SUSTAINABLE BEVERAGE PACKAGING OPTIONS IN INDIA

A COMPARATIVE LIFE CYCLE ASSESSMENT STUDY

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

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About the Study

The goal of this study is to conduct a life cycle assessment (LCA) to analyse the environmental performance of single-use packaging products. The assessment compares small-to-medium size aluminium cans and bottles to other available alternative packaging options in the Indian market such as PET bottles, glass bottles, and multilayer packaging (MLP) beverage cartons. One of the crucial focus of the study is on varying degrees of recycling rates of different substrates and refill rates (circular product design).

The study has been commissioned by Ball Corporation and the primary intended application is to provide up-to-date and objective results on various sustainability parameters associated with different beverage packaging substrates.

On the basis of this study, the primary aim is to identify various environmental hotspots in the life cycle of aluminium cans and related optimisation potential. The secondary aim is to compare and contrast various beverage packaging alternatives, with the intention of comparative assertions intended to be disclosed to the public.

The study's primary target audience are the beverage producers, at the same time, it intends to provide credible communication material to retailers, consumers, and other interested parties.

The study meets the requirements of the international standards of life cycle assessment (LCA) according to ISO 14040, 2006 and ISO 14044, 2006

The assessment is of four beverage packaging alternatives of different sizes. It includes entire life cycle of the substrates, starting from raw material extraction, and manufacture of primary and secondary packaging material (excluding beverages). The assessment also takes into account transportation between different stages and end-of-life of packaging materials.

Two to four products per packaging substrate were selected, purchased, and weighed. Ball Corporation provided the primary data on can manufacturing, while all other background and foreground data were based on industry averages and association datasets from ecoinvent Database.

To make this study an overarching reference material for today's and tomorrow's decisions, sensitivity analysis was carried out for the following entities:

- Recycling rates: 0–100%
- Lightweight: 5–10%
- Glass bottle refilling: 5–20%
- Methodology (substitution and cut-off)

The traditional LCA considerations are complemented by Material Circularity Indicator (MCI), developed by MacArthur Foundation and Granta Design. The MCI measures how restorative the material flows of a product are.

1. Introduction: Indian Beverage Packaging Market

Indian beverage sector, consisting of alcoholic and otherwise, is one of the most diverse sectors, as its people. The sector is highly influenced by country's vast geography which itself is associated with the weather. With it comes the imperative of packaging function to contain beverages, enabling transportation, and protecting beverages against mechanical stress and material loss. The beverage packaging has witnessed significant growth in recent years. The size of the Indian food and beverage packaging market was estimated to be US$33.2 billion in 2020 and is expected to grow at a significant compound annual growth rate (CAGR) of 9.3% during 2020–26 period. The key factors that will drive future growth are urbanisation, vibrant youth and their growing share in the workforce, increasing purchasing disposable income, improved connectivity particularly in smaller towns. Based on the materials used in packaging, the market can be further divided into glass, plastic, paper, and metals, predominantly aluminium).

In 2014, beverages accounted for 21% of the total consumer packaging market. Rigid packaging had the largest share (38%), followed by glass (32%), and multilayered packaging (cartons) 13%. Metal cans (mostly representing aluminium) had the least market share (7%). This is presented in Figure 1.

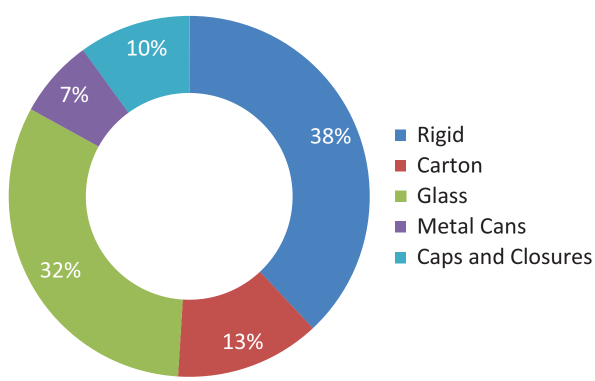

Figure 1: Beverage packaging: break up by type[1]

Almost 59% of glass is used for alcoholic and non-alcoholic beverage packaging. This is followed by aluminium cans where 42% of the total application in packaging is attributed to alcoholic and non-alcoholic beverages. In particular, the share for non-alcoholic beverages of 22% is more than that of alcoholic beverage application of 20%.

1 Details available at <http://www.consultmcg.com/blog/beverage-packaging-market-in-india-2/>

Nearly 23% of the total polyethylene terephthalate (PET) PET application in packaging goes to the beverage sector. With 19% share, multi-layered packaging (MLP) has one of the least applications in beverage packaging when compared with other packaging substrates. Further, its usage is largely confined to non-carbonated drinks. Table 1 presents the share of various substrates used across various packaging applications.

In recent years, the industry has witnessed adoption of innovative techniques for packaging. These trends include modification of structure of the packaging materials, introducing new active systems, customer acceptability, improved food security and enhancing shelf life, and so on.

Table 1: Percentage share of various substrates used in various packaging applications

	Aluminium	MLP	PET	Glass
Food products	14%	19%	50%	38%
Non-alcoholic beverage	22%		23%	13%
Alcoholic beverage	20%		0	46%
Personal care	1%	17%	10%	1%
Pharmaceuticals	19%	20%	1%	2%
Industry chemicals	22%	0	6%	
Others	2%	44%	10%	

Government directives have brought a new development in the beverage packaging market. that several Owing to the fact that packaging waste is deemed toxic for the environment, attempts have been made to curb the amount of waste generated . This has nudged the industry to make a shift towards recyclable and more sustainable packaging options.

Health and wellness are currently on high value hierarchy of the consumers as compared to the past and thus are factors that will add to growth of the beverage packaging market. Many consumers, especially in the youth segment, are becoming experimental due to increase in health consciousness try new healthier options and drinks that incorporate essential ingredients, such as vitamins and nutrients. This demand is compelling the manufacturers to come up with more innovative and eco-friendly packaging solutions to attract consumers and increase their sales and expand business. Factors such as increased disposable income of consumers, rapid growth of trade, and availability of multiple options have also altered the beverage consumption pattern of the consumers, bringing significant growth to the packaging industry. Furthermore the increase in consumption of alcoholic beverages is also expected to support the growth of the market.

2. Life Cycle Assessment Framework

Life cycle assessment (LCA) has emerged as a leading tool for driving sustainability decisions in the fields of research, industry, and policy decisions. It is considered to be a powerful and robust tool for quantifying the various environmental impacts of a product or service throughout its life cycle.[2] Based on the systematic life cycle (cradle to gate/grave) approaches it aids stakeholders in comprehending the true impacts of any given product or service. LCA results mainly help to compare products and identify hotspots in a product's life cycle. The analysis also simultaneously drew designers', engineers', and management's attention towards improvement opportunities to offset energy and emission savings obtained while sourcing raw materials and manufacturing products. It reduces the risk of problem shifting (from one life cycle to another) and helps stakeholders in locating the visible difference between an environmentally sustainable product and a less sustainable alternative. It provides clear insights on how making fundamental changes in the supply chain (replaced with sustainable fibre or used a renewable energy source) can potentially lead to impact in another stage of the product's life cycle. Calculation and communication of key environmental sustainability metrics improve an organisation's transparency, thus convincing consumers to make improved choices.

