contribution of each life-cycle stage for the Standard Gate Valve (a), Standard Gate Valve + Data Logger (b) and Data Logger (c).

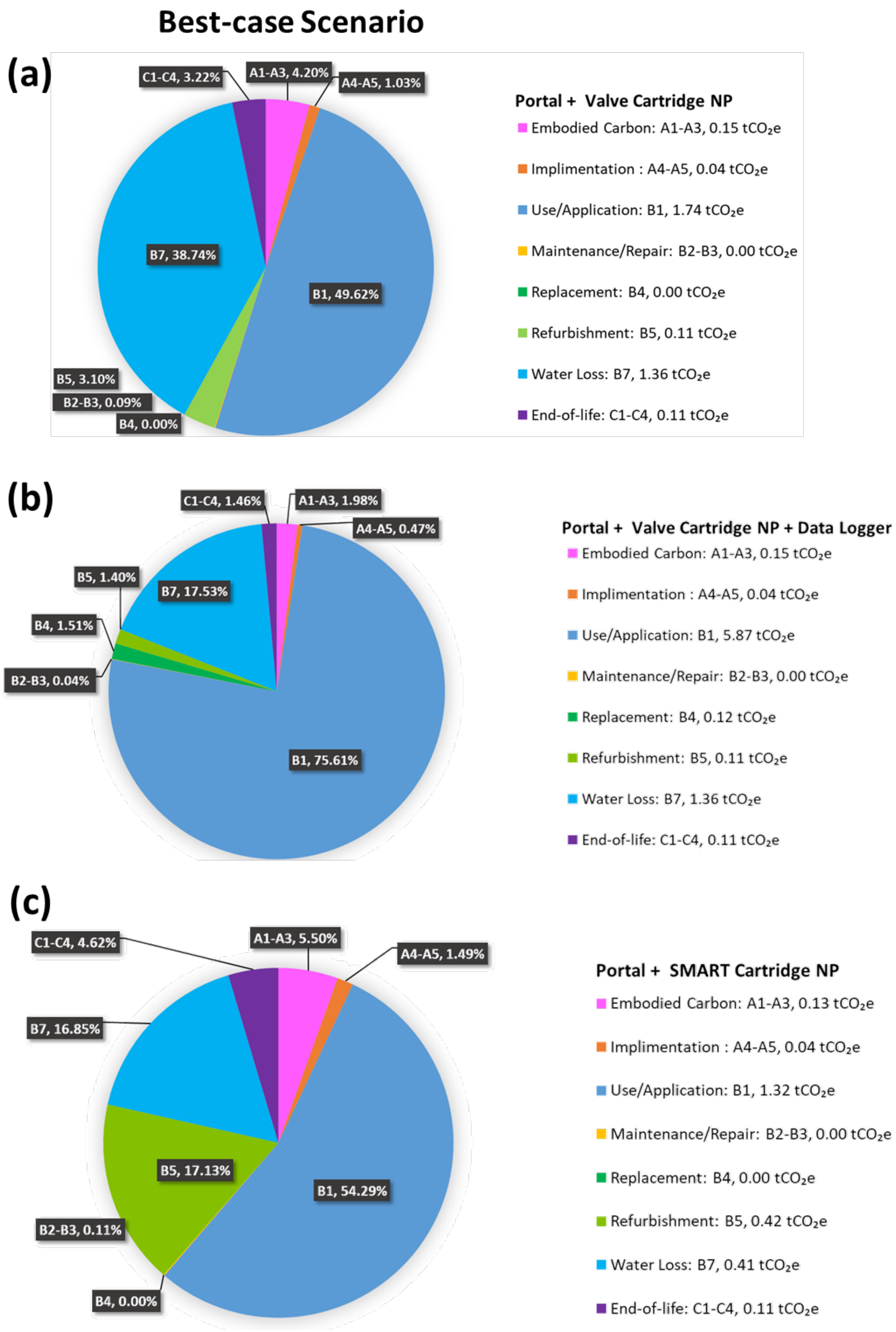


Figure S5. Detailed breakdowns of the percentage contribution of each life-cycle stage in the best-case scenario for the Portal + Valve Cartridge NP (a), Portal + Valve Cartridge NP + Data Logger (b) and Portal + SMART Cartridge NP (c).

