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Kaynemaile RE/8 Architectural Mesh Life Cycle Assessment

Background report

Created by thinkstep-anz on behalf of Kaynemaile

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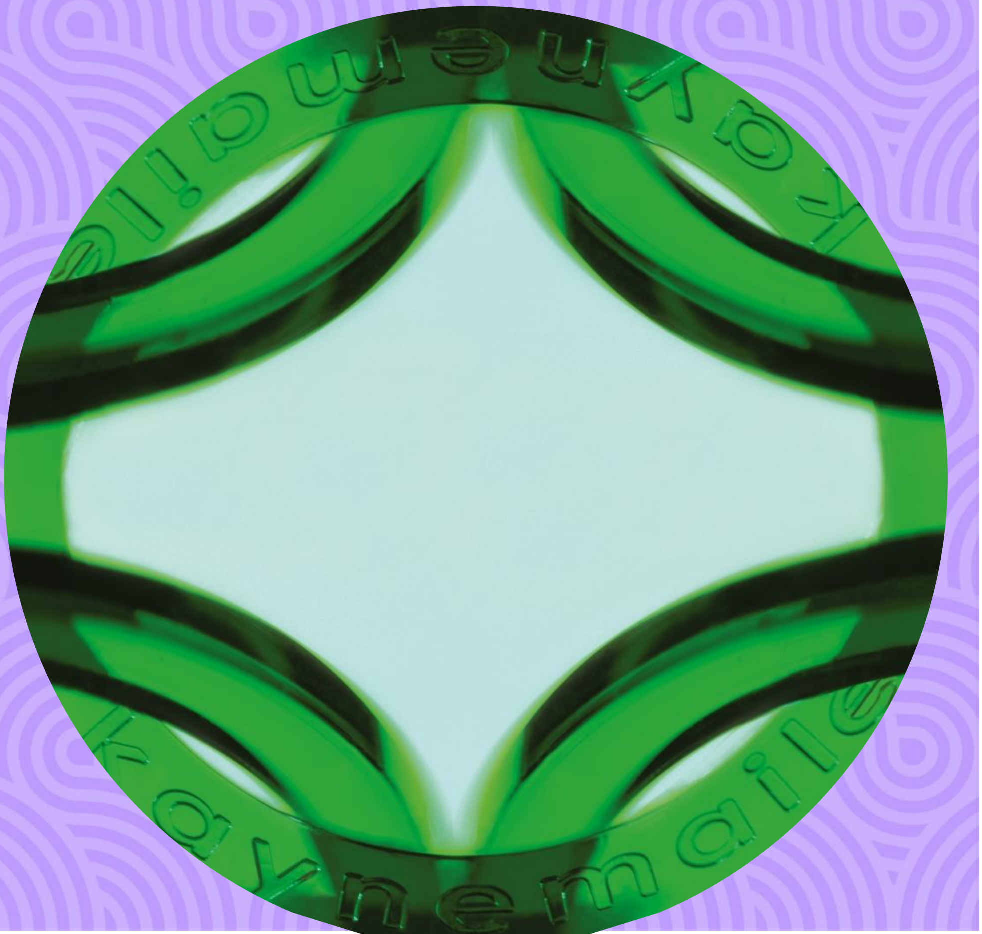

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Executive summary

Why Kaynemaile commissioned this report

You want to understand the environmental impacts of producing your architectural mesh (RE/8). You make this patented ‘chain-mail’-like product from engineering-grade polycarbonate. It is scratch-resistant, fire resistant and UV resistant. You are producing more product (particularly for the US). The main materials you are using (polycarbonate) have a low carbon footprint.

You commissioned thinkstep-anz to conduct a science-based Life Cycle Assessment (LCA) of your RE/8. This will help you promote the environmental credentials of your product, expand in green building markets and avoid ‘greenwashing’.

What we did

We carried out a Life Cycle Assessment on your RE/8. We assessed the environmental impacts of (as shown in the figure below):

- manufacturing the raw materials
- transporting the raw materials to your manufacturing facility
- manufacturing your product
- packaging the product to dispatch it to your customer
- deconstructing and removing the product after its useful life
- managing the product at its end-of-life (transporting, processing, and disposing or recycling). We assessed three end-of-life scenarios (recycling, landfill and landfill with biogenic release).

Executive Summary Figure 1 – GWP-t of RE/8 (Baseline Scenario)

Our LCA followed ISO standards ISO14040 and ISO14044 (ISO, 2006b; ISO, 2006a), and was independently reviewed.

The units we used

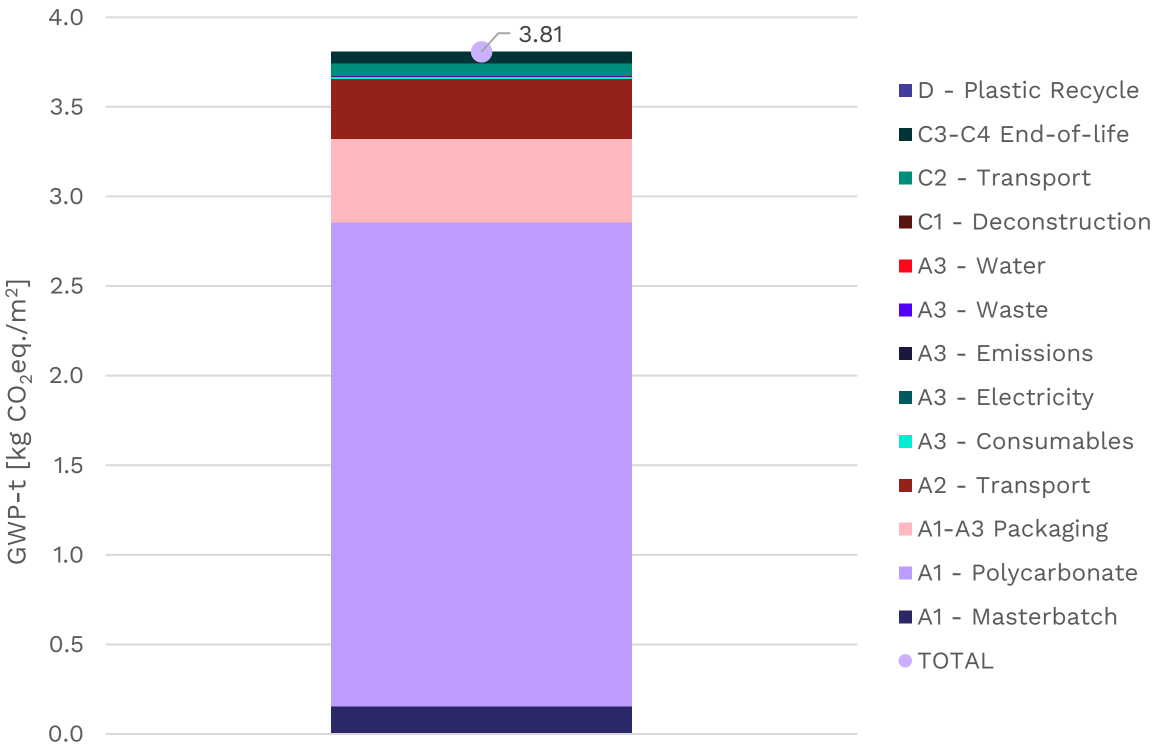
We measured the environmental impacts for one square meter of RE/8 (the ‘declared unit’).

The impacts we measured

Global Warming Potential (GWP) is the focus of this report. GWP measures how much heat greenhouse gases trap in the atmosphere relative to carbon dioxide (CO_2). We assessed other potential environmental impacts ('indicators') too, including water and land use, depleting the ozone layer and creating smog.

What we found

- Cradle to gate (A1-A3) GWP-total is 3.67 kg CO_2eq per square metre of RE/8. GWP-total for the baseline scenario (which assumes RE/8 is sent to landfill) is 3.81 kg of CO_2.eq per square metre of RE/8. GWP-total includes all categories of GWP emissions including biogenic, fossil, land use and land use change.
- Manufacturing the polycarbonate has the biggest influence for most indicators, including GWP. It is a 'hotspot' for all indicators. A hotspot is a process that significantly affects an indicator.
- Your use of waste bio-circular feedstock in the manufacturing of polycarbonate keeps the GWP-total result lower by 7 kg of CO_2.eq per square meter.
- The corrugated cardboard packaging is a hotspot for some indicators including GWP.
- Transport is a hotspot for GWP-total. It also adds pollutants to the sea (eutrophication-marine) and creates smog (photochemical ozone formation potential).



Executive Summary Figure 2 – GWP-t of RE/8 (Baseline Scenario)

Our recommendations

- Keep working with your supply chain to understand and support processes that lower the impacts of manufacturing polycarbonate.
- Assess the impacts of transporting your raw polycarbonate material to Wellington. GWP emissions from shipping are generally lower than from trucks. We recommend shipping polycarbonate material closer to the Kaynemaile manufacturing facility.
- Review the packaging of RE/8 and explore options to reduce the amount of packaging.
- Use detailed data from your polycarbonate supplier. Supplier-specific data is the highest quality. Our study relied on specific data for biogenic carbon footprint but averaged industry data from PlasticsEurope for all other impacts.
- Consider applying for a Leadership in Energy and Environmental Design (LEED) or developing Environmental Product Declaration (EPD).

Table of Contents

1. Goal of the Study

Kaynemaile is the exclusive producer of their signature Kaynemaile Architectural Mesh (RE/8). The company has recently increased production and adopted a low carbon footprint polycarbonate primary material. They commissioned this study to support the promotion of the environmental credentials of RE/8.

This study assesses the life cycle of the product and provides a detailed critically reviewed report that assesses its environmental impacts. The critical review statement can be found in Annex C.

This report is designed for public use, to assess the global warming potential of RE/8 and support Kaynemaile and its growing base of USA customers form the basis of produced Leadership in Energy and Environmental Design (LEED) application.

The study is conducted according to the requirements of ISO14040 and ISO14044 (ISO, 2006b; ISO, 2006a). The results of the report are not intended to support comparative assertions disclosed to the public (i.e., third party other than commissioner and practitioner).

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

Product Information

RE/8 is a patented ‘chain-mail’ like product made from engineering grade polycarbonate. Its interlocking polycarbonate chains are robust and scratch resistant. It has interior and exterior applications including building façade, screens, feature walls and interior ceiling or light design. RE/8 is manufactured in a variety of colours matched to the customer and the application.

The product is under tension vertically and are installed encircled by rigid frames (frame componentry not included in this study) or hung from fixing screws (not included in this study).

The product achieves Class A fire rate compliant with the 2015 Edition of the International Building Code (IBC) and NFPA5000, Building and Construction and Safety Code (2018 edition). In smoke reduction testing it is defined as Group 1s in the ISO 9705 room test with a SMOGRA of 0.5m2/s2. UL94 FR-V0 material at 3mm that is rated self-extinguishing.

More information on RE/8 performance can be found on the Kaynemaile website (Kaynemaile, 2023).

2.1. Product Function(s) and Declared Unit

RE/8’s function is to divide a space and provide aesthetically pleasing façade, visual privacy, passive solar screening, and or a decorative backdrop.

The declared unit of this study is one square meter of RE/8 ready for delivery to the customer with a density of 3 kg/m^2. Reference flows are the same as the declared unit.

The declared unit does not incorporate fixing screws or rigid frames. The quantity and type of these vary on a case-by-base basis depending on a customers chosen application and installation method.

Table 2-1: Industry Classification

Product	Classification	Code	Category
Product name/type	UN CPC Ver.2	36390	Other plates, sheets, film, foil and strip, of plastics
	ANZSIC 2006	1912	Rigid and Semi-Rigid Polymer Product Manufacturing

2.2. Software and Database

The LCA model was created using the Life Cycle for Experts (LCA FE) database (formerly known as (GaBi Software) system for life cycle engineering, developed by Sphera Solutions, Inc. The Managed LCA Content (MLC) database (Sphera, 2022) formerly known as GaBi LCI database) provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.3. System Boundary

The scope of this study is cradle-to-gate with the inclusion of the end-of-life phase, specifically:

- Manufacturing the raw materials
- Transporting the raw materials to the manufacturing facility
- Manufacturing the product
- Packaging the product ready for dispatching to the customer
- Deconstruction and removal of the product post its useful life.
- Managing the product at its end-of-life (transportation, processing, and disposal or recycling - including credit). Three different end-of-life scenarios are presented.

This study borrows from the Environmental Product Declaration (EPD) framework EN15804+A2 (CEN, 2019) to set out the unique stages of a product life cycle. This is carried through to the results section for easier reference and recognition of where the process lies within the product life cycle.

According to EN15804+A2 this study has a scope of ‘cradle-to-gate with modules C1-C4 and module D’, as shown in Table 2-2, Table 2-3, and Figure 2-1. The production stage (Modules A1-A3) includes all aspects from cradle to gate, utilising elementary and product flows.

Table 2-2: Modules of the production life cycle included in the LCA, based on EPD framework

	Product stage			**Construction process stage**		**Use stage**							**End-of-life stage**				**Recovery stage**
	Raw material supply	Transport	Manufacturing	Transport	Construction Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction /	Transport	Waste processing	Disposal	Future reuse, recycling or energy recovery potential
Module	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Included in study	X	X	X										X	X	X	X	X

Construction process and use stages have been excluded from the study: Transport to the construction site (A4), the construction process (A5), the use stage (B1-B7), as these life cycle stages vary by end use and are best considered at the building level.

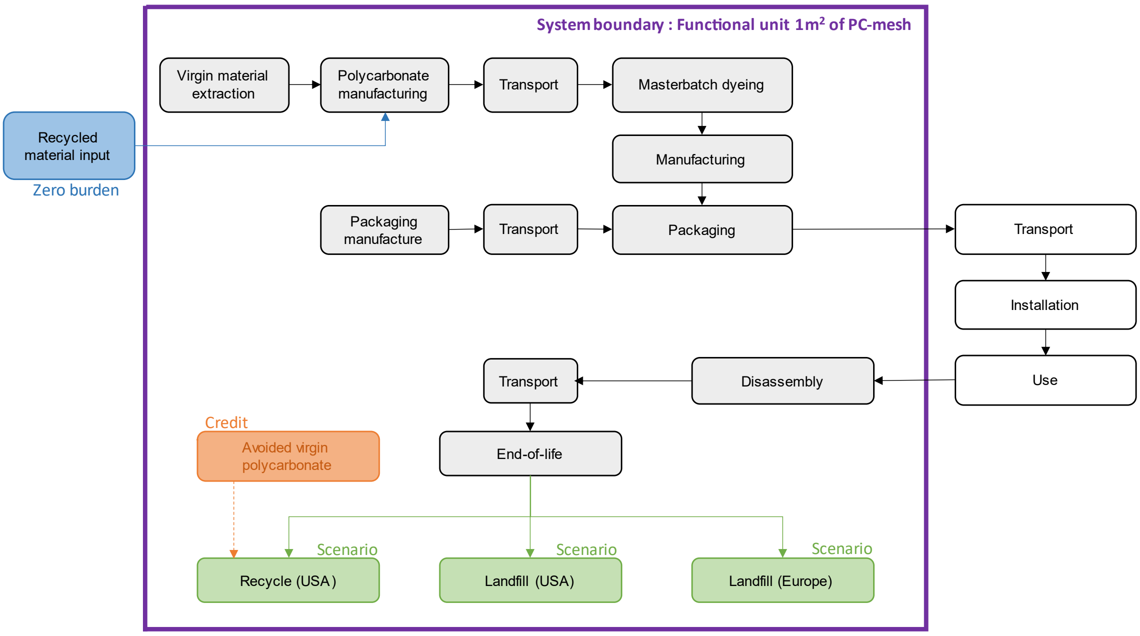


Figure 2-1 - High level system boundary

Table 2-3: Inclusions and exclusions in the System boundary

Included	**Excluded**
✓ Manufacturing of polycarbonate and additives ✓ Raw material transportation ✓ Manufacturing of chain (including energy and factory floor inputs) ✓ Manufacturing waste ✓ Packaging material ✓ Transportation of wastes ✓ End-of-life scenarios ✓ Landfilling of material at end-of-life	× Packaging of raw materials × Infrastructure, construction, production equipment and tools not consumed in the production process; × Impacts due to employees, e.g., employees commuting to and from work.

2.3.1. Time Coverage

All primary data represent an annual average from Kaynemaile 2022-04-1 to 2023-03-31.

Data for all energy inputs, transport processes, packaging and raw materials are from the MLC database (Sphera, 2022). The reference year for the data ranges from 2016-2020.

2.3.2. Technology Coverage

The collected data reflects the real technologies used to manufacture the RE/8 product. No proxies are used for any process in direct control of Kaynemaile.

2.3.3. Geographical Coverage

The manufacturing plant is located in Wellington, New Zealand. The primary data was collected for this site.

For background data, New Zealand-specific data was used wherever possible. When the use of proxy data was necessary, data from Australia, European Union and Germany were used. The use of background data is specified further in in section 3.3.

2.3.4. Boundaries to nature

System boundaries to and from nature are jointly described by so-called elementary flows. The inclusion of resource flows from nature to the technosphere corresponds to resource use and explorative impact, and on the output side emissions and resource consumption. In an ideal LCA, all flows studied shall be traceable to a natural source or recipient. As such, processes such as mineral extraction and waste production have been modelled to elementary flow level.

For example, datasets for raw materials such as metal coating materials include mineral extraction from the ground; wastes such as emissions from ovens are included as emission to air, outputs to water (from wastewater treatment) are modelled as emissions to water rather than an emission of untreated waste. Waste to landfill is modelled assuming a 100-year time horizon.

2.3.5. Boundaries to other product life cycles

Allocation of recycled material is reported in the LCI as an input or output flow when such materials leave or enter the specific product system. The boundary between the current and the next product system is defined by the willingness to pay for the recycled material. This implies that from the moment the user of a secondary material pays for the material, this (secondary) product system will also be responsible for its environmental burdens from that point onward. This is referred to as the Polluter Pays Principle within EN 15804.

For outflow of material to recycling (e.g., at end-of-life), both dismantling and transportation of the material to a sorting/recycling facility are included. The material intended for recycling is then an outflow from the product system.

Details on allocation are further described in Section 2.4.

2.3.6. Biogenic Carbon in Product and Packaging

Some of the products considered in this study and the distribution packaging contain biogenic carbon. Biogenic carbon is defined as carbon derived from materials of biological origin, excluding material embedded in geological formations (ISO, 2018). The biogenic content of these materials per declared unit (1 m^2) is shown in section 3.1.2.

This report assumes that the biogenic carbon sequestered in the bio-based materials (renewable raw materials of plant or animal origin such as wool, paper, and cardboard) is released as carbon dioxide to the atmosphere when those materials are recycled. In other words, the biogenic carbon leaves the system boundary being assessed and becomes part of another product's (or material’s) system boundary. This assumption is in line with ISO

14067:2018 and supported by non-packaging standards such as EN 16485:2014 and ISO 21930:2017.

When in landfill, the biogenic carbon sequestered in the bio-based materials may be partly emitted to air as carbon dioxide and methane and partly sequestered. The rates of these specifics emissions are determined by various factors including long-term stability and degradation factors. See more details in section 3.2.5.

2.4. Allocation

2.4.1. Multi-output allocation

Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2. When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Chapter 3. All data used in this study was supplied by Kaynemaile as per product bill of materials. Factory floor data (energy use, consumables) has been allocated according to mass of the product produced.

2.4.2. Allocation of background data

Allocation of background data (energy and materials) taken from the MLC databases is documented online at https://sphera.com/product-sustainability-gabi-data-search/.

2.4.3. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3.

Material recycling (avoided burden approach): Open scrap inputs from the production stage are subtracted from scrap to be recycled at end-of-life to give the net scrap output from the product life cycle. This remaining net scrap is sent to material recycling. The original burden of the primary material input is allocated between the current and subsequent life cycle using the mass of recovered secondary material to scale the substituted primary material, i.e., applying a credit for the substitution of primary material so as to distribute burdens appropriately among the different product life cycles. These subsequent process steps are modelled using industry average inventories.