According to International Organisation for Standardisation (ISO) 14044/40 standards LCA should be carried out in four key phases as presented in Figure 2.

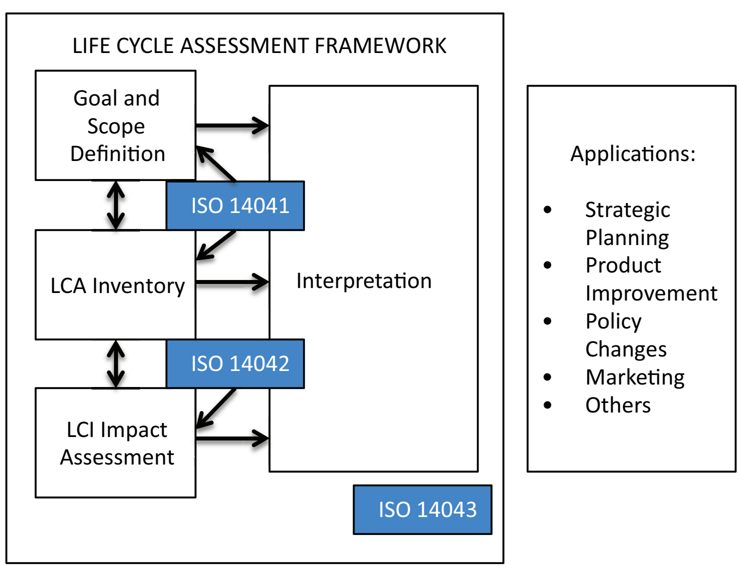

Figure 2: Phases and applications of a LCA (based on ISO14040, 1997)

[2] Details available at <https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/life-cycle-assessment>

(i) Goal and scope definition

Under the goal and scope the product system, in terms of the system boundaries of the study and a functional unit is defined. Functional unit is extremely critical as it helps in facilitating direct comparison of alternative goods or services with reference products.

(ii) Inventory analysis (LCI)

The life ccle inventory (LCI) is the methodology for estimating use of various resources, quantities of wastes generated, emissions and discharges during production, use and disposal phases, associated with each stage in a product's life cycle. The material and energy flows are modelled between the processes within a life cycle. The overall models provide mass and energy balances for the product system, its total inputs and outputs into the environment, on a per functional unit basis.

(iii) Impact assessment (LCIA)

The LCIA provides indicators for the interpretation of the inventory data, in terms of contributions to different impact categories. The indicator results of an LCIA facilitate the evaluation of a product, and each stage in its life cycle, in terms of climate change, toxicological stress, noise, land use, water consumption, and others. The scope of the evaluation, with some exceptions, impacts at both regional and global scales.

The overall indicator results of an LCIA reflect cumulative contributions to different impact categories that are summed over time and space. Unlike some other assessment approaches, these indicator results usually do not reflect risks or impacts at any particular location or point in time. The consumption of resources and the generation of wastes, emissions, and so on, often occur in a product's life cycle, for example, (i) multiple sites and in multiple regions, (ii) as different fractions of the total emissions at any one site, (iii) at different times (like the use phase of a vehicle and dismantling), and (iv) over short and long time periods (for instance, multiple generations in the case of emissions of persistent chemicals and from landfills).

(iv) Interpretation

Interpretation occurs at every stage in an LCA. If two product alternatives are compared and one alternative has a higher consumption of each resource, for example, an interpretation purely based on the LCI can be conclusive. In other studies, drawing conclusions will require at least an LCIA, a sensitivity analysis, and consideration of the statistical significance of differences in each impact category.

Some category indicators can be further cross-aggregated and compared on a natural science basis. Further, aggregation can be utilised to calculate the overall sum of years of human life lost, for example, the years of life lost that are attributable to climate change, potential carcinogenic effects, noise, traffic accidents, and others.

3. Goal of the Study

The study presents a comprehensive LCA of beverage packaging options including aluminium cans, PET bottles, glass bottles, and MLP cartons with an objective to assess the various environmental impacts of each packaging substrate across their life cycle stages.

The goal of the study is to conduct an LCA, analysing the environmental performance of single-use, small to medium-size aluminium cans compared to competing alternative beverage packages, such as PET bottles, glass bottles and beverage cartons popularly known as MLP, for India.

The goals of study are enumerated here:

- To provide up-to-date results of various environmental metrics for specific beverage packaging alternatives.
- To provide a comprehensive overview of product sustainability and potential for overall improvement by complementing LCA results with the material circularity (MCI) methodology.
- To identify the potential advantages and disadvantages of aluminium cans over competing alternatives, and to establish a benchmark between most common beverage packaging options.

A generic input and output flow across various life cycle stages of a beverage packaging substrate is presented in Figure 3.

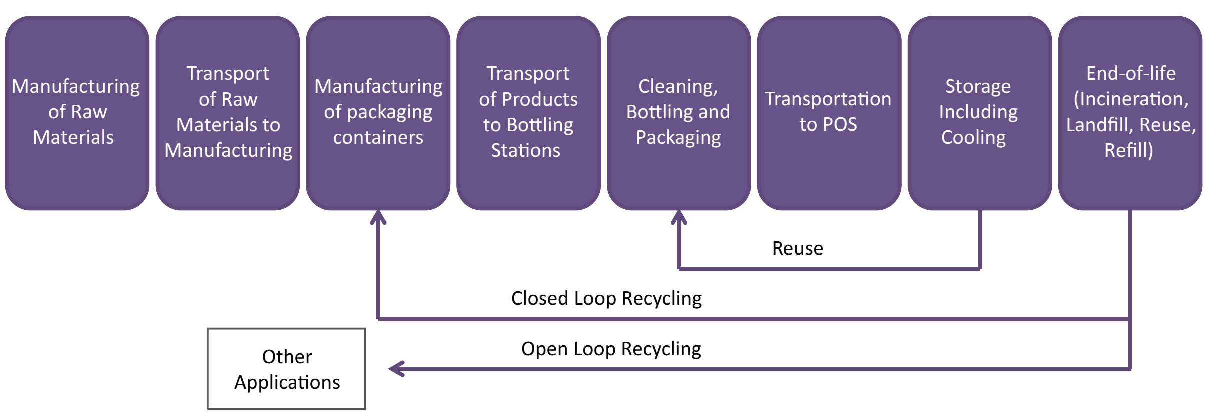

Figure 3: Standard life cycle stages of beverage packaging substrates

The study has been commissioned by Ball Corporation and is intended to be disclosed to the public. This excludes confidential primary data. Given the uniqueness of the exercise and technical complexity associated with the estimation of environmental impacts, an advisory panel comprising experts from Ministry of Environment, Forest and Climate Change (MoEFCC), Indian Institute of Technology (IIT) and National Environmental Engineering Research Institute (NEERI) was constituted for carrying out the critical review of the study.

The study meets the requirements of the international standards for LCA according to ISO 14040 (ISO, 2006)/ISO 14044 (ISO, 2006).

This study is extremely relevant and has been carried out at a time when there is growing environmental consciousness among Indian consumers and significant policy thrust by the Indian government towards promotion of circularity across various sectors. India has already drafted National Resource Efficiency Policy to identify the imperative of achieving complete circularity in various sectors including aluminium. TERI under the Resource Efficiency Initiative project, supported by European Union had developed and submitted the technical reference document for resource efficiency to Resource Efficiency Cell constituted under the MoEFCC.

