Life Cycle Assessment Report

TBC

Example Tunnel Project - UK

Date: 2 May 2024
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This LCA Study was conducted as part of the Example Tunnel Project - UK project. The LCA modeling within eTool is being managed by Example Projects. For more information see contact details below.

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eTool Disclaimer

The predictions of embodied and operational impacts (including costs) conducted in eTool software, by their very nature, cannot be exact. It is not possible to accurately track all the impacts associated with a product or service over the life of a building or structure. eTool software and the modelling workflow has been built and tested to enable informed decisions when comparing design options. Environmental impact coefficients and generic costs do not necessarily correspond to those of individual brands of the same product or service due to differences within industries in the way these products and services are delivered.

This LCA study has not been reviewed and as such does not meet the relevant section of the ISO14044 requirements. Caution should be taken when interpreting the LCA study report.

eTool PTY LTD cannot make assurances regarding the accuracy of these reports for the above reasons.

Executive Summary

This Life Cycle Assessment has been completed for the Whole Building, located at TBC. The lead author is Henrique Mendonca of Example Projects and an independent review has not yet been conducted. The goal of this study is to profile and improve the environmental performance of the construction works. The study has been conducted in accordance with ISO 14044 and EN15978 .

About the Design

The following designs were modelled in these reports:

- **Improved Design**: An aspirational design including improvement strategies for consideration of the design team and other stakeholders.
- **Benchmark**: An equivalent benchmark design (or weighted statistical mix of designs) with conventional products, construction methods and use patterns.

Results

The results of the study are shown in the table below with savings highlighted in green text and increased impacts highlighted in red.

Characterised Impacts, Absolute (No Functional Unit), No Time Scale		Benchmark	Improved Design	Improved Design Savings
Environmental Impacts				
Global Warming Potential Total, GWP	kg CO_2 eq	6.86E+8	3.41E+8	50.21%
Ozone Depletion Potential, ODP	kg CFC-11 eq	5.64E+1	3.30E+1	41.55%
Acidification Potential for Soil and Water, AP	kg SO_2 eq.	2.14E+6	1.11E+6	48.4%
Eutrophication potential, EP	kg PO_4 eq	5.76E+5	3.47E+5	39.67%
Photochemical Ozone Creation Potential, POCP	kg ethylene	1.29E+5	7.71E+4	40.11%
Abiotic Depletion Potential - Elements, ADPE	kg antimony	-1.29E+3	8.83E+3	-782.51%
Abiotic Depletion Potential - Fossil Fuels, ADPF	MJ	8.04E+9	2.18E+9	72.95%
Global Warming Potential Fossil, GWP F	kg CO_2 eq	7.81E+8	2.00E+8	74.39%
Global Warming Potential Biogenic, GWP B	kg CO_2 eq	4.69E+6	8.18E+5	82.54%
Global Warming Potential LULUC, GWP L	kg CO_2 eq	3.66E+5	3.76E+5	-2.76%
Financial				
Australian Dollars	AUD	1.28E+9	9.95E+8	22.54%
British Pounds Sterling	GBP	6.93E+8	5.36E+8	22.64%
Resource Use				
Net use of fresh water, FW	kg	6.09E+11	-4.84E+11	179.44%
Materials Efficiency				
Materials Efficiency Metric	t eq	2.15E+6	1.91E+6	11.41%
Mass of materials, total	t eq	2.18E+6	1.93E+6	11.3%

Analysis

The report shows that the Improved Design has lower Global Warming Potential Total, GWP impact than the Benchmark Design. The **Product Stage (A1A3)** GWP Impacts are the most dominant life cycle module in the Improved Design Design followed by the **Transport of Equipment and Materials (A4)** and then **Transport of Waste Offsite (C2)**.

Further analysis reveals:

- The **Substructure** is the highest impact construction category,
- **HVAC** is the highest operational impact by demand category,
- The **Electricity** is this highest impact operational impact by supply source,
- **Cementitious Binders | Portland Cement | Unspecified** is the highest impact material category,
- **Natural Gas Combustion in Construction Equipment (no transport)** is the highest people and equipment impact

Fourteen strategies were modelled in the Improved Design, the **Geopolymer Concrete (90% Flyash)** strategy had the highest saving , followed by **Concrete Replacement: 50% fly-ash blend** . See the below table for details.

				Scenario	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
●				<Business as Usual>															
			●	Concrete Replacement 30% fly-ash blend substructure	9.21%	-0.94%	0.09%	3.97%	3.73%	2.66%	1.40%	-45.72%	1.26%	-0.94%	0.03%	0.04%	7.94%	23.91%	1.00%
		●		50% BFS in concrete	9.77%	-2.86%	-0.19%	3.51%	1.76%	-0.79%	0.88%	171.04%	0.95%	-2.87%	0.00%	0.00%	8.40%	28.65%	-3.94%
	●			Concrete Replacement: 50% fly-ash blend	15.26%	-1.66%	0.05%	6.48%	5.94%	4.21%	2.25%	-74.93%	2.00%	-1.67%	0.03%	0.04%	13.15%	39.95%	0.83%
●				Geopolymer Concrete (90% Flyash)	27.35%	-3.11%	-0.02%	11.50%	10.36%	7.29%	3.96%	-133.36%	3.47%	-3.12%	0.03%	0.04%	23.57%	72.03%	0.48%
●				Optimising grout design and application	5.60%	2.36%	3.03%	3.80%	3.30%	3.02%	1.06%	25.63%	2.80%	2.37%	1.70%	1.68%	4.85%	10.19%	1.09%
●				Reduce long-duration idling for trucks	0.74%	0.18%	1.67%	0.71%	0.50%	0.79%	0.03%	-0.06%	0.96%	0.18%	0.00%	0.00%	0.65%	0.02%	0.02%
●				Electric dump truck	4.20%	1.00%	9.46%	4.04%	2.85%	4.45%	0.17%	-0.36%	5.44%	1.00%	0.00%	0.00%	3.69%	0.09%	0.14%
●				Tunnel structure and lining design optimisation	1.55%	2.61%	2.78%	2.06%	1.65%	1.88%	0.45%	17.32%	2.04%	2.62%	4.27%	4.22%	1.36%	0.18%	0.73%
	●			EPD - Steel Reinforcement Bar	3.04%	9.26%	8.89%	12.30%	25.79%	21.66%	7.47%	-118.09%	9.91%	9.27%	-0.50%	0.09%	8.01%	-9.25%	78.78%
●				Local sourcing of Sand to reduce transport	2.69%	1.09%	3.93%	3.57%	3.35%	3.94%	1.16%	73.71%	3.72%	1.09%	0.00%	0.00%	2.37%	-0.50%	2.72%
●				Waste management	2.01%	3.39%	3.56%	2.66%	2.13%	2.44%	0.59%	21.62%	2.62%	3.40%	5.58%	5.52%	1.76%	0.29%	0.94%
●				Concrete waste diverted from landfill - End of Life Scenario	3.09%	0.00%	8.40%	6.51%	5.17%	5.74%	2.51%	13.07%	5.67%	0.00%	0.00%	0.00%	2.72%	-1.54%	1.69%
●				Lighting: Light distribution efficiency and controls	0.10%	0.42%	0.36%	0.32%	0.36%	0.28%	2.83%	-3.11%	0.81%	0.42%	0.00%	0.00%	0.58%	-0.03%	-0.06%
●				Solar PV (10 MW UK Grid Connected)	2.87%	14.59%	8.38%	13.23%	10.01%	10.28%	166.68%	768.07%	45.42%	14.68%	-0.16%	-0.16%	32.83%	1.80%	-10.52%
●				<Improved Design>															

● Strategies included in Improved Design ● Strategies not included in Improved Design

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Improved Design Performance against Benchmark

Table Of Contents

1 Introduction

Managing the environmental impacts that arise from the construction and operation of buildings and infrastructure is of key importance in mitigating the damage caused directly and indirectly on the biosphere. Life Cycle Assessment (LCA) is the leading industry standard in clearly identifying optimum strategies for reducing environmental impacts. This report presents the results of the LCA completed for TBC.

The study has been conducted in accordance with the following standards:

- International Standards 14040 and 14044.
- European Standard EN 15978: *Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method*

The Author of the study is Henrique Mendonca of Example Projects, and no independent review has yet been completed.

2 Goal of the Study

The goal of this study is to profile and improve the environmental performance of the construction works at TBC. The life cycle performance of the project is compared to other designs and as such this is a comparative study. The study has been conducted on assumption the results may be made public.

3 Scope of the Study

The LCA study has been conducted in accordance with the EN 15978 standard to assess the direct and indirect potential environmental impacts associated with the construction works at TBC as part of the Example Tunnel Project - UK project.

3.1 Functional Unit

The function of the Infrastructure must reflect the core purpose of the asset such that it can be compared accurately to different designs. In this case, the functional focus is the Whole Asset and the chosen functional unit is the provision of this function over its life span.

The estimated design life of the design is 100 years which has been adopted for the LCA study period.

Note that products with expected service lives of less than the life span of the project are assumed to be replaced at increments reflecting their service life.

3.2 System Boundary

The system boundary, shown in Figure 1, follows guidance given in EN15978.

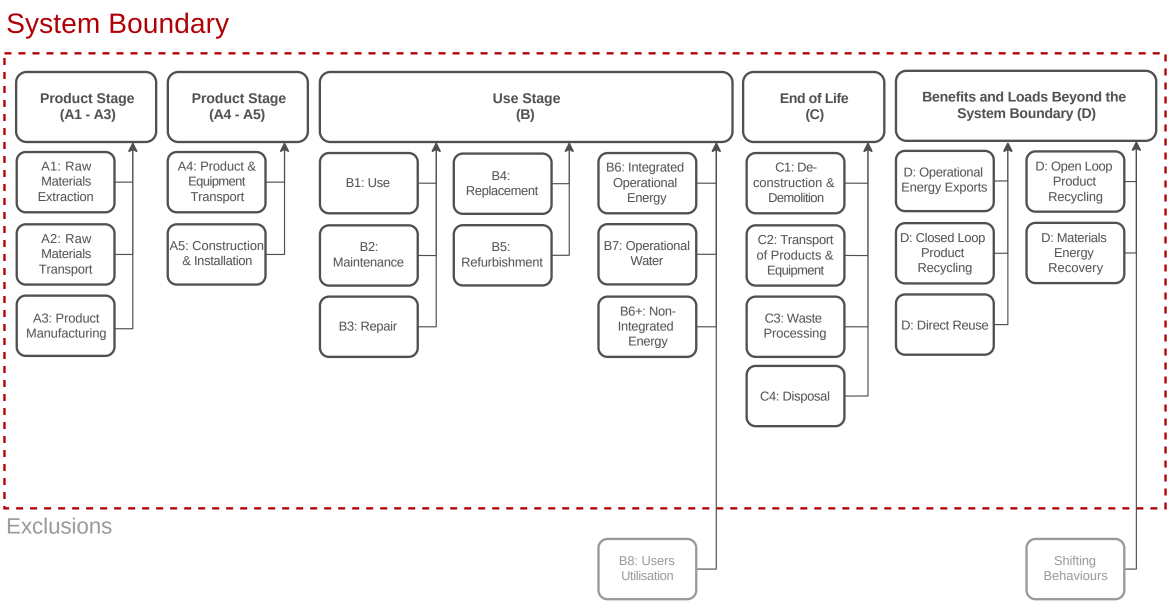

Figure 1: System Boundary Diagram

3.3 Environmental Indicators

The environmental indicators have been included in the study are detailed in Table 1. For further information regarding the environmental indicators please refer to Appendix A.

Environmental Indicator	Unit	Abbreviation	Characterisation Method
Environmental Impacts			
Global Warming Potential Total, GWP	kg CO_2 eq	GWP	CML-IA baseline V4.5
Financial			
Australian Dollars	AUD	AUD	Various Cost Models
Environmental Impacts			
Ozone Depletion Potential, ODP	kg CFC-11 eq	ODP	CML-IA baseline V4.5
Acidification Potential for Soil and Water, AP	kg SO_2 eq.	AP	CML-IA baseline V4.5
Eutrophication potential, EP	kg PO_4 eq	EP	CML-IA baseline V4.5
Photochemical Ozone Creation Potential, POCP	kg ethylene	POCP	Institute of Environmental Sciences (CML)
Resource Use			
Net use of fresh water, FW	kg	FW	Not Applicable - 1:1 factor on H2O Consumed
Environmental Impacts			
Abiotic Depletion Potential - Elements, ADPE	kg antimony	ADPE	CML-IA baseline V4.5
Abiotic Depletion Potential - Fossil Fuels, ADPF	MJ	ADPF	CML-IA baseline V4.5
Financial			
British Pounds Sterling	GBP	GBP	Various Cost Models
Materials Efficiency			
Materials Efficiency Metric	t eq	ME	eTool & HS2 Efficeincy Materials Metric
Mass of materials, total	t eq	Mtot	eTool & HS2 Efficeincy Materials Metric
Environmental Impacts			
Global Warming Potential Fossil, GWP F	kg CO_2 eq	GWP F	CML-IA baseline V4.5
Global Warming Potential Biogenic, GWP B	kg CO_2 eq	GWP B	CML-IA baseline V4.5
Global Warming Potential LULUC, GWP L	kg CO_2 eq	GWP L	CML-IA baseline V4.5

Table 1: Environmental Indicators Included in LCA study.

3.4 Cutoff Criteria

The EN15978 cut-off criteria were used to ensure that all relevant potential environmental impacts were appropriately represented:

- Mass – if a flow is less than 1% of the mass at either a product-level or individual-process level, then it has been excluded, provided its environmental relevance is not of concern.
- Energy – if a flow is less than 1% of the energy at either a product-level or individual-process level, then it has been excluded, provided its environmental relevance is not a concern.
- The total of neglected input flows per module, e.g. per module A1-A3, A4-A5, B1-B5, B6-B7, C1-C4 and module D shall be a maximum of 5% of energy usage and mass.
- Environmental relevance – if a flow meets the above criteria for exclusion, but is considered to potentially have a significant environmental impact, it has been included. All material flows which leave the system (emissions) and whose environmental impact is higher than 1% of an impact category, have been included.

The Operational Guidance for Life Cycle Assessment Studies (Wittstock et al. 2012) states:

The apparent paradox is that one must know the final result of the LCA (so one can show that the omission of a certain process is insignificant for the overall results) to be able to know which processes, elementary flows etc. can be left out.

The approach taken in this study is to continue modelling smaller inputs until confidence is gained that the criteria is safely met.

3.5 Allocation

Allocation rules follow those of EN15804 as given below:

- Allocation will respect the main purpose of the studied processes. If the main purpose of combined processes cannot be defined (e.g. combined mining and extraction of nickel and precious metals), economic allocation may be used to divide resources and emissions between the products.
- The principle of modularity is maintained. Where processes influence the product's environmental performance during its life cycle, they will be assigned to the module where they occur.
- The sum of the allocated inputs and outputs of a unit process are equal to the inputs and outputs of the unit process before allocation. This means no double counting of inputs or outputs is permissible.

3.6 Independent Review

No independent review has been conducted of this study.

3.7 System Description Introduction

The object of the assessment is the Whole Building, located at TBC. The assessment includes all the upstream and downstream processes needed to provide the primary function of the structure from construction, maintenance, operation, and finally demolition and disposal. The inventory includes the extraction of raw materials or energy and the release of substances back to the environment or to the point where inventory items exit the system boundary either during or at the end of the project life cycle.

Example tunnel project

The project location is shown in figures 2 and 3.

Figure 2: Location of the project - Global View.

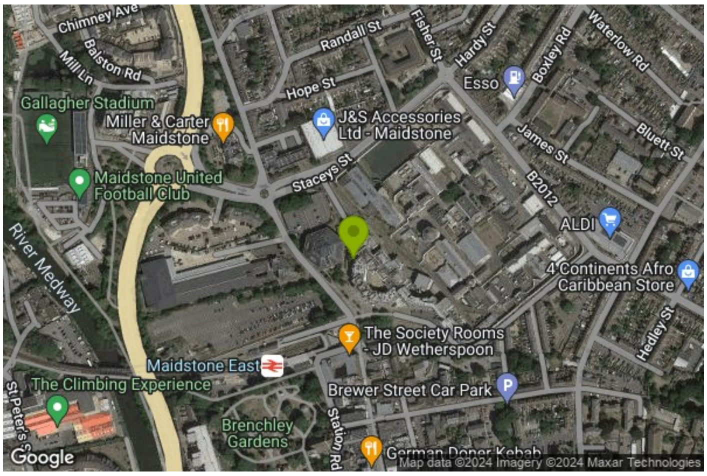

Figure 3: Location of the project - Locality View.

Example project

3.8 Building Characteristics Table

Table 2 below shows the key characteristics of the designs.

	Benchmark	Improved Design

Design Details		
Design Name	Baseline Design - Tunnel	Solar PV (10 MW UK Grid Connected)
Stories (#)	1	1
Functional Focus	Tunnel	Tunnel
Structural Service Life Limit	150	150
Predicted Design Life	100	100
Functional Characteristics		
Life Cycle Passenger Throughput	100,000,000	100,000,000
Life Cycle Freight Throughput	2,000,000,000	2,000,000,000
Pavement Area	100,423	100,423
Life Cycle Workload Units	20,100,000,000	20,100,000,000
Length	4	4
Life Cycle Passenger Kms	418,429,000	418,429,000
Life Cycle Freight Kms	8,368,580,000	8,368,580,000
Life Cycle Workload Unit Kms	84,104,229,000	84,104,229,000
Total Floor Areas		
Usable Floor Area	0	0
Net Lettable Area	0	0
Fully Enclosed Covered Area	0	0
Unenclosed Covered Area	0	0
Gross Floor Area	0	0
Usable and Lettable Yield	NaN %	NaN %

Table 2 : Design Characteristics Compared

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3.9 Structure Scope Table

Table 3 shows the structural scope of the inventory collection for the LCA. For further details on structure scope please refer to Appendix B.

Summary Structure Scope Diagram

Key: ✓ In Scope ✓ Partial ✗ Out of Scope

Category Name	Baseline Design Benchmark – Tunnel	Improved Design
Substructure	✓	✓
Superstructure	✓	✓
Internal finishes	✓	✓
Fittings, furnishings and equipment	✓	✓
Services equipment	✓	✓
Prefabricated buildings and building units	✓	✓
Work to existing building	✗	✗
External works	✓	✓
Facilitating works	✓	✓
Project/design team	✓	✓
Undefined	✗	✗

Table 3 : Structural scope of LCI collection

3.10 Operational Scope Table

Table 4 shows the operational scope of the inventory collection for the LCA. For further details on structure scope please refer to Appendix B.

Operational Scope diagram

Key: ✓ In Scope ✗ Out of Scope

Category Name	Baseline Design Benchmark – Tunnel	Improved Design
Appliances | Dishwashers	✗	✗
Appliances | Entertainment	✗	✗
Appliances | Laundry Appliances	✗	✗
Appliances | Office Workstations	✗	✗
Communications	✓	✓
Cooking and Food Preparation	✗	✗
Domestic Water Heating	✗	✗
Electrical Parasitic Loads	✓	✓
Fire Protection	✓	✓
HVAC	✓	✓
Industrial & Manufacturing Equipment	✓	✓
Lifts, Elevators and Conveying	✗	✗
Lighting	✓	✓
Miscellaneous	✗	✗
Monitoring, Control and Automation	✓	✓
Power Generation and Storage	✓	✓
Refrigeration	✓	✓
Safety and Security	✓	✓
Swimming Pools	✗	✗
Water Pumping	✓	✓
Water Removal and Treatment	✓	✓
Water Supply	✓	✓
Workshops, Garage & Misc	✗	✗

Table 4: Operational scope of LCI collection

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4 Inventory Analysis

The inventory analysis was aided by the following design document:

- Other Design Documentation: Fig-4-Cross-section-of-the-new-Nanjing-ART, 2020

The design has been modelled using the available eToolLCD elements, templates and EPDs as shown in Table 5.

eToolLCD Item Type	Count in Design	
	Baseline Design	Improved Design
Design Templates	15	17
Equipment and People Elements	28	29
Material Elements	29	33
Energy Elements	2	5
Water Elements	0	0
EPDs	0	0

Table 5: Count of elements, templates and EPDs in the design

The eToolLCD library templates are customisable and users may submit templates for validation. The template validation process is undertaken by experienced LCA practitioners and is a process of checking the user inputs and ensuring the assumptions are adequately referenced. Table 6 shows the extent to which validated templates were used in the model.

eToolLCD Item Type	Validated (%)	
	Baseline Design	Improved Design
Total Design Templates	20	17.65
Equipment and People Elements	21.43	20.69
Material Elements	10.34	9.09
Energy Elements	0	0
Water Elements	NaN	NaN

Table 6: Use of validated templates

4.1 Templates Comparison

The eToolLCD templates found in each design are provided in Table 7.

Parent Template Name	Units	Quantity		
		Benchmark	Improved Design	Difference
Substructure				
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	lm	4180	4180	0%
Tunnel Fill Removal	m3	3361760	3361760	0%
Services equipment				
Tunnel Ventilation	m2	100422.96	0	-100%
Car Park Ventilation	m2	0	100422.96	100%
Solar PV System - Grid connected	kW	0	10000	100%
External works				
Highway Lighting – Standard	#	500	500	0%

Table 7: Templates Comparison (showing master templates only)

4.2 eTool software

eTool software was used to model life cycle impacts of the project. eToolLCD uses third party background processes aggregated as mid-point indicators and stored in a number of libraries within the software which are coupled with algorithms and user inputs to output the environmental impact assessment. A map of user inputs, data sources and algorithms (outputs) is given in Figure 4.