Landfilling (avoided burden approach): In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilisation rates (flaring vs. power production). A credit is assigned for power output using the regional grid mix.

2.5. Cut-off Criteria

No cut-off criteria are defined for this study. As summarized in section 2.2, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analysed and is discussed in Chapter 4.4.

2.6. Selection of LCIA Methodology and Impact Categories

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are discussed in this section.

Whilst the LCA is not being conducted to produce a verified EPD (because the mass balance approach is not a recognised method by International EPD programme and its regional partners). It is aimed to support customers seeking to declare their environmental impacts in various programmes. EN 15804+A2 indicators and TRACI indicators are therefore included in this study.

EPD indicators are predominantly based on the CML impact assessment methodology framework (CML 2001 update April 2013). CML characterisation factors are applicable to the European context, are widely used and respected within the LCA community, and required for Environmental Product Declarations under EN15804.

2.6.1. EN15804+A2 – environmental indicators

EN15804+A2 require the Life Cycle Impact Assessment (LCIA) indicators shown in Table 2-4. The LCA FE EN15804+A2 characterisation factors from the April 2020 update are used. Long-term emissions (> 100 years) are not taken into consideration in the impact estimate.

Table 2-4: Core environmental impact indicators (based on EF 3.0)

Indicator	Description	Abbrev.	Unit	Reference
Climate change - total	A measure of greenhouse gas emissions, such as CO2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare	GWP-total	kg CO2-eq.	(IPCC, 2013)
Climate change - fossil		GWP-fossil	kg CO2-eq.	(IPCC, 2013)
Climate change - biogenic		GWP-biogenic	kg CO2-eq.	(IPCC, 2013)
Climate change - land use and land use change		GWP-luluc	kg CO_2-eq.	(IPCC, 2013)

Indicator	Description	Abbrev.	Unit	Reference
Ozone Depletion	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants	ODP	kg CFC11-eq.	(WMO, 2014)
Acidification	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	AP	Mole of H^+ eq.	(Seppälä, 2016; Posch, 2008)
Eutrophication aquatic freshwater	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	EP-fw	kg P eq.	(Struijs, 2009)
Eutrophication aquatic marine		EP-fm	kg N eq.	(Struijs, 2009)
Eutrophication terrestrial		EP-tr	Mole of N eq.	(Seppälä, 2016; Posch, 2008)

Indicator	Description	Abbrev.	Unit	Reference
Photochemical ozone formation	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	POCP	kg NMVOC eq.	(van Zelm, 2008)
Depletion of abiotic resources - minerals and metals*	The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources. Depletion of mineral resources is assessed based on ultimate reserves.	ADP-mm	kg Sb-eq.	(van Oers, de Koning, Guinée, & Huppes, 2002; Guinée, et al., 2002)
Depletion of abiotic resources - fossil fuels*	The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources.	ADP-fossil	MJ	(van Oers, de Koning, Guinée, & Huppes, 2002)
Water use*	A measure of the net intake and release of fresh water across the life of the product system.	WDP	m^3 world equiv.	(Boulay, Bare, Benini, & et al, 2018)

*The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

2.6.2. EN15804+A2 Additional environmental impact indicators

EN15804+A2 also requires the calculation and inclusion of additional indicators in the project report, as shown in Table 2-5.

The study includes an evaluation of human and ecotoxicity employing the USEtox™ characterisation model. USEtox™ is currently the best-available approach to evaluate toxicity in LCA and is the consensus methodology of the UNEP-SETAC Life Cycle Initiative. The precision of the current USEtox™ characterisation factors is within a factor of 100–1,000 for human health and 10–100 for freshwater ecotoxicity (Rosenbaum, et al., 2008).

Table 2-5: Additional environmental impact indicators

Impact Indicator	Description		Unit	Reference
IPCC AR5 GWP-GHG*	Total global warming potential, excluding biogenic carbon and including land use and change, over a 100-year period	GWP-GHG	kg CO_2-eq.	(IPCC, 2013)
Respiratory inorganics	Damage to human health from outdoor and indoor emissions of primary and secondary PM2.5 in urban and rural areas	PM	Disease incidences	(Fantke, et al., 2016)
Ionizing radiation - human health**	Impact of low dose ionizing radiation on human health of the nuclear fuel cycle and ionizing radiation from the soil, radon, and some construction materials. Effects due to possible nuclear accidents, occupational exposure nor due to radioactive waste disposal in underground facilities are not considered.	IRP	kBq U235 eq.	(Frischknecht, Braunschweig, Hofstetter, & Suter, 2000)
Eco-toxicity - freshwater	Toxic effect on aquatic freshwater species in the water column	ETP-fw	Comparative toxic units (CTU_h)	(Rosenbaum, et al., 2008)
Human toxicity, cancer***	A measure of the impact of chemical emissions on human health	HTPc	Comparative toxic units (CTU_h)	(Rosenbaum, et al., 2008)
Human toxicity, non-cancer***	A measure of the impact of chemical emissions on human health	HTPnc	Comparative toxic units (CTU_h)	(Rosenbaum, et al., 2008)
Land use related impacts / soil quality***	This index is the result of the aggregation, performed by JRC, of the 4 indicators provided by LANCA model for assessing impacts due to land use	SQP	Dimensionless, aggregated index of kg biotic production / (m^2 *a) kg soil / (m^2 *a)	(Bos, Horn, Beck, Lindner, & Fischer, 2016)

*This indicator is calculated using the characterisation factors from the IPCC AR5 report (IPCC 2013).

** This impact category deals mainly with the eventual impact of low dose ionizing radiation on human health of the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents, occupational exposure nor due to radioactive waste disposal in underground facilities. Potential ionizing radiation from the soil, from radon and from some construction materials is also not measured by this indicator.

***The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator

It shall be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.6.3. Inventory indicators

The following environmental parameters are based on the LCI. They describe the use of renewable and non-renewable material resources, renewable and non-renewable primary energy, and water, as shown in Table 2-6.

Table 2-6: Resource use indicators

Indicator	Abbrev.	Unit
Renewable primary energy as energy carrier	PERE	MJ, net calorific value
Renewable primary energy resources as material utilization	PERM	MJ, net calorific value
Total use of renewable primary energy resources	PERT	MJ, net calorific value
Non-renewable primary energy as energy carrier	PENRE	MJ, net calorific value
Non-renewable primary energy as material utilization	PENRM	MJ, net calorific value
Total use of non-renewable primary energy resources	PENRT	MJ, net calorific value
Use of secondary material	SM	kg
Use of renewable secondary fuels	RSF	MJ, net calorific value
Use of non-renewable secondary fuels	NRSF	MJ, net calorific value
Use of net fresh water	FW	m^3

EN15804+A2 also requires the declaration of waste materials and output flows, such as components for re-use and recycling, as shown in Table 2-7.

Table 2-7: Waste material and output flow indicators

Indicator	Abbrev.	Unit
Hazardous waste disposed	HWD	kg
Non-hazardous waste disposed	NHWD	kg
Radioactive waste disposed	RWD	kg
Components for re-use	CRU	kg

Indicator	Abbrev.	Unit
Materials for recycling	MFR	kg
Materials for energy recovery	MER	kg
Exported electrical energy	EEE	MJ
Exported thermal energy	EET	MJ

EN15804+A2 requires the declaration of biogenic carbon content of the product and its packaging, as shown in Table 2-8.

Table 2-8: Biogenic carbon content indicators

Indicator	Abbrev.	Unit
Biogenic carbon content - product	BCC-prod	kg
Biogenic carbon content - packaging	BCC-pack	kg

2.6.4. EN15804+A1 – environmental indicators

EN15804+A1 results are included to aid comparison and backwards compatibility with rating tools (Table 2-9).

Table 2-9: EN15804+A1 environmental indicators

EN15804+A1		Unit
Global warming potential (total)	GWP	kg CO2-eq.
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11-eq.
Acidification potential of land and water	AP	kg SO2-eq.
Eutrophication potential	EP	kg PO43-- eq.
Photochemical ozone creation potential	POCP	kg C2H4-eq.
Abiotic depletion potential – elements	ADPE	kg Sb-eq.
Abiotic depletion potential – fossil fuels	ADPF	MJ

2.6.5. TRACI 2.1

In financial year 2023 52% of produced goods was sent to the USA, up from 22% the previous year. A marketing campaign, multiple awards and increased interest from USA markets means Kaynemaile expects by FY2025 sales to the USA to be above 75% of all RE/8 produced. Therefore, a key market for RE/8 and Kaynemaile is the USA.

The Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1 indicators have also been used as they provide a more specific set of indicators relevant to the United States and are accepted by the LEED program.

TRACI 2.1 provides characterization factors for Life Cycle Impact Assessment (LCIA), industrial ecology, and sustainability metrics that was developed by the United States

Environmental Protection Agency (Environment Protection Agency, 2022). The methodologies underlying TRACI reflect state-of-the-art developments and best-available practice for life-cycle impact assessment (LCIA) in the United States (Bare J. C., 2008).

Global warming potential is a focus chosen because of their relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be the most pressing environmental issues of our time. The global warming potential results include the photosynthetically bound carbon (also called *biogenic carbon*) as well as the release of that carbon during the use or end-of-life phase as CO_2 and/or CH_4.

Eutrophication, acidification, and photochemical ozone creation potentials were chosen because they are closely connected to air, soil, and water quality and capture the environmental burdens associated with commonly regulated emissions such as NO_x, SO_2, VOC, and others.

Ozone depletion potential was chosen because of its high political relevance, which eventually led to the worldwide ban of more active ozone-depleting substances; the phase-out of less active substances is due to be completed by 2030. Current exceptions to this ban include the application of ozone depleting chemicals in nuclear fuel production. The indicator is therefore included for reasons of completeness.

The indicators considered are shown in Table 2-10.

Table 2-10: Life cycle assessment TRACI 2.1 indicators

Impact Category	Description	Unit	Reference
Acidification	Acidification is the increasing concentration of hydrogen ion (H+) within a local environment. Substances, which cause acidification, can cause damage to building materials, paints, and other human-built structures, lakes, streams, rivers, and various plants and animals.	kg SO_2 eq.	(Environment Protection Agency, 2022)
Ecotoxicity	Toxic effect on species. Ecotoxicity potentials for over 3000 substances including organic and inorganic substances.	CTUe	(Environment Protection Agency, 2022)
Eutrophication	Eutrophication is the enrichment of an aquatic ecosystem with nutrients (nitrates, phosphates) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass	kg N eq.	(Environment Protection Agency, 2022)

Impact Category	Description	Unit	Reference
Global Climate Change	Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns.	kg CO_2 eq.	(Environment Protection Agency, 2022)
Human Health Particulate	Particulate matter is a collection of small particles in ambient air which have the ability to cause negative human health effects including respiratory illness and death.	kg $PM_{2.5}$ eq.	(Environment Protection Agency, 2022)
Human toxicity (cancer)	Human health cancer and noncancer toxicity potentials and freshwater ecotoxicity potentials for over 3000 substances including organic and inorganic substances.	CTUh	(Environment Protection Agency, 2022)
Human toxicity (non-cancer)	Human health cancer and noncancer toxicity potentials and freshwater ecotoxicity potentials for over 3000 substances including organic and inorganic substances.	CTUn	(Environment Protection Agency, 2022)
Ozone depletion air	Ozone within the stratosphere provides protection from radiation, its depletion can lead to increased frequency of skin cancer, cataracts and impacts on other animal and plant life as well as the built environment.	kg CFC eq.	(Environment Protection Agency, 2022)
Resource depletion, fossil fuels	The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources. Using non-site specific fossil fuel characterisation	MJ surplus energy	(Bare, Norris, Pennington, & McKone, 2003; Goedkoop & Spriensma, 1999)
Smog formation air	Ground level ozone is created by various chemical reactions, which occur between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues.	kg O_3 eq.	(Environment Protection Agency, 2022)

2.7. Interpretation to be used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

2.8. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest quality when utilising collaborated and verified equipment, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed. An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.9. Type and format of the report

In accordance with the ISO requirements (ISO, 2006b) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.10. Critical Review

The Critical Review Statement can be found in Annex C. The Critical Review Report containing the comments and recommendations by the independent expert as well as the practitioner's responses is available upon request from the study commissioner in accordance with ISO/TS 14071.

The review of this background report was carried out by Claudia A. Peña, Director of Sustainability, ADDERE Research & Technology. She is an independent reviewer and additionally registered as a verifier and Technical Committee Member with International EPD® System.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

3.1.1. Primary data collection

Primary data were collected using customised data collection templates, which were sent out by email to the respective data providers in the participating companies. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, thinkstep-anz engaged with the data provider to resolve any open issues.

Wherever feasible, the coefficient of variation was established for the different inputs and outputs, either across different data providers or across the reported time period if a breakdown into smaller increments (e.g., 12 months) was available. Data collection and validation was provided by Kayne Horsham of Kaynemaile (kayne@kaynemaile.com). Data pertaining to the use of waste bio-circular feedstock for polycarbonate was provided by Dr Frank Buckel (frank.buckel@covestro.com) Sustainability Solutions Advocate of Covestro.

3.1.2. Calculation of carbon sequestration

3.1.2.1 Biogenic carbon in product

International Sustainability Carbon Certification (ISCC) certified biological waste and residues (defined as bio-circular) feedstock is a raw input to produce the polycarbonate used in RE/8. Whereby the bio-circular feedstock can be used to make a bisphenol A replacement. It has been assumed that the bio-circular feedstock displaces crude oil in the manufacturing of Naphtha which is then steam cracked into benzene and propylene. That is further converted to cumene then phenol and acetone used to make polycarbonate (see Figure 3-2). This assumption is based on data provided by Dr Frank Buckel, Sustainability Solutions Advocate of Covestro. This assumption is considered to be conservative as waste bio-circular feedstock is likely to require less processing than crude-oil to form naphtha. It may be further refined into the future as the supplier provides additional manufacturing date specific to the use of waste bio-circular feedstock in its polycarbonate manufacturing process.

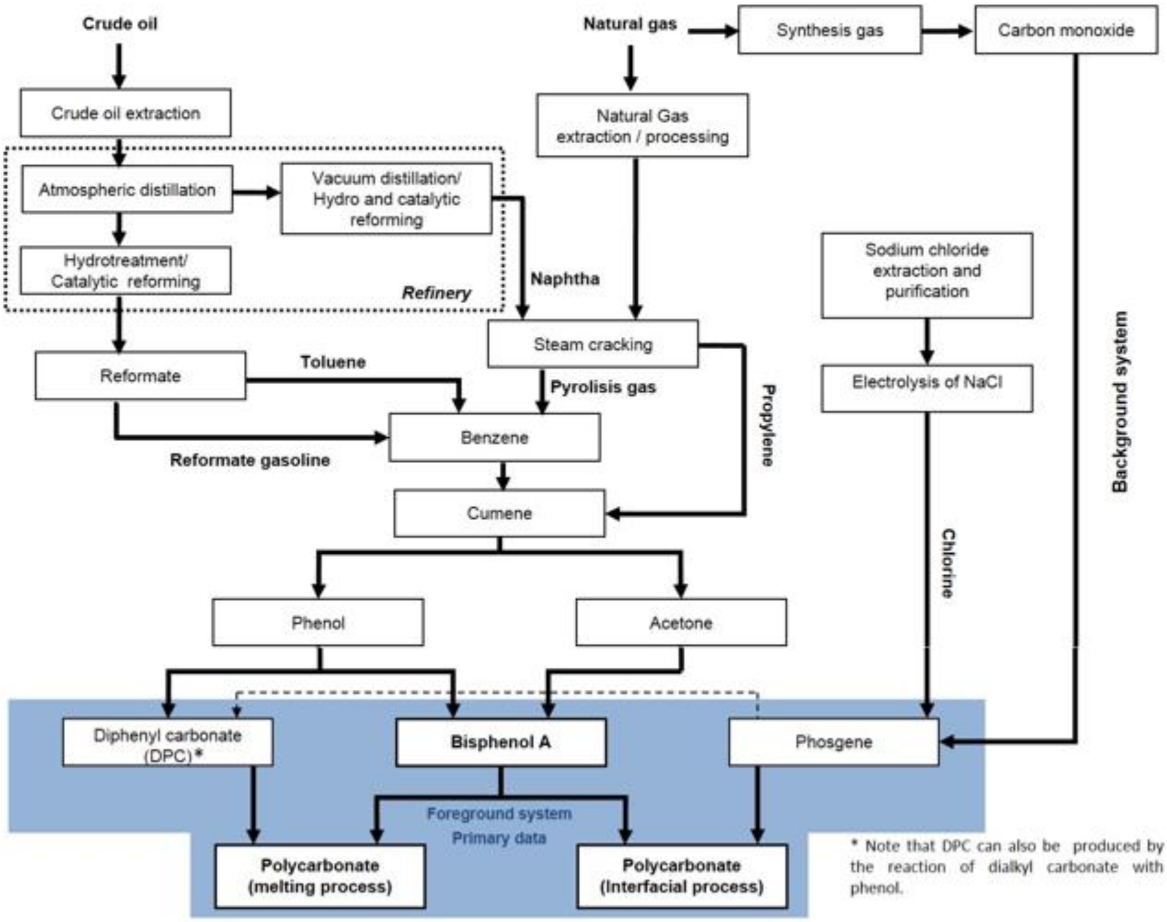


Figure 3-1 – Process flow associated with polycarbonate manufacturing according to RER: Polycarbonate, Plastics Europe (Sphera, 2022)

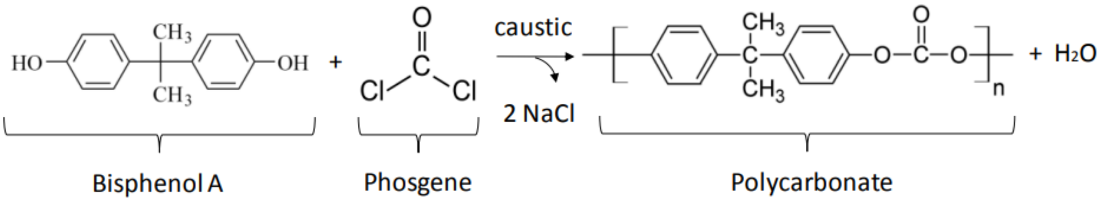


Figure 3-2 - Typical reaction of bisphenol A with phosgene to create polycarbonate

According to the ISCC PLUS certified mass balance approach provided by the polycarbonate provider; the bio-circular feedstock comprises 15 of the 16 carbon atoms in the repeating polycarbonate chain (Covestro, 2023). Accounting for 0.708 kg of biogenic C per kg of polycarbonate as per below. Note that the mass balance approach is not a recognised method by International EPD programme and its regional partners.

$$\frac{15\ (No. of\ carbon\ atoms)\ \times 12.01\ (Molar\ mass\ of\ C)}{254.28\ (molar\ mass\ of\ polycarbonate\ as\ C_{16}H_{14}O_{3})} = 70.8\%$$

3.1.2.2 Biogenic carbon in packaging

During tree growth, carbon dioxide from the air is sequestered as biogenic carbon within the tree. Various forestry steps (decomposition from residues of thinning, felling, etc.) and also natural processes (e.g., fire) release this sequestered carbon back to the air, while some biogenic carbon remains sequestered in the wood products leaving the forest.

Embodied carbon is treated as an inherent property of the wood (CEN, 2019) and the removal of carbon dioxide included within the wood must equal the carbon contained in the finished product in line with ISO/TS 14067:2013 p. section 6.4.9.6 (ISO, 2013) and the calculation specified in EN 16449:2014 (described later in this section). Including sequestered carbon is appropriate, provided that it is reported separately in the EPD (CEN, 2019) (p. section 6.4.9.6) and that forests are sustainably managed EN 16485:2014, p. section 6.3.4.2 (CEN, 2014).