At the EU–India summit held in 2020, Hon'ble Prime Minister of India and the European Commission President adopted a joint declaration to scale-up EU–India cooperation in the areas of resource efficiency and circular economy. The declaration establishes India–EU Resource Efficiency and Circular Economy Partnership, bringing together representatives of relevant stakeholders from both sides, including governments, businesses (including start-ups), academia and research institutes.[3]

This study will significantly contribute towards this ambitious initiative of the Circular Economy Mission of the Government of India, thereby helping them in making sound decisions towards strengthening resource efficiency in the beverage packaging sector. From the policymaking and adoption of sustainable production and consumption perspectives (as outlined under Goal 12 of the 2030 Development Agenda) this study will help to identify environmental hotspots for aluminium can's life cycle and related optimisation potential, understand environmental impacts associated with individual beverage packaging substrate options available in the Indian market. Further, through the sensitivity analysis sustainability implications can best understood through adoption of resource recovery and enhanced recycling rates for beverage packaging. The scientific data-driven analysis will encourage brands and other stakeholders in the Indian market to make informed choices.

The study findings clearly indicate the paramount importance of enhancing circular systems, especially for materials that have a high level of embedded energy such as aluminium and glass. This entails:

- Increasing collection rates and real recycling of the collected materials
- Increasing recycled content
- Maximising the number of refills for refillable bottles
- Supporting the logistics of closing the product loop, that is, providing the scrap input in the quality and quantity that is required by the recycling system and those that intend to incorporate recycled material in their packaging.

Given the different characteristics of packaging materials, each substrate can improve its sustainability profile through a set of different optimisation measures. As shown by this study some substrates have a higher potential to effectively reduce environmental impacts than others. Lightweighting and energy-related measures, in particular, energy efficiency improvements and the use of renewable energy, are additional optimisation measures that can benefit different packaging options to varying degrees.

[3] Details available at <https://ec.europa.eu/info/news/eu-and-india-partner-resource-efficiency-and-circular-economy_en>

4. Scope of the Study

The overall scope of the study is to achieve the stated goals, detailed in this section. This includes, but is not limited to identification of relevant product categories to be assessed, the product function, functional unit, reference flows, the system boundary, end-of-life methodology, allocation and cut-off criteria.

4.1 Product Systems

The product system analysed in this study are beverage packaging alternatives of small to medium size, used for containing carbonated and non-carbonated drinks. The study is limited to the container and excludes beverage production. The overview of the scenarios analysed in the study is provided in Table 2. The sample product categories are treated as single use in baseline scenario, even though glass bottles are resaleable and PET bottles are reused at households. Aluminium cans and MLP are not resalable. The effect of re-use of the glass bottles is analysed as an additional scenario. The competing products in Indian beverage market based on the penetration share are selected in consultation with Ball India.

Table 2: Product categories assessed for the Indian market

Baseline scenario			Additional scenario
Substrate/material	**Size**	**EoL/treatment of secondary materials**	**EoL/treatment of secondary materials**
Aluminium can	250 mL (A) 500 mL (A)	Substitution	Cut-off (recycling rate (0–100%)
PET bottle	200 mL (NA)	Substitution	Recycling rate (0–100%)
	600 mL (NA)	Substitution	
	1000 mL (NA)	Substitution	
Glass bottle	330 mL (A) 650 mL (A) 300 mL (NA)	Substitution	Cut-off, refills (5, 10, 20)
Multi-layered packaging	200 mL (NA) 1000 mL (NA)	Substitution	Recycling rate (0–100%)

A – alcoholic, NA – non-alcoholic

4.2 Product Function

The function of the assessed products is to contain beverages, enable their transportation, protecting beverages against mechanical stress, and material loss up to their consumption. It is understood that the National Legal Standards (Packaging and Labelling Regulations, 2011) applicable to all products that come in contact with food and beverage items are fulfilled by all product categories.

- **Mechanical protection:** It is considered that that all product categories are equivalent regarding mechanical protection of packaged beverage during transport, storage and point of sale.
- **Protective performance:** While mechanical performance of all products is comparable, they may differ in terms of their physic–chemical properties due to the materials that go into their manufacturing. External factors like UV transmittance and air tightness may affect the shelf life of beverages. While transparent packaging substrates like PET and glass bottle are UV transmittant, tinted glass bottles, aluminium cans and MLP cartons are not. The shelf life of some beverages may be negatively affected by UV permeability of the packaging. Moreover, aluminium cans are 100% airtight whereas packaging systems having a lid with screw cork mechanism may not be, this can also affect the shelf life of a beverage. However, for the purpose of this study, these factors are accounted to have negligible impacts on the product life and therefore the potential difference between substrates are not considered.
- **Consumer behaviour:** Based on design of the beverage package, the amount of beverage that is left behind in the packet differs. PET bottles are emptied more efficiently than aluminium cans and MLP cartons. The difference in residue in products' post-consumption may affect the impacts if considered for large volumes. However, because consumer behaviour is not foreseeable and there is no method to measure the residue remaining, it is not taken into consideration in this study.
- **Product comparison:** The same aluminium cans can be used to store a variety of beverages including carbonated, non-carbonated drinks, and alcoholic beverages; while MLP cartons are only used for non-carbonated fruit juices. PET bottles involve design change as per the requirements of carbonated and non-carbonated so does glass bottles for alcoholic and not alcoholic beverages. Therefore, a spectrum of packaging alternatives is taken into consideration for conducting the LCA exercise to incorporate market-relevant applications and competing products.

4.3 Functional Unit

Functional unit provides a reference to which the inputs and outputs are related/converted and is necessary to ensure comparability of results. The functional unit of this study was taken as 1 litre of fill volume of beverage and accordingly number of units of each product category needed is calculated for the analysis. The reference flows of the product system are given in Table 3.

Table 3: Reference flows

Packaging material	Size	Reference flow (kg) per function unit (litre)	Pieces of product per functional unit (litre)
Aluminium can	250 mL	10.39	4
	500 mL	14.92	2
Glass bottle	250 mL	190	4
	330 mL	265	3.03
	650 mL	510	1.53
PET bottle	200 mL	15.9	5
	600 mL	22.2	1.66
	750 mL	30.7	1.33
MLP	200 mL	10	5
	1000 mL	27	1

4.4 System Boundary

The system under consideration is a cradle-to-grave system—starting from raw material extraction to end-of-life. The system description of each substrate is presented in Chapter 5. The stages which are included and excluded are listed in Table 4.

The boundaries included with the system are outlined here:

- Raw materials extraction and processing
- Transport of raw materials to bottle/can manufacturing
- Product manufacturing
- Transport of assembled packaging system to filling stations
- Transport of filled cans to retailers/PoS
- Secondary packaging (shrink wrap, corrugated carton, trays)
- In some cases different numbers of reuse and returns in the use phase is considered for substrates such as glass bottles (refer to Additional Scenarios)
- End-of-life (incineration, landfill, recycling)

The system boundary excludes the following:

- Packaging materials except the final beverage packaging under study (primary and secondary packaging) because they are assumed to have negligible impact on overall results and also because data on them is not consistently available. This includes:
    - » packaging of preproducts used for manufacturing of packaging systems
    - » packaging used to transport empty beverage containers to filling stations
    - » tertiary packaging

- Energy consumed during filling of beverage into different containers, assumed not to be very different.
- Energy consumed in cooling of beverages as not all types of packaging require cooling and hence its inclusion will make results incomparable.
- The beverages includes its ingredients and additives.
- Wasted beverage products, in terms of spillage and half consumed.
- Consideration of the durability and protective capabilities of the containers as use phase and shelf life are not focal points of the study. Thus aluminium's intrinsic protective properties are not considered in the study, making the results conservative.
- Capital goods used across the entire value chain like machines, trucks, and so on are not considered.