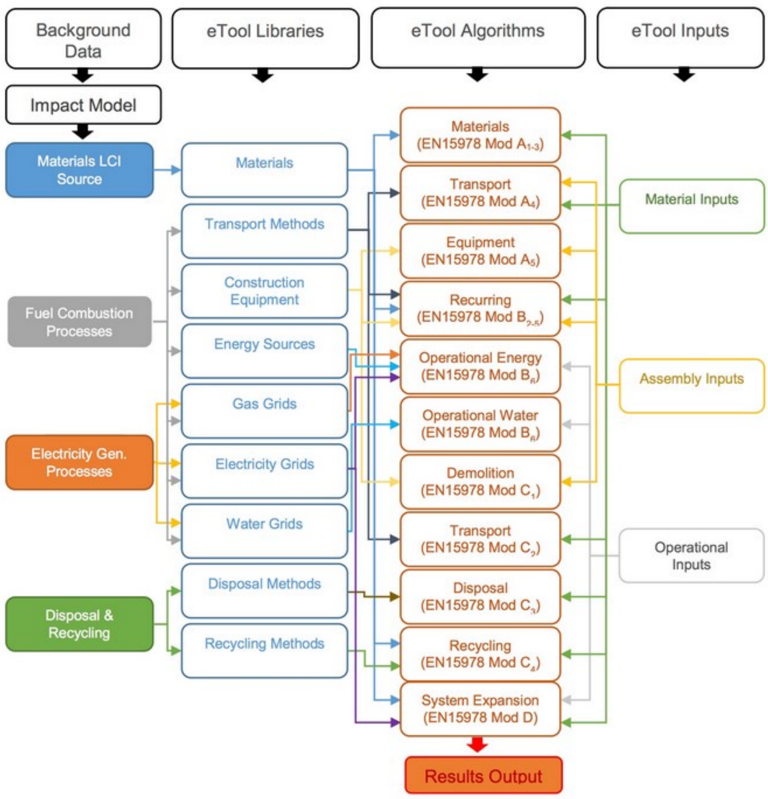


Figure 4: Relationship between LCI background data, eToolLCD software library, inputs and algorithms.

4.3 Data Quality

The data quality requirements for the background data are detailed in Table 8. Each of the criteria has been assessed for compliance and results presented below.

Criteria	Background Data Requirement	Compliance	
		Baseline Design	Improved Design
Temporal Relevancy	For annually fluctuating processes like Grid electricity fuel mixes the datasets must have been updated within the last 2 years. More static processes like materials production must have been updated within the last 10 years. Product specific EPDs must have been updated in the last 5 years.	Failed Grid Passed Materials	Failed Grid Passed Materials
Geographical Relevancy	The background data should be specifically compiled for the same country (preferable) or continent as the project location.	Passed(Same Continent)	Passed(Same Continent)
Precision	No requirement specified however a qualitative review undertaken to ensure no erroneous values.	Passed	Passed
Completeness	Qualitative assessment of the process to ensure no obvious exclusions.	Passed	Passed
Technological Relevancy	Ensure that technology assumptions are representative for the product or product group.	Passed	Passed
Consistency	The study methodology holds for the background data.	Passed	Passed
Reproducibility	The information available about the methodology and the data values reported should allow an independent practitioner to reproduce the results reported in the study.	Passed	Passed

Table 8: Summary of data quality requirements for the study.

Criteria	Inventory Collection Requirement (eToolLCD User Inputs)	Compliance	
		Baseline Design	Improved Design
Temporal Relevancy	All inputs into eToolLCD to be reflective of the project being assessed and if assumptions are made these are to be based on industry practices that are consistent with the project commissioning date.	Passed 5/5 Checks	Passed 1/2 Checks
Geographical Relevancy	All inputs into eToolLCD must be reflective of the project being assessed and if assumptions are made these are based on the current practices employed in the project country.	Passed 5/5 Checks	Passed 3/3 Checks
Precision	To avoid aggregated errors a high level of precision is expected inputs into eToolLCD software, being either to 3 significant figures or: • Two significant figures or nearest 10 hours for equipment run time • Two significant figures or nearest 10kg for material quantities • Two significant figures or nearest 100MJ / annum for operational energy • Two significant figures or nearest 100kL / annum for operational water use	Passed 4/4 Checks	Passed 1/2 Checks
Completeness	Inputs to cover all life cycle phases and elements identified in the system boundary. The link between background data, eToolLCD algorithms and subsequent LCA results is not to introduce significant gaps in the data.	Passed 8/9 Checks	Passed 5/6 Checks
Technological Relevancy	All inputs into eToolLCD must be reflective of the project being assessed and if assumptions are made these must be drawn from appropriate examples of like technology.	Passed 5/5 Checks	Passed 1/1 Checks
Consistency	All inputs into eToolLCD must be reflective of the project being assessed and if assumptions are made these are drawn from the same reference library.	Passed 9/9 Checks	Passed 3/5 Checks
Reproducibility	The information available about the methodology and the data values reported should allow an independent practitioner to reproduce the results reported in the study.	Passed 9/9 Checks	Passed 2/3 Checks

Table 9: Summary of data quality requirements for the study.

4.4 Completeness

The study aims to follow EN15804 procedures for exclusion of inputs and outputs:

- All inputs and outputs to a (unit) process shall be included in the calculation, for which data are available.
- Data gaps may be filled by conservative assumptions with average or generic data. Any assumptions for such choices shall be documented.
- In case of insufficient input data or data gaps for a unit process, the cut-off criteria shall be 1 % renewable and non-renewable primary energy usage and 1 % of the total mass input of that unit process.
- The total of neglected input flows per module, e.g. per module shall be a maximum of 5 % of energy usage and mass.
- Conservative assumptions in combination with plausibility considerations and expert judgement can be used to demonstrate compliance with these criteria.

- Particular care should be taken to include material and energy flows known to have the potential to cause significant emissions into air and water or soil related to the environmental indicators.

Two major tests were run to determine the compliance with the above cut-off rules.

4.4.1 Inventory Mass Quantities

The cumulative mass of inventory entries is shown in Figure 5. Given that 24 material elements within the LCA base design make up the last 1% of mass inventory entries a high level of confidence exists that the cut off rules have been upheld.

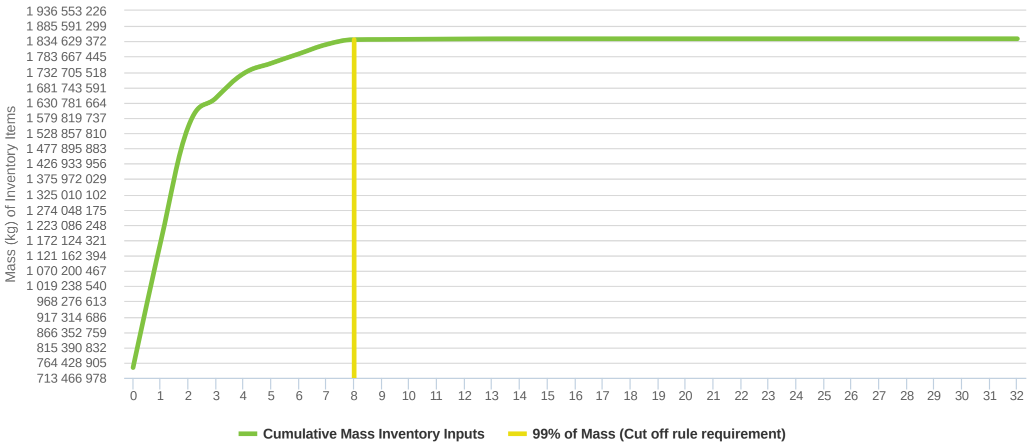


Figure 5: Cumulative Mass Inventory Entries. In this case 72.73% make up the last 5% of mass inventory entries.

4.4.2 Inventory Energy Analysis

The cumulative embodied energy of inventory entries is shown in Figure 6. Given that 41 elements within the LCA base design make up the last 1% of embodied energy inventory entries a high level of confidence exists that the cut off rules have been upheld.

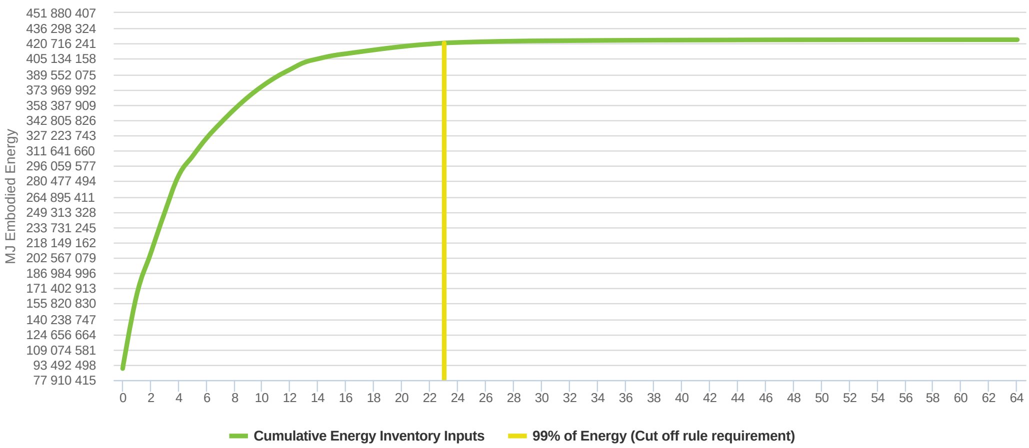


Figure 6 : Cumulative Energy Inventory Entries. In this case 63.08% make up the last 5% of energy inventory entries.

5 Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) results are provided in Tables 10 to 13 in the EN15978 reporting format. The red and orange figures within each row highlight the largest and second largest contributing life cycle modules for the indicator. Modules not assessed are abbreviated with "MNA".

The green figures in the comparison section highlight the most improved life cycle modules for the indicator.

5.1 Environmental Impacts

Table 10: Benchmark vs Improved Design, Environmental Impacts of Each Life Cycle Phase.

Characterised Impacts Per Absolute (No Functional Unit) Per No Time Scale		Construction Phases			Use Phases								End of Life Phases				Benefits and Loads Beyond the System Boundary	Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B6+	B7	C1	C2	C3	C4	D	
Benchmark																		
GWP	kg CO_2 eq	4.53E+8	7.03E+7	7.37E+7	0.00E0	2.35E+5	0.00E0	2.40E+6	0.00E0	1.76E+7	0.00E0	0.00E0	0.00E0	5.23E+7	0.00E0	1.36E+7	2.54E+6	6.86E+8
ODP	kg CFC-11 eq	2.20E+1	8.55E0	9.40E0	0.00E0	1.76E-2	0.00E0	2.40E-1	0.00E0	5.22E0	0.00E0	0.00E0	0.00E0	6.28E0	0.00E0	4.61E0	8.37E-2	5.64E+1
AP	kg SO_2 eq.	1.08E+6	2.92E+5	2.49E+5	0.00E0	2.64E+3	0.00E0	2.33E+4	0.00E0	1.78E+5	0.00E0	0.00E0	0.00E0	2.17E+5	0.00E0	9.76E+4	7.41E+3	2.14E+6
EP	kg PO_4 eq	3.21E+5	7.31E+4	3.31E+4	0.00E0	1.13E+3	0.00E0	1.08E+4	0.00E0	5.38E+4	0.00E0	0.00E0	0.00E0	5.46E+4	0.00E0	1.94E+4	8.90E+3	5.76E+5
POCP	kg ethylene	6.19E+4	2.04E+4	1.56E+4	0.00E0	1.28E+2	0.00E0	1.18E+3	0.00E0	9.45E+3	0.00E0	0.00E0	0.00E0	1.44E+4	0.00E0	4.06E+3	1.64E+3	1.29E+5
ADPE	kg antimony	8.01E+2	-1.61E+3	-2.48E+2	0.00E0	8.60E+1	0.00E0	6.71E+2	0.00E0	1.04E+3	0.00E0	0.00E0	0.00E0	-2.70E+3	0.00E0	-2.33E+1	6.84E+2	-1.29E+3
ADPF	MJ	2.76E+9	1.13E+9	1.14E+9	0.00E0	2.61E+6	0.00E0	3.03E+7	0.00E0	1.69E+9	0.00E0	0.00E0	0.00E0	8.48E+8	0.00E0	4.29E+8	1.82E+7	8.04E+9
GWP F	kg CO_2 eq	4.48E+8	7.03E+7	7.38E+7	0.00E0	2.36E+5	0.00E0	2.41E+6	0.00E0	1.18E+8	0.00E0	0.00E0	0.00E0	5.23E+7	0.00E0	1.38E+7	2.54E+6	7.81E+8
GWP B	kg CO_2 eq	5.09E+6	-7.12E+4	-2.48E+4	0.00E0	-2.77E+2	0.00E0	-2.04E+3	0.00E0	-3.37E+4	0.00E0	0.00E0	0.00E0	-6.60E+4	0.00E0	-1.99E+5	-1.79E+3	4.69E+6
GWP L	kg CO_2 eq	3.01E+5	3.37E+4	4.79E+3	0.00E0	4.20E+1	0.00E0	4.19E+2	0.00E0	-5.82E+3	0.00E0	0.00E0	0.00E0	2.82E+4	0.00E0	2.83E+3	1.64E+2	3.66E+5
Improved Design																		
GWP	kg CO_2 eq	2.26E+8	5.27E+7	3.44E+7	0.00E0	2.35E+5	0.00E0	2.22E+7	0.00E0	6.57E+6	-1.04E+7	0.00E0	0.00E0	4.14E+7	2.81E+6	4.18E+6	-3.89E+7	3.41E+8
ODP	kg CFC-11 eq	2.09E+1	6.49E0	2.26E0	0.00E0	1.76E-2	0.00E0	6.38E0	0.00E0	1.95E0	-3.07E0	0.00E0	0.00E0	4.97E0	4.27E-1	1.40E0	-8.70E0	3.30E+1
AP	kg SO_2 eq.	7.64E+5	2.24E+5	1.21E+5	0.00E0	2.64E+3	0.00E0	1.44E+5	0.00E0	6.64E+4	-1.05E+5	0.00E0	0.00E0	1.72E+5	6.24E+3	2.98E+4	-3.19E+5	1.11E+6
EP	kg PO_4 eq	2.56E+5	5.55E+4	7.74E+3	0.00E0	1.13E+3	0.00E0	6.91E+4	0.00E0	2.00E+4	-3.17E+4	0.00E0	0.00E0	4.33E+4	9.63E+2	6.00E+3	-8.05E+4	3.47E+5
POCP	kg ethylene	5.05E+4	1.58E+4	7.29E+3	0.00E0	1.28E+2	0.00E0	9.72E+3	0.00E0	3.52E+3	-5.56E+3	0.00E0	0.00E0	1.14E+4	3.33E+2	1.24E+3	-1.73E+4	7.71E+4
ADPE	kg antimony	1.28E+3	-9.96E+2	-2.34E+1	0.00E0	8.60E+1	0.00E0	1.12E+4	0.00E0	3.89E+2	-6.15E+2	0.00E0	0.00E0	-2.13E+3	2.47E+1	-5.78E0	-3.78E+2	8.83E+3
ADPF	MJ	2.25E+9	8.53E+8	5.25E+8	0.00E0	2.61E+6	0.00E0	3.13E+8	0.00E0	6.29E+8	-9.94E+8	0.00E0	0.00E0	6.71E+8	4.21E+7	1.31E+8	-2.25E+9	2.18E+9
GWP F	kg CO_2 eq	2.25E+8	5.28E+7	3.44E+7	0.00E0	2.36E+5	0.00E0	2.23E+7	0.00E0	4.40E+7	-6.96E+7	0.00E0	0.00E0	4.14E+7	2.82E+6	4.23E+6	-1.57E+8	2.00E+8
GWP B	kg CO_2 eq	1.17E+6	-6.49E+4	-9.69E+3	0.00E0	-2.77E+2	0.00E0	-1.13E+5	0.00E0	-1.26E+4	1.99E+4	0.00E0	0.00E0	-5.21E+4	-6.95E+3	-5.45E+4	-5.40E+4	8.18E+5
GWP L	kg CO_2 eq	3.00E+5	2.53E+4	1.61E+3	0.00E0	4.20E+1	0.00E0	2.08E+4	0.00E0	-2.17E+3	3.43E+3	0.00E0	0.00E0	2.23E+4	1.19E+3	8.67E+2	2.28E+3	3.76E+5
Savings (Benchmark Compared to Improved Design)																		
GWP	kg CO_2 eq	2.27E+8	1.76E+7	3.94E+7	0.00E0	0.00E0	0.00E0	-1.98E+7	0.00E0	1.11E+7	1.04E+7	0.00E0	0.00E0	1.09E+7	-2.81E+6	9.46E+6	4.15E+7	**50.21%**
ODP	kg CFC-11 eq	1.15E0	2.06E0	7.15E0	0.00E0	0.00E0	0.00E0	-6.14E0	0.00E0	3.28E0	3.07E0	0.00E0	0.00E0	1.31E0	-4.27E-1	3.20E0	8.79E0	**41.55%**
AP	kg SO_2 eq.	3.14E+5	6.81E+4	1.27E+5	0.00E0	0.00E0	0.00E0	-1.21E+5	0.00E0	1.12E+5	1.05E+5	0.00E0	0.00E0	4.45E+4	-6.24E+3	6.78E+4	3.26E+5	**48.4%**

Characterised Impacts Per Absolute (No Functional Unit) Per No Time Scale		Construction Phases			Use Phases								End of Life Phases				Benefits and Loads Beyond the System Boundary	Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B6+	B7	C1	C2	C3	C4	D	
EP	kg PO_4 eq	6.49E+4	1.76E+4	2.54E+4	0.00E0	0.00E0	0.00E0	-5.82E+4	0.00E0	3.38E+4	3.17E+4	0.00E0	0.00E0	1.14E+4	-9.63E+2	1.34E+4	8.94E+4	**39.67%**
POCP	kg ethylene	1.15E+4	4.56E+3	8.26E+3	0.00E0	0.00E0	0.00E0	-8.55E+3	0.00E0	5.93E+3	5.56E+3	0.00E0	0.00E0	2.99E+3	-3.33E+2	2.82E+3	1.89E+4	**40.11%**
ADPE	kg antimony	-4.80E+2	-6.11E+2	-2.24E+2	0.00E0	0.00E0	0.00E0	-1.05E+4	0.00E0	6.55E+2	6.15E+2	0.00E0	0.00E0	-5.68E+2	-2.47E+1	-1.75E+1	1.06E+3	**-782.51%**
ADPF	MJ	5.07E+8	2.74E+8	6.18E+8	0.00E0	0.00E0	0.00E0	-2.82E+8	0.00E0	1.06E+9	9.94E+8	0.00E0	0.00E0	1.77E+8	-4.21E+7	2.98E+8	2.26E+9	**72.95%**
GWP F	kg CO_2 eq	2.23E+8	1.76E+7	3.94E+7	0.00E0	0.00E0	0.00E0	-1.99E+7	0.00E0	7.42E+7	6.96E+7	0.00E0	0.00E0	1.09E+7	-2.82E+6	9.60E+6	1.60E+8	**74.39%**
GWP B	kg CO_2 eq	3.92E+6	-6.28E+3	-1.51E+4	0.00E0	0.00E0	0.00E0	1.11E+5	0.00E0	-2.12E+4	-1.99E+4	0.00E0	0.00E0	-1.39E+4	6.95E+3	-1.45E+5	5.22E+4	**82.54%**
GWP L	kg CO_2 eq	1.19E+3	8.40E+3	3.18E+3	0.00E0	0.00E0	0.00E0	-2.03E+4	0.00E0	-3.65E+3	-3.43E+3	0.00E0	0.00E0	5.91E+3	-1.19E+3	1.96E+3	-2.11E+3	**-2.76%**

5.2 Financial

Table 11: Benchmark vs Improved Design, Financial Impacts of Each Life Cycle Phase.

Characterised Impacts Per Absolute (No Functional Unit) Per No Time Scale		Construction Phases			Use Phases								End of Life Phases				Benefits and Loads Beyond the System Boundary	Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B6+	B7	C1	C2	C3	C4	D	
Benchmark																		
AUD	AUD	4.86E+8	6.10E+7	2.56E+8	0.00E0	7.52E+5	0.00E0	1.59E+7	0.00E0	1.41E+8	0.00E0	0.00E0	0.00E0	3.97E+7	0.00E0	2.83E+8	0.00E0	1.28E+9
GBP	GBP	2.63E+8	3.29E+7	1.38E+8	0.00E0	4.06E+5	0.00E0	8.58E+6	0.00E0	7.64E+7	0.00E0	0.00E0	0.00E0	2.15E+7	0.00E0	1.53E+8	0.00E0	6.93E+8
Improved Design																		
AUD	AUD	4.94E+8	4.75E+7	2.21E+8	0.00E0	7.52E+5	0.00E0	1.31E+8	0.00E0	5.27E+7	-8.33E+7	0.00E0	0.00E0	3.15E+7	0.00E0	2.66E+8	-1.67E+8	9.95E+8
GBP	GBP	2.67E+8	2.57E+7	1.19E+8	0.00E0	4.06E+5	0.00E0	7.05E+7	0.00E0	2.85E+7	-4.50E+7	0.00E0	0.00E0	1.70E+7	0.00E0	1.43E+8	-9.00E+7	5.36E+8
Savings (Benchmark Compared to Improved Design)																		
AUD	AUD	-7.98E+6	1.34E+7	3.51E+7	0.00E0	0.00E0	0.00E0	-1.15E+8	0.00E0	8.88E+7	8.33E+7	0.00E0	0.00E0	8.20E+6	0.00E0	1.76E+7	1.67E+8	**22.54%**
GBP	GBP	-4.31E+6	7.25E+6	1.90E+7	0.00E0	0.00E0	0.00E0	-6.19E+7	0.00E0	4.79E+7	4.50E+7	0.00E0	0.00E0	4.43E+6	0.00E0	9.50E+6	9.00E+7	**22.64%**

5.3 Resource Use

Table 12: Benchmark vs Improved Design, Resource Use Impacts of Each Life Cycle Phase.