This section describes the procedure for calculation of the biogenic carbon sequestered in wood products, a parameter that is affected by the density and the moisture content of the wood product (i.e., cardboard).

The moisture content (MC) of wood product can be expressed as the oven dry moisture content (MC_{OD}) which uses only the mass of wood after all water is evaporated. Alternatively, the moisture content can be expressed as the wet moisture content (MC_W) which uses the mass of wood which includes the mass of water (Briggs, 1994). These moisture contents are calculated as follows (Briggs, 1994):

- % MCOD = 100 * mass of water / oven-dry mass
- % MCW = 100 * mass of water / original mass including water

Note that the two measures for moisture content can be converted using the following expressions:

- % MCOD = (MCW/ (100 - MCW)) *100
- % MCw = (MCOD/(100 + MCOD)) *100

The oven dry basis is more common in the solid wood industry, while the wet basis is more common in the wood fuels industry. Data in this report are reported in the original measures provided by the producers in data collection.

The CO_2 sequestered per cubic metre of wood was calculated using the formula specified in European standard EN 16449 (CEN, 2014):

$$P_{CO_2} = \frac{44}{12} \times cf \times \frac{\rho_\omega \times V_\omega}{1 + \frac{\omega}{100}}$$

Where:

- P_{CO_2} is the biogenic carbon sequestered in the wood that can be oxidised to a carbon dioxide emission to air
- $\frac{44}{12}$ is the molecular weight of carbon dioxide divided by the atomic weight of carbon
- cf is the carbon fraction of oven dry mass of woody biomass (0.5 is the default value)
- ω is the moisture content of the product on a dry basis, e.g., 12 (%)
- ρ_ω is the density of woody biomass at that moisture content (kg/m^3)
- V_ω is the volume of the solid wood product at that moisture content (m^3)

In New Zealand, 50±2% of the dry weight of the wood of non-native *Pinus radiata* is a carbon (Gifford, 2000). As a result, the default value of 0.5 is applied for *cf*.

The density ($\rho\omega$, the density of wood) was taken from the product density.

Moisture content is calculated based on the percent moisture content of the wood product when receiving the wood inputs (corrugated cardboard assumed to be 10%)

3.1.3. PENRM and PERM

The model calculated the contribution to non-renewable primary energy as material utilisation (PENRM) and Use of Primary Energy (Renewable) as Material (PERM) by scaling the net calorific value (NCV) according to solid content of respective materials in the products.

The NCVs and solid contents used in the LCA model are given in Table 3-1.

Table 3-1 NCV inputs for PERM and PENRM calculations

Input	NCV (MJ/kg)	Moisture content (%)	Comment
Polycarbonate	35	<1%	NCV value from Association of Plastics Europe (Plastics Europe, 2023)

The NCV was multiplied by per centage (by mass) of the polycarbonate arising from waste bio-circular feedstock (0.89) this provided the PERM value. The remaining per centage by mass of polycarbonate is derived from fossil fuels (0.11) this was multiplied by the NCV of polycarbonate and treated as PENRM.

3.1.4. Land use

Land use is split into two components:

- Land transformation
- Occupational land use

Land transformation is modelled in LCA FE using flows that represent the area of land transformed to and from per unit mass of product, based on the predicted time period of occupation and total production rate for each of their sites. The annual production rate for the specified time period for data used in this LCA is assumed to be representative of all years that Kaynemaile will occupy the site. Parameters and flow values for land transformation is presented in Table 3-2 and Table 3-3. All values have been supplied by Kayne Horsham of Kaynemaile including estimations of years in operation and anticipated closing date.

Table 3-2: Land transformation parameters and flow totals for the indicator Land use related impacts / soil quality

Land transformation parameter	Wellington	Unit
Landscape prior to operation total	300	m^2
Forest	-	m^2
Agriculture	-	m^2

Land transformation parameter	Wellington	Unit
Pasture/meadow	-	m^2
Landscape post operation total		m^2
Industrial area	300	m^2
Shrub land	-	m^2
Agriculture	-	m^2
Dump site	-	m^2
Commission year	2005	
Anticipated closing year	2050*	
Years in operation	45*	years
Annual production rate	40,500	kg
Total lifespan production	1,822,500	kg
Transformation from forest	-	m^2/kg
Transformation from agricultural	-	m^2/kg
Transformation from pasture/meadow	-	m^2/kg
Transformation to agricultural	-	m^2/kg
Transformation to industrial area	1.65E-04	m^2/kg
Transformation to shrub land	-	m^2/kg
Transformation to dump site	-	m^2/kg

*Estimated

Occupational land use accounts for use of the land year-on-year, opposed to the transformation of land due to occupation of the land. Parameters for calculation of flows used to model occupational land use are presented in Table 3-3.

Table 3-3: Occupational land use parameters and flow totals for the indicator Land use related impacts / soil quality

Occupational land use parameter	Wellington	Unit
Owned/leased land area total	300	m^2
Industrial area	300	m^2
Agriculture	-	
Shrub land	-	
Dump site	-	
Annual production rate	40.5	t/yr
Occupational flow - Industrial	7.41E-03	m^2*year/kg

Occupational land use parameter	Wellington	Unit
Occupational flow – shrub land	-	m²*year/kg
Occupational flow – agriculture	-	m²*year/kg
Occupational flow – dump site	-	m²*year/kg

This modelling applies conservative assumptions, since throughput is expected to increase in future years, due to the likelihood of increased demand for product.

3.2. Product System

This section describes the foreground system on a high level. Summarising production process and individual steps and unit processes.

3.2.1. Overview of Product System

Figure 3-3 illustrates the process for manufacturing RE/8.

Polycarbonate pellets (dyed and non-dyed) and packaging are the primary raw materials that are manufactured upstream of the Kaynemaile process. These raw materials are received at the manufacturing facility.

Polycarbonate pellets are received in bulk bags onsite. They are dried and mixed with a small quantity of masterbatch polycarbonate that has been dyed the desired product colour. Once mixed they enter an injection moulding process. Here they are moulded and with the help of stock rolls, joined via an additional moulding process into the distinctive chain mail style polycarbonate. Moulds are cut to size with offcuts granulated and reprocessed. A small fraction of plastic (<0.6%) is wasted in the manufacturing process. Correctly sized products are packaged and prepared for distribution to the customer.

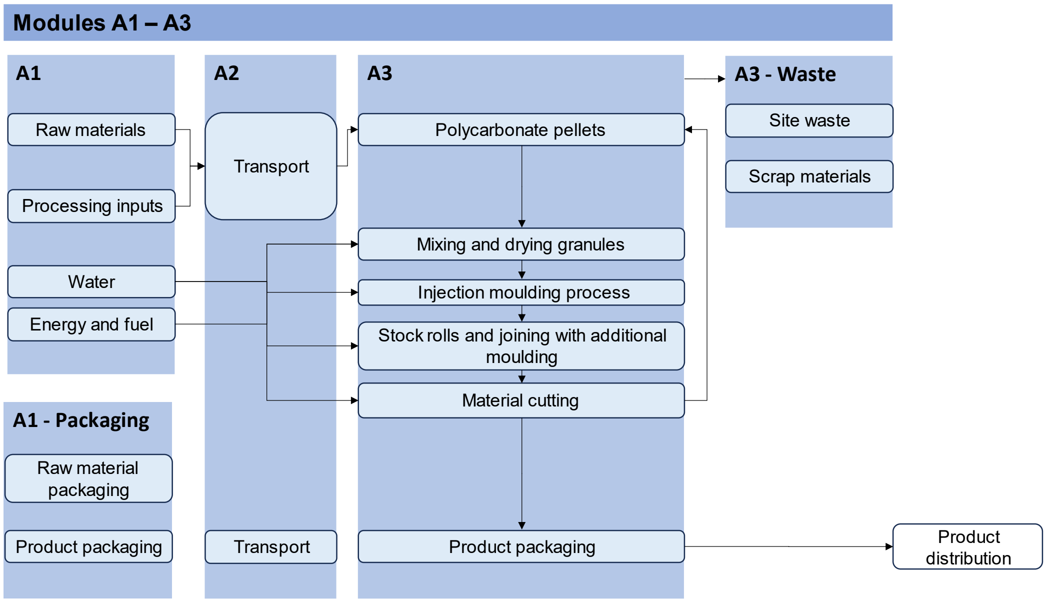


Figure 3-3 - Kaynemaile manufacturing process

3.2.2. Product Composition

RE/8 is made from 99.9% polycarbonate. With additives the remaining 0.1% responsible for the colour of the product. Table 3-4 provides the product composition.

Table 3-4: Material composition product RE/8 per declared unit (one square meter of RE/8)

Material	Mass (kg)	Mass (%)	DQI*
Polycarbonate	**2.95**	**98.3%**	**Measured**
From virgin inputs	0.30	10.0%	Calculated
From waste bio-circular feedstock input	2.65	88.3%	Calculated
Masterbatch (dyed) polycarbonate	0.05	1.70%	Measured
Polycarbonate (breakdown as above)	0.046	1.53%	Measured
Colourant	0.004	0.17%	Measured

* measured / calculated / estimated / literature

3.2.2.1 Biogenic carbon

The biogenic carbon sequestered in RE/8 derives from the use of bio-circular feedstock in the manufacturing of polycarbonate pellets. The determination of biogenic carbon in RE/8 is covered in more detail in section 3.1.2.

The biogenic carbon sequestered in RE/8, is directly accounted for in the inventory as an input or uptake of carbon dioxide, which is treated as a negative emission of carbon dioxide to air, i.e., a removal of CO_2 from the atmosphere, in module A1.

Biogenic carbon present in the corrugated cardboard derives from wood uptake. This biogenic carbon is fully released in A3 as carbon dioxide. Therefore, no credit for recycling packaging cardboard is granted.

3.2.3. Raw materials

Polycarbonate pellets are sourced from Thailand and transported by ocean going ship to the Port of Auckland. The polycarbonate is then sent to Kaynemaile's Wellington facility by truck. A small proportion of the polycarbonate is sent to a dying facility in Rosedale where it is turned into a masterbatch. It too is then directed to Wellington by truck. Total distances associated with raw material transport are provided in Table 3-5.

Table 3-5 Transport distances raw materials

Material	Distance (km)		DQI*
	Ship	Truck	
Polycarbonate	12,900	635	Estimated
Masterbatch (dyed) polycarbonate	12,900	650	Estimated

3.2.4. Manufacturing

The process of manufacturing uses electricity to dry and mix pellets of polycarbonate and heat to ensure the pellets are malleable and can be moulded into interlocked chains. All electricity purchased is sourced from a certified 100% renewable electricity retail plan.

A small quantity of water is used but this is evaporated in the cooling tower along with small amounts of volatile organic compounds. Waste plastic from offcuts is mostly collected and reprocessed with any not able to be reprocessed sent to a nearby landfill (10km). An LPG driven forklift is used to load and unload items as required and a small quantity of lubricant oil is used for machine maintenance.

Manufacturing inventory can be found in Table 3-6. Polycarbonate inputs, energy and water values have been measured or calculated. Value for waste use is an estimate based on limited data. Hydraulic oil has been calculated on expected maintenance schedules and volatile organic emissions was from an industry source.

Table 3-6 Manufacturing inventory per declared unit (one square meter of RE/8)

Type	Flow	Value	Unit	DQI*
Inputs	Electricity (Green certified)	0.365	kWh	Calculated
	Liquid Petroleum Gas (LPG)	0.002	kg	Measured
	Water (treated)	1	L	Calculated
	Lubricant oil	0.0015	Kg	Calculated
Outputs	Product	3.00	kg	Measured
	Evaporation (water only)	1	L	Estimated
Waste	Factory waste for landfill	0.017	kg	Estimated
	Volatile Organic Compounds	6.0E-05	kg	Literature

3.2.5. End-of-Life

The end-of-life phase includes removal of RE/8 during the building's deconstruction (C1), transport of waste material to a sorting facility (C2). and either processing for recycling (C3) or disposal (C4) specific to different end-of-life scenarios.

End-of-life is assumed to be in the USA as RE/8's biggest market is in the USA. due to current and future sales (section 2.6.5).

Module C1 is estimated by using a 100 kW excavator modelled as deconstructing the RE/8. Truck is used as the transport mode for C2 travelling an assumed 100 km to the point of end-of-life management. An additional transport mode of ship to China is noted below for Recycling Scenario.

Three different scenarios are used for the end-of-life of Kaynemaile RE/8. Representing methodological or physical differences in handling the biogenic carbon in polycarbonate material at end-of-life. The scenarios are based on the disposal or recycling alternatives adopted in module C3/C4 and are detailed here.

3.2.5.1 Landfill Scenario – Sequestered (Baseline)

This scenario involves all RE/8 being sent to landfill in the USA as inert material i.e., no degradation. There is no artificial release of biogenic carbon.

This is the current and most probable scenario as 86% of all plastic discarded in the USA is sent to landfill (Heffernan, 2022). Aromatic polycarbonate (RE/8) is also a non-biodegradable substance (Artham & Doble, 2008). It is considered to be inert (Commonwealth Government of Australia, 2022). Biogenic carbon within the product is not released as CO_2 or CH_4 during biodegradation in a landfill.

3.2.5.2 Landfill Scenario – EN15804

This scenario involves all RE/8 being sent to landfill in USA as inert material, as per the above scenario. Biogenic carbon is artificially released entirely as CO_2 in module C4.

The release in full as CO_2 represents a methodological difference from the first scenario and is a EN15804 requirement, i.e., the specifications directly linked to an EPD.EN15804:2019 (CEN, 2019) clause 6.3.5.5 states *"The degradation of a product's biogenic carbon content in a solid waste disposal site, declared as GWP-biogenic, shall be calculated without time limit. Any remaining biogenic carbon is treated as an emission of biogenic* CO_2 *from the Technosphere to nature."*

3.2.5.3 Recycling Scenario

This scenario involves all RE/8 being recycled. This is assumed to occur in the USA at the polycarbonate supplier's Baytown Texas facility. Therefore, material is sent by truck (assumed to be on average 2000 km) from waste sorting facility to Texas. Whereby RE/8 is processed (C3) and used as secondary material input into polycarbonate formation. Biogenic carbon is artificially released in module C4 so it can be counted within its next system boundary.

Credit is received for the displacement of virgin polycarbonate material. Whereby 2.57 kg of credit for every 3 kg or 1m^2 of RE/8 due to losses in the recycling and production process based on the Sphera data US: Plastic recycling (clean scrap) noted in Table 3-15.

Table 3-7 End-of-life inventory

Input	**Value**	**Unit**	**DQI***
All Scenarios			
Diesel for excavator (C1)	1.55E-03	kg	Estimated
Diesel for truck (C2)	0.0600	kg	Estimated
Landfill Scenario - Sequestered			
Landfill (inert matter)	3.00	kg	Measured
Biogenic carbon released	0	kg	Calculated
Landfill Scenario – EN15804			
Landfill (inert matter)	3.00	kg	Measured
Biogenic carbon released	2.60	kg	Calculated
Recycling Scenario			
Diesel truck (C3)	0.380	kg	Assumed
Plastic processing for recycling (C3)	3.00	Kg	Measured
Polycarbonate (credit) (D)	2.57	kg	Estimated
Biogenic carbon released	2.60	kg	Calculated

3.2.5.4 Calculation of biogenic carbon at end-of-life

Biogenic carbon released or sequestered as kg CO_2eq was calculated using the biogenic carbon in the product 0.708 kg of biogenic C per kg of polycarbonate determined in Section 3.1.2.1.

$$0.708\ kg\ of\ Biogenic\ Carbon\ in\ product \times \frac{44}{12} = 2.60\ kg\ of\ CO_2$$

With the exception of end-of-life *Landfill Scenario – USA*, biogenic carbon sequestered in product is released at end-of-life. Where the material is sent for recycling, the sequestered biogenic carbon is released as carbon dioxide to the atmosphere.

When the material is managed by *Landfill Scenario – EN15804,* the biogenic carbon sequestered in the bio-based materials is considered completely released as carbon dioxide. These biogenic carbon emissions were modelled consistent with ISO 14067 (ISO, 2018). The biogenic carbon sequestered in the material during growth is assumed to be released back to the atmosphere at end-of-life. Biogenic carbon in landfill generally is partly emitted to air as carbon dioxide and methane and partly sequestered depending on its degradation rate.

In the end-of-life *Landfill Scenario – Sequestered*, it is assumed that plastics do not break down in landfills and that the fossil carbon content is not released to the air as greenhouse gases. Note the decision to include biogenic carbon in *Landfill Scenario – Sequestered* is based on evidence that suggests many plastics are unlikely to degrade at all in landfill for many hundreds of years (Ximenes, Brooks, Wilson, & Giles, 2013). This scenario is therefore differing from Landfill Scenario – EN15804.

The time horizon considered within this study for landfills is 100 years. However, it should be noted that the DOCf values below have been calculated/extrapolated from short term studies (e.g., desktop bioreactor which are designed to simulate an environment that degrades the material as completely as possible in anaerobic conditions). As such, applying a longer-term time horizon should not affect the results for biodegradable materials such as wool and paper, as all biogenic carbon emissions will have already been accounted for.

3.2.5.5 Degradable Organic Carbon Fraction (DOC_f)

The degradable organic carbon fraction (DOC_f) is a fraction of the biogenic carbon in a material that will break down and be emitted to the atmosphere as gaseous compounds over time (very long term time horizons half-life of 3 to 5) (Pipatti et al., 2006), in this case in a landfill. DOC_f values vary by material, as seen in Table 3-8. The degradation of a product's biogenic carbon content in solid waste disposal site is assumed to be without time limit.

Carbon present in the corrugated cardboard packaging is fully released in A3 as carbon dioxide. Therefore, no credit for recycling packaging cardboard is granted.

Table 3-8: DOC_f values of materials

Material Type	DOCf	Carbon content (%)	Source/Description
Polycarbonate	0.0	50	DOCf Based on inert material (Commonwealth Government of Australia, 2022)

3.2.5.6 Methane Capture Rate

Of the landfill gases produced from decomposition, methane capture rates for specific landfills can range from 0% (uncovered landfill with no gas collection) to near 100% (covered landfill with highly effective gas collection). Given the degradation (DOCf) value associated with RE/8 methane capture rate is irrelevant as no methane is believed to be produced in landfill.

3.3. Background Data

The most relevant LCI datasets used in modelling the product systems are detailed below. All background datasets were obtained from the MLC Database and documentation can be found at:

https://sphera.com/product-sustainability-gabi-data-search/

Note that all MLC datasets have as a minimum their energy upstream (and any energy upstream present in their material upstream) updated on an annual basis. In addition, all MLC datasets are updated whenever the technology or geographical mix of the producers of a product change significantly.

The proxy column is used to indicate whether a dataset accurately represents the desired material or process; a No* indicates the use of a geographical proxy for a correct dataset where the region of manufacture is expected to have little influence on its environmental profile; and a Yes* indicates the use of a geographical proxy for a correct dataset where the region of manufacture is expected to materially influence its environmental profile.

3.3.1. Fuels and Energy

National averages for fuel inputs and electricity grid mixes were obtained from the MLC databases.

The NZ Kaynemaile facility purchases certified renewable electricity from their retailer. The mix of the renewable electricity is 90.5% from hydro power and 9.5% from wind, resulting in 0.00742 kg CO_2eq./kwh.

The emission factor for hydro and wind generation in NZ is shown in Table 3-9.

Table 3-9: Key electricity datasets used in inventory analysis

Material	Geographic Reference	Dataset	Emission factor (kg CO_2eq./kwh)	Data Provider	Reference Year	Proxy?
Electricity (hydro)	New Zealand	NZ: Electricity from hydro power	7.46E-03	Sphera	2018	No
Electricity (wind)	New Zealand	NZ: Electricity from wind power	7.02E-03	Sphera	2018	No

Table 3-10: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Diesel	GLO	AU: Diesel mix at filling station	Sphera	2019	No*
LPG	NZ	AU: Liquefied Petroleum Gas (LPG)	Sphera	2019	No*
Diesel	USA	US: Diesel mix at filling station	Sp**hera**	2019	No

3.3.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the MLC database. Table 3-11 shows the most relevant LCI datasets used in modelling the product systems. Documentation for all MLC datasets can be found at https://sphera.com/product-sustainability-gabi-data-search/.