Table 4: System boundary of modelled product categories

Included	Excluded
Manufacturing of raw materials	Packaging of raw materials
Transport of raw materials to manufacturing plant	Production of beverages
Transport to filling station	Tertiary packaging
Secondary packaging	Filling and refilling processes
Distribution to retailer	Cooling of filled beverage containers
Reuse, if applicable	Capital goods
End-of-life	

4.5 Data Quality Requirements

The data used to develop the inventory is precise, complete, concise and representative with regards to the goal and scope of the study under given time and budget constraints.

- Precision: The measured primary data is considered to be of highest precision, followed by calculated data, literature data, and estimated data.
- Completeness: Completeness is judged based on completeness of inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all 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, emissions factors, or other artefacts.
- Reproducibility: It expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in the report.
- Representativeness: This expresses the degree to which that data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The aim is to use

most representative primary data for all foreground processes and most representative industry-average data for all background processes. Whenever any data is not available, best available proxy data was used.

Temporal coverage:

- The time reference for primary data collected for aluminium cans is 2021.
- The time reference for other beverage packaging substrates is 2021, as products were purchased, weighed, and measured in 2021
- It is assumed that results are valid at least/at most for next 5 years as long as no technological changes are introduced to manufacturing of the compared products.
- The collected data is documented in details in Chapter 5

Geographical coverage:

The study covers the Indian market and the popular available packaging substrates in the country.

Technological coverage:

The technological configuration was used, based on the then available industry average reference. The Ball India provided the primary data for sheet making, and can manufacturing, the datasets included average across various sites. In the absence of an exact technological configuration in the datasets, alternative technologies were chosen by making conservative assumptions, so that the results were reliable. The PET bottle blow-moulding process was approximated with the blow-moulding process of HDPE bottles. For secondary data, it was assumed that the technology used was comparable with that of the primary data.

4.6 Allocation

4.6.1 Multi-output allocation

Multi-output allocation generally follows the requirements of ISO 14044, Section 4.3.4.2. Allocation refers to the distribution of environmental burden between co-products in a studied product system. A few industrial processes produce more than one product and those products are sold or recycled and used as raw materials. The materials, energy, and environmental burdens are allocated to the different co-products created. There are no significant multi-output processes within the foreground system. As a result, all impacts from the foreground system are fully allocated to the products under study.

4.6.2 End-of-life allocation

End-of-life allocation follows requirements of ISO 14044. This section describes the different methods used in this study. The methods help to present a holistic picture of environmental impacts and also aid sensitivity analysis as incremental changes in environmental impacts with respect to different scenarios can be found.

Material recycling

Substitution approach: A value of scrap burden was calculated for the input amount of scrap metal (recycled content enters the product system with corresponding burdens), while recovered material at the end-of-life is assigned a credit. These subsequent process steps are modelled using industry average inventories.

Energy recovery and landfilling

Substitution approach: When materials are sent for incineration (waste), they are linked to an inventory that accounts for waste composition and heating values as well as regional efficiencies and heat-to-power ratios. Credits are assigned for power and heat outputs using the regional grid mix. When materials are sent to landfills, they are linked to an inventory that accounts for a waste composition, regional leakage rates, landfill gas capture as well as utilisation rates. A credit is assigned for power output using Indian electricity grid mix.

Cut-Off: The cut-off method is applied in additional scenarios for the end-of-life whereby credits, as well as secondary materials, are outside of the system boundary.

4.7 Cut-off Criteria

No cut-off criteria for the foreground system were defined for this study during the primary data collection.

4.8 Selection of LCIA Methodology and Impact Categories

The scope of the study covers the Indian market, the scientific community in India uses ReCiPe LCIA methodology. The methodology is selected in consultation with Advisory Committee Experts. This method translates emissions and resource extractions into limited number of environmental impact scores by means of characterisation factors. Two prime ways of deriving characterisation factors are at mid-point and end-point levels. As per ReCiPe, there are

- 18 mid-point indicators
- 3 end-point indicators

Mid-point indicators focus on single environmental problem, for example, global warming potential, acidification or water footprint. End-point indicators show environmental impacts on three higher aggregation levels: (1) effect on human health, (2) biodiversity, and (3) resource scarcity. Converting mid-points to end-points simplifies the interpretation of LCIA results. Figure 4 provides an overview of the structure of ReCiPe.

Not all impact categories will be included in the main report. Only those categories that are relevant to the goals of the study will be demonstrated. However, the results of all the categories for all product categories can be found in the Annexure.

A few impact categories are excluded in the study due to lack of robustness. These are:

- Human toxicity (both carcinogenic and non-carcinogenic)
- Depletion of fossil resources

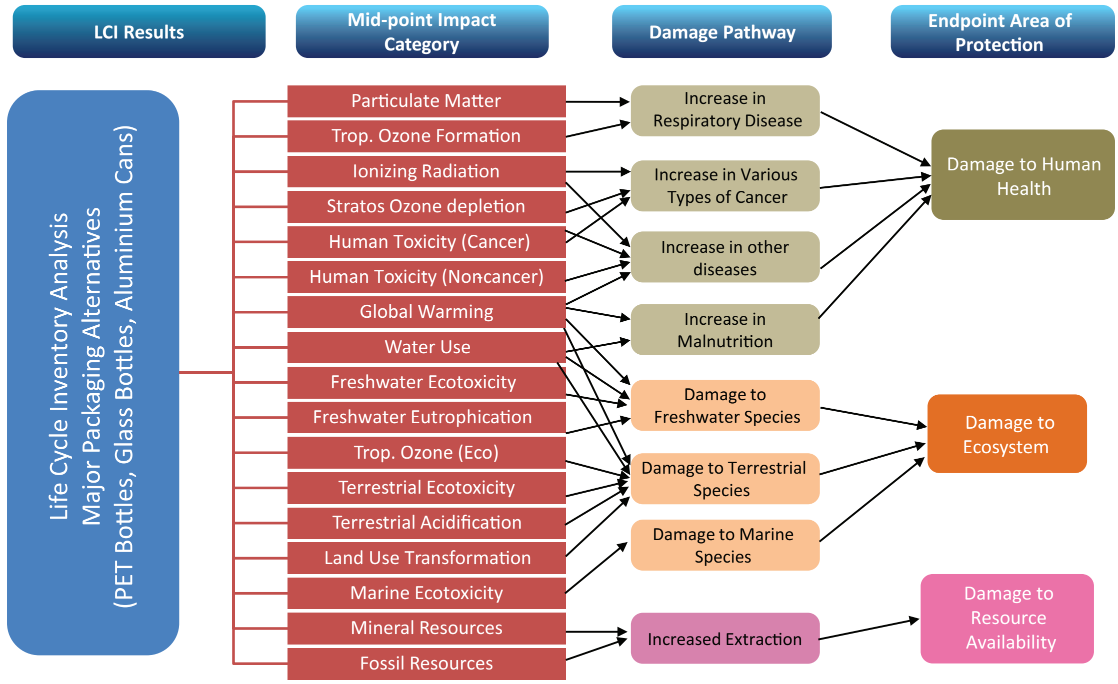

Figure 4: Impact categories and damage pathways as per ReCiPe methodology

Other categories that are excluded from interpretation, based on similarity of patterns to climate change, as driven by energy consumption are:

- Photochemical ozone formation
- Fine particulate matter formation
- Ionising radiation

Table 5 gives the description of ReCiPe impact categories and applicable references for each of the impact categories.