Characterised Impacts Per Absolute (No Functional Unit) Per No Time Scale		Construction Phases			Use Phases								End of Life Phases				Benefits and Loads Beyond the System Boundary	Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B6+	B7	C1	C2	C3	C4	D	
Benchmark																		
FW	kg	1.06E+11	2.49E+10	5.37E+9	0.00E0	9.81E+7	0.00E0	8.31E+8	0.00E0	4.47E+11	0.00E0	0.00E0	0.00E0	2.01E+10	0.00E0	4.49E+9	-2.77E+8	6.09E+11
Improved Design																		
FW	kg	8.46E+10	1.87E+10	2.10E+9	0.00E0	9.81E+7	0.00E0	3.34E+10	0.00E0	1.67E+11	-2.63E+11	0.00E0	0.00E0	1.59E+10	1.20E+9	1.38E+9	-5.44E+11	-4.84E+11
Savings (Benchmark Compared to Improved Design)																		
FW	kg	2.16E+10	6.21E+9	3.27E+9	0.00E0	0.00E0	0.00E0	-3.26E+10	0.00E0	2.81E+11	2.63E+11	0.00E0	0.00E0	4.19E+9	-1.20E+9	3.11E+9	5.44E+11	179.44%

5.4 Materials Efficiency

Table 13: Benchmark vs Improved Design, Materials Efficiency Impacts of Each Life Cycle Phase.

Characterised Impacts Per Absolute (No Functional Unit) Per No Time Scale		Construction Phases			Use Phases								End of Life Phases				Benefits and Loads Beyond the System Boundary	Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B6+	B7	C1	C2	C3	C4	D	
Benchmark																		
ME	t eq	2.14E+6	6.88E+3	0.00E0	0.00E0	9.71E+1	0.00E0	6.50E+2	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	4.49E+2	2.15E+6
Mtot	t eq	2.17E+6	6.95E+3	0.00E0	0.00E0	1.10E+2	0.00E0	7.33E+2	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	2.18E+6
Improved Design																		
ME	t eq	1.90E+6	5.89E+3	0.00E0	0.00E0	9.71E+1	0.00E0	3.05E+3	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	4.96E+2	1.91E+6
Mtot	t eq	1.92E+6	5.95E+3	0.00E0	0.00E0	1.10E+2	0.00E0	3.13E+3	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	1.93E+6
Savings (Benchmark Compared to Improved Design)																		
ME	t eq	2.47E+5	9.98E+2	0.00E0	0.00E0	0.00E0	0.00E0	-2.40E+3	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	-4.74E+1	**11.41%**
Mtot	t eq	2.47E+5	9.98E+2	0.00E0	0.00E0	0.00E0	0.00E0	-2.40E+3	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	**11.3%**

6 Detailed Analysis

This section provides a more detailed results of the life cycle impacts with the aim of identifying the hotspots by analysing temporal, spatial, functional, end-use demand and supply chain dimensions.

For each indicator being assessed the following charts are provided

The Time Series Charts articulate when impacts occur during the life of the design. This exposes insights such as the temporal hotspots signified by jumps in the plot during the life of the project (for example, relating to a large replacement item) and the payback period of design options

The Top Five Life Cycle Charts express impacts by different modules, categories and classes enabling a detailed understanding of what is responsible for the greatest impacts and also compares these impacts between designs . The pie chart within each bar chart shows the proportion of the life cycle impacts represented in the bar chart. A brief description of the categories is provided below:

- **LC Module Impacts:** The EN15978 Life Cycle Modules. Generally 100% building impacts will be included in the bar chart.
- **Construction Category:** The breakdown of the impacts by construction category. The bar chart will generally only part of the total building impacts.
- **Operational Demand:** The building end use demands that are driving environmental impacts.
- **Energy Supply:** The supply of fuels to the building, in effect the upstream fuel sources supplying energy for on site use during construction, operational and demolition.
- **Materials:** The materials (grouped into common categories) that are driving the environmental impacts.
- **Equipment and People:** The equipment and people required during construction, maintenance and demolition and all associated transport trips that are driving the environmental impacts

All impact figures are quoted as Absolute (No Functional Unit) for the study.

6.1 Global Warming Potential Total, GWP (kg CO_2 eq)

Figure 7: Time series Global Warming Potential Total, GWP chart

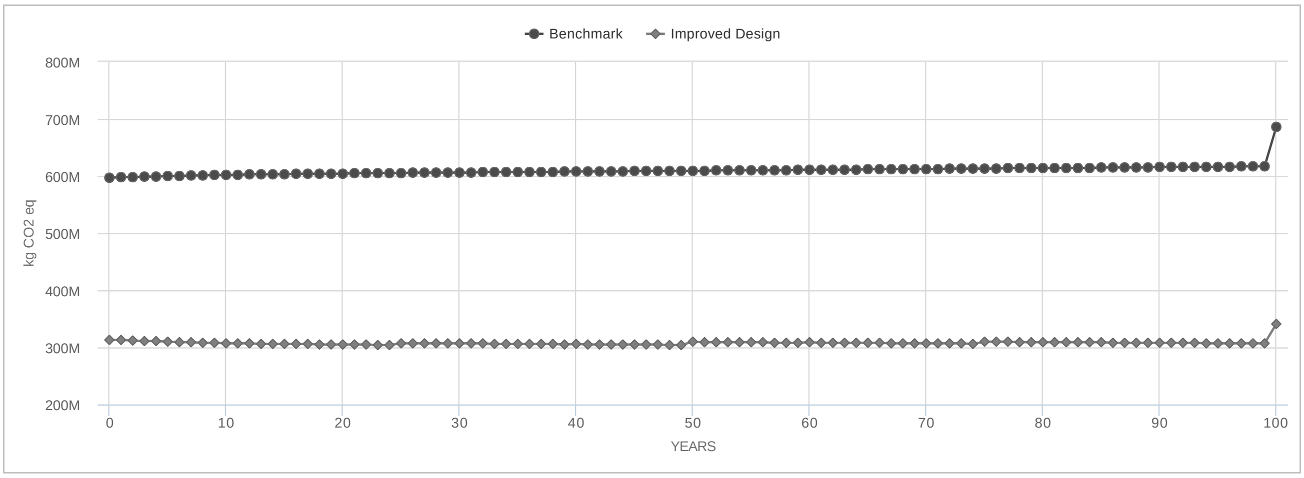


Figure 8: Top Five Global Warming Potential Total, GWP chart

Highest and Lowest Impact Materials (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Biogenic	Total
Top 10 Impact Materials						
Cementitious Binders | Portland Cement | Unspecified	85939823.18	0	2540917.68	0	1114494.28	89595235.14
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	65827795.78	0	21000643.68	-9130085.78	118382.33	77816736.01
Ferrous Metals | Steel | Reinforcement bar | Unspecified	52551825.55	0	6290843.14	4011436.79	-433558.45	62420547.04
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	39583337.26	0	12916968.08	-5611241.94	96969.51	46986032.91
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	4933380.07	13666401.09	409472	-4728914.73	-147810.23	14132528.2
Bulk Aggregates Sands and Soils | Sand | Unspecified	7682437.08	0	5075292.36	0	-56341.09	12701388.35
Metals (Non-Ferous) | Aluminium Unspecified	2626953.21	2722533.67	69619.99	-1466356.59	-5254.14	3947496.13
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	204216.26	1846895.53	994.35	0	-10767.03	2041339.11
Ferrous Metals | Steel | Accessories | Unspecified	2227662.33	0	82813.09	-484185.56	134597.16	1960887.02
Rubber | Synthetic	1832066.73	0	17291.76	0	-28819.52	1820538.97
Bottom 5 Impact Materials						
Metals (Non-Ferous) | Brass	36250.88	0	2593.82	-4372.35	-486.14	33986.21
Ferrous Metals | Steel | General | Unspecified	8728	28440.16	752.05	-10024.88	-61.6	27833.73
Metals (Non-Ferous) | Aluminium Sheet	1074.03	8031.93	73.39	-2201.01	-4.73	6973.61
Glazing | Glass and Films | Flat Glass	589.2	4248.65	17.75	0	17.23	4872.83
Finished Products | Electrical Goods | Electric Motors | Unspecified	596.42	3629.85	8.55	0	-27.69	4207.14

Highest and Lowest Impact Templates (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Biogenic	Total
Top 5 Impact Templates									
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	285043816.45	0	0	0	0	47975758	-11254191.11	951843.12	322717226.46
Tunnel Fill Removal	19087907.52	0	0	0	0	0	0	-15658.98	19072248.54
Car Park Ventilation	35601.25	88917.43	15393486.35	0	0	1921.55	-11721.04	-29278.65	15478926.89
Highway Lighting – Standard	411144.89	2553126.28	1586170.62	0	0	28121.72	-664630.33	-4280.28	3909652.9
Solar PV System - Grid connected	7783680.61	19889563.52	-10400064.78	-10400064.78	0	475744.23	-26948444.24	-84379.82	-19683965.26
Bottom 5 Impact Templates									
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	285043816.45	0	0	0	0	47975758	-11254191.11	951843.12	322717226.46
Tunnel Fill Removal	19087907.52	0	0	0	0	0	0	-15658.98	19072248.54
Car Park Ventilation	35601.25	88917.43	15393486.35	0	0	1921.55	-11721.04	-29278.65	15478926.89
Highway Lighting – Standard	411144.89	2553126.28	1586170.62	0	0	28121.72	-664630.33	-4280.28	3909652.9
Solar PV System - Grid connected	7783680.61	19889563.52	-10400064.78	-10400064.78	0	475744.23	-26948444.24	-84379.82	-19683965.26

6.2 Australian Dollars (AUD)

Figure 9: Time series Australian Dollars chart

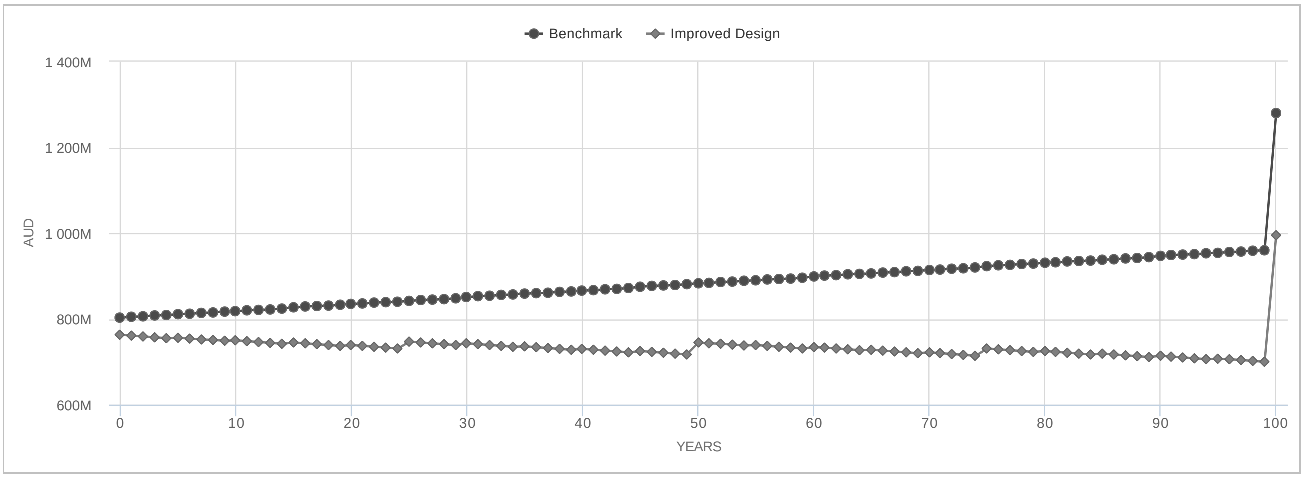


Figure 10: Top Five Australian Dollars chart

Highest and Lowest Impact Materials (AUD)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	154978509.44	0	131423132.28	0	286401641.72
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	93624596.45	0	80835065.36	0	174459661.81
Ferrous Metals | Steel | Reinforcement bar | Unspecified	112692009.99	0	6230519.74	0	118922529.73
Bulk Aggregates Sands and Soils | Sand | Unspecified	51922274.84	0	64421244.26	0	116343519.1
Cementitious Binders | Portland Cement | Unspecified	57164724.98	0	13663740.14	0	70828465.12
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	14082554.07	42535668.56	96002.12	0	56714224.74
Ferrous Metals | Steel | Accessories | Unspecified	31432333.56	0	82018.99	0	31514352.55
Metals (Non-Ferous) | Aluminium Unspecified	12327138.85	12616893.29	183874.2	0	25127906.34
Rubber | Synthetic	11048727.94	0	91225.97	0	11139953.91
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	430344.13	3918877.98	5086.76	0	4354308.87
Bottom 5 Impact Materials					
Glazing | Glass and Films | Flat Glass	12988.74	91521.05	85.7	0	104595.48
Ferrous Metals | Steel | General | Unspecified	21356.27	66303.34	744.84	0	88404.45
Water | Untreated | Unspecified	47257.75	0	27922.55	0	75180.3
Metals (Non-Ferous) | Aluminium Sheet	5577.83	39503.68	65.56	0	45147.07
Finished Products | Electrical Goods | Electric Motors | Unspecified	3000.51	18172.49	28.24	0	21201.23

Cerclos

Highest and Lowest Impact Templates (AUD)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	623078345.07	0	0	0	0	296793191.73	0	919871536.8
Car Park Ventilation	516803.6	1148148.51	123312693.52	0	0	2206.86	0	124979852.49
Tunnel Fill Removal	107219141.04	0	0	0	0	0	0	107219141.04
Highway Lighting – Standard	2072291.03	15545482.25	12706346.48	0	0	97209.79	0	30421329.55
Solar PV System - Grid connected	30104477.56	115481963.43	-83311861.35	-83311861.35	0	281349.65	-166708995.85	-187464927.92
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	623078345.07	0	0	0	0	296793191.73	0	919871536.8
Car Park Ventilation	516803.6	1148148.51	123312693.52	0	0	2206.86	0	124979852.49
Tunnel Fill Removal	107219141.04	0	0	0	0	0	0	107219141.04
Highway Lighting – Standard	2072291.03	15545482.25	12706346.48	0	0	97209.79	0	30421329.55
Solar PV System - Grid connected	30104477.56	115481963.43	-83311861.35	-83311861.35	0	281349.65	-166708995.85	-187464927.92

6.3 Ozone Depletion Potential, ODP (kg CFC-11 eq)

Figure 11: Time series Ozone Depletion Potential, ODP chart

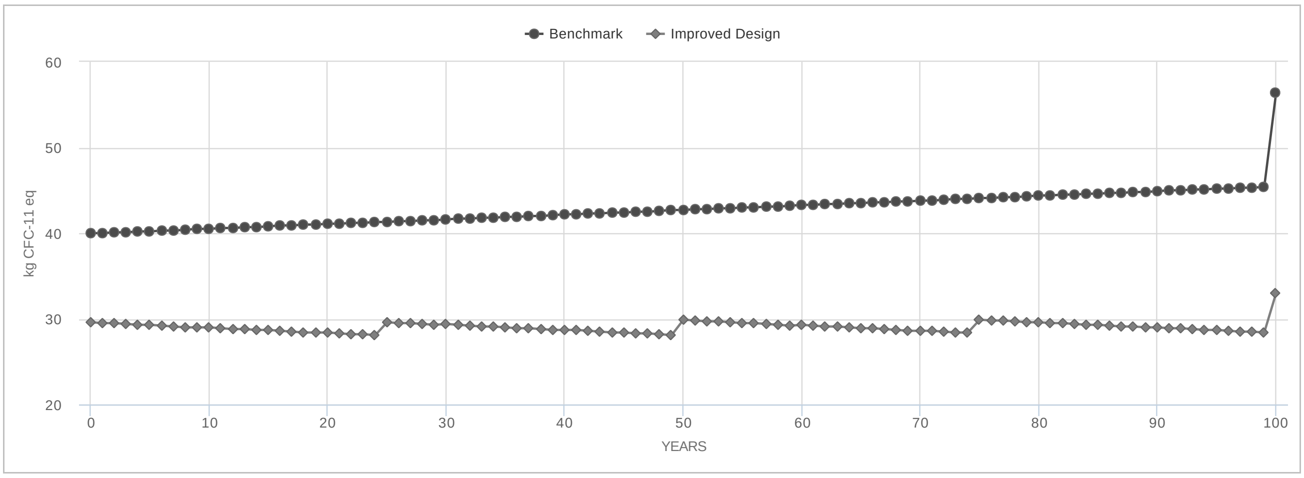
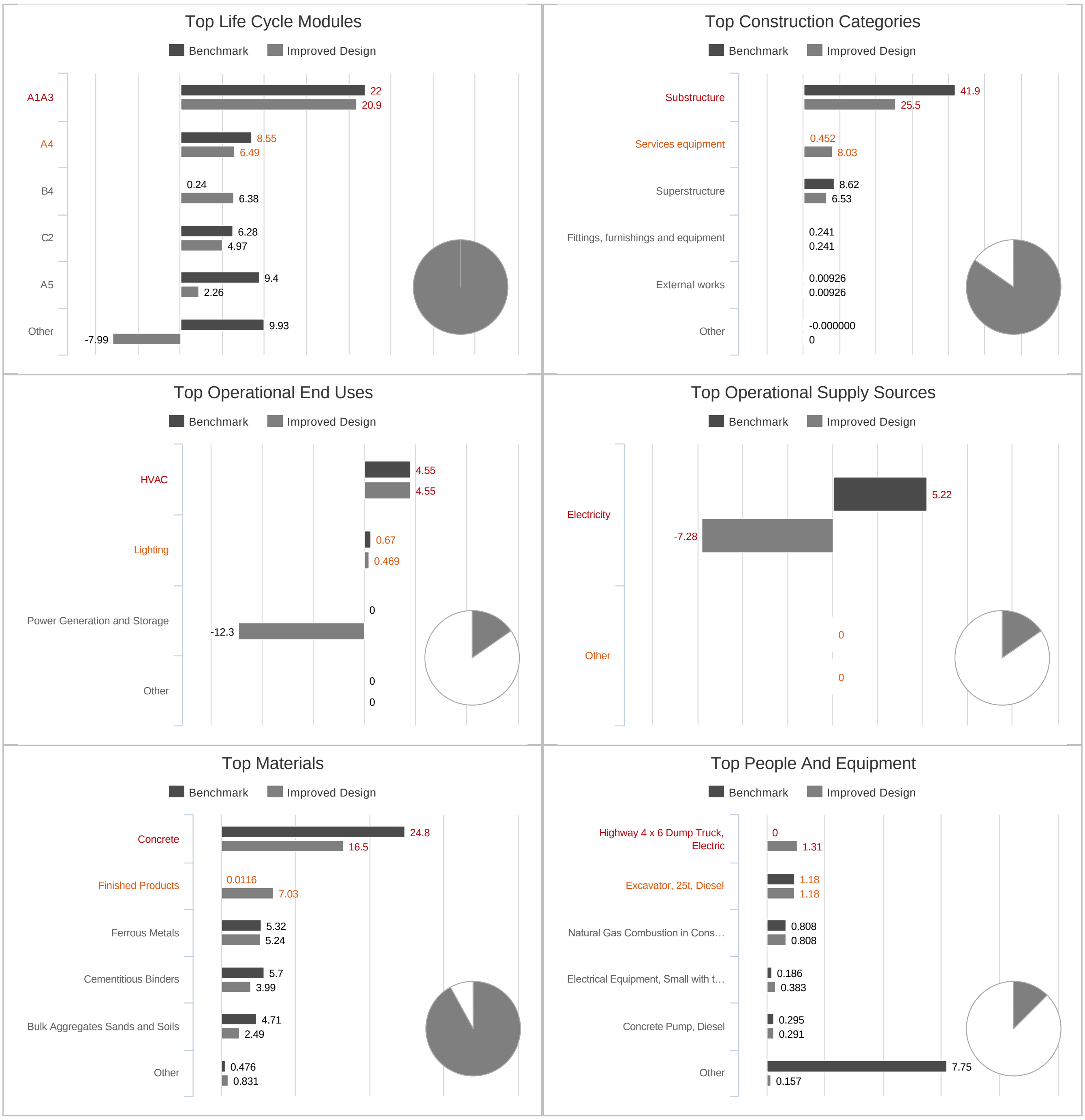