Table 3-11: Key material and process datasets used in inventory analysis

Material/ process	Location	Dataset	Data Provider	Reference Year	Proxy?
Polycarbonate	TH	RER: Polycarbonate	Plastics Europe	2016	Yes*
Colourant	NZ	DE: Pigment (red)	Sphera	2022	No*

3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities Table 3-12.

The MLC database was used to model transportation. Transportation was modelled using the MLC global transportation datasets. Fuels were modelled using the geographically appropriate datasets.

Table 3-12: Transportation and road fuel datasets

Mode / fuels	Geographic Reference	Dataset	Data Provider	Reference Year	Proxy?
Truck	GLO	GLO: Truck, Euro 0 - 6 mix, 7.5 - 12t gross weight / 5t payload capacity Sphera <u-so>	Sphera	2022	No*
Container Ship	GLO	GLO: Container ship, 5.000 to 200.000 dwt payload capacity, deep sea	Sphera	2022	No*
Diesel	GLO	AU: Diesel mix at filling station	Sphera	2019	No*
Heavy fuel oil	GLO	AU: Heavy fuel oil at refinery (1.0 wt. % S)	Sphera	2019	No*

3.3.4. Packaging

The datasets used for modelling product packaging materials are provided in Table 3-13.

Table 3-13: Key material and process datasets used in packaging

Material/ process	Location	Dataset	Data Provider	Reference Year	Proxy?
Cardboard corrugated	GLO	RER: Corrugated board incl. paper production, average composition	Sphera	2022	No*
Packing tape	GLO	DE: Biaxial oriented polypropylene film (BOPP)	Sphera	2022	No*
Plastic film	GLO	DE: Plastic foil (Polyethylene, PE)	Sphera	2022	No*
Plastic strapping	GLO	DE: Polyethylene terephthalate foil (PET) (without additives)	Sphera	2022	No*

3.3.5. Waste treatment processes

The datasets used for modelling waste treatment are provided in Table 3-14.

Table 3-14: Waste treatment processes

Treatment/ Process	Location	Dataset	Data Provider	Reference Year	Proxy?
Landfill of polycarbonate	USA	USA: Inert matter (Glass) on landfill	Sphera	2022	No
Landfill of factory waste	NZ	RER: Plastic waste on landfill	Sphera	2022	No*

3.3.6. End-of-life & recovery

The processes used for modelling end-of-life (Module C) and recycling (Module D) are shown in Table 3-15.

Table 3-15: End-of-life processes

Process	Location	Dataset	Data Provider	Reference Year	Proxy?
Excavator (C1)	GLO	Excavator, 100 kW, construction	Sphera	2019	No
	USA	US: Diesel mix at filling station	Sphera	2019	No
Truck (C2)	GLO	Truck, Euro 0 - 6 mix, 7.5-12t gross weight / 17.3t payload capacity	Sphera	2019	No
	USA	US: Diesel mix at filling station	Sphera	2019	No
Processing waste polycarbonate	USA	US: Plastic recycling (clean scrap)	Sphera	2022	No
Polycarbonate recycling credit	USA	RER: Polycarbonate	Plastics Europe	2016	No*

4. Life Cycle Impact Assessment

This chapter contains the results for the impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Assessment Results

This report is to assess the global warming potential of RE/8 and form the basis of a Kaynemaile produced Leadership in Energy and Environmental Design (LEED) application.

All assessment results across all indicators can be found in Table 4-1 to Table 4-4.

All assessment results including hot spot analysis for EN15804+A2 indicators and TRACI 2.1 indicators can be found in Annex B.

4.1.1. EN15804+A2 environmental indicator assessment results

Assessment results for EN15804+A2 environmental indicators are detailed in Table 4-1, Table 4-2, and Table 4-3. Results are divided into modules A1-A3, C1-C4 and D.

Table 4-1 - EN15804+A2 assessment results

EN15804+A2 – Environmental Impact Indicators	**Abb.**	**Unit**	**A1-A3**	**C1-C4**	**D**
Global warming potential	GWP	kg CO2-eq.	3.67	10.3	-9.01
Global warming potential (fossil)	GWPf	kg CO2-eq.	11.3	2.51	-8.97
Global warming potential (biogenic)	GWPb	kg CO2-eq.	-7.65	7.81	-3.48E-02
Global warming potential (land use change)	GWPluc	kg CO2-eq.	5.09E-03	1.76E-03	-3.48E-03
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11-eq.	2.16E-07	3.94E-12	-1.85E-07
Acidification potential - terrestrial and freshwater	AP	Mole of H+ eq.	2.67E-02	3.98E-03	-1.63E-02
Eutrophication potential - freshwater	EPfw	kg P eq.	7.09E-05	1.87E-05	-5.47E-05
Eutrophication potential - marine	EPm	kg N eq.	8.28E-03	1.61E-03	-4.33E-03
Eutrophication potential - terrestrial	EPt	Mole of N eq.	8.89E-02	1.77E-02	-4.63E-02
Photochemical ozone formation potential	POFP	kg NMVOC eq.	2.68E-02	3.48E-03	-1.54E-02
Abiotic depletion potential – minerals & metals	ADPmm	kg Sb-eq.	1.59E-06	1.52E-07	-1.28E-06
Abiotic depletion potential – fossil fuels	ADPf	MJ	289	33.9	-235
Water scarcity	WDP	m^3 world equiv.	2.17	0.275E	-1.75

Table 4-2 EN15804+A2 additional indicators assessment results

EN15804+A2 - Additional Indicators	Abb.	Unit	A1-A3	C1-C4	D
IPCC AR5 GWP (excluding biogenic carbon)	GWP-GHG	kg CO2-eq.	1.11E+01	2.48E+00	-8.79E+00
Respiratory inorganics	PM	Disease incidences	3.33E-07	2.99E-08	-1.24E-07
Ionizing radiation - human health	IR	kBq U235 eq.	5.79E-01	1.10E-01	-4.70E-01
Ecotoxicity freshwater	ETf	CTUe	1.29E+02	2.16E+01	-1.06E+02
Human toxicity, cancer	HTc	CTUh	7.92E-09	3.89E-10	-6.57E-09
Human toxicity, non-canc.	HTnc	CTUh	1.39E-07	1.46E-08	-1.06E-07
Land use	SQP	Pt	4.88E+01	5.00E+00	-9.42E+00

Table 4-3 EN15804+A1 assessment results

EN15804+A1 – Environmental Impact Indicators	Abb.	Unit	A1-A3	C1-C4	D
Global warming potential (total)	GWP	kg CO2-eq.	3.30E+00	1.03E+01	-8.70E+00
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11-eq.	2.17E-07	4.64E-12	-1.86E-07
Acidification potential of land and water	AP	kg SO2-eq.	2.06E-02	2.86E-03	-1.29E-02
Eutrophication potential	EP	kg PO43-- eq.	3.24E-03	7.29E-04	-1.79E-03
Photochemical ozone creation potential	POCP	kg C2H4-eq.	2.60E-03	-4.93E-04	-1.87E-03
Abiotic depletion potential – elements	ADPE	kg Sb-eq.	1.62E-06	1.61E-07	-1.31E-06
Abiotic depletion potential – fossil fuels	ADPF	MJ	2.75E+02	2.29E+01	-2.23E+02

4.1.2. TRACI 2.1 environmental indicator assessment results

Assessment results for EN15804+A2 environmental indicators are detailed in Table 4-4.

TRACI2.1 results are commonly used in USA as the indicators have been developed specifically for the United States. As such it may be appropriate to use these values when discussing the product in the USA as customers may be more familiar with these indicators than EN15804+A2.

Both sets of environmental indicators often cover the same environmental phenomenon (i.e. acidification) however, may use differing units of measurement and use different background assessment methodologies, and boundaries. This explains the differences in values and means it is not possible to compare values across indicator sets.

Table 4-4 TRACI 2.1 assessment results

TRACI 2.1 – Environmental Impact Indicators	Unit	A1-A3	C1-C4	D
TRACI 2.1, Acidification	kg SO2 eq.	2.46E-02	3.79E-03	-1.51E-02
TRACI 2.1, Acidification Air	kg SO2 eq.	2.43E-02	3.78E-03	-1.48E-02
TRACI 2.1, Acidification Water	kg SO2 eq.	2.93E-04	1.36E-05	-2.40E-04
TRACI 2.1, Ecotoxicity	CTUe	1.03E+00	1.51E-01	-8.43E-01
TRACI 2.1, Eutrophication	kg N eq.	2.18E-03	5.09E-04	-1.39E-03
TRACI 2.1, Eutrophication Air	kg N eq.	4.61E-03	2.25E-04	-2.73E-03
TRACI 2.1, Eutrophication Water	kg N eq.	1.25E-03	3.25E-04	-9.07E-04
TRACI 2.1, Global Warming Air, excl biogenic carbon, incl LUC, no norm/weight	kg CO2 eq.	1.10E+01	2.46E+00	-8.68E+00
TRACI 2.1, Global Warming Air, excl. biogenic carbon	kg CO2 eq.	1.10E+01	2.46E+00	-8.68E+00
TRACI 2.1, Global Warming Air, incl biogenic carbon, incl LUC, no norm/weight	kg CO2 eq.	3.30E+00	1.03E+01	-8.70E+00
TRACI 2.1, Global Warming Air, incl. biogenic carbon	kg CO2 eq.	3.30E+00	1.03E+01	-8.70E+00
TRACI 2.1, Global Warming Air, LUC only, no norm/weight	kg CO2 eq.	5.09E-03	1.76E-03	-3.48E-03
TRACI 2.1, Human Health Particulate Air	kg PM2.5 eq.	1.73E-03	1.44E-04	-7.70E-04
TRACI 2.1, Human toxicity, cancer	CTUh	1.63E-08	1.04E-09	-1.32E-08
TRACI 2.1, Human toxicity, non-canc.	CTUh	7.41E-07	8.16E-08	-5.54E-07
TRACI 2.1, Ozone Depletion Air	kg CFC 11 eq.	2.15E-07	8.32E-14	-1.84E-07
TRACI 2.1, Resources, Fossil fuels	MJ surplus energy	3.77E+01	3.78E+00	-3.05E+01
TRACI 2.1, Smog Air	kg O3 eq.	5.16E-01	7.51E-02	-2.69E-01

4.1.3. Global Warming potential

This section is focused on GWP (GWP-total, GWP-fossil, GWP-biogenic, and GWP-luluc) with key environmental indicators looked at in Section 4.2. Results are present in kg of CO_2.eq per declared unit (m^2 of RE/8).

Cradle to gate (A1-A3) GWP-Total for the baseline scenario is 3.67 kg of CO_2.eq per m^2 of RE/8.

Results for key GWP indicators are presented in Table 4-5. When only fossil derived carbon emissions are accounted for (GWP-fossil) RE/8 has a total of 11.9 kg of CO_2.eq/m^2.

When looking exclusively at biogenic carbon (GWP-biogenic) RE/8 has a negative value, -7.65 kg of CO_2.eq/m^2. This is due to the carbon associated with the waste bio-circular feedstock making up the majority of the 3 kg of RE/8. Therefore, the use of waste bio-circular feedstock as a feedstock lowers GWP-total by more than 7 kg of CO_2.eq/m^2.

Table 4-5 GWP results for Landfill Scenario – Sequestered (baseline scenario)

Indicator	**Abbreviation**	**Unit**	**Module**			
			A1-A3	**C1-C4**	**Total (A1-A3, C)**	**D**
Global warming potential	GWP-total	kg CO_2-eq.	3.67	0.138	3.81	0
Global warming potential (fossil)	GWPf	kg CO_2-eq.	11.3	0.137	11.5	0
Global warming potential (biogenic)	GWPb	kg CO_2-eq.	-7.65	6.05E-04	-7.65	0
Global warming potential (land use change)	GWPluc	kg CO_2-eq.	0.00509	1.07E-04	5.20E-03	0

4.2. Hotspot analysis and scenario comparison

Hotspot analysis has been conducted providing a more detailed analysis of individual processes contribution across all indicators. Hotspot analysis aims to highlight processes that are having the most significant impacts for any indicator. These processes, if able to be changed, altered, or removed, are likely to provide the most benefit in reducing impact.

EN15804+A2 indicators are presented in this section. All additional indicators, including TRACI 2.1 indicators, have been analysed and can be found in Annex B

4.2.1. EN15804 Core Environmental Impact Indicators

4.2.1.1 Climate change – Total (GWP-Total)

The main contributors to GWP are shown in Figure 4-1. A1 - Polycarbonate is the most significant contributor (56%) of GWP-total. This is an upstream process representing the production of polycarbonate from vegetable bio-circular feedstock. Fossil fuel derived energy requirements and non-biogenic material use GWP-total contribution is still positive despite having a negative biogenic value associated with the use of vegetable bio-circular feedstock.

The A1-Polycarbonate process incurs a GWP-total emission of 0.901 kg of CO_2.eq per kg of polycarbonate produced. Whereas typical polycarbonate production that does not use waste bio-circular feedstock has a GWP-total emission of 3.5 kg of CO_2.eq per kg of polycarbonate produced (RER: Polycarbonate, Plastics Europe (Sphera, 2022)).

Transport and packaging material have smaller but similar contributions of 8.8% and 19.5% respectively. Transport emissions are from the use of diesel in truck transport mostly from internal NZ transportation, and heavy fuel oil in shipping polycarbonate from Thailand. Packaging material is mostly due to the use of corrugated cardboard.

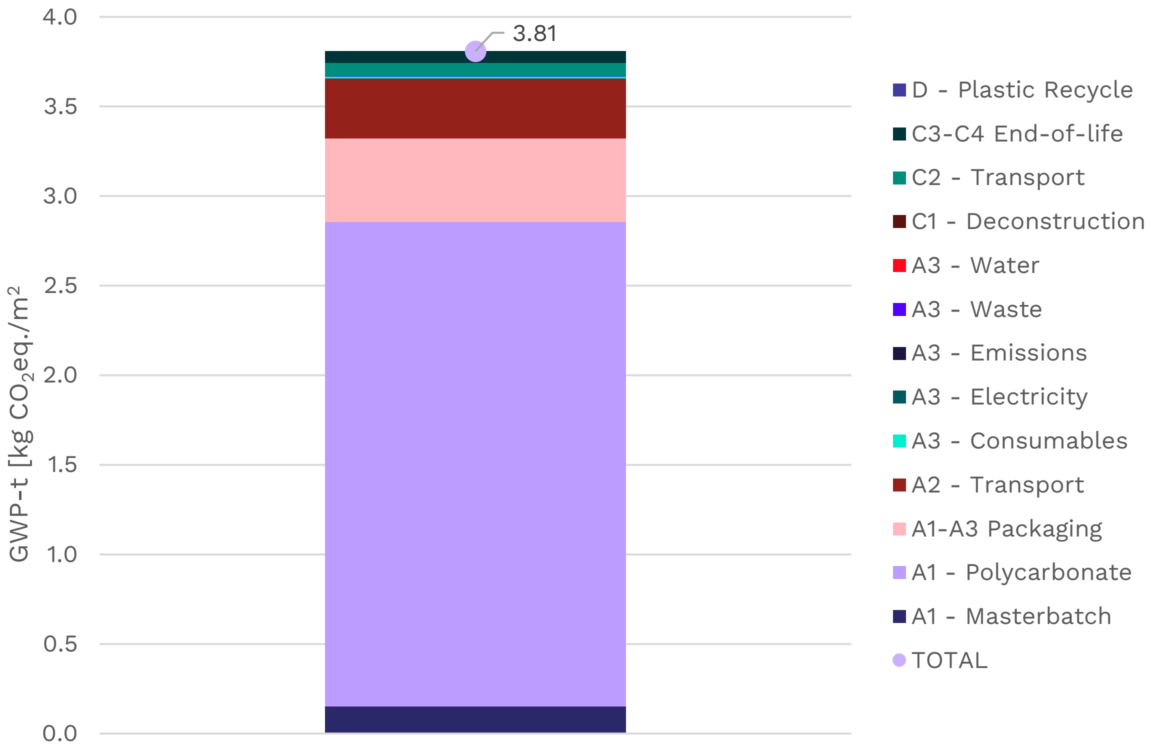


Figure 4-1 - GWP-total impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.2 Climate change – fossil (GWP-Fossil)

Results for GWP-fossil are presented in Figure 4-2. The upstream production of polycarbonate is the largest contributor with 91% of the total impact.

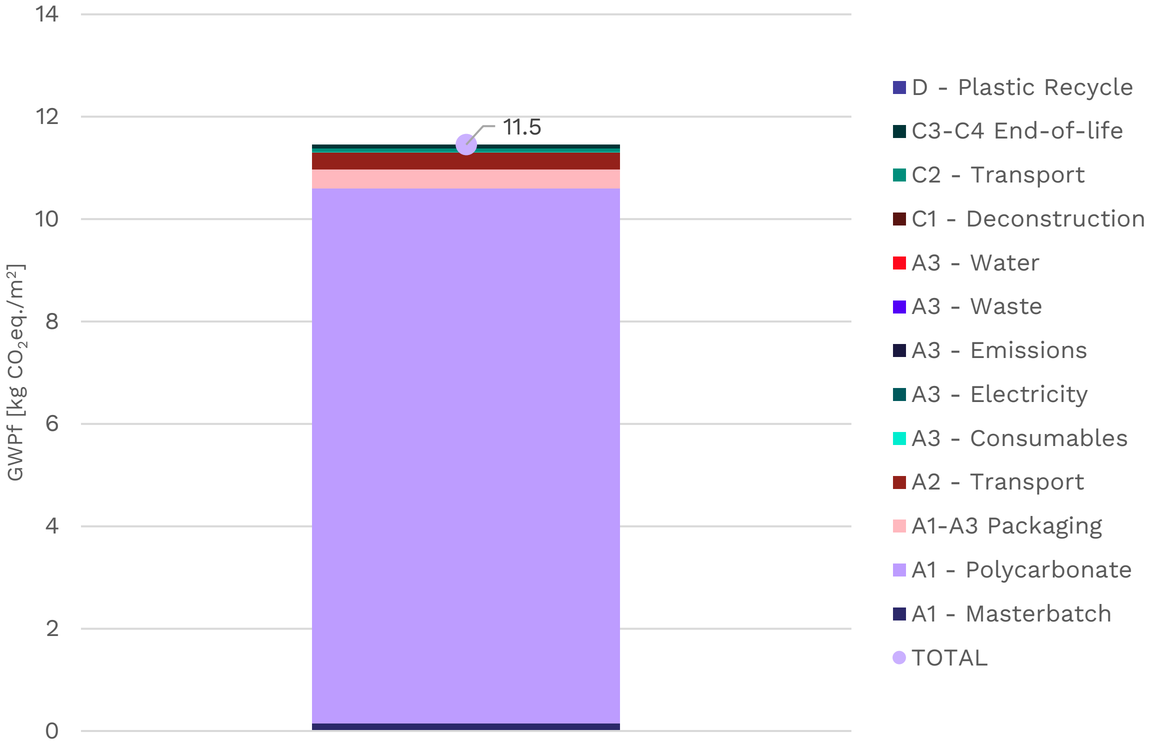


Figure 4-2 - GWP-fossil impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.3 Climate change – biogenic (GWP-biogenic)

GWP-biogenic results (Figure 4-3) is dominated by the use of waste bio-circular feedstock as raw input in the upstream production of polycarbonate.