Table 5: ReCiPe impact categories

Impact category	Description	Unit	Reference	Main report	Annexure
Global warming potential	Amount of energy absorbed by certain mass of greenhouse gas in comparison to amount of energy absorbed by equivalent amount of CO_2.	kg CO_2 eq.	IPCC, 2013	✓	✓

Contd..

Table 5: contd...

Impact category	Description	Unit	Reference	Main report	Annexure
Stratospheric ozone depletion	Ozone depletion potential: calculating destructive effects of stratospheric ozone layer over time horizon of 100 years	kg CFC-11 eq.	(Hayashi, Nakagawa, Isubo and Inaba, 2006) (De Schryver, *et al.*, 2011)		✓
Ionising radiation	Absorbed dose increase	kBq Co-60 eq.	(Frischknecht, Braunschweig Hofstetter, and Suter, 2000) (De Schryver, *et al.*, 2011)		✓
Ozone formation	Terrestrial/tropospheric ozone formation	kg NO_x eq.	(Van Zelm, Preis, Van Goethem, Van Dingenen, and Huijbregts, 2016)		✓
Fine particulate matter	$PM_{2.5}$ population intake increase	kg $PM_{2.5}$ eq.	(Van Zelm, Preis, Van Goethem, Van Dingenen, Huijbregts, 2016)		✓
Terrestrial acidification	Ability of certain substances to build and release H^+ ions	kg SO_2 eq.	(Van Zelm, Preis, Van Goethem, Van Dingenen and Huijbregts, 2016)	✓	✓
Freshwater eutrophication	Phosphorous increase in freshwater	kg P eq.	(Helmes. Huijbregts, Henderson, and Jolliet, 2012) (Azevedo, Henderson van Zelm, Jolliet, and M.A.J., 2013a) (Azevedo, *et al.*, 2013b) (Azevedo, Development and application of stressor-response relationships of nutrients, 2014)	✓	✓
Terrestrial ecotoxicity	Hazard weighted increase in natural soils	kg 1,4-DCB eq.	–		✓
Marine ecotoxicity	Hazard weighted increase in marine waters	kg 1,4-DCB eq.	(Van Zelm, Huijbregts, and Van de Meent, 2009)		✓

Contd..

Table 5: contd...

Impact category	Description	Unit	Reference	Main report	Annexure
Freshwater ecotoxicity	Hazard weighted increase in fresh waters	kg 1,4-DCB eq.	–		✓
Land use	Occupation and time integrated transformation	M_2a crop eq.	(De Baan, Alkemade, and Kollner, 2013) (Elshout, Van Zelm, Karuppiah, Launrenzi, and Huijbregts, 2014) (Kollner and and Sholz, 2007)		✓
Mineral resource scarcity	Surplus ore potential	kg Cu eq.	–		✓
Fossil resource scarcity	Fossil fuel potential	kg oil eq.	–		✓
Water consumption	Freshwater use	m^3	–	✓	✓

4.9 Material Circularity Indicator

Resource exploitation and waste generation during the industrial processes, at the product use stage and disposal of end-of-life, are accompanied by serious environmental issues. While there are impact categories to assess the burdens using LCA approach, material circularity indicator (MCI) goes beyond traditional LCA considerations and helps explore the circularity of the product. Product circularity refers to the concept of circular economy, which considers products and systems to be restorative and regenerative rather than depleting finite virgin material and creating dumps of waste.

Ellen MacArthur Foundation has developed methodology to assess the MCI scores at product level and company level as well. The scores are assessed on a 0–1 scale. One represents a theoretical perfectly circular product where all input and output flows are restorative and there are no losses associated with activities such as recycling. While the product that is manufactured from virgin raw material only and ends up in landfill post usage can be considered as fully 'linear' product with 0 MCI score.

The MCI is constructed from combination of three main characteristics:

(1) Proportion of input material flows that are restorative, that is, from reused or recycled sources)

(2) Proportion of waste flows that are used restoratively, that is, reused or recycled at end-of-life)

(3) Product utility compared to that of an average product in the market, such as use intensity, serviceable lifetime, and others. For textile applications, the number of use cycles can be considered as a suitable measure of product utility. Any products durability may be compared to fast-fashion products in an average situation which has relatively low-use cycles.

India has framed new policies, for instance, Extended Producer Responsibility (EPR) in E-Wastes and Plastics, and Vehicle Scrappage Policy which clearly indicates the current government's intensions of incorporating circularity in the economy. Companies also look at opportunity for growing business value by adopting a circular economic strategy, as it theoretically captures additional value from products and materials which might otherwise be discarded as waste. Reducing waste flows and resource depletion can have significant benefits to the environmental performance of products and systems.

MCI metrics reveal the circularity of a product, they do not account for environmental impacts of the product itself that are assessed through LCAs. It is essential to use MCI scores in tandem with the impact indicators provided by the LCA study, which will help identify whether pursuing product circularity is the best pathway to optimise the environmental performance of the product. For example, a product with high durability might have a high circularity score because it has an extended number of use cycles, however, much higher embodied environmental impacts. If the benefits of pursuing the more circular product do not improve or even worsen the environmental impacts of the original product, then a circular economy may not be the most desirable sustainability strategy in this instance. The results returned from an LCA provide the knowledge to determine whether this is the case.

4.10 Interpretation

The interpretation of the results largely relies upon the goal and scope of the study. The interpretation addresses the following aspects:

- Identification of main processes, inputs (material and energy), outputs (waste and emissions) which contribute to overall results
- Evaluate sensitivity, consistency to make results more robust as to justify usage of proxy data to fill data gaps
- Conclusion, limitations, and recommendations

4.11 Type and Format of the Report

As per requirements of ISO (ISO, 2006) this document reports the results and conclusion of the study without any bias to the intended audience. The results, data, methods, assumptions, limitations, and recommendations are presented in a detailed and transparent manner to convey the prime message very clear to the reader. This allows the results to be interpreted and used in a manner consistent with goals of the study.

4.12 Software and Database

The LCA models were created using the SimaPro 9.3.0.3 software system for life cycle engineering, developed by PRé Sustainability. The ecoinvent 3.8 (2020) Database provided the upstream life cycle inventory data for the background process.

5. Developing Life Cycle Inventory

The life cycle inventory (LCI) provides a detailed account of all the flows entering and leaving the studied product system. It consists of all the inputs such as raw materials, energy, water, chemicals, and others required for the production of beverage container to fulfil the functional unit (that is, 1 litre of beverage filled) and the outputs—emissions, waste and final products leaving the system.

5.1 Data Collection Procedure

The data for foreground systems is collected using primary sources while the background systems data is sourced from the ecoInvent Database. The distinction between them has to do with the part of the system which is under direct influence of the commissioner of the study—Ball India.