Figure 12: Top Five Ozone Depletion Potential, ODP chart



Highest and Lowest Impact Materials (kg CFC-11 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	9.18	0	2.59	-1.29	10.48
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	1.54	5.04	0.13	-0.43	6.27
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	5.26	0	1.59	-0.79	6.05
Ferrous Metals | Steel | Reinforcement bar | Unspecified	4.11	0	0.77	0.14	5.02
Cementitious Binders | Portland Cement | Unspecified	3.56	0	0.43	0	3.99
Bulk Aggregates Sands and Soils | Sand | Unspecified	1.23	0	1.26	0	2.49
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	0.07	0.68	0	0	0.75
Rubber | Synthetic	0.41	0	0	0	0.41
Metals (Non-Ferous) | Aluminium Unspecified	0.24	0.25	0.01	-0.14	0.37
Ferrous Metals | Steel | Accessories | Unspecified	0.13	0	0.01	-0.02	0.12
Bottom 5 Impact Materials					
Plastics | General | Unspecified	0	0	0	0	0
Water | Untreated | Unspecified	0	0	0	0	0
Finished Products | Electrical Goods | Electric Motors | Unspecified	0	0	0	0	0
Metals (Non-Ferous) | Aluminium Sheet	0	0	0	0	0
Glazing | Glass and Films | Flat Glass	0	0	0	0	0

Highest and Lowest Impact Templates (kg CFC-11 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	25.12	0	0	0	0	6.66	-1.96	29.82
Car Park Ventilation	0	0.01	4.55	0	0	0	0	4.56
Tunnel Fill Removal	2.6	0	0	0	0	0	0	2.6
Highway Lighting – Standard	0.04	0.25	0.47	0	0	0	-0.03	0.73
Solar PV System - Grid connected	1.86	6.14	-3.07	-3.07	0	0.13	-6.72	-4.73
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	25.12	0	0	0	0	6.66	-1.96	29.82
Car Park Ventilation	0	0.01	4.55	0	0	0	0	4.56
Tunnel Fill Removal	2.6	0	0	0	0	0	0	2.6
Highway Lighting – Standard	0.04	0.25	0.47	0	0	0	-0.03	0.73
Solar PV System - Grid connected	1.86	6.14	-3.07	-3.07	0	0.13	-6.72	-4.73

6.4 Acidification Potential for Soil and Water, AP (kg SO_2 eq.)

Figure 13: Time series Acidification Potential for Soil and Water, AP chart

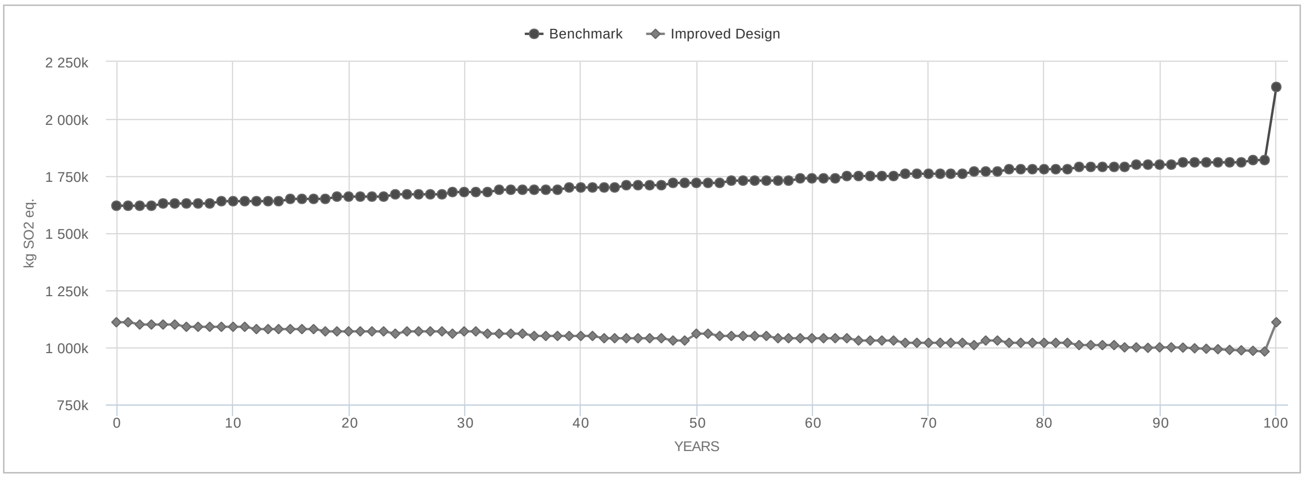
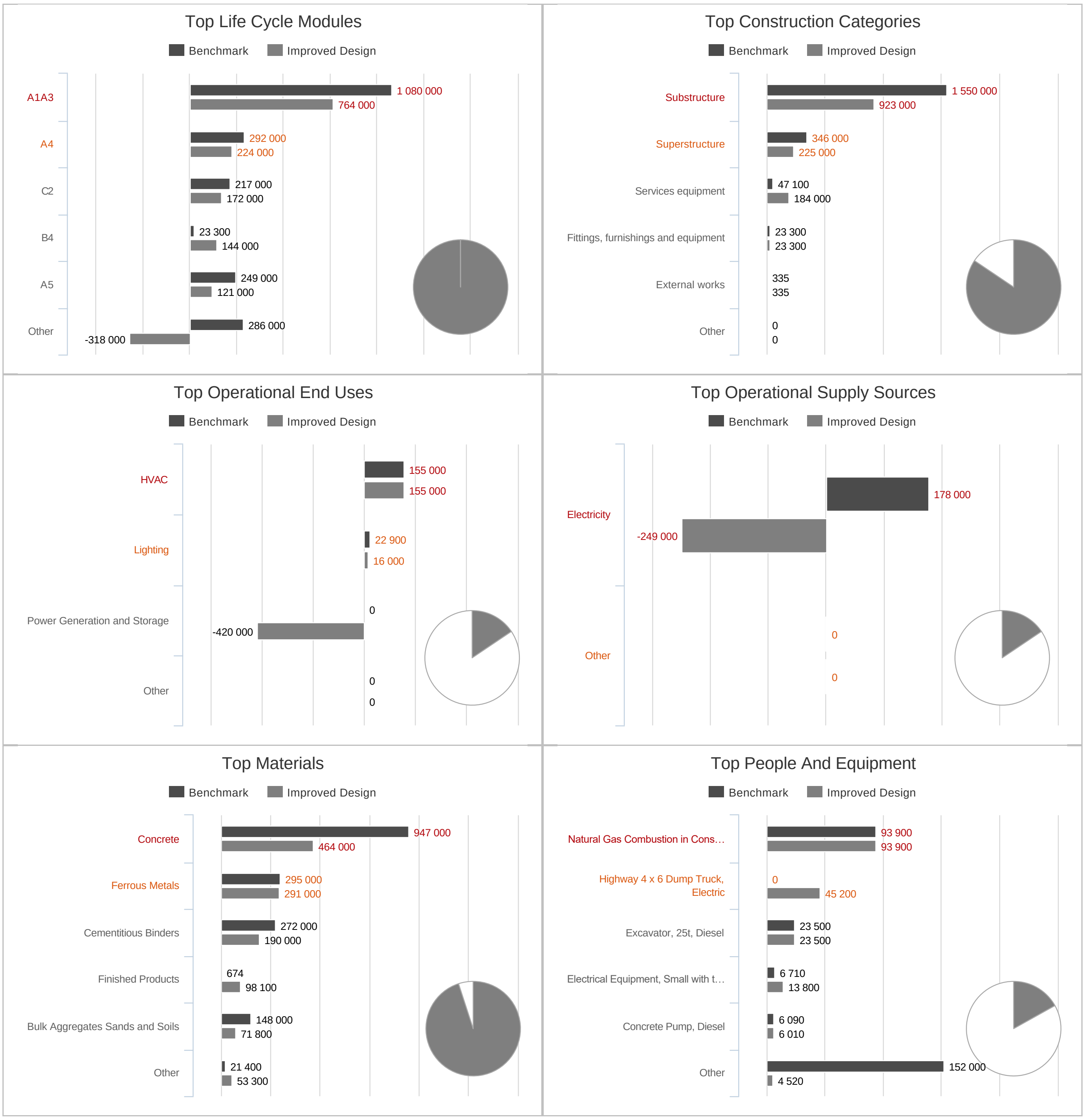


Figure 14: Top Five Acidification Potential for Soil and Water, AP chart



Highest and Lowest Impact Materials (kg SO_2 eq.)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	257308.32	0	84487.47	-50410.42	291385.37
Ferrous Metals | Steel | Reinforcement bar | Unspecified	220187.34	0	26235.39	17370.13	263792.86
Cementitious Binders | Portland Cement | Unspecified	178138.16	0	12244.62	0	190382.78
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	151375.07	0	51966.12	-30981.65	172359.55
Bulk Aggregates Sands and Soils | Sand | Unspecified	41861.04	0	29946.7	0	71807.75
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	21851.27	55333.47	1462.89	-25088.26	53559.38
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	4381.49	39476.21	4.75	0	43862.46
Metals (Non-Ferous) | Aluminium Unspecified	18698.48	19877.96	1016.61	-9883.13	29709.91
Ferrous Metals | Steel | Galvanised Structural | Unspecified	2396.92	17142.8	52.05	-2540.6	17051.17
Metals (Non-Ferous) | Copper Unspecified	11107.23	2630.32	38.44	-3152.49	10623.51
Bottom 5 Impact Materials					
Water | Untreated | Unspecified	12.75	0	151.84	0	164.59
Ferrous Metals | Steel | General | Unspecified	37.06	120.58	3.14	-43.41	117.37
Finished Products | Electrical Goods | Electric Motors | Unspecified	8.28	49.94	0.04	0	58.26
Glazing | Glass and Films | Flat Glass	5.32	37.85	0.08	0	43.26
Metals (Non-Ferous) | Aluminium Sheet	6.82	49.85	0.3	-14.61	42.36

Highest and Lowest Impact Templates (kg SO_2 eq.)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	982117.72	0	0	0	0	205533.35	-68798.83	1118852.24
Car Park Ventilation	1421.07	374.2	155452.93	0	0	8.06	-345.64	156910.61
Tunnel Fill Removal	72651.35	0	0	0	0	0	0	72651.35
Highway Lighting – Standard	3786.87	25558.22	16018.13	0	0	115.33	-3671.65	41806.9
Solar PV System - Grid connected	49040.94	120546.22	-105026.27	-105026.27	0	2466.25	-245731.22	-283730.37
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	982117.72	0	0	0	0	205533.35	-68798.83	1118852.24
Car Park Ventilation	1421.07	374.2	155452.93	0	0	8.06	-345.64	156910.61
Tunnel Fill Removal	72651.35	0	0	0	0	0	0	72651.35
Highway Lighting – Standard	3786.87	25558.22	16018.13	0	0	115.33	-3671.65	41806.9
Solar PV System - Grid connected	49040.94	120546.22	-105026.27	-105026.27	0	2466.25	-245731.22	-283730.37

6.5 Eutrophication potential, EP (kg PO_4 eq)

Figure 15: Time series Eutrophication potential, EP chart

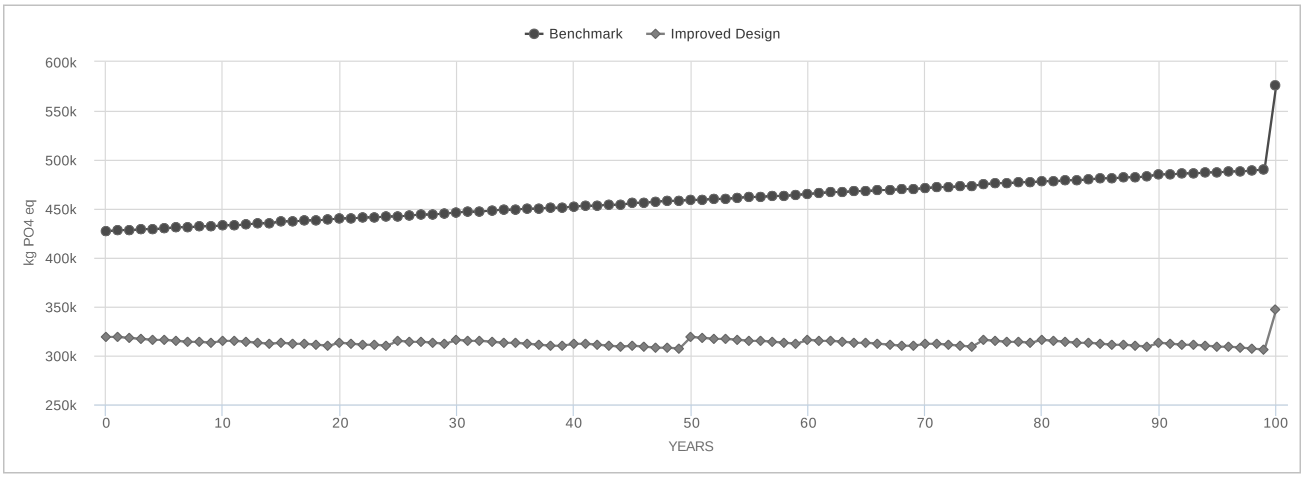
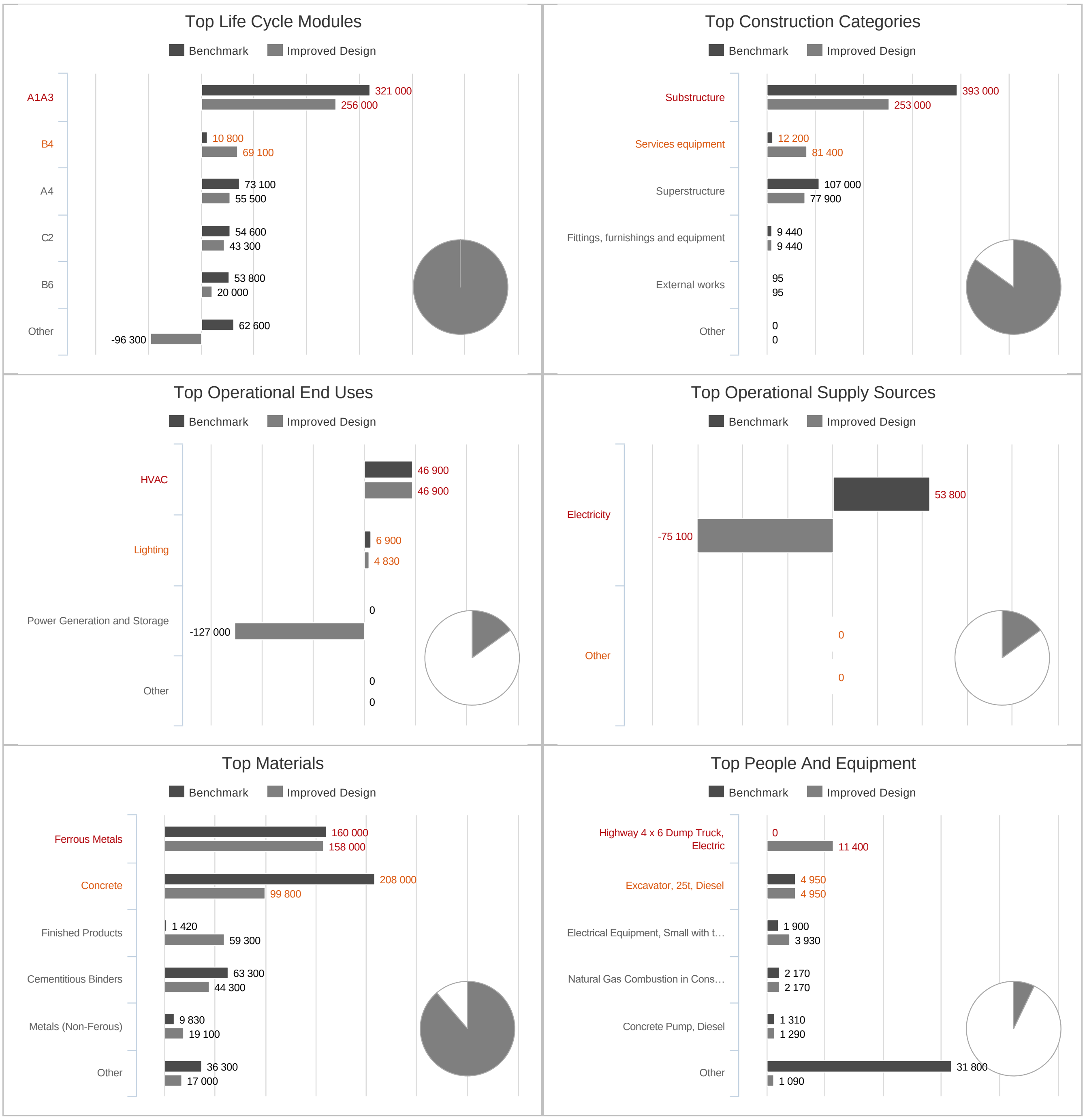


Figure 16: Top Five Eutrophication potential, EP chart



Highest and Lowest Impact Materials (kg PO_4 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Ferrous Metals | Steel | Reinforcement bar | Unspecified	123740.71	0	6589.74	18105.7	148436.15
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	52834.12	0	20897.68	-11122.95	62608.85
Cementitious Binders | Portland Cement | Unspecified	41446.65	0	2862.13	0	44308.78
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	31159.56	0	12853.64	-6836.03	37177.16
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	3272.88	29466.19	1.14	0	32740.21
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	8486.83	22432.14	250.82	-5983.32	25186.47
Bulk Aggregates Sands and Soils | Sand | Unspecified	8968.09	0	6384.68	0	15352.77
Metals (Non-Ferous) | Copper Unspecified	9167.52	2165.78	9.69	-2615.82	8727.17
Metals (Non-Ferous) | Aluminium Unspecified	4494.48	4643.22	107.31	-2516.98	6728.03
Ferrous Metals | Steel | Galvanised Structural | Unspecified	992.83	7041.34	13.07	-2648.18	5399.07
Bottom 5 Impact Materials					
Concrete | Unreinforced | Portland Cement Blends | 20 MPa	43.86	0	13.11	-7.64	49.33
Plastics | General | Unspecified	25.24	19.31	0.61	0	45.16
Finished Products | Electrical Goods | Electric Motors | Unspecified	4.6	27.66	0.01	0	32.27
Metals (Non-Ferous) | Aluminium Sheet	1.73	12.66	0.08	-3.71	10.76
Glazing | Glass and Films | Flat Glass	0.55	3.99	0.02	0	4.56

Highest and Lowest Impact Templates (kg PO_4 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	278732.04	0	0	0	0	49836.61	-4091.35	324477.3
Car Park Ventilation	1128.6	146.77	46906.04	0	0	2.02	-296.03	47887.4
Tunnel Fill Removal	17492.57	0	0	0	0	0	0	17492.57
Highway Lighting – Standard	1679.68	11835.14	4833.28	0	0	28.77	-3426.45	14950.42
Solar PV System - Grid connected	19836.62	58231.34	-31690.41	-31690.41	0	354.75	-72650.65	-57608.76
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	278732.04	0	0	0	0	49836.61	-4091.35	324477.3
Car Park Ventilation	1128.6	146.77	46906.04	0	0	2.02	-296.03	47887.4
Tunnel Fill Removal	17492.57	0	0	0	0	0	0	17492.57
Highway Lighting – Standard	1679.68	11835.14	4833.28	0	0	28.77	-3426.45	14950.42
Solar PV System - Grid connected	19836.62	58231.34	-31690.41	-31690.41	0	354.75	-72650.65	-57608.76