Worst-case Scenario

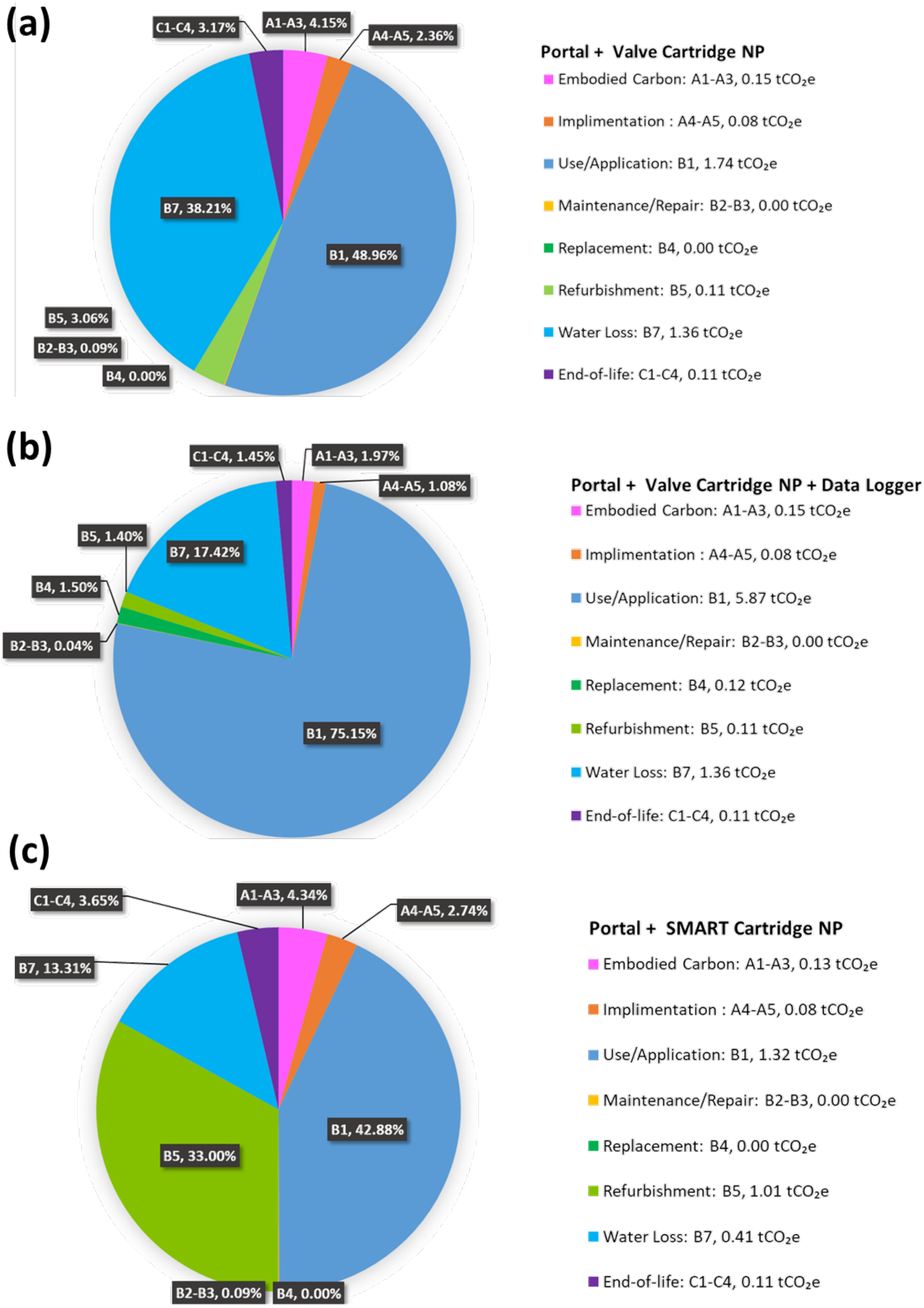


Figure S6. Detailed breakdowns of the percentage contribution of each life-cycle stage in the worst-case scenario for the Portal + Valve Cartridge NP (a), Portal + Valve Cartridge NP + Data Logger (b) and Portal + SMART Cartridge NP (c).

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