Aluminium cans:

Primary data was collected using customised data collection template from Ball Corporation for life cycle stages that can be affected directly by measures taken from the Ball India. These questionnaires were cross-checked for their completeness and plausibility using mass balance, stoichiometry, and internal and external benchmarking. Gaps and inconsistencies were filled through constant engagement with data provider.

The primary data was thus collected for can sheet manufacturing, can body and can end manufacturing for two sizes popular in Indian market. The secondary packaging data was also collected through devised questionnaires.

PET bottles, glass bottles and MLP cartons:

For all other beverage packaging substrates, information on transport distance, energy and water consumption was collected using secondary sources and validated through primary consultation. While weight had been measured directly after purchasing the selected packaging sizes at TERI labs with precision factor of 99.99%. For all necessary background data need for these substrates, ecoinvent Database available in SimaPro software was used.

5.2 Overview of the Product Systems

This section gives an overview of the different product systems assessed and the processes involved.

5.2.1 Aluminium cans

Aluminium cans at Ball are manufactured from specific alloys, AA3104 for the body stock and AA5182 for the can end and the tab stock. The dominant alloying element, albeit in minute quantities, in both stock are magnesium and manganese with remaining elements as zinc, iron, and others with limited share. The alloying elements, iron and manganese are modelled as mixture, that is, ferro-manganese as proxy dataset available in the ecoinvent.

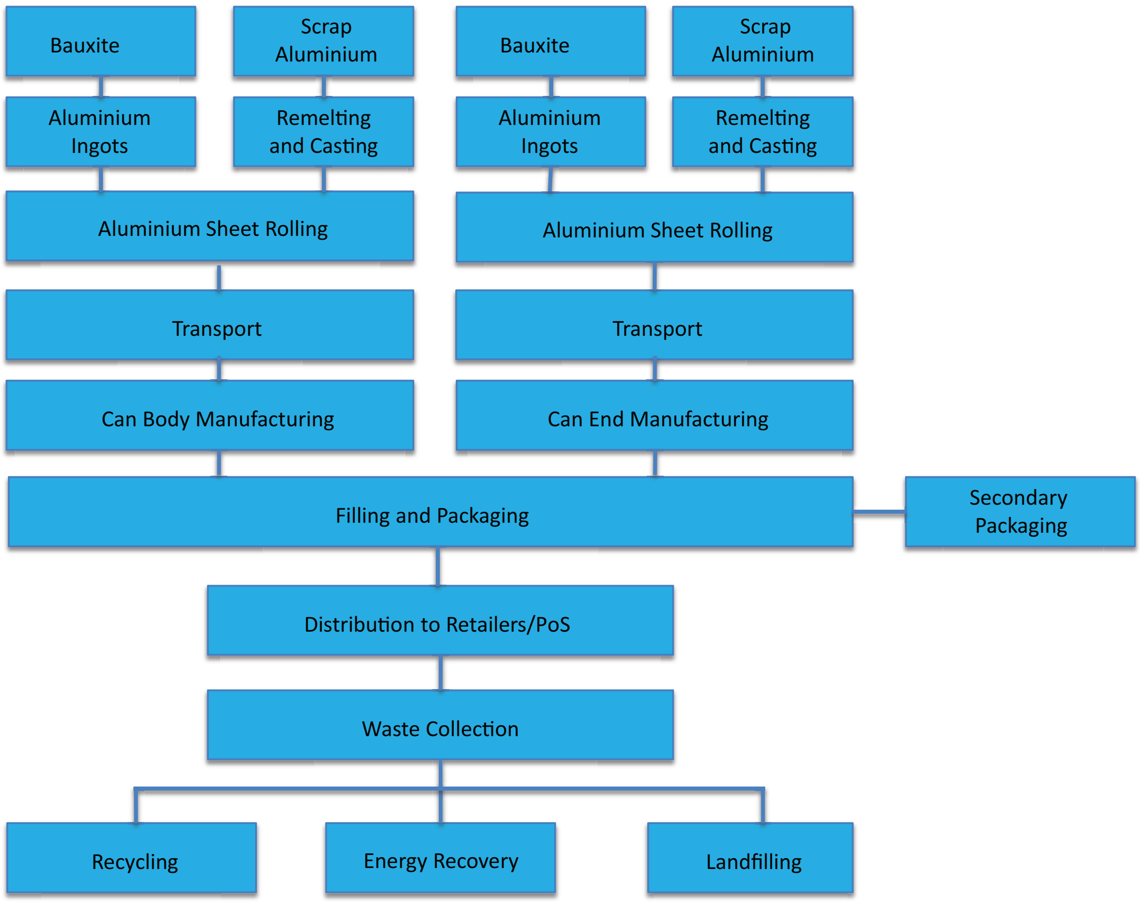

Figure 5: Schematic representation of the life cycle of aluminium cans

The primary aluminium produced from Bauxite processing mixed with the specified alloying element to form the input mass of the aluminium ingot that goes into sheet making. The sheet- making process uses both primary and secondary aluminium with average share of 24% and 76%, respectively specific for Ball India supply chain. The source of secondary aluminium are Class-I scrap, that is, at plant scrap, Class-II scrap, that is, used beverage can, and Class-III scrap , that is, aluminium from other industries, for example, automobile. The primary data for sheet-making process was used to model the LCI.

The aluminium sheets (can body stock and can end stock) are then transported to manufacturing site where further processing in terms of cutting, welding, forming, coating, spraying, and so on takes place. The input for these processes are taken in terms of energy, water, and chemical consumption. The primary data for sheet making and can manufacturing are represented as single aggregate process as confidential data.

After the cans stocks (body and end) are manufactured, they are shipped to the beverage producer where they are filled, assembled, and sealed and put into secondary packaging. The transportation to distributors/PoS is modelled as transportation by truck. The end-of-life considers both primary and secondary packaging and is modelled based on the Indian statistics, and the best available databases which are detailed in further section.

5.2.2 PET bottles

The PTA and MEG—majorly produced from fossil route—are used to produce PET granulate. However, bio-based routes are also used to produce these chemicals which are insignificant in the market share. These granulates are then converted to pellets, followed by preform production. As per regulations in India no recycled PET can be used for any beverage or food packaging and thus not considered in the study. These preforms are then transported to the beverage manufacturers where they undergo blow-moulding process to gain the desired shape and size. After this, further processes are performed similar to processing of aluminium cans which we have already discussed.