6.6 Photochemical Ozone Creation Potential, POCP (kg ethylene)

Figure 17: Time series Photochemical Ozone Creation Potential, POCP chart

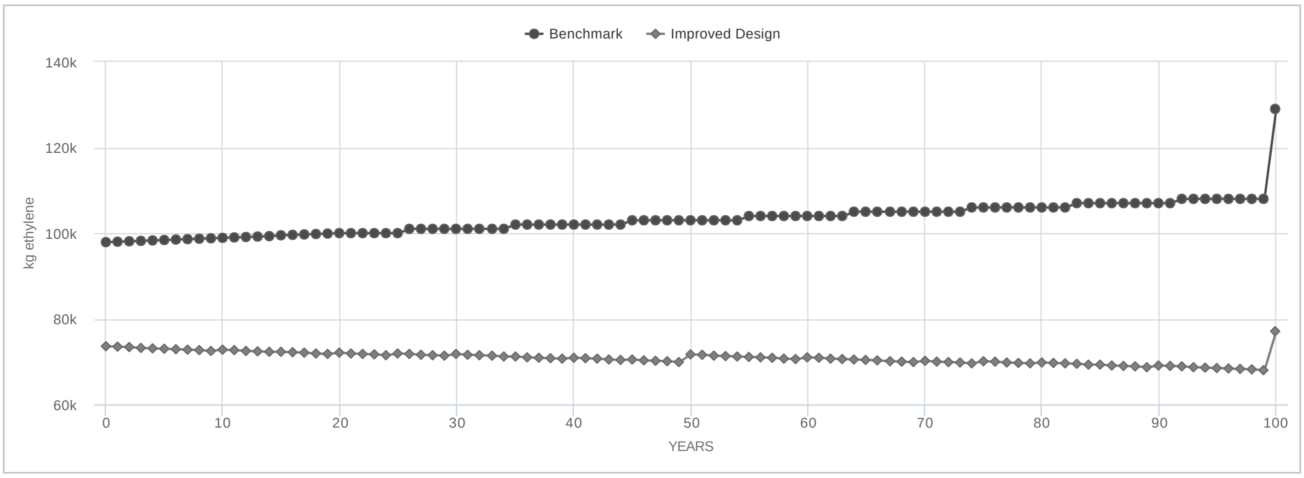
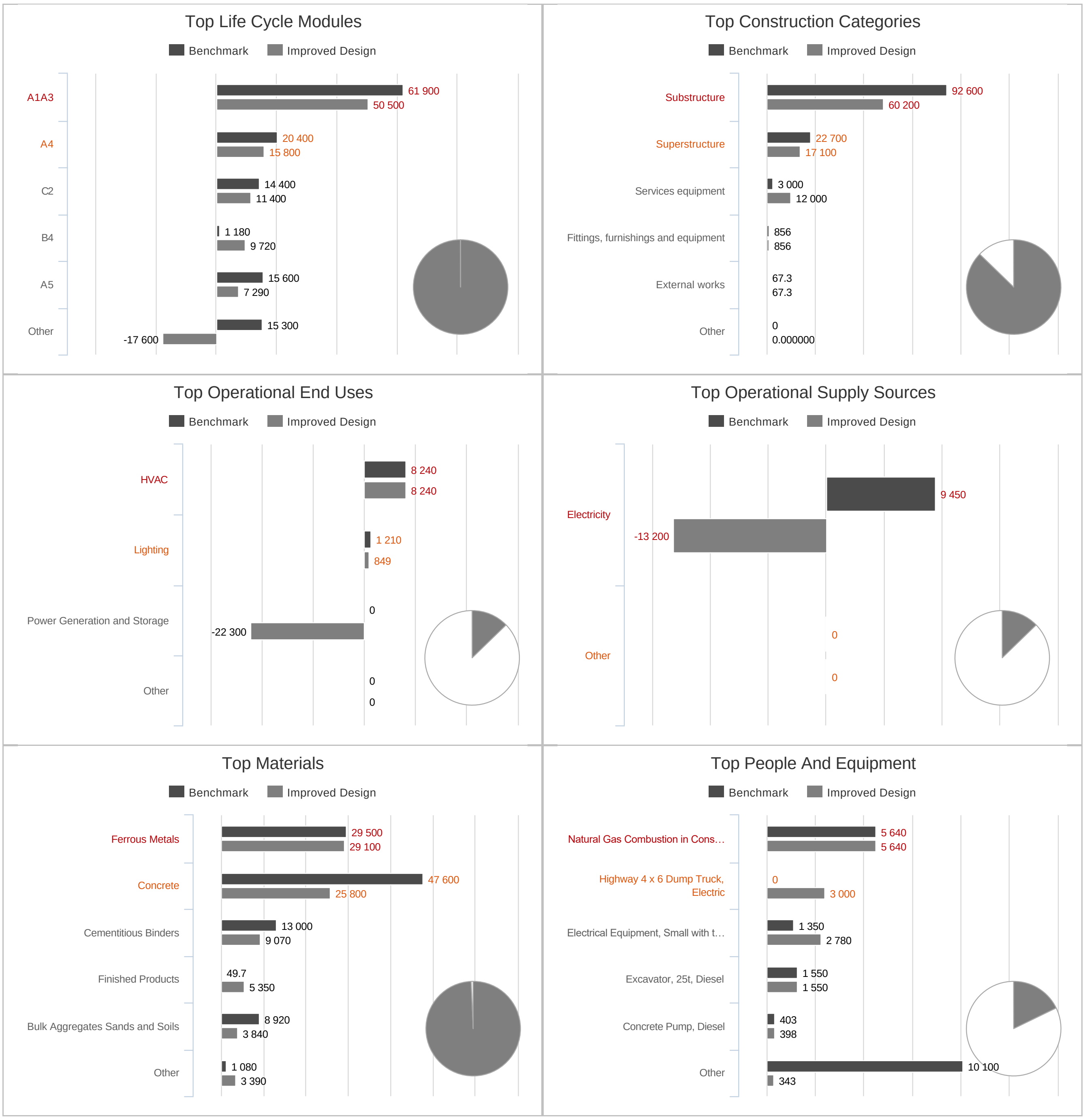


Figure 18: Top Five Photochemical Ozone Creation Potential, POCP chart



Highest and Lowest Impact Materials (kg ethylene)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Ferrous Metals | Steel | Reinforcement bar | Unspecified	23371.99	0	1726.5	2772.06	27870.55
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	13721.7	0	5514.26	-3097.99	16137.97
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	8140.95	0	3391.69	-1903.99	9628.64
Cementitious Binders | Portland Cement | Unspecified	8366.01	0	708.43	0	9074.44
Bulk Aggregates Sands and Soils | Sand | Unspecified	2392.95	0	1451.95	0	3844.9
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	319.39	2876.96	0.28	0	3196.63
Metals (Non-Ferous) | Aluminium Unspecified	1520.43	1568.96	34.87	-852.3	2271.96
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	1315.93	2817.26	76.24	-2101.27	2108.17
Ferrous Metals | Steel | Accessories | Unspecified	982.38	0	22.73	-334.59	670.52
Ferrous Metals | Steel | Galvanised Structural | Unspecified	109.63	791.38	3.43	-405.45	498.98
Bottom 5 Impact Materials					
Concrete | Unreinforced | Portland Cement Blends | 20 MPa	9.78	0	3.46	-2.13	11.11
Water | Untreated | Unspecified	0.59	0	7.26	0	7.84
Metals (Non-Ferous) | Aluminium Sheet	0.58	4.17	0.02	-1.26	3.51
Finished Products | Electrical Goods | Electric Motors | Unspecified	0.48	2.88	0	0	3.37
Glazing | Glass and Films | Flat Glass	0.2	1.41	0	0	1.61

Highest and Lowest Impact Templates (kg ethylene)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	64617.22	0	0	0	0	12832.42	-2676.05	74773.59
Car Park Ventilation	65.65	48.4	8235.96	0	0	0.53	-18.59	8331.95
Tunnel Fill Removal	5355.01	0	0	0	0	0	0	5355.01
Highway Lighting – Standard	181.34	1255.19	848.65	0	0	7.56	-476.81	1815.93
Solar PV System - Grid connected	3340.17	8548.12	-5564.34	-5564.34	0	110.19	-14090.75	-13220.94
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	64617.22	0	0	0	0	12832.42	-2676.05	74773.59
Car Park Ventilation	65.65	48.4	8235.96	0	0	0.53	-18.59	8331.95
Tunnel Fill Removal	5355.01	0	0	0	0	0	0	5355.01
Highway Lighting – Standard	181.34	1255.19	848.65	0	0	7.56	-476.81	1815.93
Solar PV System - Grid connected	3340.17	8548.12	-5564.34	-5564.34	0	110.19	-14090.75	-13220.94

6.7 Net use of fresh water, FW (kg)

Figure 19: Time series Net use of fresh water, FW chart

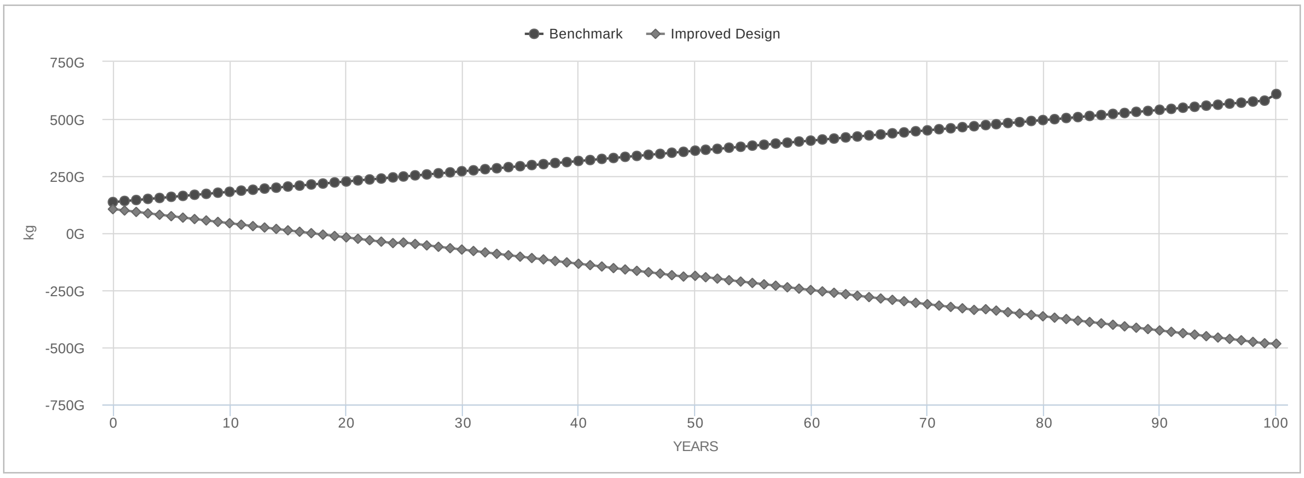
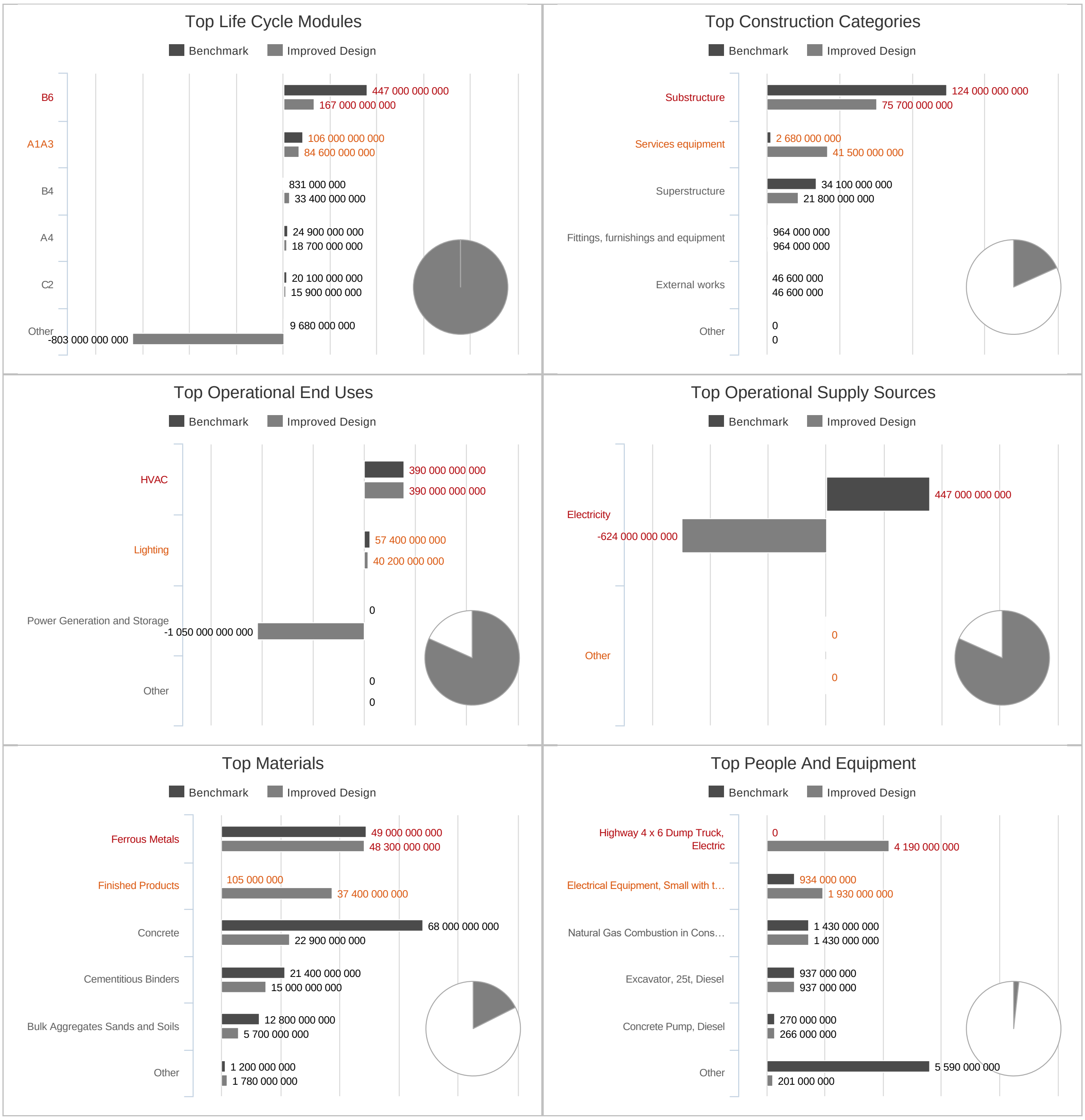


Figure 20: Top Five Net use of fresh water, FW chart



Highest and Lowest Impact Materials (kg)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Ferrous Metals | Steel | Reinforcement bar | Unspecified	43448939364.99	0	2407514814.71	-374465969.46	45481988210.25
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	9098495424.5	28845693366.91	786686777.22	-4204117752.08	34526757816.56
Cementitious Binders | Portland Cement | Unspecified	14064559084.51	0	939089088.42	0	15003648172.93
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	14386985794.09	0	7722062009	-7894701489.96	14214346313.13
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	8790683563.29	0	4749646248.28	-4851989475.59	8688340335.98
Bulk Aggregates Sands and Soils | Sand | Unspecified	3937705955.57	0	1764765357.29	0	5702471312.86
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	272946810.05	2459835784.43	368277.11	0	2733150871.59
Ferrous Metals | Steel | Accessories | Unspecified	1903054804.02	0	31692691.79	45198520.37	1979946016.18
Rubber | Synthetic	998225970.77	0	6396064.94	0	1004622035.71
Ferrous Metals | Steel | Galvanised Structural | Unspecified	82425613.71	610415877.47	4776654.5	54770280.94	752388426.62
Bottom 5 Impact Materials					
Concrete | Unreinforced | Portland Cement Blends | 20 MPa	14494073.89	0	4844441.52	-5422003.2	13916512.21
Plastics | General | Unspecified	3865824.45	3036834.59	199391.08	0	7102050.12
Metals (Non-Ferous) | Aluminium Sheet	239939.14	1876315.94	28106	-270701.41	1873659.66
Finished Products | Electrical Goods | Electric Motors | Unspecified	259918.22	1578783.92	3212.43	0	1841914.58
Glazing | Glass and Films | Flat Glass	131777.12	968572.67	6590.4	0	1106940.2

Highest and Lowest Impact Templates (kg)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
Car Park Ventilation	20393316.57	35881901.17	389794926706.27	0	0	734471.97	-976723.59	389850959672.39
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	89811665124	0	0	0	0	17640678283.67	-13096594271.59	94355749136.08
Highway Lighting – Standard	130079201.8	893147346.4	40165122127.7	0	0	10564785.34	42170306.67	41241083767.91
Tunnel Fill Removal	5682960869.05	0	0	0	0	0	0	5682960869.05
Solar PV System - Grid connected	9791871995.31	32608497036.98	-263351160066.73	-263351160066.73	0	813119390.87	-531353832661.43	-1014842664371.75
Bottom 5 Impact Templates								
Car Park Ventilation	20393316.57	35881901.17	389794926706.27	0	0	734471.97	-976723.59	389850959672.39
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	89811665124	0	0	0	0	17640678283.67	-13096594271.59	94355749136.08
Highway Lighting – Standard	130079201.8	893147346.4	40165122127.7	0	0	10564785.34	42170306.67	41241083767.91
Tunnel Fill Removal	5682960869.05	0	0	0	0	0	0	5682960869.05
Solar PV System - Grid connected	9791871995.31	32608497036.98	-263351160066.73	-263351160066.73	0	813119390.87	-531353832661.43	-1014842664371.75

6.8 Abiotic Depletion Potential - Elements, ADPE (kg antimony)

Figure 21: Time series Abiotic Depletion Potential - Elements, ADPE chart

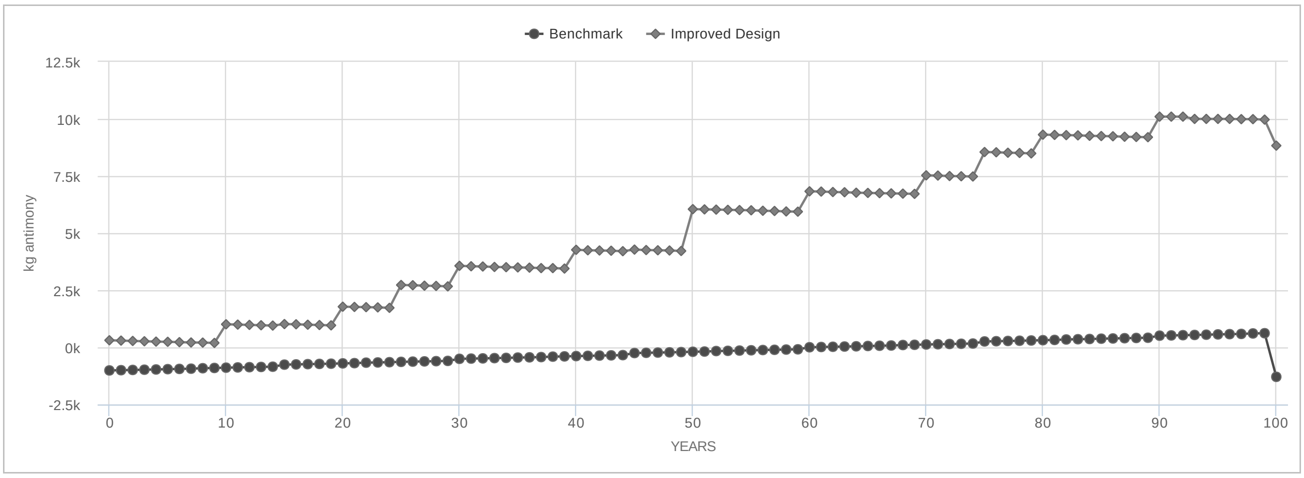


Figure 22: Top Five Abiotic Depletion Potential - Elements, ADPE chart

Highest and Lowest Impact Materials (kg antimony)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	826.57	7438.76	-0.04	0	8265.28
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	1010.32	3041.06	4.08	-22.15	4033.3
Ferrous Metals | Steel | Reinforcement bar | Unspecified	738.36	0	-320.77	1110.16	1527.74
Ferrous Metals | Steel | Galvanised Structural | Unspecified	76.73	532.62	-0.64	-162.37	446.33
Finished Products | Electrical Goods | Electronics | Electronics For Control Unit	10.07	140.97	0	0	151.04
Metals (Non-Ferous) | Copper Unspecified	140.56	33.06	-0.47	-40.5	132.65
Ferrous Metals | Steel | Accessories | Unspecified	226.14	0	-4.22	-134	87.92
Ferrous Metals | Steel | Coated Sheet | Galvanised (zinc coated)	8.5	50.78	-0.03	-7.1	52.14
Metals (Non-Ferous) | Copper Wire	54.89	0	-0.18	-12.8	41.91
Rubber | Synthetic	40.81	0	-0.7	0	40.12
Bottom 5 Impact Materials					
Concrete | Unreinforced | Portland Cement Blends | 20 MPa	-0.05	0	-0.61	0.06	-0.61
Bulk Aggregates Sands and Soils | Sand | Unspecified	-250.35	0	-109.24	0	-359.6
Cementitious Binders | Portland Cement | Unspecified	-672.05	0	-101.5	0	-773.54
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	-425.52	0	-602.33	50.03	-977.82
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	-913.63	0	-979.28	81.41	-1811.5

Highest and Lowest Impact Templates (kg antimony)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
Solar PV System - Grid connected	1902.56	10528.62	-614.73	-614.73	0	4.1	-1269.56	9936.27
Car Park Ventilation	18	3.95	909.88	0	0	-0.1	-6.66	925.06
Highway Lighting – Standard	100.32	753.14	93.76	0	0	-1.38	-178.58	767.26
Tunnel Fill Removal	-641.04	0	0	0	0	0	0	-641.04
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	-1117.97	0	0	0	0	-2117.05	1076.97	-2158.05
Bottom 5 Impact Templates								
Solar PV System - Grid connected	1902.56	10528.62	-614.73	-614.73	0	4.1	-1269.56	9936.27
Car Park Ventilation	18	3.95	909.88	0	0	-0.1	-6.66	925.06
Highway Lighting – Standard	100.32	753.14	93.76	0	0	-1.38	-178.58	767.26
Tunnel Fill Removal	-641.04	0	0	0	0	0	0	-641.04
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	-1117.97	0	0	0	0	-2117.05	1076.97	-2158.05