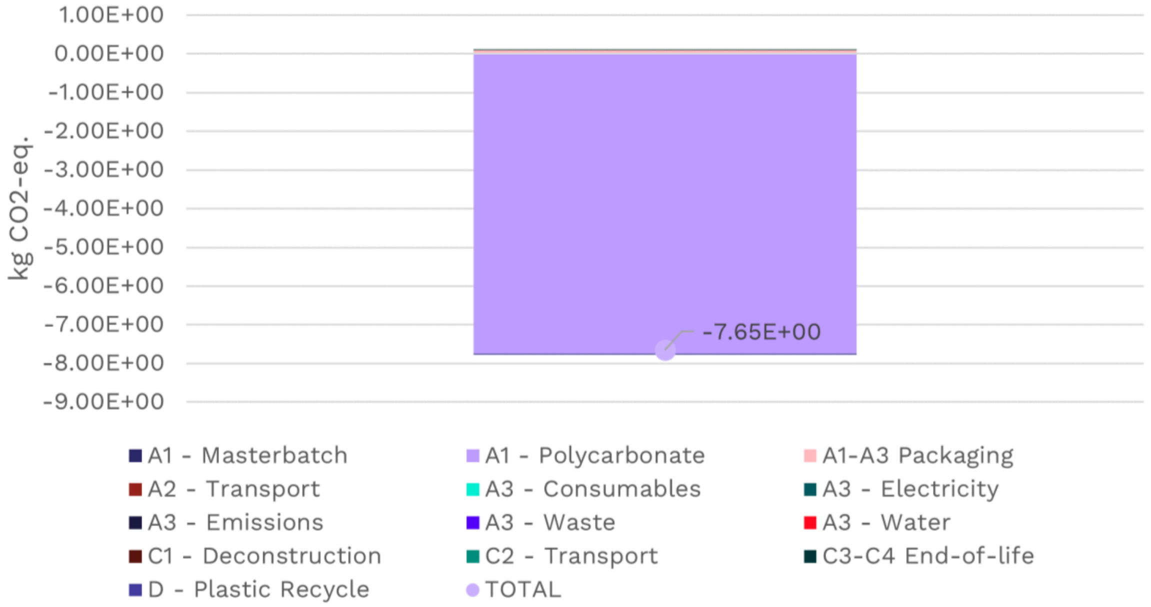


Figure 4-3 - GWP-biogenic impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.4 Climate change – land use and land use change (GWP-luluc)

The upstream process of polycarbonate also has the biggest impact for GWP-luluc. The upstream process of packaging also makes an impact. This is driven by the use of corrugated cardboard derived from forestry land use and land use change impacts.

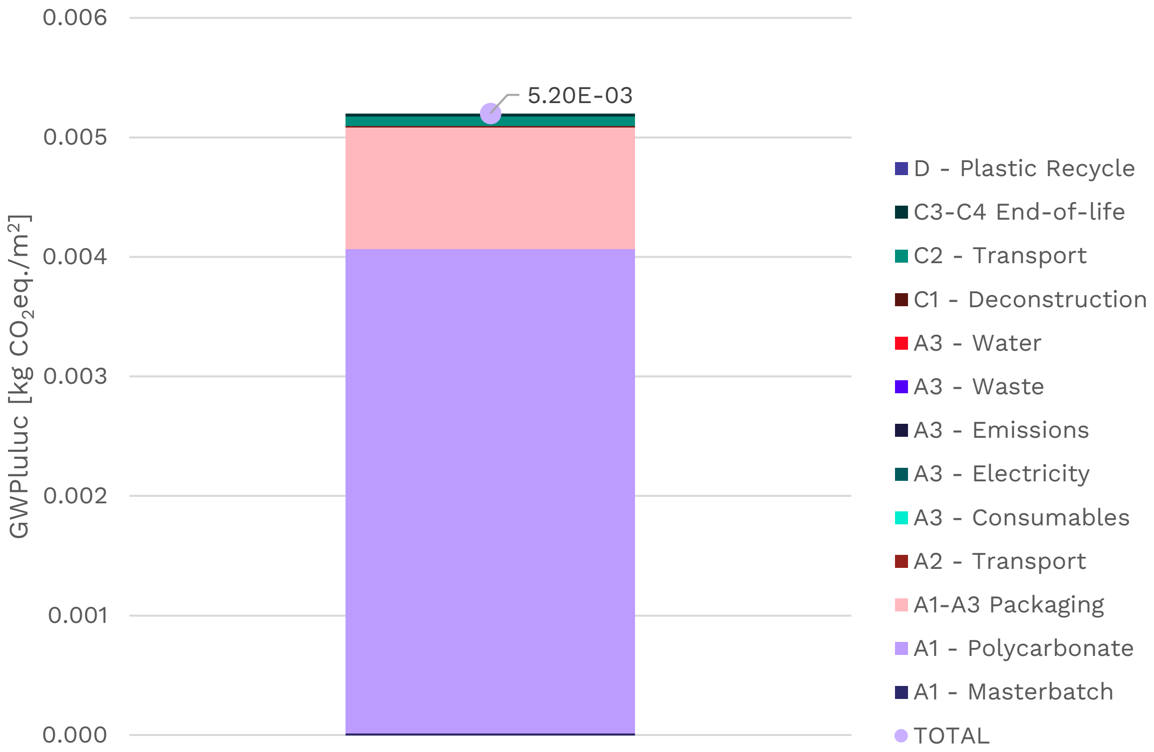


Figure 4-4 - GWP-luluc impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.5 Depletion potential of the stratospheric ozone layer (ODP)

Ozone depletion is generally driven by trace amounts of ozone depletion substances in background datasets.

The main contributors (Figure 4-5) are chemicals, additives associated with polycarbonate production.

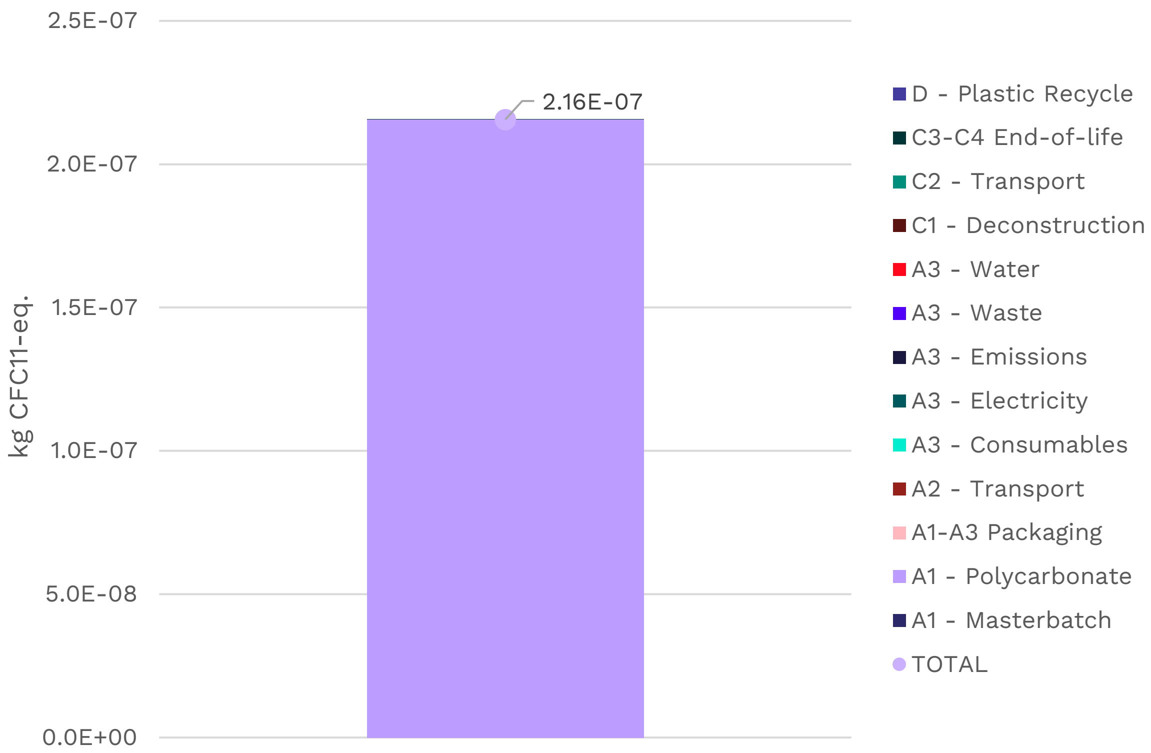


Figure 4-5 – Ozone depletion impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.6 Acidification potential - terrestrial and freshwater

The acidification impacts for RE/8 are shown in Figure 4-6. Acidification is driven by emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) from the combustion of fossil fuels. As expected, polycarbonate production that uses fossil fuels as raw inputs was a significant hotspot. So too was transport where fuel oil and diesel are consumed. Packaging is a minor contributor as fossil fuel derived plastics are used.

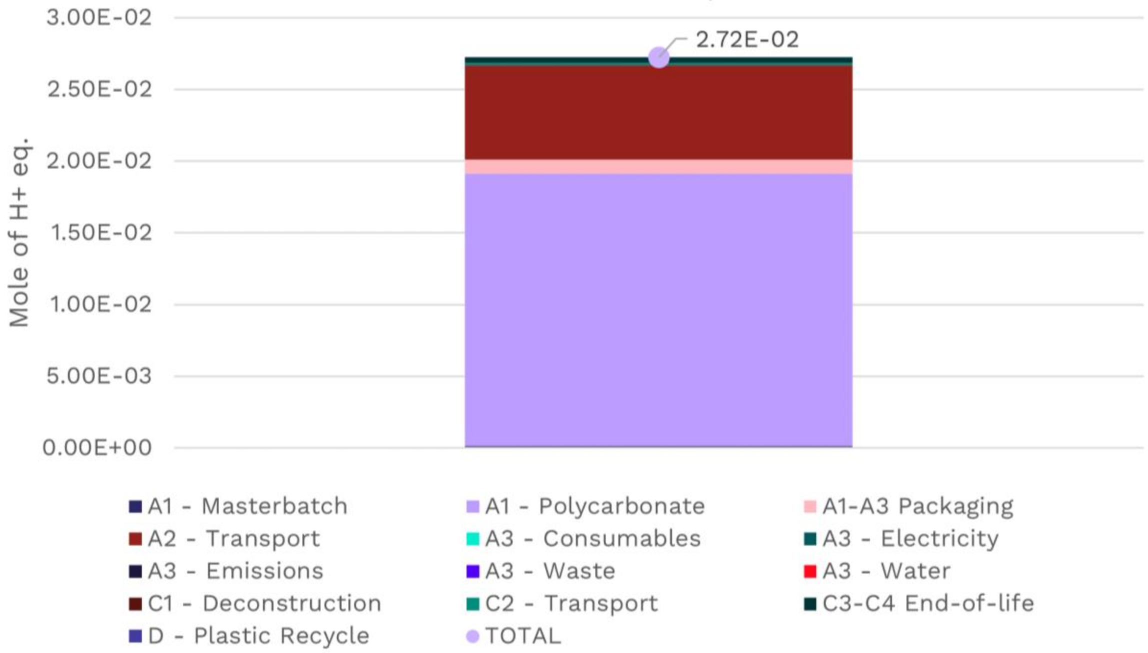


Figure 4-6 – Acidification impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.7 Eutrophication potential - freshwater

Freshwater eutrophication is driven by emissions of phosphorus and phosphate to freshwater, which are both strongly linked to water treatment.

The EP-freshwater impacts are shown in Figure 4-7. The impacts broadly depend on the amount of wastewater emitted when each material input is manufactured. Therefore, as expected the material inputs of polycarbonate and packaging materials (namely carboard) are significant hotspots. There is no water treatment in the A3 manufacturing process as water is a minor input and only used for cooling of the machinery and emitted as water vapour (A3-emissions). Due to the formation of relatively small quantities of leachate associated with the landfilling of RE/8 there is a minor contribution from the C3-C4 – End-of-life process.

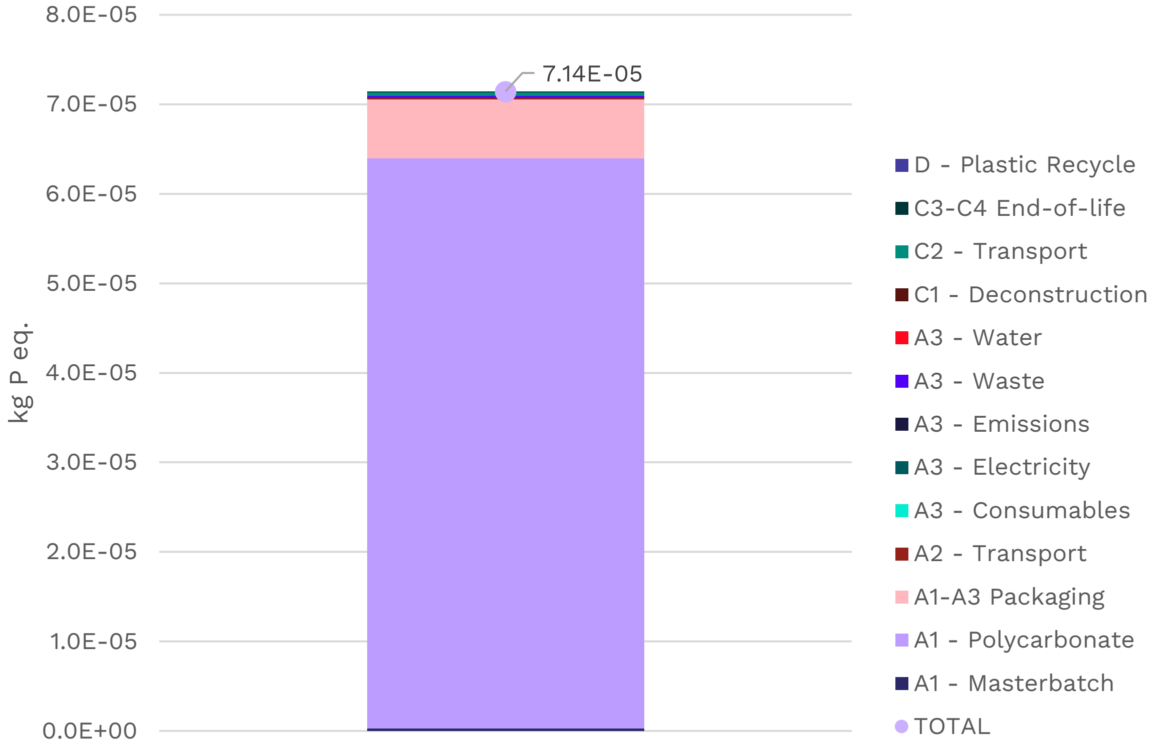


Figure 4-7 – Eutrophication freshwater impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.8 Eutrophication potential – marine

Marine eutrophication is driven by emissions of nitrogen oxides into air, which arise from the combustion of fossil fuels, waste, and emissions of nitrogen to sea water.

Depicted in Figure 4-8 transport, in particular sea transport, has a significant impact. So too A1 – Polycarbonate.

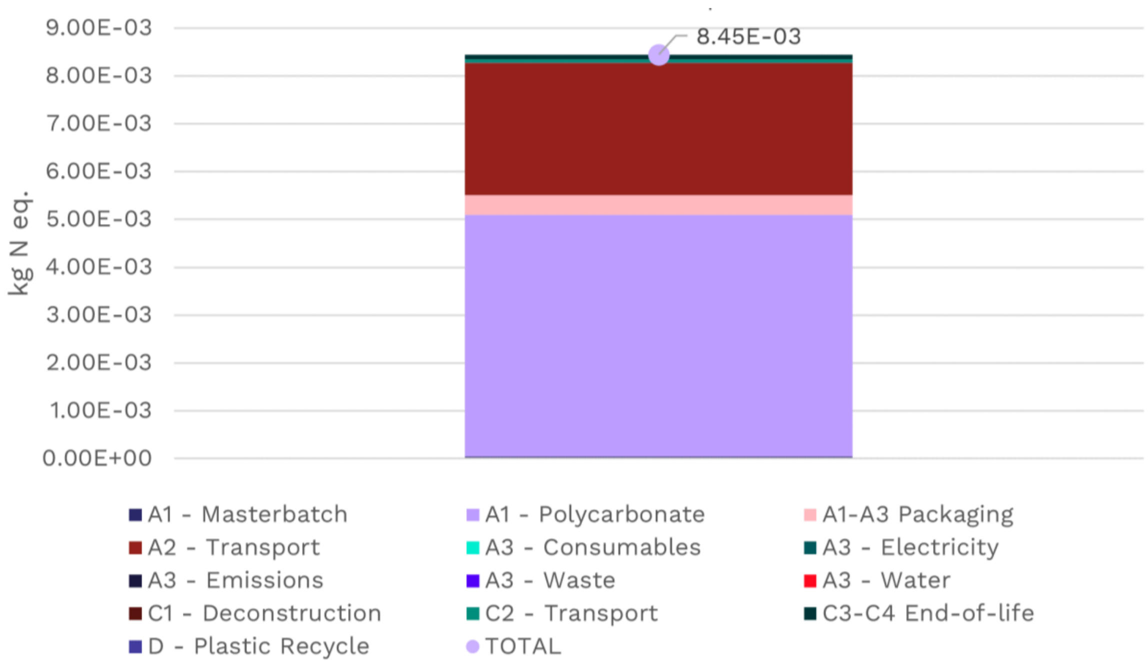


Figure 4-8 – Eutrophication marine impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.9 Eutrophication potential – terrestrial

Terrestrial eutrophication is driven by the emissions of nitrogen oxides and ammonia into air, which arise from the combustion of fossil fuels and waste.

The EP-terrestrial impacts for the product groups are shown in Figure 4-9. As expected, these follow the same trend as for EP-marine, with production impacts again dominated by emissions to air in shipping and polycarbonate manufacturing.

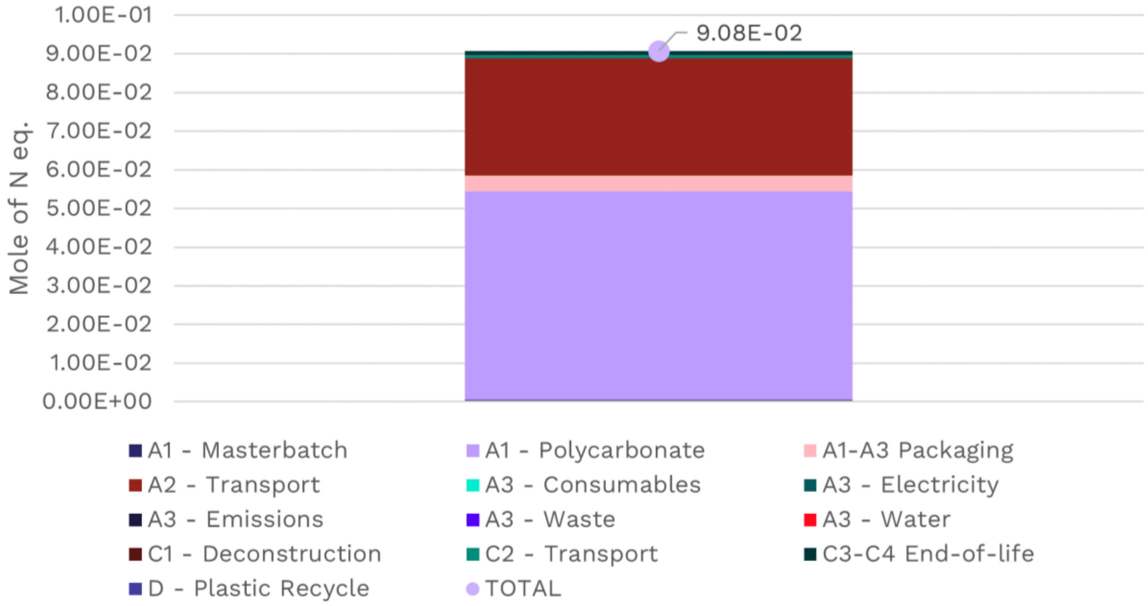


Figure 4-9 – Eutrophication terrestrial impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.10 Photochemical ozone formation potential

Photochemical oxidation formation is driven by emissions of nitrogen oxides, carbon monoxide, and sulphur dioxide, all from fossil fuel combustion. POCP is also influenced by aerosol use and solvent use.