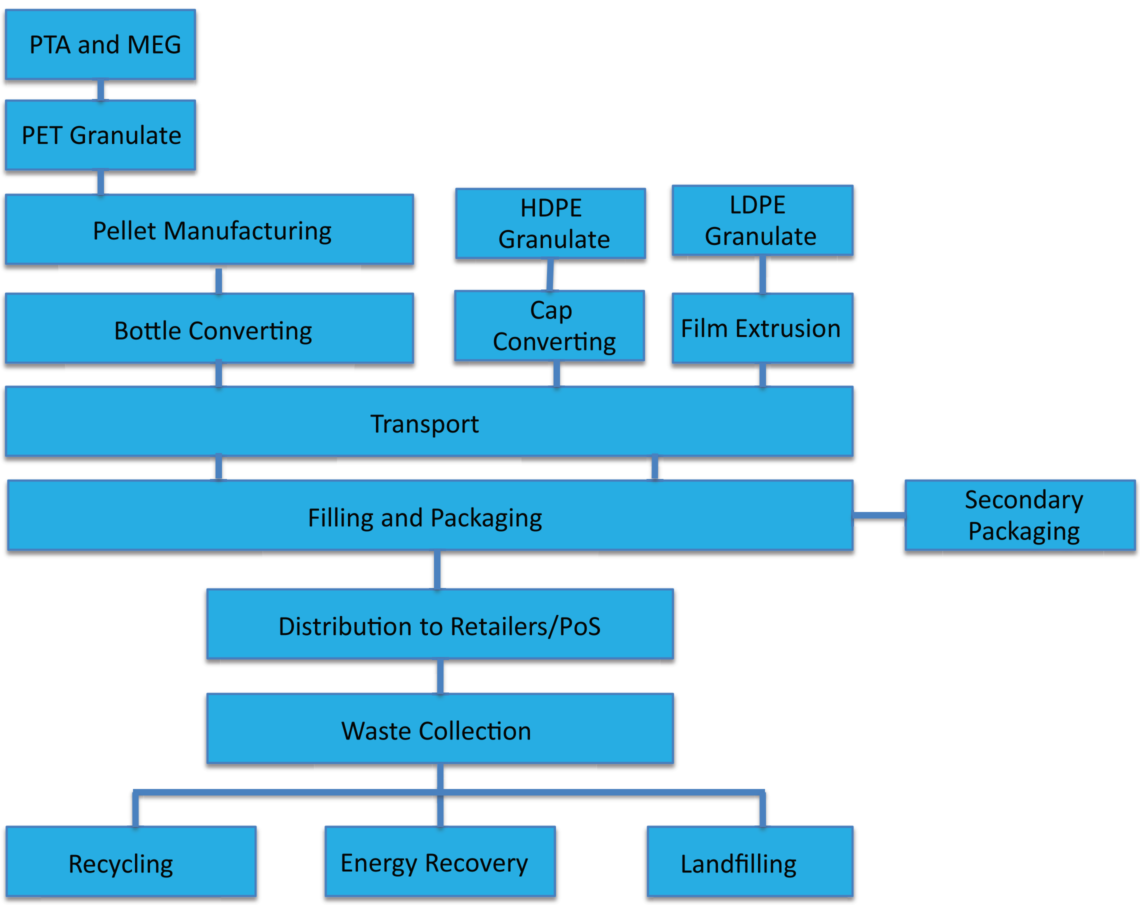

Figure 6: System boundary for PET bottle system

5.2.3 Glass bottles

Glass bottle production through the primary route generally uses silica sand, dolomite, limestone, and other minerals. However, in India significant share of cullets (broken pieces of glass) are used while producing glass. The capsules of glass undergo injection moulding process, to rather than top achieve the shape of the glass bottle. The tin-plated steel caps are used for closures. Rest of the processes are same as previously discussed for other substrates. The glass bottles can be reused after consumption, for which it is transported back to filling centre from retailers or PoS. The bottles undergo washing steps before refilling.

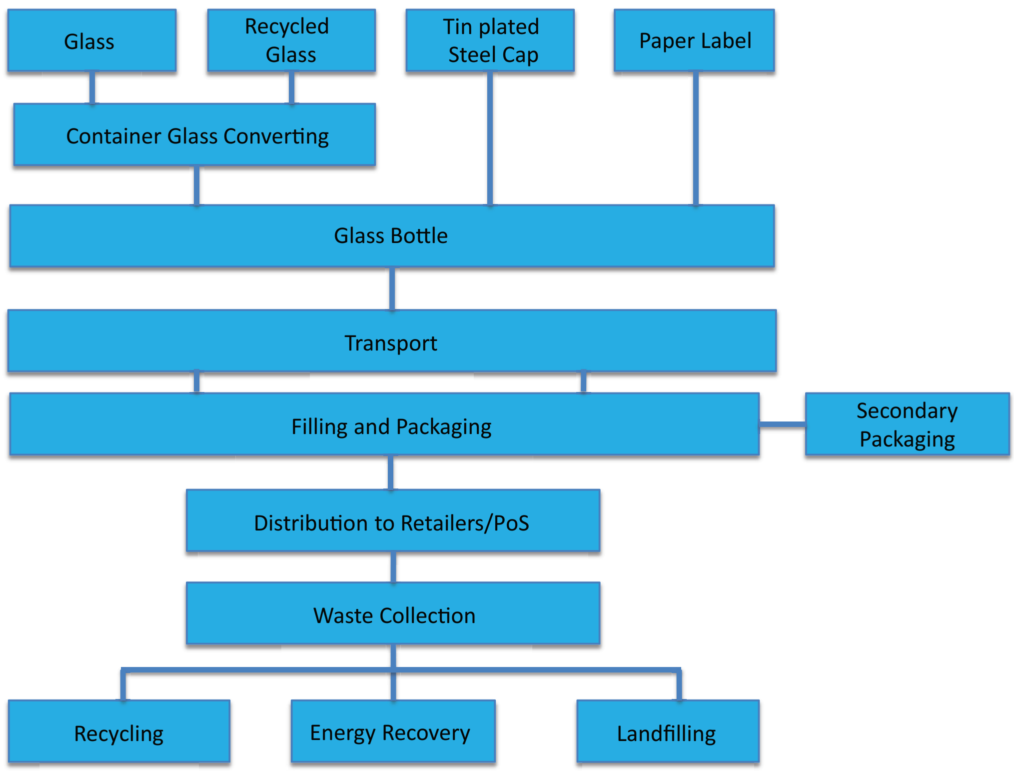

Figure 7: System boundary for single-use glass bottle system

Note: Refilling, whenever relevant, is considered with a step of washing but additional logistics not depicted here.

5.2.4 MLP cartons

The materials for multi-layer packaging range from papers to plastics to metals. LDPE, aluminium foil, and paper board are generally used for manufacturing beverage packaging containers. The base or bulk is made up of bleached or unbleached pulp while the top layer is made of bleached pulp to enable printing. While aluminium foil and LDPE layer is used as barrier. The packaging board are generally heat sealed. Further processes from filling to distribution are nearly the same as already discussed.