6.9 Abiotic Depletion Potential - Fossil Fuels, ADPF (MJ)

Figure 23: Time series Abiotic Depletion Potential - Fossil Fuels, ADPF chart

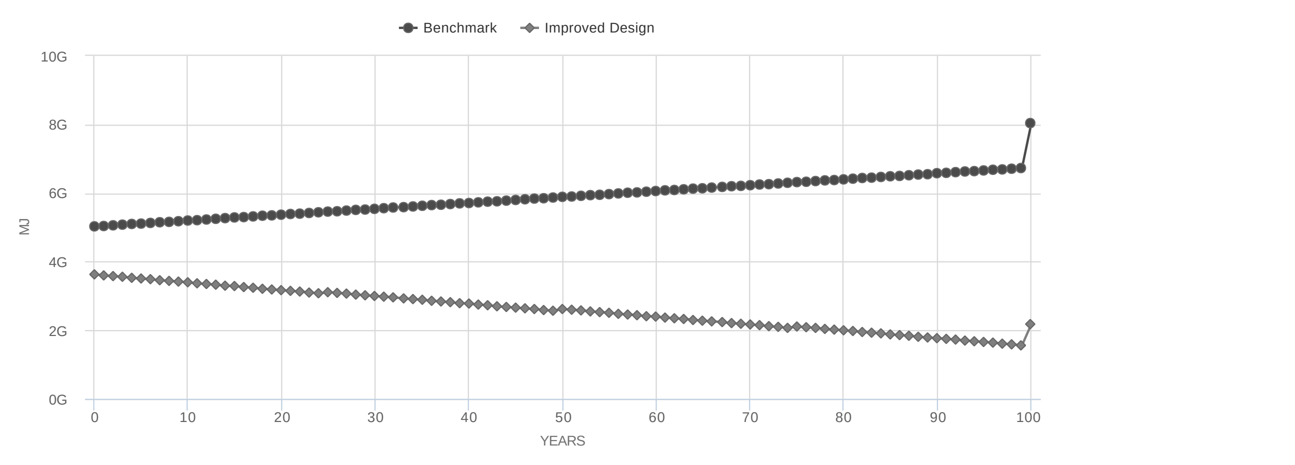


Figure 24: Top Five Abiotic Depletion Potential - Fossil Fuels, ADPF chart

Highest and Lowest Impact Materials (MJ)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	910567342.34	0	342174211.73	-134063832.73	1118677721.34
Ferrous Metals | Steel | Reinforcement bar | Unspecified	665019669.49	0	102922317.46	29064542.35	797006529.3
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	526948080.16	0	210462757.11	-82394034.31	655016802.96
Cementitious Binders | Portland Cement | Unspecified	475987326.5	0	49943848.55	0	525931175.04
Bulk Aggregates Sands and Soils | Sand | Unspecified	127183000.6	0	127647032.47	0	254830033.07
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	69091844.93	208146940.79	6311794.01	-48385331.83	235165247.9
Rubber | Synthetic	53421790.88	0	338561.85	0	53760352.73
Metals (Non-Ferous) | Aluminium Unspecified	22999854.04	24282472.33	1025716.75	-12475945.66	35832097.45
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	2763678.26	25047247.53	19349.24	0	27830275.03
Ferrous Metals | Steel | Accessories | Unspecified	25134903.12	0	1354876.52	-3508127.54	22981652.1
Bottom 5 Impact Materials					
Water | Untreated | Unspecified	57088.12	0	374237.11	0	431325.23
Ferrous Metals | Steel | General | Unspecified	103143.11	346341.53	12304.07	-72634.46	389154.25
Metals (Non-Ferous) | Aluminium Sheet	10313.89	80564.19	1195.28	-18875.12	73198.24
Glazing | Glass and Films | Flat Glass	7119.36	52226.83	341.61	0	59687.8
Finished Products | Electrical Goods | Electric Motors | Unspecified	7130.28	43711.84	155.02	0	50997.15

Highest and Lowest Impact Templates (MJ)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	3225327219.1	0	0	0	0	835503453.59	-191276092.1	3869554580.59
Car Park Ventilation	552393.46	1557075.3	1471420835.64	0	0	31666.27	-90651.53	1473471319.14
Tunnel Fill Removal	302112080.65	0	0	0	0	0	0	302112080.65
Highway Lighting – Standard	4458216.87	31399700.1	151617667.43	0	0	459173.46	-4928692.75	183006065.12
Solar PV System - Grid connected	95624298.6	282192064.88	-994113461.88	-994113461.88	0	7286336.25	-2049628145.68	-3652752369.7
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	3225327219.1	0	0	0	0	835503453.59	-191276092.1	3869554580.59
Car Park Ventilation	552393.46	1557075.3	1471420835.64	0	0	31666.27	-90651.53	1473471319.14
Tunnel Fill Removal	302112080.65	0	0	0	0	0	0	302112080.65
Highway Lighting – Standard	4458216.87	31399700.1	151617667.43	0	0	459173.46	-4928692.75	183006065.12
Solar PV System - Grid connected	95624298.6	282192064.88	-994113461.88	-994113461.88	0	7286336.25	-2049628145.68	-3652752369.7

6.10 British Pounds Sterling (GBP)

Figure 25: Time series British Pounds Sterling chart

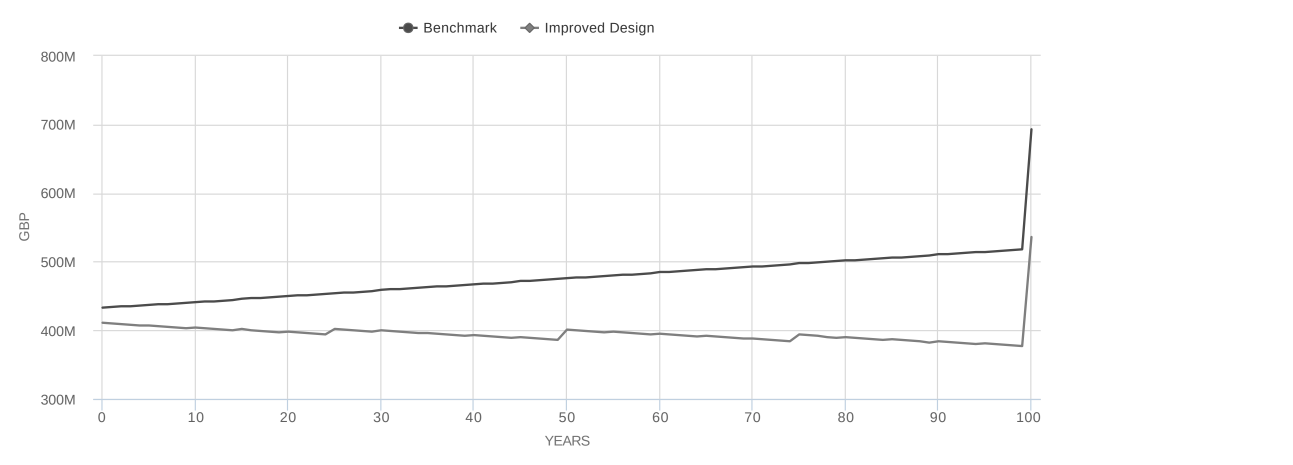
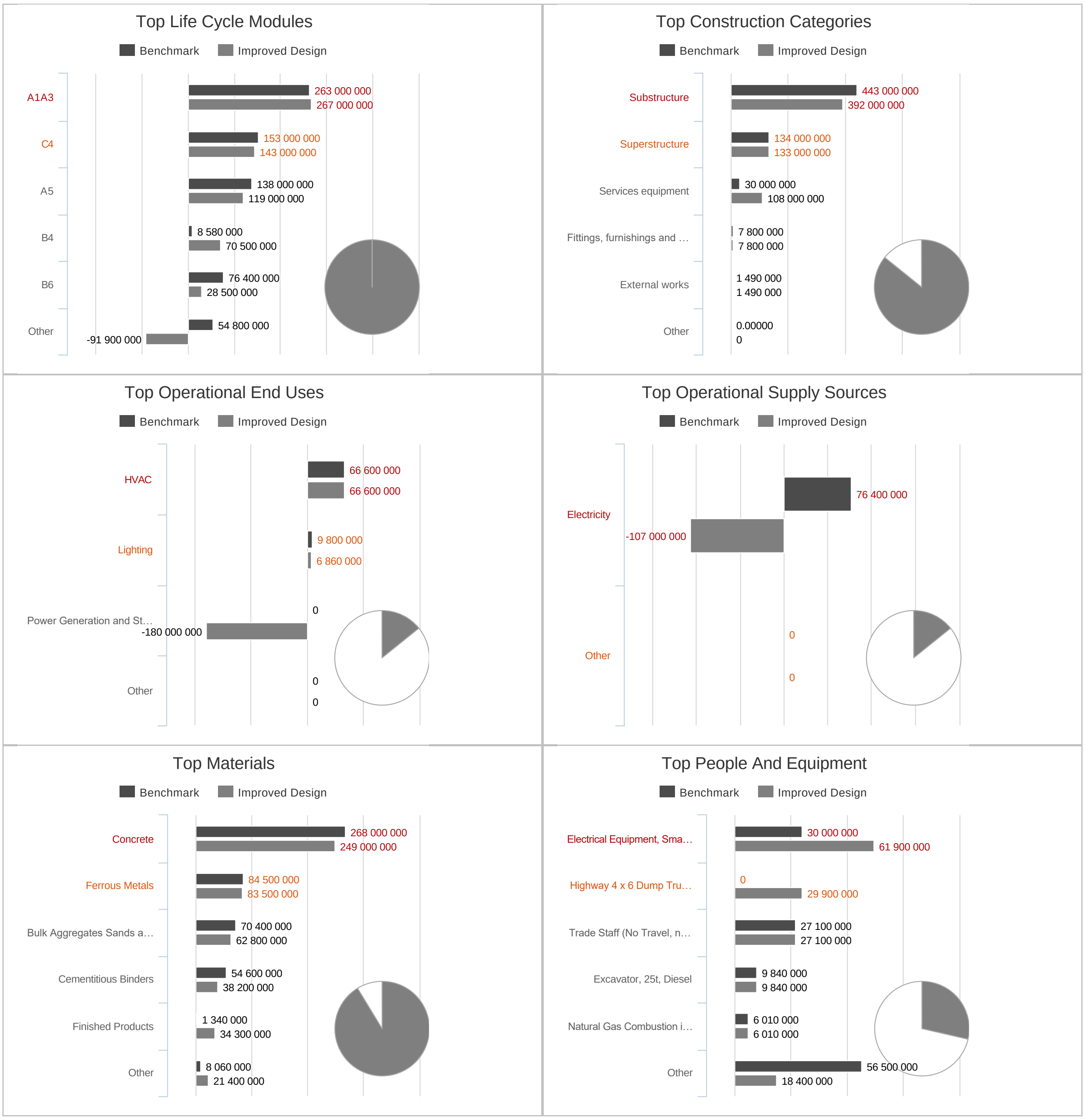


Figure 26: Top Five British Pounds Sterling chart



Highest and Lowest Impact Materials (GBP)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	83688395.1	0	70968491.43	0	154656886.53
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	50557282.08	0	43650935.29	0	94208217.38
Ferrous Metals | Steel | Reinforcement bar | Unspecified	60853685.4	0	3364480.66	0	64218166.06
Bulk Aggregates Sands and Soils | Sand | Unspecified	28038028.41	0	34787471.9	0	62825500.31
Cementitious Binders | Portland Cement | Unspecified	30868951.49	0	7378419.68	0	38247371.16
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	7604579.2	22969261.02	51841.14	0	30625681.36
Ferrous Metals | Steel | Accessories | Unspecified	16973460.12	0	44290.26	0	17017750.38
Metals (Non-Ferous) | Aluminium Unspecified	6656654.98	6813122.38	99292.07	0	13569069.42
Rubber | Synthetic	5966313.09	0	49262.02	0	6015575.11
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	232385.83	2116194.11	2746.85	0	2351326.79
Bottom 5 Impact Materials					
Glazing | Glass and Films | Flat Glass	7013.92	49421.37	46.28	0	56481.56
Ferrous Metals | Steel | General | Unspecified	11532.39	35803.8	402.21	0	47738.4
Water | Untreated | Unspecified	25519.18	0	15078.18	0	40597.36
Metals (Non-Ferous) | Aluminium Sheet	3012.03	21331.99	35.4	0	24379.42
Finished Products | Electrical Goods | Electric Motors | Unspecified	1620.28	9813.14	15.25	0	11448.67

Highest and Lowest Impact Templates (GBP)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	335843091.89	0	0	0	0	160268323.54	0	496111415.43
Car Park Ventilation	276751.16	613031.85	66588854.5	0	0	1191.7	0	67479829.21
Tunnel Fill Removal	57639144.47	0	0	0	0	0	0	57639144.47
Highway Lighting – Standard	1116142.4	8375863.67	6861427.1	0	0	52493.29	0	16405926.46
Solar PV System - Grid connected	16233287.88	61920790.25	-44988405.13	-44988405.13	0	151928.81	-90022857.76	-101693661.07
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	335843091.89	0	0	0	0	160268323.54	0	496111415.43
Car Park Ventilation	276751.16	613031.85	66588854.5	0	0	1191.7	0	67479829.21
Tunnel Fill Removal	57639144.47	0	0	0	0	0	0	57639144.47
Highway Lighting – Standard	1116142.4	8375863.67	6861427.1	0	0	52493.29	0	16405926.46
Solar PV System - Grid connected	16233287.88	61920790.25	-44988405.13	-44988405.13	0	151928.81	-90022857.76	-101693661.07

6.11 Materials Efficiency Metric (t eq)

Figure 27: Time series Materials Efficiency Metric chart

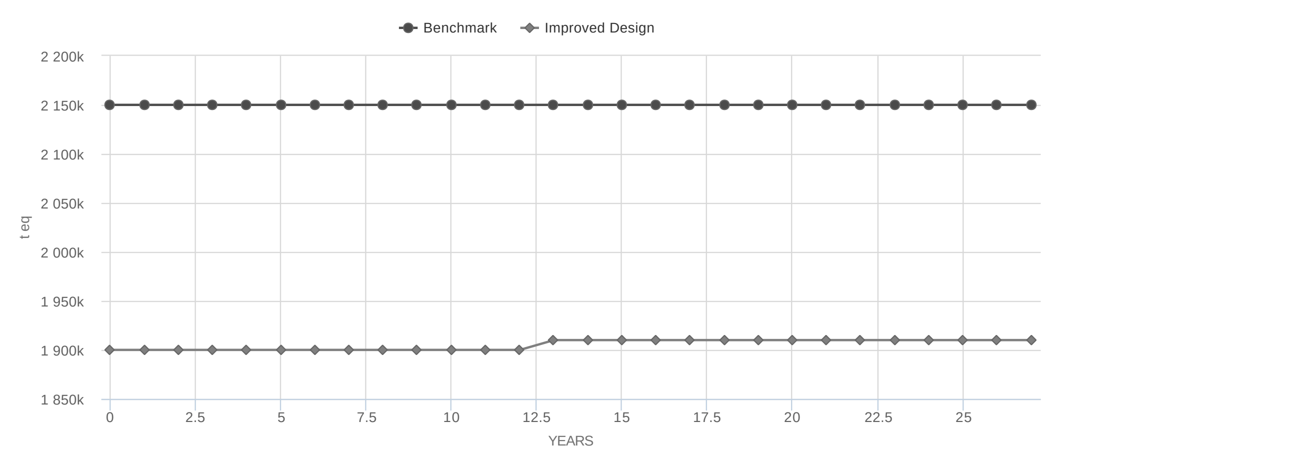


Figure 28: Top Five Materials Efficiency Metric chart

Highest and Lowest Impact Materials (t eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	786577.43	0	0	0	786577.43
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	483421.12	0	0	0	483421.12
Bulk Aggregates Sands and Soils | Sand | Unspecified	482202.16	0	0	0	482202.16
Cementitious Binders | Portland Cement | Unspecified	85302.67	0	0	0	85302.67
Ferrous Metals | Steel | Reinforcement bar | Unspecified	39734.75	0	0	686.9	40421.66
Water | Untreated | Unspecified	22930.81	0	0	0	22930.81
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	566	1698	0	0	2264
Metals (Non-Ferous) | Aluminium Unspecified	446.58	450.36	0	0	896.95
Ferrous Metals | Steel | Galvanised Structural | Unspecified	92.76	649.3	0	-100.47	641.59
Rubber | Synthetic	594.75	0	0	0	594.75
Bottom 5 Impact Materials					
Metals (Non-Ferous) | Brass	7.71	0	0	0	7.71
Finished Products | Electrical Goods | Electronics | Electronics For Control Unit	0.31	4.28	0	0	4.59
Glazing | Glass and Films | Flat Glass	0.53	3.69	0	0	4.22
Metals (Non-Ferous) | Aluminium Sheet	0.16	1.14	0	0	1.3
Finished Products | Electrical Goods | Electric Motors | Unspecified	0.16	0.95	0	0	1.11

Highest and Lowest Impact Templates (t eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	1901438.61	0	0	0	0	0	603.99	1902042.61
Solar PV System - Grid connected	1035.79	2396.96	0	0	0	0	0	3432.75
Highway Lighting – Standard	643.03	718.26	0	0	0	0	-104.86	1256.43
Car Park Ventilation	11.73	28.62	0	0	0	0	-3.03	37.32
Tunnel Fill Removal	0	0	0	0	0	0	0	0
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	1901438.61	0	0	0	0	0	603.99	1902042.61
Solar PV System - Grid connected	1035.79	2396.96	0	0	0	0	0	3432.75
Highway Lighting – Standard	643.03	718.26	0	0	0	0	-104.86	1256.43
Car Park Ventilation	11.73	28.62	0	0	0	0	-3.03	37.32
Tunnel Fill Removal	0	0	0	0	0	0	0	0

6.12 Mass of materials, total (t eq)

Figure 29: Time series Mass of materials, total chart

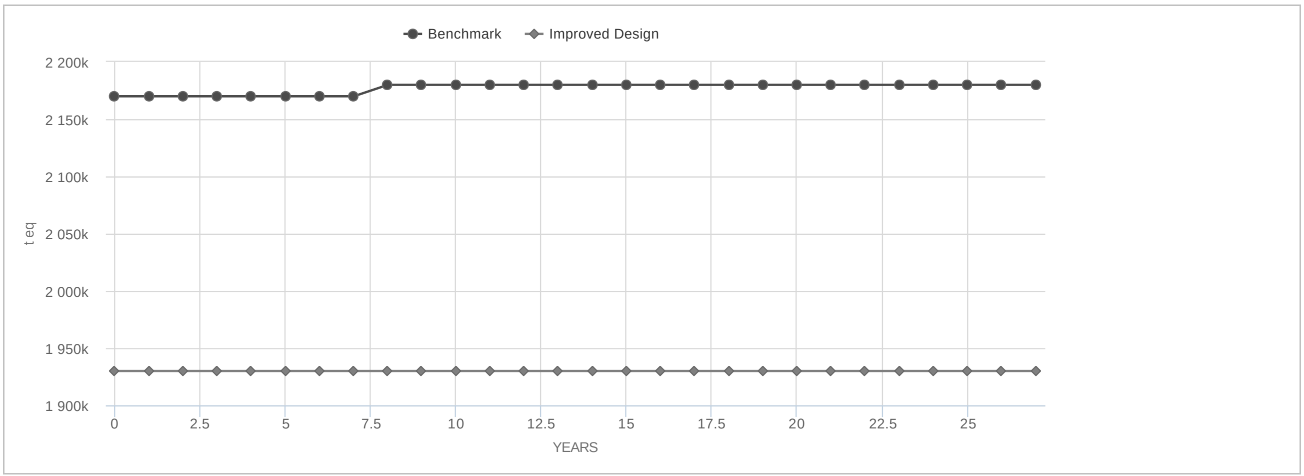


Figure 30: Top Five Mass of materials, total chart

Highest and Lowest Impact Materials (t eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	786577.43	0	0	0	786577.43
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	483421.12	0	0	0	483421.12
Bulk Aggregates Sands and Soils | Sand | Unspecified	482202.16	0	0	0	482202.16
Cementitious Binders | Portland Cement | Unspecified	85302.67	0	0	0	85302.67
Ferrous Metals | Steel | Reinforcement bar | Unspecified	53186.39	0	0	0	53186.39
Water | Untreated | Unspecified	32758.3	0	0	0	32758.3
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	566	1698	0	0	2264
Metals (Non-Ferous) | Aluminium Unspecified	446.58	450.36	0	0	896.95
Ferrous Metals | Steel | Galvanised Structural | Unspecified	105.52	738.67	0	0	844.2
Ferrous Metals | Steel | Accessories | Unspecified	696.67	0	0	0	696.67
Bottom 5 Impact Materials					
Metals (Non-Ferous) | Brass	7.71	0	0	0	7.71
Finished Products | Electrical Goods | Electronics | Electronics For Control Unit	0.31	4.28	0	0	4.59
Glazing | Glass and Films | Flat Glass	0.53	3.69	0	0	4.22
Metals (Non-Ferous) | Aluminium Sheet	0.16	1.14	0	0	1.3
Finished Products | Electrical Goods | Electric Motors | Unspecified	0.16	0.95	0	0	1.11

Highest and Lowest Impact Templates (t eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	1924802.03	0	0	0	0	0	0	1924802.03
Solar PV System - Grid connected	1035.79	2396.96	0	0	0	0	0	3432.75
Highway Lighting – Standard	656.44	811.47	0	0	0	0	0	1467.9
Car Park Ventilation	12.5	30.92	0	0	0	0	0	43.42
Tunnel Fill Removal	0	0	0	0	0	0	0	0
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	1924802.03	0	0	0	0	0	0	1924802.03
Solar PV System - Grid connected	1035.79	2396.96	0	0	0	0	0	3432.75
Highway Lighting – Standard	656.44	811.47	0	0	0	0	0	1467.9
Car Park Ventilation	12.5	30.92	0	0	0	0	0	43.42
Tunnel Fill Removal	0	0	0	0	0	0	0	0