Figure 4-10 shows POCP impacts for the product groups. These follow the same trend as for EP-marine and EP-terrestrial. Production impacts are dominated by fossil fuel use, either directly or in upstream processes.

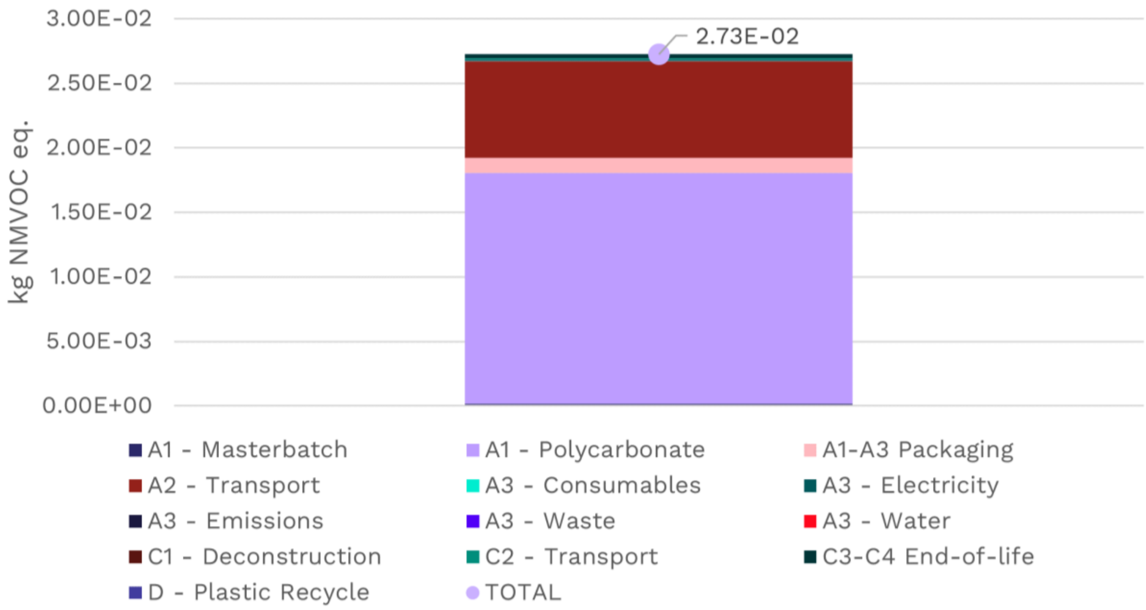


Figure 4-10 – Photochemical ozone formation, human health impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.11 Abiotic depletion potential – minerals & metals

Minerals and metals depletion tends to be driven by the use of rare metals; these are not present in quantities that would interfere with the results of this study.

Figure 4-11 shows the results for all groups. Upstream processes for polycarbonate drive most of the impact in this indicator. Use of significant quantities of electricity and land transport typically drive these processes higher.

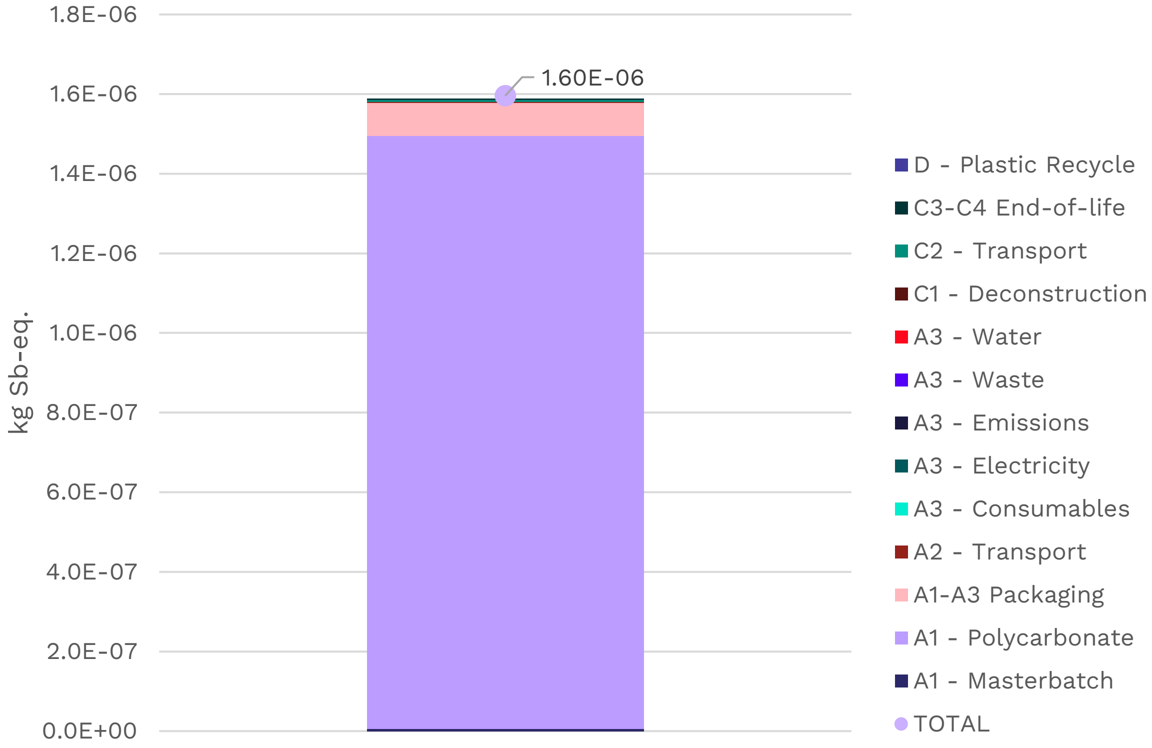


Figure 4-11 – Resource use, minerals and metals impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.12 Abiotic depletion potential – fossil fuels

Abiotic depletion of fossil fuel impacts for the product groups are shown in Figure 4-12.

Polycarbonate manufacturing due to its use of fossil fuels and it being the greatest contributor by mass to the overall product drives this result. Transport and packaging also make minor contributions.

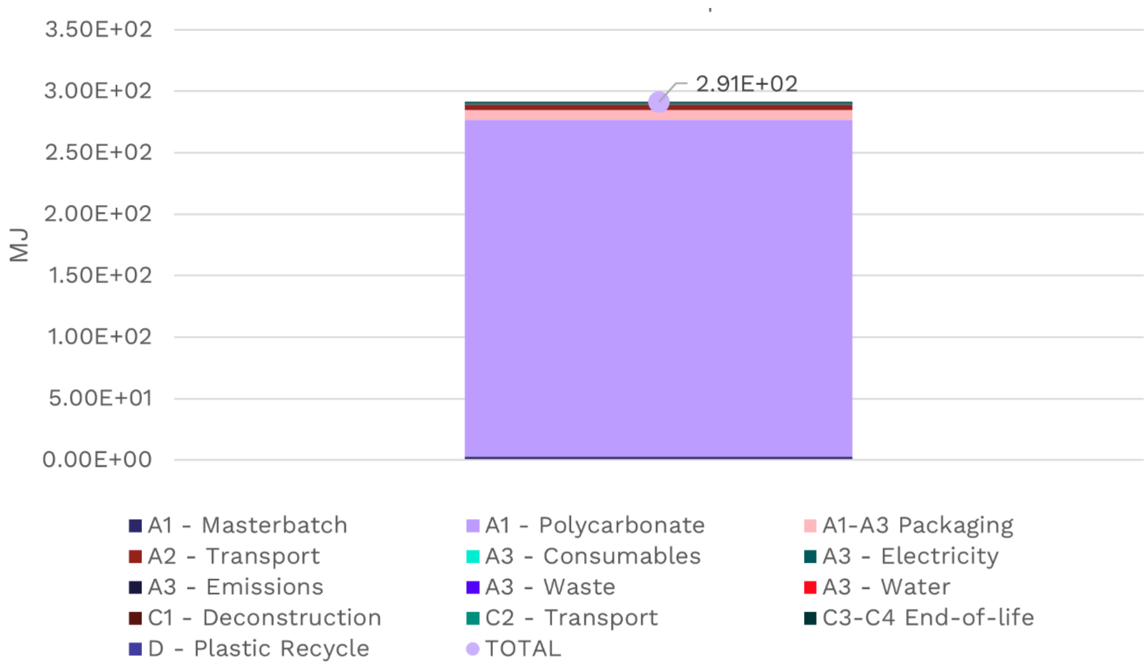


Figure 4-12 – Resource use, fossil impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.13 Water use

The WDP impacts for RE/8 are shown in Figure 4-13. The main hotspots are related to the direct use of electricity and water.

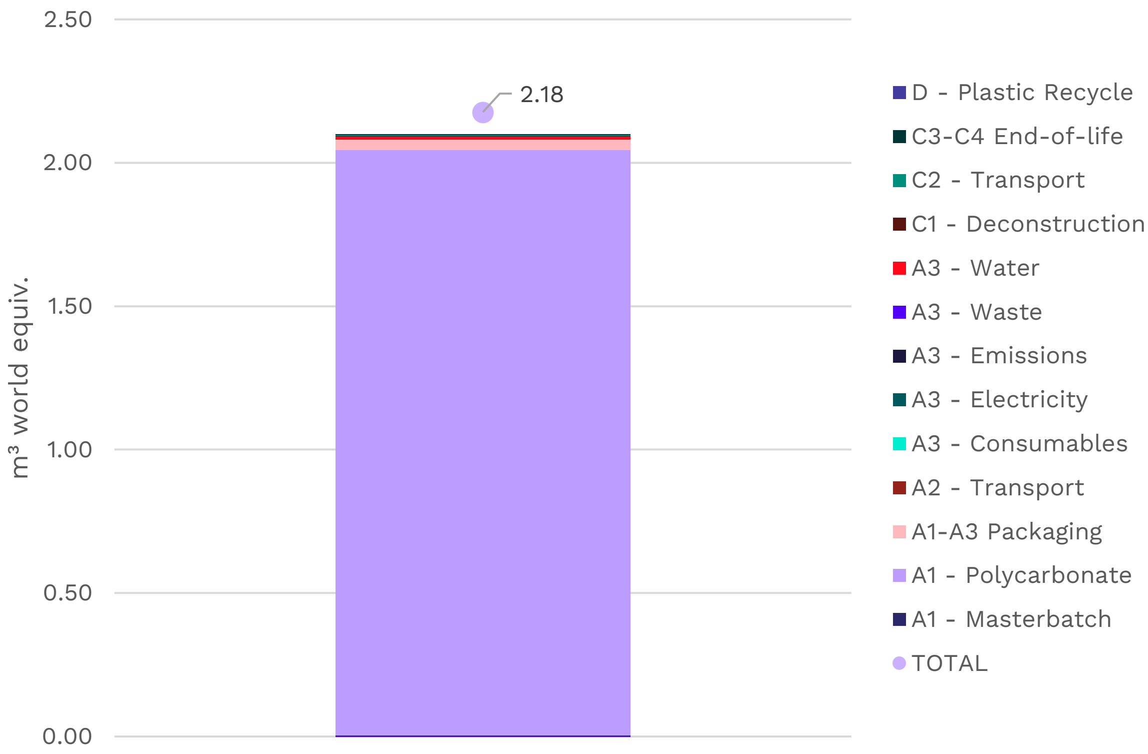


Figure 4-13 – Water use (WDP) for Landfill Scenario – Sequestered (baseline scenario)

4.2.1.14 Biogenic carbon in product and packaging

Table 4-6 shows the amount of biogenic carbon in the product and packaging. Biogenic carbon in the product stems from the use of waste bio-circular feedstock. This was calculated as per section 3.1.2. Biogenic carbon in the packaging is derived from the use of corrugated cardboard.

Table 4-6 Biogenic carbon in product and packaging

Biogenic carbon content	**Unit**	**A1-A3**
Biogenic carbon content – product	kg	2.12
Biogenic carbon content – packaging	kg	0.11

4.2.2. Hotspot analysis – Additional Environmental Impact Indicators

Hotspot analysis has been conducted to identify the processes that contribute to significant impacts.

4.2.2.1 Respiratory Inorganics - Particulate matter

Respiratory inorganics are strongly associated with emissions of dust (PM2.5 and PM10) and sulphur dioxide and nitrogen oxides from the combustion of fossil fuels. PM emissions are also associated with particulates from forestry and timber production.

The PM impacts for the product groups are shown in Figure 4-14. Transport is a significant contributor. Sea transportation in particular drives PM2.5 emissions. It is prevalent in all due to the transportation of polycarbonate from Thailand to New Zealand. Land transportation is also relevant.

The upstream process of corrugated cardboard contributes to PM impact due to emissions associated with board production at the paper mill.

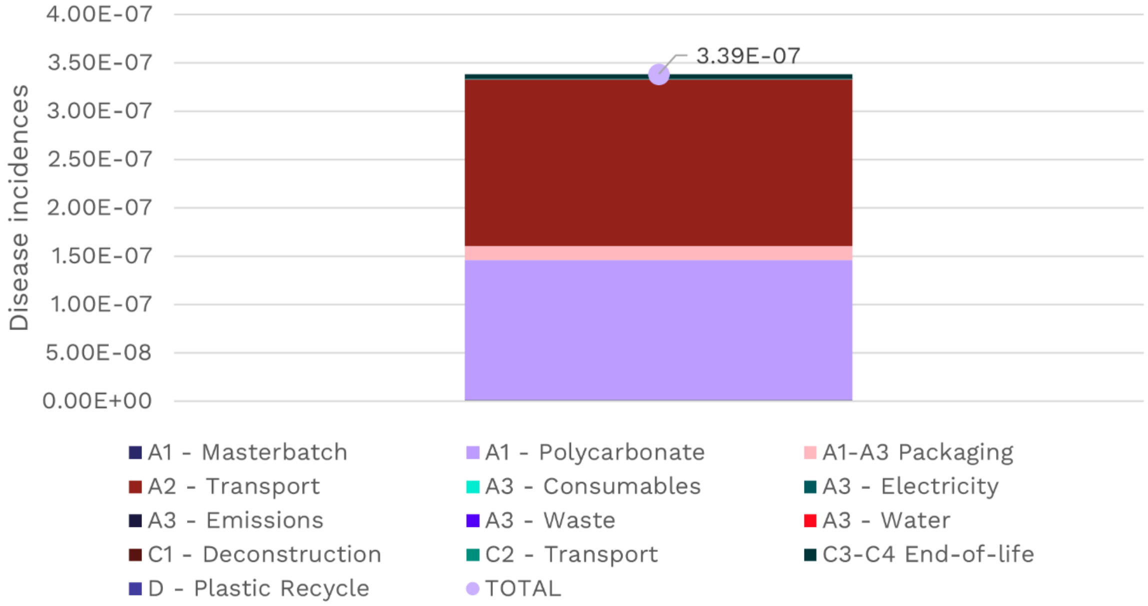


Figure 4-14 – Particulate matter impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.2.2 Ionising radiation

Ionising radiation impacts are associated with radioactive emissions from nuclear energy production. New Zealand or Thailand do not use nuclear energy. The indicator however shows A1-Polycarbonate production having the most IR impacts. This is because the dataset used for polycarbonate manufacturing is a rest of world average not specific for the energy mix of the country of production. As such includes some nuclear energy. This result should always be contextualised in the context of the process being a regional proxy.

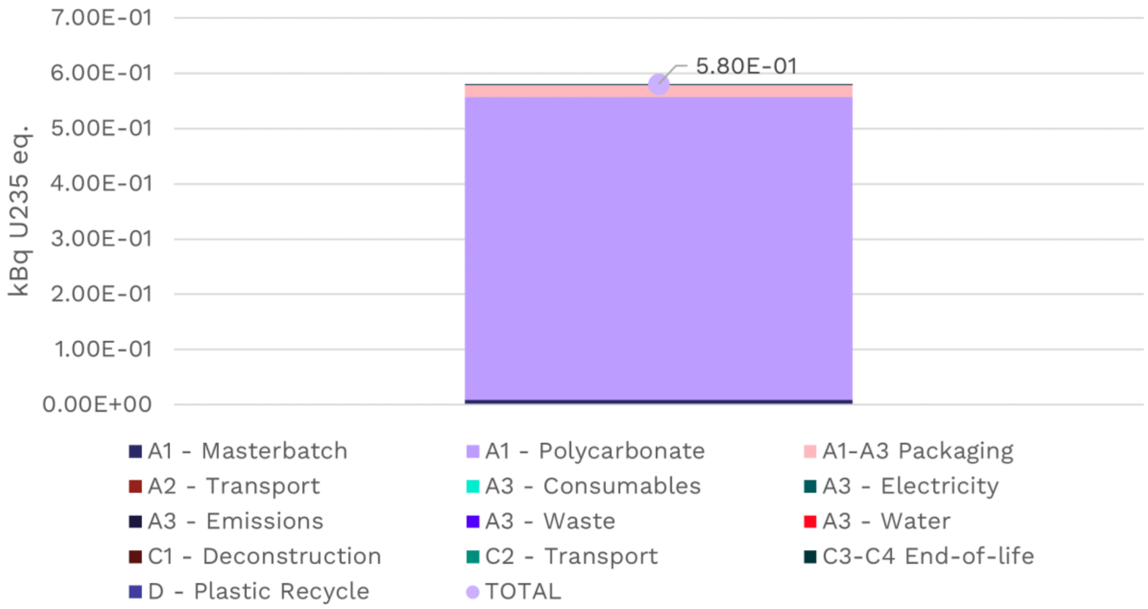


Figure 4-15 – Ionising radiation impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.2.3 Ecotoxicity, freshwater

Ecotoxicity – freshwater impacts are linked to inorganic emissions to fresh water, particularly chloride emissions. Anthropogenic inorganic emissions to freshwater arise from various sources, such as wastewater treatment, chemical fertilisers and road salt.

The ecotoxicity impacts for the product groups are shown in Figure 4-16. Aside from polycarbonate which makes up the 99% of the mass of RE/8. Processes with electricity use in New Zealand has significant impacts due to hydro power's impact on freshwater from direct electricity use.

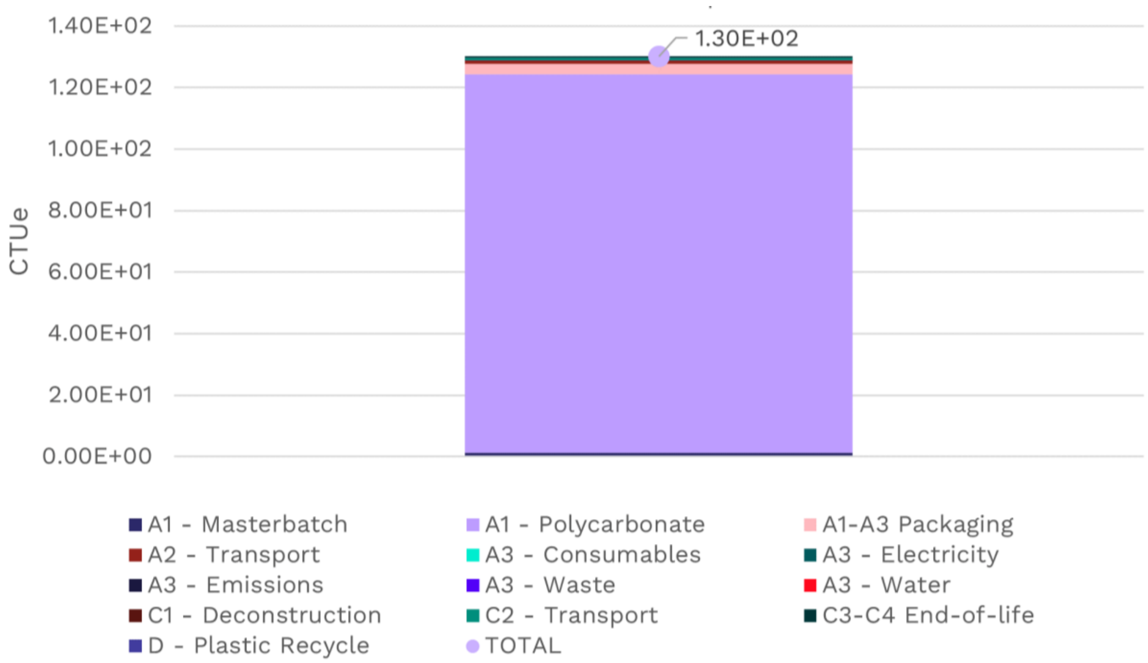


Figure 4-16 – Ecotoxicity freshwater impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.2.4 Human toxicity

Human toxicity, cancer (HTPc) impacts are linked with emissions of heavy metals to air, particularly mercury, NMVOCs to air, and heavy metals to fresh water. These predominantly arise from the combustion of fossil fuels and process emissions.