6.13 Global Warming Potential Fossil, GWP F (kg CO_2 eq)

Figure 31: Time series Global Warming Potential Fossil, GWP F chart

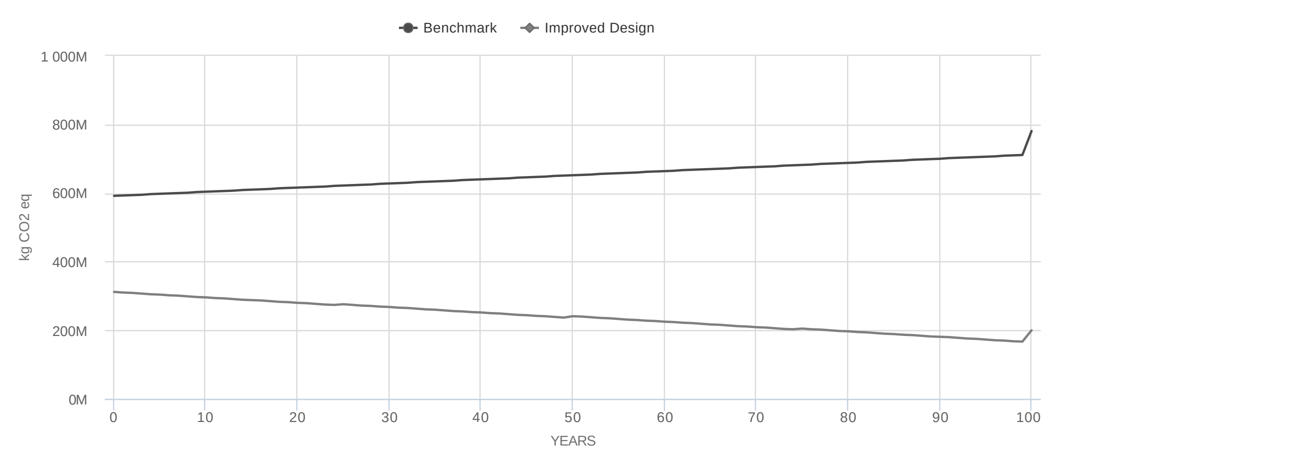


Figure 32: Top Five Global Warming Potential Fossil, GWP F chart

Highest and Lowest Impact Materials (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Cementitious Binders | Portland Cement | Unspecified	85931666.1	0	2539748.53	0	88471414.63
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	65816520.6	0	20990237.39	-9127393.94	77679364.05
Ferrous Metals | Steel | Reinforcement bar | Unspecified	52267484.69	0	6287481.62	4011148.09	62566114.39
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	39576898.86	0	12910567.43	-5609587.57	46877878.72
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	4930545.18	13650984.23	408279.14	-4728619.58	14261188.97
Bulk Aggregates Sands and Soils | Sand | Unspecified	7679558.88	0	5073585.23	0	12753144.11
Metals (Non-Ferous) | Aluminium Unspecified	2626781.46	2722338.51	69600.29	-1466129.13	3952591.13
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	203769.59	1842871.29	993.89	0	2047634.76
Rubber | Synthetic	1831280.86	0	17283.78	0	1848564.64
Ferrous Metals | Steel | Accessories | Unspecified	2227444.8	0	82768.84	-484150.72	1826062.92
Bottom 5 Impact Materials					
Metals (Non-Ferous) | Copper Wire	36769.79	0	3611.74	-5907.28	34474.25
Ferrous Metals | Steel | General | Unspecified	8726.73	28435.15	751.65	-10024.16	27889.38
Metals (Non-Ferous) | Aluminium Sheet	1074.1	8032.14	73.35	-2199.72	6979.87
Glazing | Glass and Films | Flat Glass	589.12	4248.05	17.74	0	4854.91
Finished Products | Electrical Goods | Electric Motors | Unspecified	595.83	3626.28	8.55	0	4230.66

Highest and Lowest Impact Templates (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	284728139.55	0	0	0	0	47952641.75	-11249947.74	321430833.56
Car Park Ventilation	35588.41	88897.1	103033171.34	0	0	1920.53	-11718.6	103147858.77
Tunnel Fill Removal	19080487.24	0	0	0	0	0	0	19080487.24
Highway Lighting – Standard	411088.36	2552691.88	10616710.55	0	0	28107.21	-664572.94	12944025.05
Solar PV System - Grid connected	7780170.55	19869291.58	-69610719.22	-69610719.22	0	474533.55	-145429839.84	-256527282.61
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	284728139.55	0	0	0	0	47952641.75	-11249947.74	321430833.56
Car Park Ventilation	35588.41	88897.1	103033171.34	0	0	1920.53	-11718.6	103147858.77
Tunnel Fill Removal	19080487.24	0	0	0	0	0	0	19080487.24
Highway Lighting – Standard	411088.36	2552691.88	10616710.55	0	0	28107.21	-664572.94	12944025.05
Solar PV System - Grid connected	7780170.55	19869291.58	-69610719.22	-69610719.22	0	474533.55	-145429839.84	-256527282.61

6.14 Global Warming Potential Biogenic, GWP B (kg CO_2 eq)

Figure 33: Time series Global Warming Potential Biogenic, GWP B chart

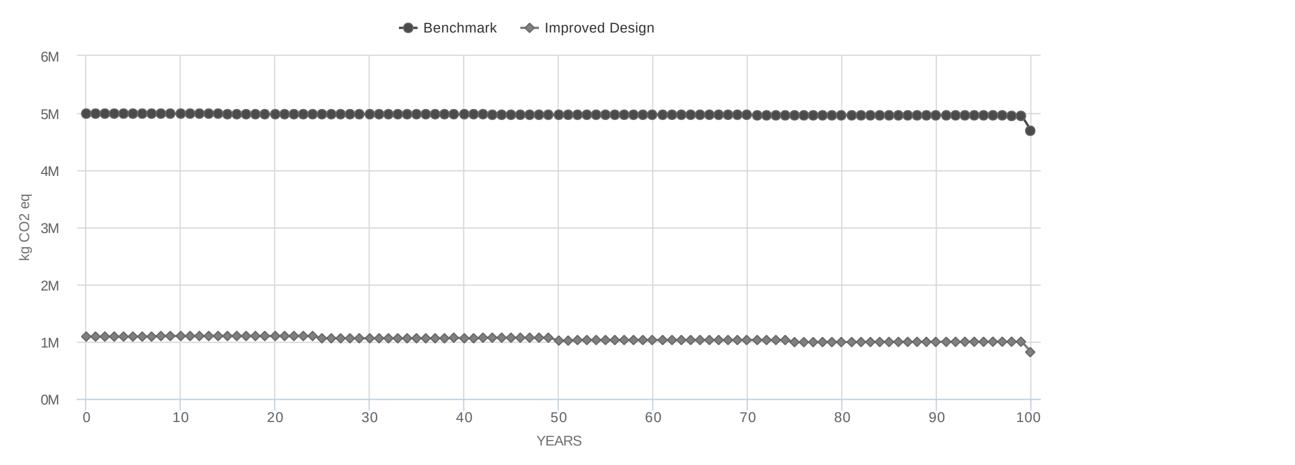
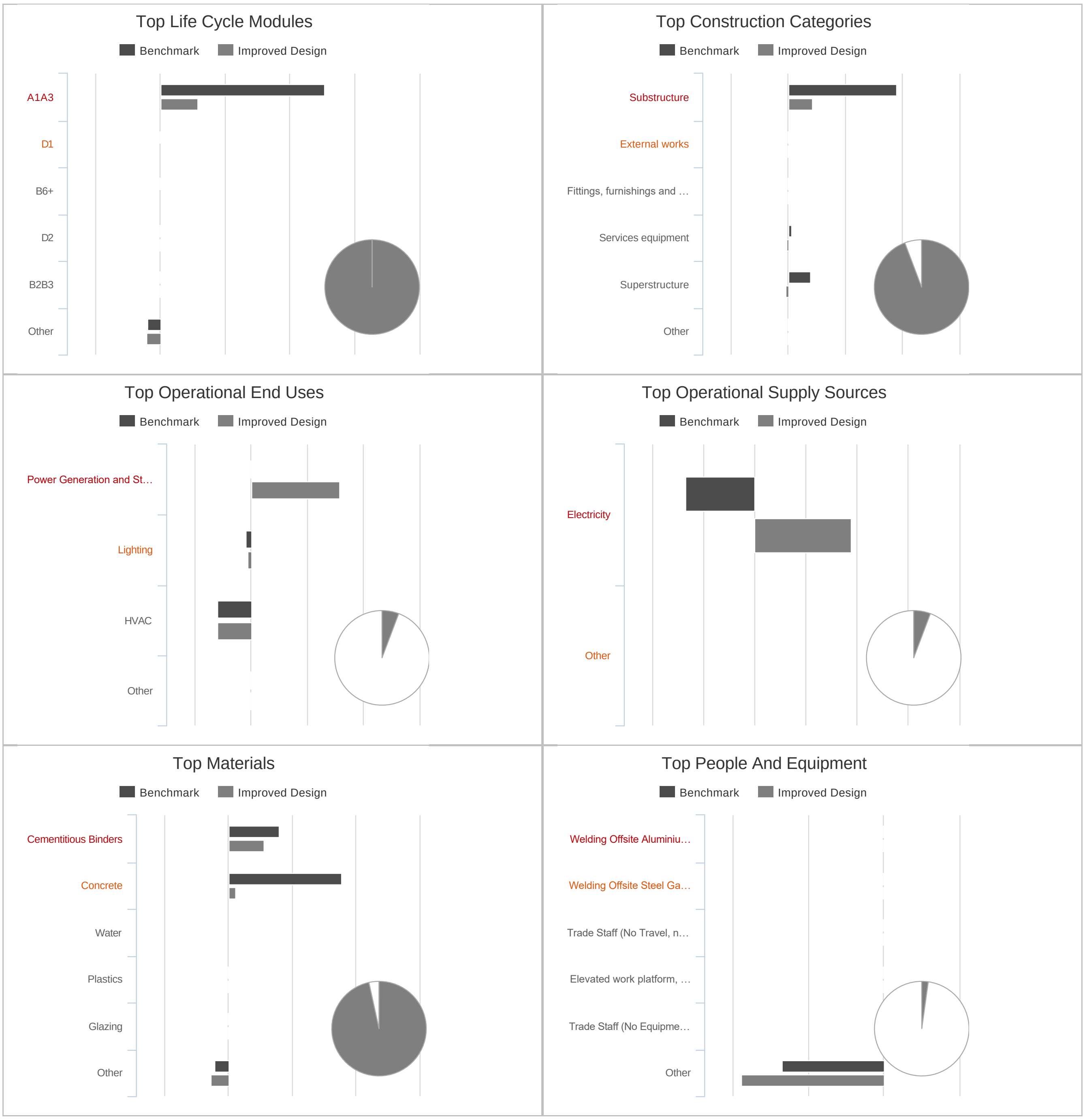


Figure 34: Top Five Global Warming Potential Biogenic, GWP B chart



Highest and Lowest Impact Materials (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Cementitious Binders | Portland Cement | Unspecified	1125911.61	0	-11417.34	0	1114494.28
Ferrous Metals | Steel | Accessories | Unspecified	134329.4	0	-117.78	385.54	134597.16
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	184399.55	0	-28254.36	-37762.86	118382.33
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	137556.66	0	-17378.55	-23208.6	96969.51
Water | Untreated | Unspecified	450.87	0	8908.09	0	9358.96
Concrete | Unreinforced | Portland Cement Blends | 20 MPa	957.47	0	-17.73	-25.94	913.81
Plastics | General | Unspecified	337.11	250.05	-2.38	0	584.77
Metals (Non-Ferous) | Copper Wire	35.45	0	-5.08	16.34	46.72
Glazing | Glass and Films | Flat Glass	2.23	15.08	-0.07	0	17.23
Metals (Non-Ferous) | Aluminium Sheet	-0.91	-7.07	-0.1	3.36	-4.73
Bottom 5 Impact Materials					
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	-1072.42	-9690.33	-4.29	0	-10767.03
Rubber | Synthetic	-28743.06	0	-76.47	0	-28819.52
Bulk Aggregates Sands and Soils | Sand | Unspecified	-7543.89	0	-48797.2	0	-56341.09
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	-9637.37	-97868.44	-7387.3	-32917.13	-147810.23
Ferrous Metals | Steel | Reinforcement bar | Unspecified	-421417.18	0	-8947.13	-3194.14	-433558.45

Highest and Lowest Impact Templates (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	1121513.21	0	0	0	0	-106105.84	-63564.25	951843.12
Highway Lighting – Standard	660.7	-2413.29	-3028.26	0	0	-38.95	539.52	-4280.28
Tunnel Fill Removal	-15658.98	0	0	0	0	0	0	-15658.98
Car Park Ventilation	0.57	99.45	-29388.66	0	0	-2.95	12.93	-29278.65
Solar PV System - Grid connected	-14263.42	-111459.04	19855.41	19855.41	0	-7417.02	9048.84	-84379.82
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	1121513.21	0	0	0	0	-106105.84	-63564.25	951843.12
Highway Lighting – Standard	660.7	-2413.29	-3028.26	0	0	-38.95	539.52	-4280.28
Tunnel Fill Removal	-15658.98	0	0	0	0	0	0	-15658.98
Car Park Ventilation	0.57	99.45	-29388.66	0	0	-2.95	12.93	-29278.65
Solar PV System - Grid connected	-14263.42	-111459.04	19855.41	19855.41	0	-7417.02	9048.84	-84379.82

6.15 Global Warming Potential LULUC, GWP L (kg CO_2 eq)

Figure 35: Time series Global Warming Potential LULUC, GWP L chart

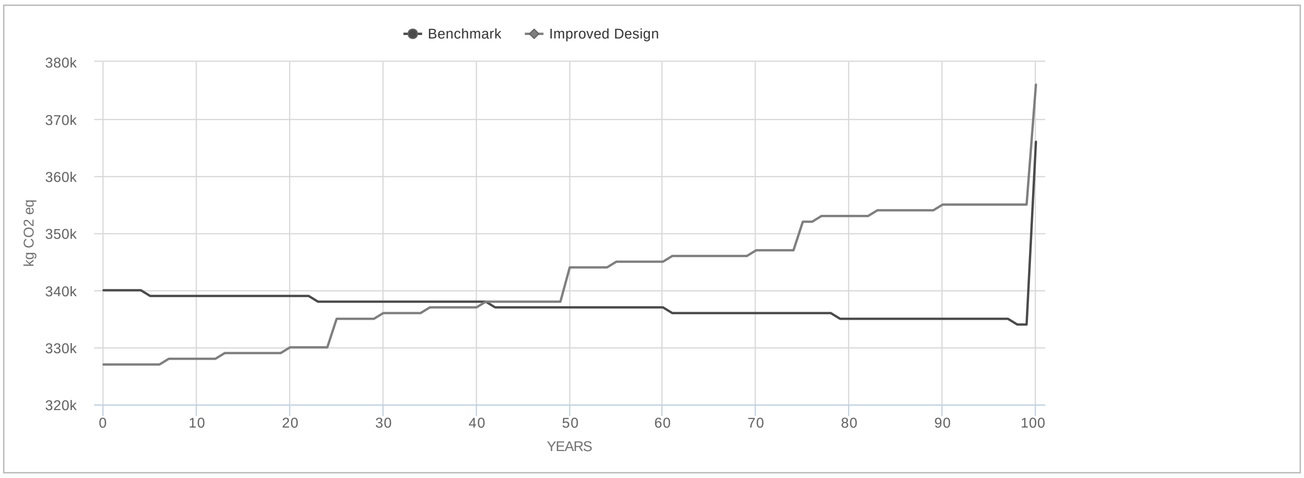
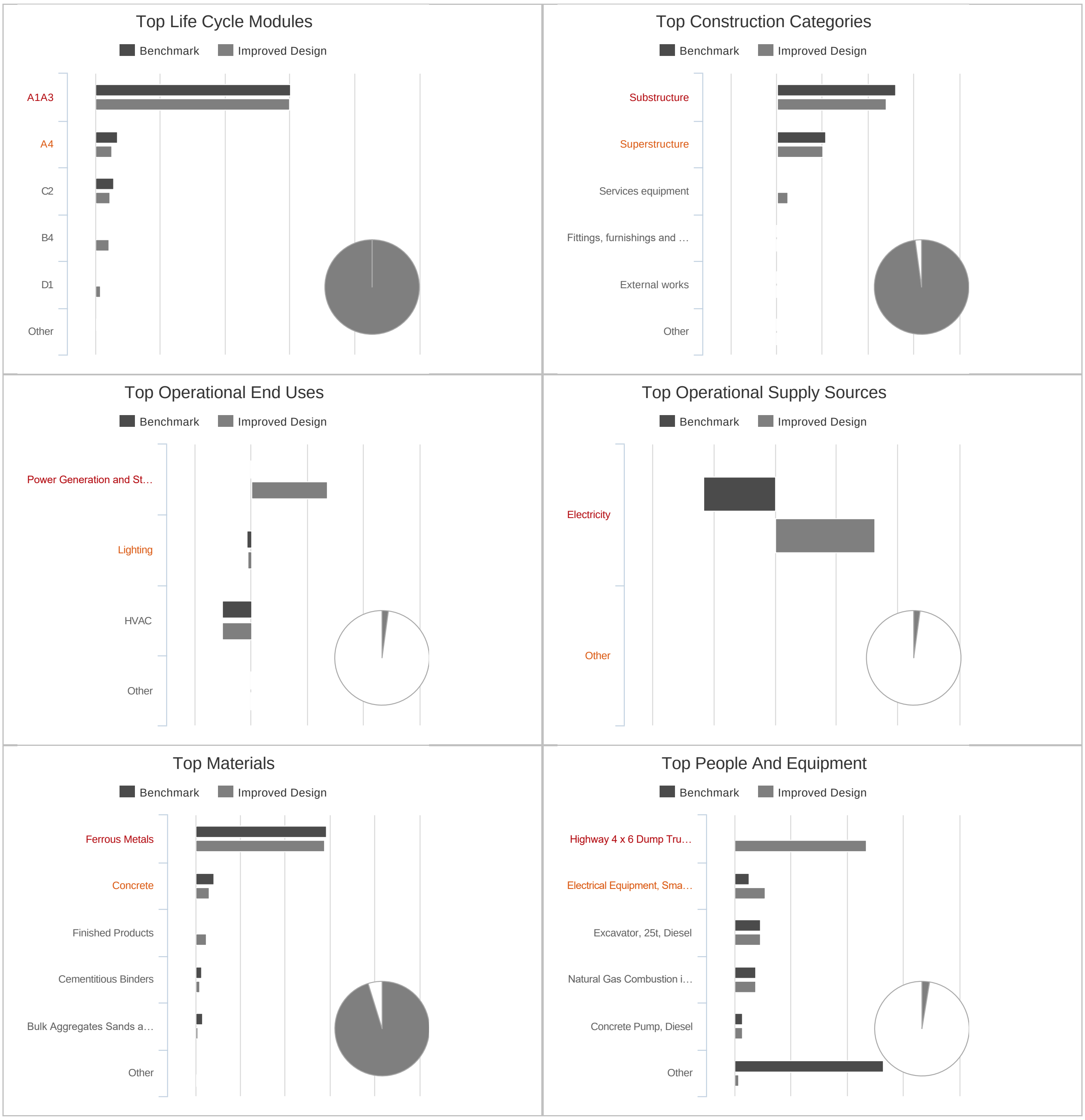


Figure 36: Top Five Global Warming Potential LULUC, GWP L chart



Highest and Lowest Impact Materials (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 10 Impact Materials					
Ferrous Metals | Steel | Reinforcement bar | Unspecified	284340.86	0	3361.53	288.71	287991.1
Finished Products | Electrical Goods | Solar PV Panels | Monocystalline	2834.89	15416.86	1192.86	-295.14	19149.47
Concrete | Unreinforced | Fly Ash Blends | 50 MPa | 90% FA	11275.18	0	10406.29	-2691.84	18989.63
Concrete | Unreinforced | Fly Ash Blends | 40 MPa | 90% FA	6438.41	0	6400.65	-1654.37	11184.68
Cementitious Binders | Portland Cement | Unspecified	8157.09	0	1169.15	0	9326.24
Bulk Aggregates Sands and Soils | Sand | Unspecified	2878.21	0	1707.13	0	4585.33
Finished Products | Electrical Goods | Solar Inverters | Solar Inverter Generic	446.68	4024.25	0.46	0	4471.39
Rubber | Synthetic	785.87	0	7.99	0	793.86
Metals (Non-Ferous) | Aluminium Unspecified	250.65	274.72	19.69	-128.78	416.29
Ferrous Metals | Steel | Galvanised Structural | Unspecified	27.74	240.87	6.67	-42.23	233.05
Bottom 5 Impact Materials					
Ferrous Metals | Steel | General | Unspecified	1.27	5.01	0.4	-0.72	5.96
Plastics | General | Unspecified	2.22	1.84	0.25	0	4.3
Finished Products | Electrical Goods | Electric Motors | Unspecified	0.59	3.58	0	0	4.17
Metals (Non-Ferous) | Aluminium Sheet	0.15	1.34	0.04	-0.19	1.33
Glazing | Glass and Films | Flat Glass	0.08	0.6	0.01	0	0.69

Highest and Lowest Impact Templates (kg CO_2 eq)

	Initial Materials & Construction (A1-A5)	Use Stage Materials & Construction (B1-B5)	Integrated Energy Use (B6)	Plug Load Energy Use (B6+)	Water Supply & Treatment (B7)	End of Life (C1-C4)	Recycling & Energy Export (D)	Total
Top 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	315882.97	0	0	0	0	23116.25	-4108.45	334890.77
Solar PV System - Grid connected	3585.85	20347.75	3430.13	3430.13	0	1210.68	6440.33	38444.88
Tunnel Fill Removal	7420.28	0	0	0	0	0	0	7420.28
Highway Lighting – Standard	57.43	440.5	-523.15	0	0	14.52	-53	-63.71
Car Park Ventilation	13.24	20.33	-5077.05	0	0	1.02	-2.18	-5044.63
Bottom 5 Impact Templates								
(TS) - Roadway - Complete Bored 4 Lane Highway Tunnel	315882.97	0	0	0	0	23116.25	-4108.45	334890.77
Solar PV System - Grid connected	3585.85	20347.75	3430.13	3430.13	0	1210.68	6440.33	38444.88
Tunnel Fill Removal	7420.28	0	0	0	0	0	0	7420.28
Highway Lighting – Standard	57.43	440.5	-523.15	0	0	14.52	-53	-63.71
Car Park Ventilation	13.24	20.33	-5077.05	0	0	1.02	-2.18	-5044.63

7 Scenarios Summary Tables

7.1 Improved Design Scenarios Summary

Table 14: While modelling the Improved Design the following scenarios were modelled.

				Scenario	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
●				<Business as Usual>															
			●	Concrete Replacement 30% fly-ash blend substructure	9.21%	-0.94%	0.09%	3.97%	3.73%	2.66%	1.40%	-45.72%	1.26%	-0.94%	0.03%	0.04%	7.94%	23.91%	1.00%
		●		50% BFS in concrete	9.77%	-2.86%	-0.19%	3.51%	1.76%	-0.79%	0.88%	171.04%	0.95%	-2.87%	0.00%	0.00%	8.40%	28.65%	-3.94%
	●			Concrete Replacement: 50% fly-ash blend	15.26%	-1.66%	0.05%	6.48%	5.94%	4.21%	2.25%	-74.93%	2.00%	-1.67%	0.03%	0.04%	13.15%	39.95%	0.83%
●				Geopolymer Concrete (90% Flyash)	27.35%	-3.11%	-0.02%	11.50%	10.36%	7.29%	3.96%	-133.36%	3.47%	-3.12%	0.03%	0.04%	23.57%	72.03%	0.48%
●				Optimising grout design and application	5.60%	2.36%	3.03%	3.80%	3.30%	3.02%	1.06%	25.63%	2.80%	2.37%	1.70%	1.68%	4.85%	10.19%	1.09%
●				Reduce long-duration idling for trucks	0.74%	0.18%	1.67%	0.71%	0.50%	0.79%	0.03%	-0.06%	0.96%	0.18%	0.00%	0.00%	0.65%	0.02%	0.02%
●				Electric dump truck	4.20%	1.00%	9.46%	4.04%	2.85%	4.45%	0.17%	-0.36%	5.44%	1.00%	0.00%	0.00%	3.69%	0.09%	0.14%
●				Tunnel structure and lining design optimisation	1.55%	2.61%	2.78%	2.06%	1.65%	1.88%	0.45%	17.32%	2.04%	2.62%	4.27%	4.22%	1.36%	0.18%	0.73%
	●			EPD - Steel Reinforcement Bar	3.04%	9.26%	8.89%	12.30%	25.79%	21.66%	7.47%	-118.09%	9.91%	9.27%	-0.50%	0.09%	8.01%	-9.25%	78.78%
●				Local sourcing of Sand to reduce transport	2.69%	1.09%	3.93%	3.57%	3.35%	3.94%	1.16%	73.71%	3.72%	1.09%	0.00%	0.00%	2.37%	-0.50%	2.72%
●				Waste management	2.01%	3.39%	3.56%	2.66%	2.13%	2.44%	0.59%	21.62%	2.62%	3.40%	5.58%	5.52%	1.76%	0.29%	0.94%
●				Concrete waste diverted from landfill - End of Life Scenario	3.09%	0.00%	8.40%	6.51%	5.17%	5.74%	2.51%	13.07%	5.67%	0.00%	0.00%	0.00%	2.72%	-1.54%	1.69%
●				Lighting: Light distribution efficiency and controls	0.10%	0.42%	0.36%	0.32%	0.36%	0.28%	2.83%	-3.11%	0.81%	0.42%	0.00%	0.00%	0.58%	-0.03%	-0.06%
●				Solar PV (10 MW UK Grid Connected)	2.87%	14.59%	8.38%	13.23%	10.01%	10.28%	166.68%	768.07%	45.42%	14.68%	-0.16%	-0.16%	32.83%	1.80%	-10.52%
●				<Improved Design>															

● Strategies included in Improved Design ● Strategies not included in Improved Design

8 Low Impact Strategies

The following low impact design strategies were modelled in the LCA study to determine the relative benefits and aid the design decision making process.

The relative saving of each progressed recommendation against the Benchmark is provided in the following tables for each strategy. Further information regarding each strategy is also provided regarding motivation and logistical constraints.

8.1 Improved Design Strategies

The following low impact strategies are included in the Improved Design.

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
<Business as Usual>															
Geopolymer Concrete (90% Flyash)	27.35 %	-3.11 %	-0.02 %	11.50 %	10.36 %	7.29 %	3.96 %	-133.36 %	3.47 %	-3.12 %	0.03 %	0.04 %	23.57 %	72.03 %	0.48 %
Optimising grout design and application	5.60 %	2.36 %	3.03 %	3.80 %	3.30 %	3.02 %	1.06 %	25.63 %	2.80 %	2.37 %	1.70 %	1.68 %	4.85 %	10.19 %	1.09 %
Reduce long-duration idling for trucks	0.74 %	0.18 %	1.67 %	0.71 %	0.50 %	0.79 %	0.03 %	-0.06 %	0.96 %	0.18 %	0.00 %	0.00 %	0.65 %	0.02 %	0.02 %
Electric dump truck	4.20 %	1.00 %	9.46 %	4.04 %	2.85 %	4.45 %	0.17 %	-0.36 %	5.44 %	1.00 %	0.00 %	0.00 %	3.69 %	0.09 %	0.14 %
Tunnel structure and lining design optimisation	1.55 %	2.61 %	2.78 %	2.06 %	1.65 %	1.88 %	0.45 %	17.32 %	2.04 %	2.62 %	4.27 %	4.22 %	1.36 %	0.18 %	0.73 %
Local sourcing of Sand to reduce transport	2.69 %	1.09 %	3.93 %	3.57 %	3.35 %	3.94 %	1.16 %	73.71 %	3.72 %	1.09 %	0.00 %	0.00 %	2.37 %	-0.50 %	2.72 %
Waste management	2.01 %	3.39 %	3.56 %	2.66 %	2.13 %	2.44 %	0.59 %	21.62 %	2.62 %	3.40 %	5.58 %	5.52 %	1.76 %	0.29 %	0.94 %
Concrete waste diverted from landfill - End of Life Scenario	3.09 %	0.00 %	8.40 %	6.51 %	5.17 %	5.74 %	2.51 %	13.07 %	5.67 %	0.00 %	0.00 %	0.00 %	2.72 %	-1.54 %	1.69 %
Lighting: Light distribution efficiency and controls	0.10 %	0.42 %	0.36 %	0.32 %	0.36 %	0.28 %	2.83 %	-3.11 %	0.81 %	0.42 %	0.00 %	0.00 %	0.58 %	-0.03 %	-0.06 %
Solar PV (10 MW UK Grid Connected)	2.87 %	14.59 %	8.38 %	13.23 %	10.01 %	10.28 %	166.68 %	768.07 %	45.42 %	14.68 %	-0.16 %	-0.16 %	32.83 %	1.80 %	-10.52 %
<Improved Design>															

Table 15: Design Strategies in Improved Design

8.1.1 Geopolymer Concrete (90% Flyash)

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Geopolymer Concrete (90% Flyash)	27.35 %	-3.11 %	-0.02 %	11.50 %	10.36 %	7.29 %	3.96 %	-133.36 %	3.47 %	-3.12 %	0.03 %	0.04 %	23.57 %	72.03 %	0.48 %

Table 16: Impact savings (or increases) associated with the Geopolymer Concrete (90% Flyash) as a percentage of the Improved Design.

Geopolymer Concrete (90% Flyash)

8.1.2 Optimising grout design and application

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Optimising grout design and application	5.60 %	2.36 %	3.03 %	3.80 %	3.30 %	3.02 %	1.06 %	25.63 %	2.80 %	2.37 %	1.70 %	1.68 %	4.85 %	10.19 %	1.09 %

Table 17: Impact savings (or increases) associated with the Optimising grout design and application as a percentage of the Improved Design.

Optimising grout design and application to achieve a 30% reduction in cement use.

8.1.3 Reduce long-duration idling for trucks

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Reduce long-duration idling for trucks	0.74 %	0.18 %	1.67 %	0.71 %	0.50 %	0.79 %	0.03 %	-0.06 %	0.96 %	0.18 %	0.00 %	0.00 %	0.65 %	0.02 %	0.02 %

Table 18: Impact savings (or increases) associated with the Reduce long-duration idling for trucks as a percentage of the Improved Design.

Reduce long-duration idling for trucks utilising auxiliary power units or battery operated system.

8.1.4 Electric dump truck

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Electric dump truck	4.20 %	1.00 %	9.46 %	4.04 %	2.85 %	4.45 %	0.17 %	-0.36 %	5.44 %	1.00 %	0.00 %	0.00 %	3.69 %	0.09 %	0.14 %

Table 19: Impact savings (or increases) associated with the Electric dump truck as a percentage of the Improved Design.

Reduce diesel consumption by adopting electric powered dump trucks.

8.1.5 Tunnel structure and lining design optimisation

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Tunnel structure and lining design optimisation	1.55 %	2.61 %	2.78 %	2.06 %	1.65 %	1.88 %	0.45 %	17.32 %	2.04 %	2.62 %	4.27 %	4.22 %	1.36 %	0.18 %	0.73 %

Table 20: Impact savings (or increases) associated with the Tunnel structure and lining design optimisation as a percentage of the Improved Design.

Tunnel structure and lining design optimisation assuming a 10% reduction in concrete use.

8.1.6 Local sourcing of Sand to reduce transport

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Local sourcing of Sand to reduce transport	2.69 %	1.09 %	3.93 %	3.57 %	3.35 %	3.94 %	1.16 %	73.71 %	3.72 %	1.09 %	0.00 %	0.00 %	2.37 %	-0.50 %	2.72 %

Table 21: Impact savings (or increases) associated with the Local sourcing of Sand to reduce transport as a percentage of the Improved Design.

The transport of sand is the biggest impact associated with the product life cycle impacts. Reducing the transport distance by sourcing the sand locally will help reduce the impacts of the Injected Grout Mortar.

The modelling assumes products will be sourced from within 10km as opposed to 50km assumed under BAU.

8.1.7 Waste management

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Waste management	2.01 %	3.39 %	3.56 %	2.66 %	2.13 %	2.44 %	0.59 %	21.62 %	2.62 %	3.40 %	5.58 %	5.52 %	1.76 %	0.29 %	0.94 %

Table 22: Impact savings (or increases) associated with the Waste management as a percentage of the Improved Design.

Concrete waste reduction, assuming a 50% reduction following a waste managament plan.

8.1.8 Concrete waste diverted from landfill - End of Life Scenario

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Concrete waste diverted from landfill - End of Life Scenario	3.09 %	0.00 %	8.40 %	6.51 %	5.17 %	5.74 %	2.51 %	13.07 %	5.67 %	0.00 %	0.00 %	0.00 %	2.72 %	-1.54 %	1.69 %

Table 23: Impact savings (or increases) associated with the Concrete waste diverted from landfill - End of Life Scenario as a percentage of the Improved Design.

Concrete waste diverted from landfill and sent to concrete recycling plant to be processed and reused.

8.1.9 Lighting: Light distribution efficiency and controls

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Lighting: Light distribution efficiency and controls	0.10 %	0.42 %	0.36 %	0.32 %	0.36 %	0.28 %	2.83 %	-3.11 %	0.81 %	0.42 %	0.00 %	0.00 %	0.58 %	-0.03 %	-0.06 %

Table 24: Impact savings (or increases) associated with the Lighting: Light distribution efficiency and controls as a percentage of the Improved Design.

Selection of the most efficient light distribution and controls to allow for dimming schedules, fault detection or remote control. Design improvement is expected to generate a 30% savings in electricity consumption.

In order to meet the performance modelled in the LCA for this strategy the lighting solutions must utilise fittings with a system luminous efficacy of 100lm/watt.

LED lighting is a highly energy efficient option, that will assist in meeting NCC lighting requirements, Subclause J6.2 (b) - lighting for commercial buildings.

Contractors must be registered and comply with all Australian regulations and standards, including Electrical Safety Regulations (AS/NZS 61347.2.11), Electro-magnetic compatibility regulations (AS/NZS CISPR15) and energy efficient regulations. Electrical contractors are responsible for installation safety and must refuse to install non-compliant products.

Australian lighting regulations (AS1680) and NCC Section J6 refers to interior lighting energy efficiency, lux levels, and maximum illumination power density per sqm2 but not specifically LED lighting.

Equipment must be registered on the Australian Government National Equipment Registration System and contain the Regulatory Compliance Mark (RCM).

Vendor must specify:

- Fitting type, size, beam angle and dimming compatibility of LEDs. Dimming and motion sensor functions can be included with a fixture, or LED compatibility will need to be ensured, as not all LED's are compatible.
- Colour rendering needs to match building function, a cool white light, 4000K is the standard for offices. AS1680 recommends minimum light levels for different spaces and uses.

Ensure that the lumens per watt of LED lights are sufficient to meet the required illumination to avoid occupants replacing under-lit areas with less efficient lighting. We have assumed average of 100 lumens per watt for LED lights.

8.1.10 Solar PV (10 MW UK Grid Connected)

% Changes Against the Benchmark

Design Strategy Performance	GWP	AUD	ODP	AP	EP	POCP	FW	ADPE	ADPF	GBP	ME	Mtot	GWP F	GWP B	GWP L
Solar PV (10 MW UK Grid Connected)	2.87 %	14.59 %	8.38 %	13.23 %	10.01 %	10.28 %	166.68 %	768.07 %	45.42 %	14.68 %	-0.16 %	-0.16 %	32.83 %	1.80 %	-10.52 %

Table 25: Impact savings (or increases) associated with the Solar PV (10 MW UK Grid Connected) as a percentage of the Improved Design.

With the rising price of electricity, the economics of solar are very favourable in life cycle terms

Using solar-generated power on-site results in much lower emissions associated with the project compared to using the fossil fuel powered grid. Feeding out to the grid assumes a net environmental credit as the electricity will be consumed by a neighbouring consumer therefore reducing the demand on the grid.

The embodied impacts of the solar PV system have been included in the calculations.

(Image source: www.forceofthesun.com)

9 Conclusion

The report shows that the Improved Design has lower Global Warming Potential Total, GWP impact than the Benchmark Design. The **Product Stage (A1A3)** GWP Impacts are the most dominant life cycle module in the Improved Design Design followed by the **Transport of Equipment and Materials (A4)** and then **Transport of Waste Offsite (C2)**.

Further analysis reveals:

- The **Substructure** is the highest impact construction category,
- **HVAC** is the highest operational impact by demand category,
- The **Electricity** is this highest impact operational impact by supply source,
- **Cementitious Binders | Portland Cement | Unspecified** is the highest impact material category,
- **Natural Gas Combustion in Construction Equipment (no transport)** is the highest people and equipment impact

14 strategies were modelled in the Improved Design, the **Geopolymer Concrete (90% Flyash)** strategy had the highest saving followed by **Concrete Replacement: 50% fly-ash blend** . See full LCA report for details of other environmental strategies.

In addition to GWP, other indicators were included in the study, the results of which are summerised below.

The Improved Design shows an expected performance improvement against the Benchmark Design for 13 indicators:

- 50.21% **saving** in GWP impacts
- 22.54% **saving** in AUD impacts
- 41.55% **saving** in ODP impacts
- 48.4% **saving** in AP impacts
- 39.67% **saving** in EP impacts
- 40.11% **saving** in POCP impacts
- 179.44% **saving** in FW impacts
- 782.51% **increase** in ADPE impacts
- 72.95% **saving** in ADPF impacts
- 22.64% **saving** in GBP impacts
- 11.41% **saving** in ME impacts
- 11.3% **saving** in Mtot impacts
- 74.39% **saving** in GWP F impacts
- 82.54% **saving** in GWP B impacts
- 2.76% **increase** in GWP L impacts

Appendix A: Environmental Indicators Description

Global Warming Potential Total, GWP

Anthropogenic global warming is caused by an increase of greenhouse gasses (GHG) in the earth's atmosphere. These gasses reflect some of the heat radiated from the earth's surface that would normally escape into space back to the surface of the earth. Overtime this warms the earth. Common GHGs include CO2, N2O, CH4 and volatile organic compounds (VOCs). Global Warming Potential Total (GWP) is expressed in equivalent GHGs released, usually in kgCO2e.
Global Warming Potential Total (GWP) = GWP Fossil + GWP Biogenic + GWP LULUC.

Australian Dollars

Expressed in Australian Dollars, the cost to procure goods, services, energy, water and other inputs to the asset over it's life time, in addition to the net cost of services required to decommission the asset at the end of its useful life.

Ozone Depletion Potential, ODP

Ozone is formed and depleted naturally in the earth's stratosphere (between 15-40 km above the earth's surface). Halocarbon compounds are persistent synthetic halogen containing organic molecules that can reach the stratosphere leading to more rapid depletion of the ozone. As the ozone in the stratosphere is reduced more of the ultraviolet rays in sunlight can reach the earth's surface where they can cause skin cancer and reduced crop yields. Ozone Depletion Potential (ODP) is expressed in equivalent ozone depleting gasses (normally kgCFC11e).

Acidification Potential for Soil and Water, AP

Acidification is a consequence of acids (and other compounds which can be transformed into acids) being emitted to the atmosphere and subsequently deposited in surface soils and water. Increased acidity can result in negative consequences for flora and fauna in addition to increased corrosion of manmade structures (buildings vehicles etc.). Acidification Potential (AP) is an indicator of such damage and is usually measured in kgSO₂e

Eutrophication potential, EP

Over enrichment of aquatic ecosystems with nutrients leading to increased production of plankton, algae and higher aquatic plants leading to a deterioration of the water quality and a reduction in the value and/or the utilisation of the aquatic ecosystem. Eutrophication is primarily caused by surplus nitrogen and phosphorus. Sources of nutrients include agriculture (fertilisers and manure), aquaculture, municipal wastewater, and nitrogen oxide emissions from fossil fuel combustion.

Photochemical Ozone Creation Potential, POCP

Photochemical Ozone Creation Potential (POCP), commonly known as smog, is toxic to humans in high concentration. Although ozone is protective in the stratosphere at low levels it is problematic from both a health and nuisance perspective. Plant growth is also effected through damaged leaf surfaces and reduced photosynthesis. POCP is formed when sunlight and heat react with Volatile Organic Compounds (VOCs).

Net use of fresh water, FW

The pressure on global freshwater resources arises from the demand for everyday goods and services which use water in their production. The interconnected nature of global economic systems means that water abstraction can occur far from where final consumption occurs. Globally, water use has been increasing at more than twice the rate of population growth, and most withdrawals are in watersheds already experiencing water stress. Managing water resources is extremely important for the health of the environment and our current and future agricultural, industrial and personal water requirements. Fresh water can be derived from renewable sources (rain water) and somewhat non-renewable resources (aquifers). Consumptive water (H2O C) use is abstracted water that is no longer available for other uses because it has evaporated, transpired, been incorporated into products and crops, or consumed by man or livestock.

Abiotic Depletion Potential - Elements, ADPE

Abiotic Resource Depletion of energy (ADPM) is a measure of the extraction and consumption of primary resources from the earth. Such exploitation reduces resources available to future generations and as such must be managed.

Abiotic Depletion Potential - Fossil Fuels, ADPF

Abiotic Resource Depletion of energy (ARDE) is a measure of the extraction and consumption of non-renewable energy sources (primarily fossil fuels, but also inclusive of other energy sources such as uranium). Primary energy content of non-renewable energy sources including the embodied energy to extract, process and deliver the non renewable fuels, or manufacture, transport and install the renewable generator. Hence there is usually and non-renewable energy content associated with renewable fuels also.

British Pounds Sterling

British Pounds Stirling

Materials Efficiency Metric

Materials Efficiency Metric

Mass of materials, total

Mass of materials total

Global Warming Potential Fossil, GWP F

This indicator accounts for GWP from greenhouse gas emissions and removals to any media originating from the oxidation or reduction of fossil fuels or materials containing fossil carbon by means of their transformation or degradation (e.g. combustion, incineration, landfilling, etc). This indicator also accounts for GWP from GHG emissions, e.g. From peat and calcination as well as GHG removals, from carbonation of cement-based 123 and lime, etc.

Global Warming Potential Biogenic, GWP B

This indicator accounts for GWP from removals of CO2 into biomass from all sources except native forests, as transfer of carbon, sequestered by living biomass, from nature into the product system declared as GWP-biogenic. This indicator also accounts for GWP from transfer of any biogenic carbon from previous product systems into the product system under study. This indicator also covers biogenic emissions to air from biomass from all sources except native forests due to oxidation or degradation (e.g. combustion, solid waste disposal) as well as all transfer of biogenic carbon from biomass from all sources except native forests into subsequent product systems in the form of biogenic CO2.

Global Warming Potential LULUC, GWP L

This indicator accounts for GHG emissions and removals (CO2, CO and CH4) originating from changes in the defined carbon stocks caused by land use and land use changes associated with the declared/functional unit. This indicator includes biogenic carbon exchanges resulting e.g. from deforestation or other soil activities (including soil carbon emissions). Calculation rules for GWP-luluc shall follow the latest available version of PEF Guidance document. For native forests, all related CO2 emissions are included and modelled under this sub-category (including connected soil emissions, products derived from native forest and residues). CO2 uptake related to the carbon content of biomass entering the product system from native forests is set to zero. Impacts are declared in the modules where they occur. Any biomass-based net increase in carbon stocks, including soil carbon uptake (accumulation), shall not be considered in GWP-lulac, and is set to zero. Soil carbon storage may be included as additional environmental information when proof is provided.