Human toxicity, non-cancer (HTPnc) impacts are driven by inorganic emissions into air, particularly carbon monoxide, and emission of heavy metals into air, particularly mercury. These predominantly arise from incomplete combustion of fossil fuels and from process emissions.

The HTPc and HTPnc impacts are shown in Figure 4-17 and Figure 4-18 respectively, follow similar trends.

RE/8 has significant impacts from upstream production of polycarbonate.

Other discernible hotspots in HTPnc are the colourant additive in the A1 – Masterbatch, additives in the packaging manufacturing and leachate released in landfill.

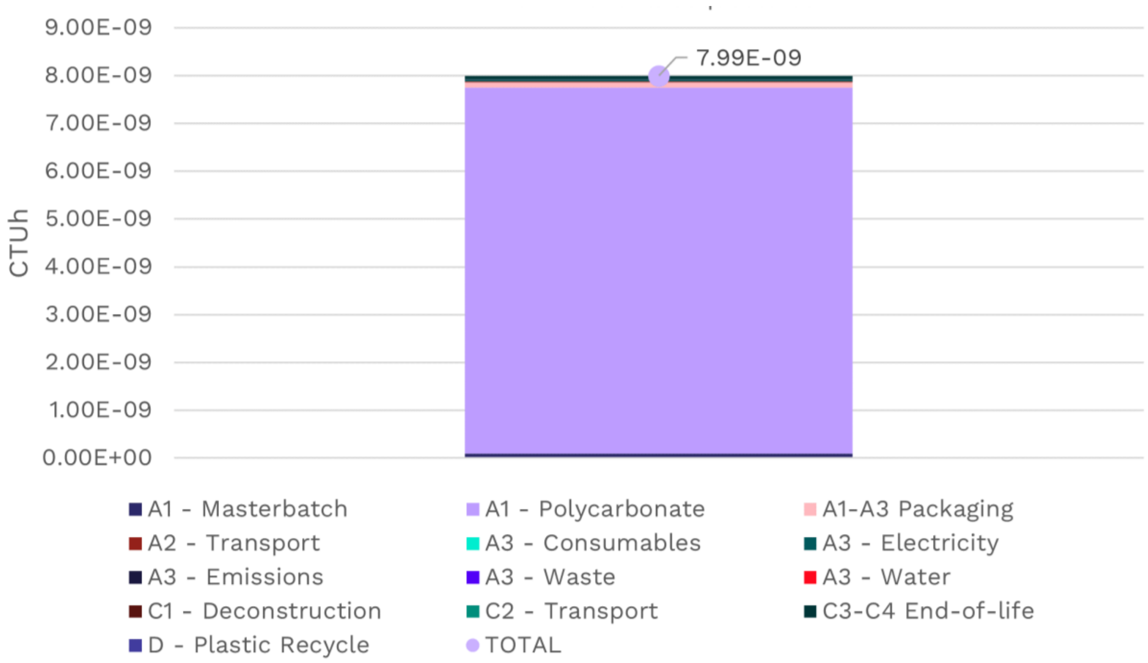


Figure 4-17 – Human toxicity cancer impacts for Landfill Scenario – Sequestered (baseline scenario)

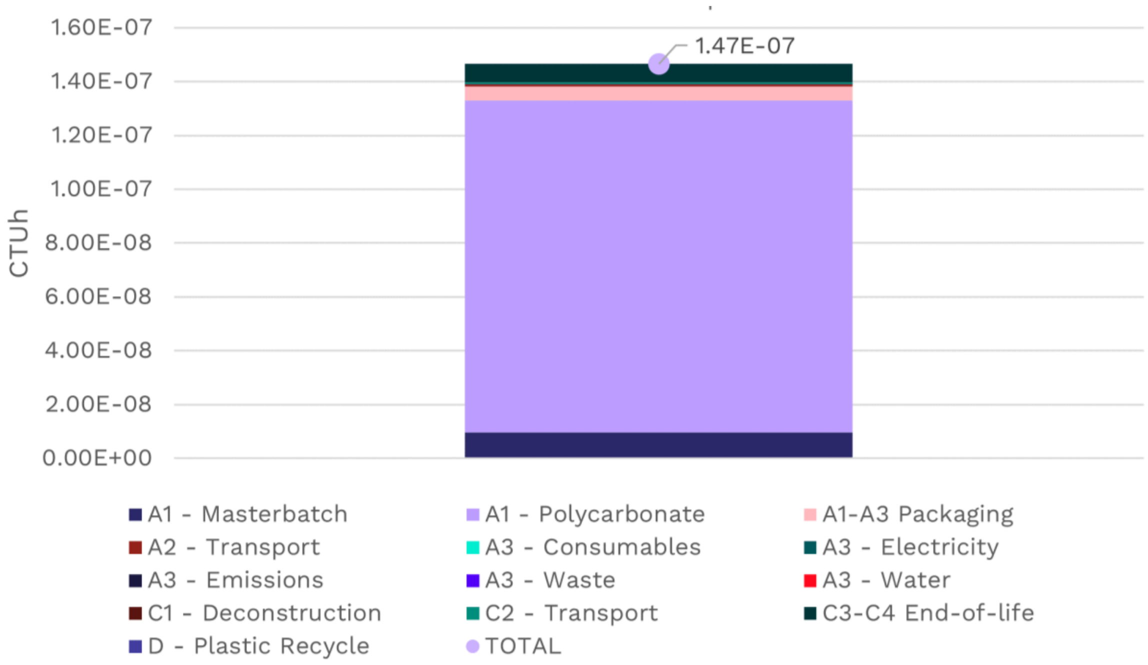


Figure 4-18 – Human toxicity non-cancer impacts for Landfill Scenario – Sequestered (baseline scenario)

4.2.2.5 Land use

The Land use impacts for the product groups are shown in Figure 4-19The impacts are mostly derived from direct land use in upstream operations. Cardboard manufacturing as part of the packaging having the majority of the impact. Polycarbonate manufacturing the next significant.

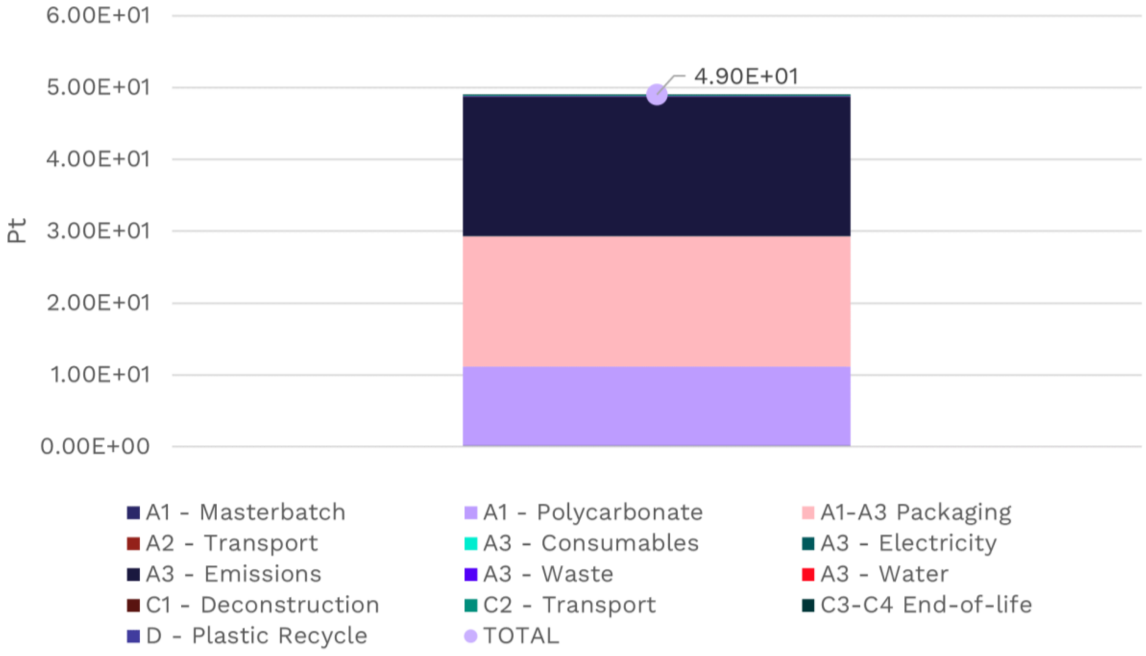


Figure 4-19 – Land use impacts for Landfill Scenario – Sequestered (baseline scenario)

4.3. Scenario Analysis

Scenario analyses compare results between discrete sets of parameter settings or model choices. As described in Section 3.2.5 three different end-of-life scenarios were studied; Landfill – Scenario Sequestered (Baseline), Landfill Scenario – EN15804 and Recycling Scenario.

Landfill Scenario EN15804 has a GWP-total of 11.6 kg of CO_2.eq/m^2. This is higher than the baseline result as the requirements of EN15804 necessitate the release of all biogenic carbon when a material's end-of-life is landfill.

Recycling Scenario has a GWP-total including Module D of 4.99 kg of CO_2.eq/m^2. Note EPD results declare only A1-C4 with Module D as a separate value. This scenario necessitates the release of all biogenic carbon as CO_2. However, the system gains credit for displacing virgin polycarbonate made from fossil fuel derived material. The GWP-total result is slightly more than the baseline scenario as the recycling process is not 100% efficient i.e. not all the polycarbonate is recycled. It follows a rate of 1.17 kg of waste polycarbonate input to 1 kg of recycled polycarbonate for new product. There is also greater transport required to get the waste to the recycling facility where it becomes a new product.

Figure 4-20, Figure 4-21, and Figure 4-22 illustrates the differences in the scenarios. The baseline scenario incurs the lowest GWP-total impact. *Scenario – Recycling* incurs the second lowest impact even though biogenic carbon is released in full. This is because it gains credit for the recycling of polycarbonate. This scenario shows the potential benefit of a recycling scheme for RE/8. Though if recycling of polycarbonate becomes mainstream. Reducing the use of fossil fuel inputs in polycarbonate production as more recycled content is included. It may reduce the effect of the credit as less virgin material is displaced.

Scenario-EN15804 shows the potential impact of the artificial release of biogenic carbon. This scenario attracts the largest GWP-total impact. Nearly three times greater than the baseline scenario modelled using the same disposal method.

Table 4-7 GWP results – Landfill Scenario EN15804

Indicator	Abbreviation	Unit	Module			
			A1-A3	C1-C4	Total (A1-A3, C)	D
Global warming potential	GWP-total	kg CO_2-eq.	3.67	7.93	11.6	0
Global warming potential (fossil)	GWPf	kg CO_2-eq.	11.3	0.137	11.5	0
Global warming potential (biogenic)	GWPb	kg CO_2-eq.	-7.65	7.79	0.142	0
Global warming potential (land use change)	GWPluc	kg CO_2-eq.	5.09E-03	1.07E-04	5.20E-03	0

Table 4-8 GWP results – Recycling Scenario

Indicator	Abbreviation	Unit	Module			
			A1-A3	C1-C4	Total (A1-A3, C)	D
Global warming potential	GWP-total	kg CO2-eq.	3.67	10.3	13.97	-9.01
Global warming potential (fossil)	GWPf	kg CO2-eq.	11.3	2.51	13.81	-8.97
Global warming potential (biogenic)	GWPb	kg CO2-eq.	-7.65	7.81	0.16	-0.03
Global warming potential (land use change)	GWPluc	kg CO2-eq.	5.09E-03	1.76E-03	6.85E-03	-3.48E-03

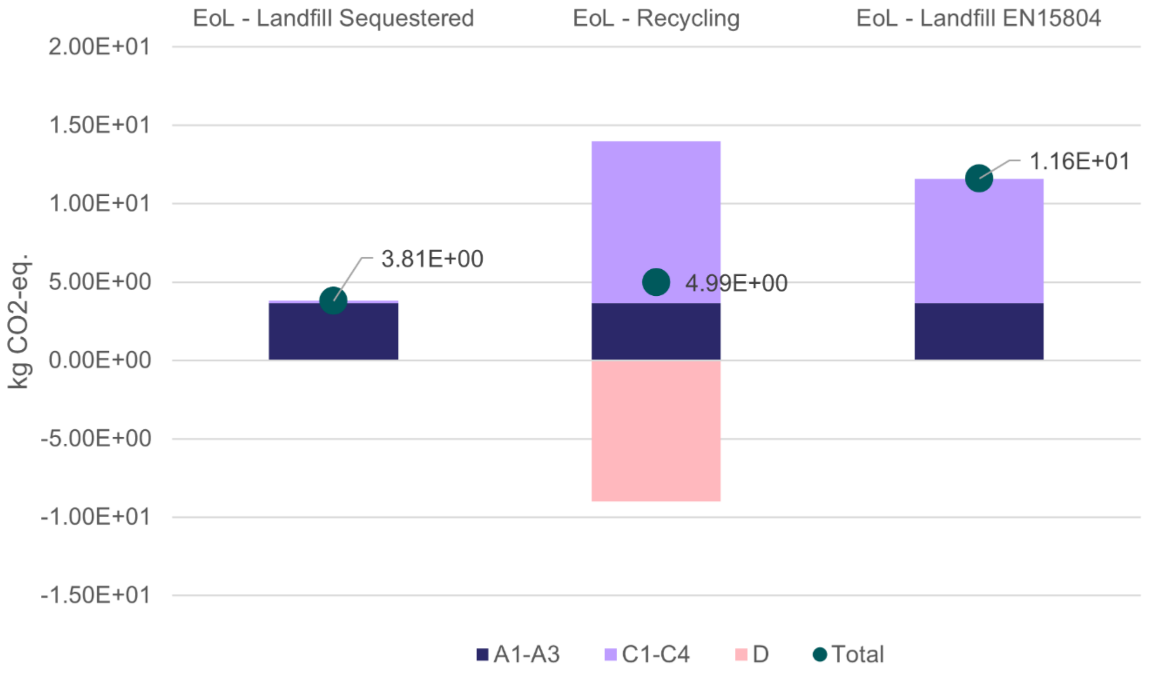


Figure 4-20 – GWP-total results, all scenarios

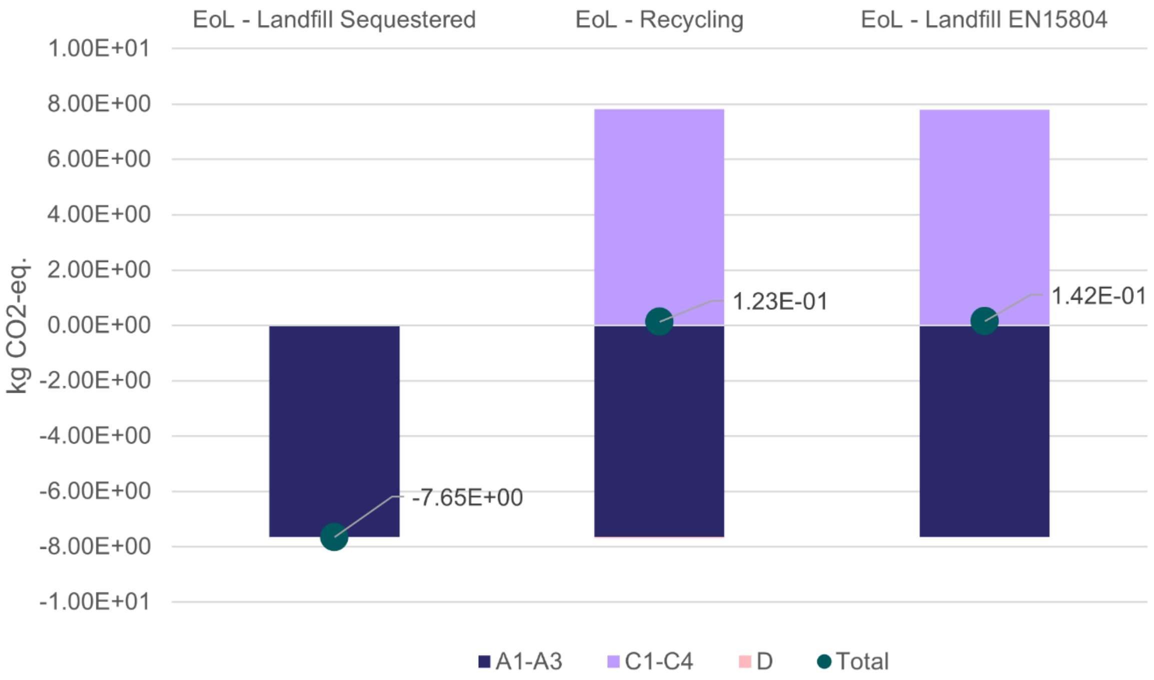


Figure 4-21 – GWP-biogenic results, all scenarios

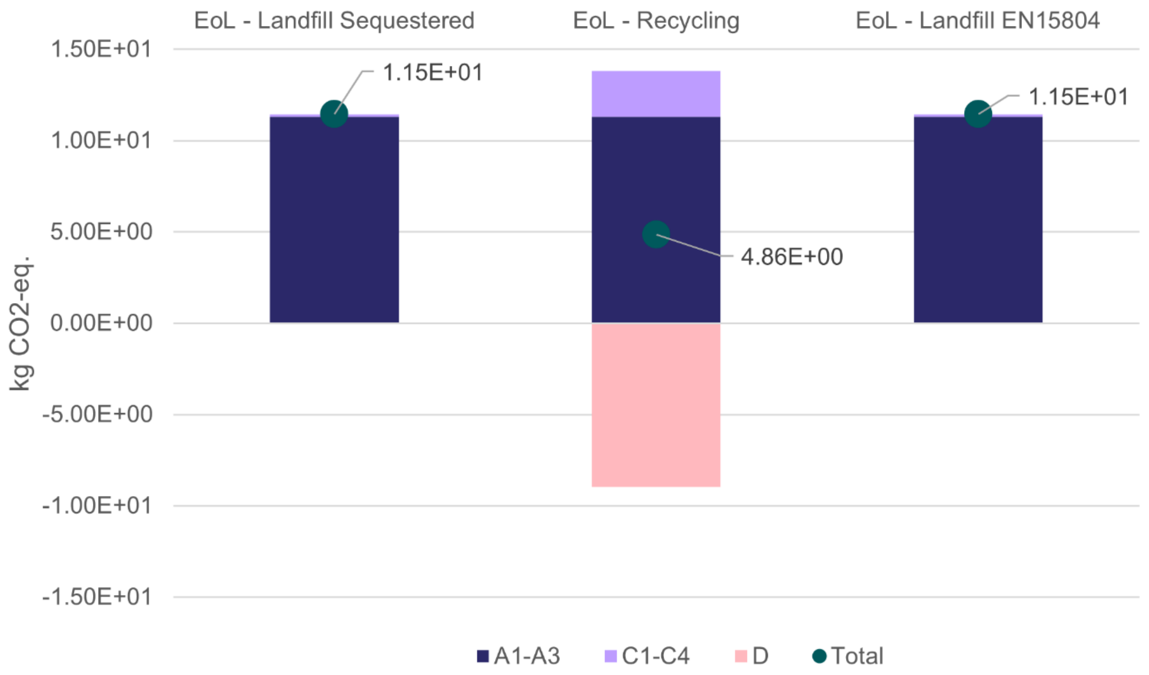


Figure 4-22 – GWP-fossil results, all scenarios

4.4. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the MLC database were used. The LCI datasets from the MLC database are widely distributed and used with the LCA FE Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

4.5. Representativeness

- **Temporal:** All primary data were collected for the year 1.4.2022 ending 31.3.2023. All secondary data come from the MLC databases and are representative of the years 2016-2019. As the study intended to compare the product systems for the reference year 2022, temporal representativeness is considered to be good.

- **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used that was average data from an area with similar production conditions e.g. polycarbonate production. Geographical representativeness is considered to be fair.

- **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used this is the case for the polycarbonate manufacturing process whereby no existing data on the use of waste bio-circular feedstock as a feedstock was available. Technological representativeness is considered to be good.

4.6. Proxy data

Proxy data was used to model the upstream process of polycarbonate pellet production. This process as shown in section 4.2 has a significant impact on most of the indicators. Using GWP-total as an example the proxy dataset contributes 71% of the total value. Therefore, it warrants close detailing of the qualitative decisions for its use.

As per section 2.8 the polycarbonate proxy data has been chosen as it is an industry-average dataset. It has good representation of the technology and process involved in making polycarbonate. The supplier of polycarbonate contributing data directly to create the dataset. Some limitation exists as the technology uses fossil derived feedstock, largely natural gas, and not waste bio-circular feedstock. Though a more technologically representative dataset was not available.

The supplier of polycarbonate producing the pellets is in Thailand, therefore the geographical representativeness does not match the European dataset. However, no alternative datasets were able to improve the geographical representativeness.

The temporal representativeness of the polycarbonate proxy data is considered fair. More up to date datasets exist though they would lower the technological and geographical representativeness values.

The use of polycarbonate proxy data is a limitation of this study. Where primary data or more representative datasets become available, it should be used in its place.

4.7. Precision and Completeness

- **Precision:** The majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology. Kaynemaile uses internal monitoring equipment during manufacturing and validates with financial and project cost of goods sold (COGS) reporting. Their material tracking system has been independently audited and passed during certification by International Sustainability and Carbon Certification Plus. Variations across different manufacturers were balanced out by using yearly averages. All background data are sourced from MLC databases with the documented precision. Precision is considered to be high.
- **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from MLC databases with the documented completeness.

4.8. Consistency and Reproducibility

- **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the MLC databases.
- **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

4.9. Model Completeness and Consistency

4.9.1. Completeness

All relevant process steps for each product system were considered and modelled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

4.9.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimised by exclusively using LCI data from the MLC databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5. Interpretation

5.1. Identification of Relevant Findings

- The upstream manufacturing of polycarbonate is the most influential process for most indicators including GWP-total, and a hotspot in all indicators.
- Packaging, namely the corrugated cardboard, is a hotspot for a number of indicators including GWP-total.
- Transport is also a hotspot in GWP-total as well as eutrophication-marine and photochemical ozone formation potential. Transport impacts for GWP-total could be reduced by lowering the amount of truck kilometres perhaps by exploring the use of ports near to Wellington.
- The use of waste bio-circular feedstock as a feedstock in the polycarbonate process reduces the GWP-total by just over 7 kg of CO_2.eq/m^2.

5.2. Assumptions and Limitations

- It has been assumed that the vegetable bio-circular feedstock displaces crude oil in the manufacturing of Naphtha which is then steam cracked into benzene and propylene. This assumption may be further refined into the future as the supplier provides additional manufacturing date specific to the waste bio-circular feedstock process.
- Biogenic carbon in the product has been calculated using mass balance methodology provided by the polycarbonate supplier. The scientific basis for this method has not been verified by thinkstep-anz as it sits outside our area of expertise. The method has been verified by ISCC PLUS (Covestro, 2023).
- The mass balance approach is not a recognised method by International EPD programme and its regional partners. This study is therefore limited to other environmental declaration programmes.
- This study relies on proxy data for the polycarbonate production process. All effort has been made to ensure this dataset is representative. Sourcing primary data direct from upstream suppliers would assist in improving data representativeness.
- Transport distances to waste processing and disposal from demolition site are assumed. This assumption is unlikely to make significant impacts on the overall results given transport is not a critical contributor to the carbon footprint.

5.2.1. Scenario Analysis

- Scenario analysis was performed to compare results between different end-of-life options.
- As described in Section 3.2.5 three different end-of-life scenarios were studied; Landfill – Scenario Sequestered (Baseline), Landfill Scenario – EN15804 and Recycling Scenario.
- *Landfill Scenario EN15804* has a GWP-total of 12.1 kg of CO_2.eq/m^2. This is higher than the baseline scenario as the requirements of EN15804 necessitate the release of all biogenic carbon when a material's end-of-life is landfill.
- *Recycling Scenario* has a GWP-total of 4.99 kg of CO_2.eq/m^2 (including Module D – which is reported separately in EPDs). This scenario also necessitates the release of all

biogenic carbon as CO_2. However, the system gains credit for displacing virgin polycarbonate made from fossil fuel derived material. The GWP-total result is slightly more than the baseline scenario as the recycling process is not 100% efficient i.e. not all the polycarbonate is recycled. It follows a rate of 1.17 kg of waste polycarbonate input to 1 kg of recycled polycarbonate for new product.

- End-of-life scenarios show that different methods of accounting for biogenic carbon and recycling credits can significantly alter the results of GWP-total. It is important when communicating GWP-total values that the end-of-life biogenic accounting method is clearly stated to avoid misleading statements (i.e. green washing). If seeking an EPD, LEED or other form of environmental certification the method of biogenic accounting must match the certification method.

5.3. Conclusions, Limitations, and Recommendations

5.3.1. Conclusions

This study assessed the life cycle of Kaynemaile 's exclusive polycarbonate mesh product. The study is conducted according to the requirements of ISO14040 and ISO14044 (ISO, 2006b; ISO, 2006a). It has provided a detailed critically reviewed report that assess the products environmental impacts, particularly for GWP-total.

The Kaynemaile product has a GWP-Total of 3.67 kg of CO_2eq per m^2 of product. The use of biogenic derived waste bio-circular feedstock in place of fossil-fuel based inputs like naphtha is responsible for keeping the result low. The A1-Polycarbonate process incurs a GWP-total emission of 0.901 kg of CO_2.eq per kg of polycarbonate produced. Whereas typical polycarbonate production that does not use waste bio-circular feedstock has a GWP-total emission of 3.5 kg of CO_2.eq per kg of polycarbonate produced (RER: Polycarbonate, Plastics Europe (Sphera, 2022)).

Further reduction to GWP-Total could come from reducing truck transport distances, reducing the mass of packaging or seeking alternative packaging options, and continuing to support innovative polycarbonate processes that reduce or replace the need for fossil based raw inputs.

End-of-life scenarios assess the different methods of accounting for biogenic carbon and recycling credits showing they can significantly alter the results of GWP-total. This should be considered carefully when looking at any future LCA certification method.

It may be appropriate when presenting the environmental impacts of RE/8 to a USA audience to use TRACI2.1 indicator values. TRACI 2.1, Global Warming Air, incl. biogenic carbon result was 3.30 kg of CO_2eq per m^2 of product.

5.3.2. Limitations

This study does not allow for comparisons between different brands or types of polycarbonate producing systems. This study is specific to the system and technology studied, based on the collected data, literature and assumptions (as noted) and is not necessarily transferrable to other markets or geographies. Future changes in technology and may result in these results becoming out of date.

5.3.3. Recommendations

- The study could be improved by gathering detailed data from the polycarbonate provider relevant to the production site. Such data would enable localised modelling of this key input including a greater understanding of the impacts of using waste bio-circular feedstock. Ideally, data would be detailed enough to produce a site specific or product specific LCA made publicly available e.g. an EPD. This will help to overcome the potential impact of proxy data and the current assumption of waste bio-circular feedstock replacing crude oil in the manufacturing of naphtha and. This assumption is considered to be conservative as waste bio-circular feedstock is likely to require less processing than crude-oil to form naphtha.
- Continue to support innovations that lower polycarbonate impacts. Promoting greater use of recycled biogenic based materials as input and investigate methods that lower the use of fossil fuel inputs in the polycarbonate production line.
- Assess the transport of raw polycarbonate material to Wellington. Transport by truck distances in particular should be a focus, in general shipping emissions are lower than truck movements. Therefore, if viable it will be better to have polycarbonate material shipped closer to the Kaynemaile manufacturing facility.
- Review the packaging of RE/8 and where possible reduce the mass of packaging material used.
- Consider applying for a Leadership in Energy and Environmental Design (LEED) or developing Environmental Product Declaration (EPD).

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Abbreviations and glossary

Term	Definition
ADP	Abiotic Depletion Potential
AP	Acidification Potential, Accumulated Exceedance
CEN	European Committee for Standardization
CML	Centre of Environmental Science at Leiden
DOCf	Degradable Organic Carbon Fraction
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
ETP	Potential Comparative Toxic Unit for ecosystems
ff	fossil fuels
fw	fresh water
GHG	Greenhouse Gas
GWP	Global Warming Potential (Climate Change)
HTP	Potential Comparative Toxic Unit for humans
ISC	Infrastructure Sustainability Council
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCA FE	Life Cycle Assessment for Experts (software)
luluc	Land use and land use change
MLC	Managed LCA Content database
NMVOC	Non-Methane Volatile Organic Compound
NZ	New Zealand
ODP	Depletion potential of the stratospheric ozone layer
PM	Potential incidence of disease due to PM emissions
POCP	Formation potential of tropospheric ozone
RSL	Reference service life
VOC	Volatile Organic Compound
WDP	Water (user) deprivation potential, deprivation-weighted water consumption

Glossary

Life cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life cycle interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Environmental Product Declaration (EPD)

"Independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products."

Product Category Rule (PCR)

"Defines the rules and requirements for EPDs of a certain product category."

Functional / Declared unit

"Quantified performance of a product system for use as a reference unit." (ISO 14040:2006, section 3.20)

Functional unit = LCA/EPD covers entire life cycle "cradle to grave".

Declared unit = LCA/EPD is not based on a full "cradle to grave" LCA, common in construction product EPDs.

Allocation

“Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006, section 3.17)

Foreground system

“Those processes of the system that are specific to it … and/or directly affected by decisions analysed in the study.” (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

“Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good.…” (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Closed-loop and open-loop allocation of recycled material

“An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.”

“A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.”

(ISO 14044:2006, section 4.3.4.3.3)

Critical Review

“Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment” (ISO 14044:2006, section 3.45).

Applicability and limitations

Restrictions and intended purpose

This report has been prepared by thinkstep-anz with all reasonable skill and diligence within the agreed scope, time and budget available for the work. thinkstep-anz does not accept responsibility of any kind to any third parties who make use of its contents. Any such party relies on the report at its own risk. Interpretations, analyses, or statements of any kind made by a third party and based on this report are beyond thinkstep-anz's responsibility.

If you have any suggestions, complaints, or any other feedback, please contact us at: feedback@thinkstep-anz.com

Legal interpretation

Opinions and judgements expressed herein are based on our understanding and interpretation of current regulatory standards and should not be construed as legal opinions. Where opinions or judgements are to be relied on, they should be independently verified with appropriate legal advice.

Annex A Confidential data

See attached file – ts-ZP103024-Kaynemaile-Appendix A-LCI Data-v1.0.xlsx

Annex B Results detailed

See attached file – ts-ZP103024-Kaynemaile-Appendix Appendix B_EN15804+A2_Results_Indicators v1.0.xlsx

Annex C Critical Review Statement

Dialogue between external critical reviewer and LCA owner during the critical review process

REVIEWED DOCUMENT, VERSION: Kaynemaile RE/8 Architectural Mesh Life Cycle Assessment Background report, V.02rA.(September 2023).

Critical Review (CR) Iteration Number: 2

AUTHOR OF THE LCA STUDY; FILIATION: Joel Edwards, Senior Sustainability Specialist; Thinkstep Ltd, NZ
SUBMISSION DATE: 2023-09-27

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CR submission date: 2023-09-29

NO	CHAPTER, PAGE(1), ARTICLE, PARAGRAPH, TABLE	TYPE OF COMMENT*	REFERENCE DOCUMENTS	CRITICAL REVIEW (CR) COMMENT AND RECOMMENDATION	LCA TEAM ANSWER	FINAL CR STATEMENT
1	Page 9, section 1 Pages 70 and 74 (conclusions)	Ge	ISO	*"…detailed critically reviewed report that demonstrates its environmental impacts"* Change this to: …shows (or assess) its potential environmental impacts **CR2:** Ok page 9 However, the same sentence is included in the Conclusion page 70. Please correct this as well; Also in page **74**: "*It has provided a detailed critically reviewed report that demonstrates the products environmental impacts, particularly for GWP-total.*" This is not according to ISO as the results are relative expressions and do not predict the actual impacts. You must re-phrase it in a way that reflects that you assessed the potential environmental impacts. If there is any other expression of this type in the Report, please correct it as well.	Cheers – actioned	**Correct this in the final version of the LCA Report**
2	Page 10, section 2.1	Te	EN15804	Remove "Functional or"	Cheers – actioned	Ok
3	Page 10, section 2.1	Te	EN15804	DU: Include a conversion factor to kg *[For the development of scenarios, for example for transport and disposal, conversion factors to mass per declared unit shall be provided]*	Actioned added conversion of 3 kg/m2	Ok

4	Page 14 section 2.3.6	Te	EN15804	*"…per functional unit (1 m2) .."* Change this to per declared unit (1 m2)	Cheers – actioned	Ok
5	Page 15 section 2.5	Te	ISO	*"The influence of these proxy data on the results of the assessment has been carefully analysed and is discussed in Chapter* ***Error! Reference source not found.****."* There is only a general mention to the proxy data in section 4.4; its influence is not analysed there.	Added 4.6 to discuss impact of proxy data.	Ok
6	Page 19	Ge		*"This indicator is calculated using the characterisation factors from the IPCC AR5 report (IPCC 2013) and has been included in the EPD following the PCR. "* What does this mean? What EPD? And Why the PCR is a reference now and not only the EN15804?	Apologies - missed in internal QA - this should have been customised according to this study (non-EPD) i.e. remove reference to EPD and PCR. Fixed now.	Ok
7	Page 21 section 2.6.5	Ge	EN15804	*A key market for RE/8 and Kaynemaile is the USA.* Why Is USA the reference for EoL scenario? Is it the main destination of Kaynemaile products? What does percentage of its market USA represent?	They have expanded the market significantly in the US. Sales to the US were 22% in FYE 22, 52% of production in FYE23 and by 2025 they expect it to be 75% of all sales. This and more detailed context has been added in section 3.2.5	Ok
8	Page 23, section 2.8	Te	EN15804	*Measured primary data are considered to be of the highest precision,…* How do you support this claim? Does the company has an environmental management system in place?	A good question - though in the referred text we are talking generically about the hierarchy of data quality. I have added a bit more detail to qualify the statement. As for Kaynemaile and how their measured data Have added extra information in section 4.7	Ok

9	Page 29, table 3-2	Ge	EN15804	Please include references for those parameters Provide the references of the LCIA Method	Cheers, added	Ok
10	Page 27, section 3.1.2.2	Te		*In line with the PCR….* Why is the PCR the reference for treatment of the embodied carbon (and not EN15804)?	This was included, along with other reference to PCR, as EPD was the initial goal. Missed in QA - have now removed thanks	Ok
11	Page 33, section 3.2.5	Te	EN15804	*The scenarios are based on the disposal or recycling alternatives adopted in module C4 and are detailed here.* Where does the considered scenarios come from? Are they the most current probable scenario? How was the process of their definition and selection for the EoL calculations? Please elaborate.	Added and edited details across section to explain choice of scenarios. See marked up document.	Ok
12	Page 64 section 4.4	Te	ISO	The influence of proxy data used should be included here. What percentage of the impacts are associated to proxy data?	Added section and text marked up but mostly in section 4.6	Ok
13	Page 66	Te	EN15804	Please include a section with all the results tables together (ie. not just in the excel files to easier revision and comparison, before the Interpretation section. Also, I cannot find the analysis of the results of some indicators in the report, such as ADP in the interpretation analysis, nor a conclusion derived from additional indicators for USA.	Added tables to body of work. Separated to EN15804+A2 and TRACI*2.1* Some graphs were not presenting due to the drop down not taking full list. This has been fixed now so should be fine in the excel.	OK
General Comments and Requierements	CONCLUSION: Approved.					

CRITICAL REVIEW STATEMENTS

- The critical review was based on the LCA report, and supporting excel sheets with data and LCI calculations.
- The methods used to carry out the LCA study are consistent with ISO 14040:2006 and 14044:2006.
- The study was carried out by a team of LCA practitioners, who professionally and substantiated responded to all comments made during the critical review process, resulting in a final revised approved LCA report.
- The data used for the LCA study are well documented and appropriate for the defined goal and scope.
- The study clearly identified a number of key limitations, which are mainly related to the use of proxy data for polycarbonate pellet production, and mass balance to determine biogenic carbon using a methodology provided by the polycarbonate supplier. The influence of these limitations on the results is considered significant and therefore it is necessary to address and improve them as soon as better data are available.
- The limitations and assumptions and their influence on the results and conclusions must be included in any communication to third parties (stakeholders, or general public) to ensure the transparency of the conclusions and avoid any missinterpretation.
- The model and calculations are based on the international standard EN15804 for construction products, which is globally used and recognized, making the study consistent with present communication strategies of the sector in the era of hyper-transparency in business.
- The study evaluated the environmental impacts of the LCA of the Kaynemaile RE/8 architectural mesh according to ISO. Coherently, any expression referring to the results "demonstrating the LC impacts" should be avoided, since these are relative expressions derived from the data used, the LCA model and the interpretation phase, ie., they do not predict actual impacts.

Claudia A. Peña
LCA Critical reviewer

- Editorial (Ed), General (Ge) or Technical (Te)

About thinkstep-anz

Our mission is to enable organisations to succeed sustainably. We develop strategies, deliver roadmaps, and implement leading software solutions. Whether you're starting out or want to advance your leadership position, we can help no matter your sector or size.

Why us? Because we are fluent in both languages of sustainability and business. We are translators.

We've been building business value from sustainability for 15 years, for small or large businesses, family-owned and listed companies, or government agencies.

Our approach is science-based, pragmatic, and flexible.

Our work helps all industries in Australia and New Zealand, including manufacturing, building and construction, FMCG, packaging, energy, apparel, tourism, and agriculture.

Our services range from ready-to-go packages to solutions tailored to your needs.

As a certified B Corp with an approved science-based target, we make sure we are walking the talk.

Our services cover:

Product

- Life Cycle Assessment (LCA)
- Environmental Product Declarations (EPD)
- Carbon footprint
- Circular Economy (CE)
- Cradle to Cradle (C2C)
- Water footprint
- Packaging
- Independent reviews

Carbon

- Carbon Footprint
- Scope 3 emissions
- Reduction strategy
- Carbon targets
- Science-based targets (SBT)
- Offsetting strategies
- Inventory verification

Strategy

- Materiality assessment
- Green Star
- Sustainable Development Goals (SDGs)
- Foresighting & regenerative futures
- Roadmaps & action plans
- Responsible procurement & supply chain engagement

Software & tools

- GaBi LCA software
- GaBi Envision
- Material Circularity Indicator (MCI)
- OpenLCA
- eTool
- Packaging calculator
- SoFi sustainability reporting

Reporting & disclosures

- Task Force on Climate-related Financial Disclosures (TCFD)
- Global Reporting Initiative (GRI) & Integrated reporting (<IR>)
- B Corp
- Voluntary & compliance reporting
- CDP

Communications

- Short form reports
- Case studies
- Infographics
- Workshops
- Storytelling
- Stakeholder engagement
- Sustainability reports

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