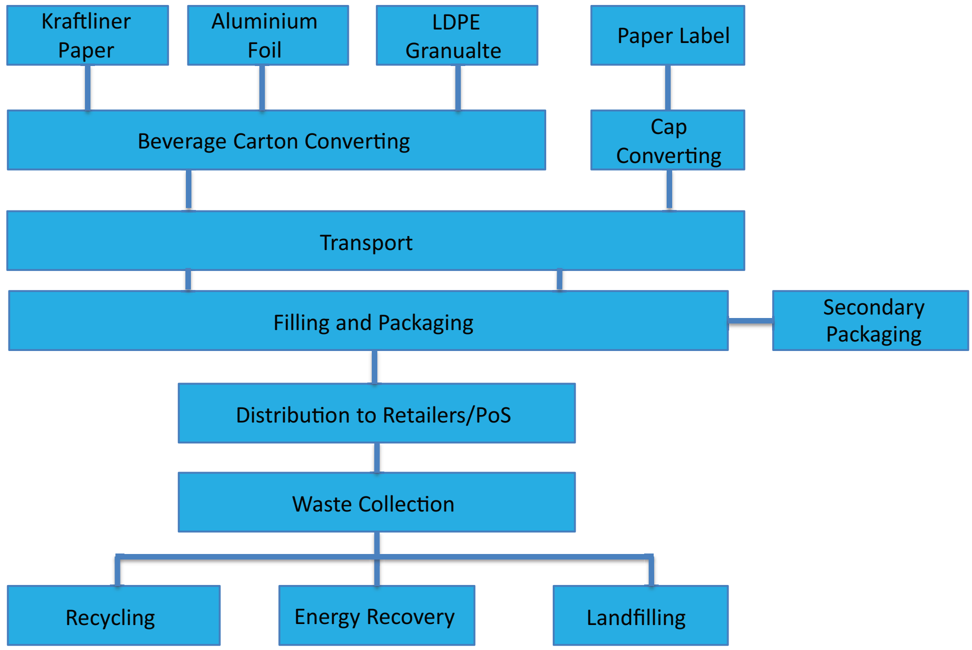

Figure 8: System boundary for MLP beverage carton system

5.2.5 Transport to filling and distribution

The transportation of empty containers to filling station and transportation of packed beverages to distributors is included as part of the system boundary. For transportation to filling site, an average estimated distance of 500 kilometres is considered for all products due to lack of better data. Transportation to distribution centres is taken after consultations with different beverage industries. These numbers can be understood with the help of Table 6.

Table 6: Transportation distance to distribution centres

Packaging substrate	Transportation distance to distribution centre
Aluminium	1000 km
PET	500 km
Glass	500 km
MLP	500 km

5.2.6 Recycling rate and recycled content

The LCA modelling follows the substitution approach which means the burdens or credits are allocated at end-of-life phase while the recycled content approach or cut-off approach has been analysed as additional scenarios for aluminium cans and glass bottles where burdens associated with the scrap or cullets processing are combined with primary material processing stage.

Table 7: Recycled content of considered packaging options

Beverage container	Recycling rate	Recycled content	Source
Aluminium	85%	76%	Based on inputs from Ball and validation by stakeholder
PET	70%	0%	United Nations Environment Programme (2020). Single-use plastic bottles and their alternatives. Recommendations from Life Cycle Assessments
Glass (flint, colourless)	60%	56%	Based on Inputs from Beverage Manufacturers, AIGMF, glass bottle producers in Firozabad clusters
Carton	54%	0%	T E R I. 2011 Post Consumer Tetra Pak Cartons (PCCs) Management

Overview product specifications for undertaking the detailed life cycle assessment for various packaging substrates is presented in Table 8.

Table 8: Product specifications for various packaging substrates

Substrate	Application segment	Container volume (mL)	Container weight (g)	Data source	Cap/ lid weight (g)	Data source	Standard number of units per pack (pc)	Secondary packaging/ nesting (per unit)
Aluminium can	Carbonated drinks	250	8.09	P	2.3	P	24	1.67 (shrink wrap)
								14.2 g (cardboard)
		330	9.51	P	2.5	P	24	1.67 (shrink wrap)
								14.2 g (cardboard)
	Beer	500	12.42	P	2.5	P	24	1.67 (shrink wrap)
								14.2 g (cardboard)

Contd..

Table 8: contd...

Substrate	Application segment	Container volume (mL)	Container weight (g)	Data source	Cap/ lid weight (g)	Data source	Standard number of units per pack (pc)	Secondary packaging/ nesting (per unit)
PET bottle	Carbonated/ non-carbonated drinks	200	15.9	P	1.6	P	30	1.45 g (shrink wrap) 6.05 g (cardboard)
		600	22.2	P			12	1.45 g (shrink wrap) 6.05 g (cardboard)
		750	30.7	P				1.45 g (shrink wrap) 6.05 g (cardboard)
		1250	34.1	P			6	
Glass	Beer	330	305	P	2.22	M	12	54.6 g (plastic crate)
		650	510	P			12	
	Carbonated/ non-carbonated drinks	200	160	P			24	54.6 g (plastic crate)
		300	250	P	2.22	M		
MLP	Non-carbonated drinks	200	10	M	1.1	M	40	5.04 g (cardboard) 0.078 g (shrink wrap)

E – estimated; M – measured; L – literature review; P – primary source

5.3 Life Cycle Assessment Datasets Used

This section discusses in detail regarding the datasets which were used to model the inventory for different substrates. Most of the datasets were not readily available for India in ecoinvent Database. To enhance the representativeness of the study, India-specific data from literature was plugged into best available data from ecoinvent for other regions. This implies the datasets which were referred in tables in further section are not suitable for global (GLO) or rest-of-world (RoW) region. However, some India-specific operations were also used to model.

5.3.1 Aluminium cans

Recycled content: The aluminium can produced by Ball India has very high-recycled content of 76%. But the LCA modelling of inputs in the baseline scenario follows the substitution approach that means it follows the recycling rate approach.

Background data: India-specific background data have been applied wherever possible, sourced from the ecoinvent database. Wherever not available, the best available data in the similar geography has been used. The data on energy and fuels is used as per Indian electricity grid mix.

Foreground data: The sheet-making, can body, and end manufacturing data was collected from the Ball India for the studied sizes. The model applied best available datasets for consumables, however global or rest-of-world datasets were used as proxy datasets.

Transport: The can sheets are typically transported from Rayong to LCB through truck trailers and then further through sea route to Chennai and again to Sricity through truck trailers. The outbound aluminium scrap is transported back through the same route to Rayong facility.

End-of-life: At the end-of-life, aluminium cans are collected at 85% for recycling. As, there is no circular footprint formula for India like PEF CFF, the perfect 1:1 switching rate is considered while allocating the credits.

Table 9: Dataset used to model aluminium can body, can end, and can manufacturing

Material	Material process	ecoinvent database	Documentation	Reference year
Aluminium ingot	Primary aluminium	Aluminium production, primary, ingot (IAI Area, Asia, without China and GCC)	https://v35.ecoquery.ecoinvent.org/Details/PDF/BCB2F78F-6270-43DA-AD18-60C19C6C5115/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Secondary aluminium	treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter (RoW)	https://v35.ecoquery.ecoinvent.org/Details/PDF/186B9EC3-05DB-44A3-857D-1654941B6CA9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

Contd..

Table 9: contd...

Material	Material process	ecoinvent database	Documentation	Reference year
Alloying elements	Magnesium	Market for magnesium GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/69B17264-C8D2-4F6D-80B9-EB0E45373756/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Ferromanganese	Market for ferromanganese, high coal, 74.5% Mn GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/B5833A9A-CF4D-4270-8FCD-6C19229E4CB9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Silicon	Market for silicon, multi-Si, casted RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/F99A6A7A-879F-4DF8-84C2-D3A1B7D40459/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Zinc	Market for zinc GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/6D397C26-952B-4458-A2E6-9D0E2AF48204/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Aluminium sheet-making	Lubricating oil	Market for lubricating oil RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/09D7DA3F-B98F-43B5-9293-D9FA468AD4DA/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

Contd..

Table 9: contd...

Material	Material process	ecoinvent database	Documentation	Reference year
Aluminium can body and can end manufacturing	Bisphenol	Bisphenol A/EU-25	https://v35.ecoquery.ecoinvent.org/Details/PDF/C2E1C0F2-A5A7-4199-B1A5-A512AB8D9748/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Hydrogen fluoride	Market for hydrogen fluoride RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/133E4154-00EE-4CB8-98F1-560A762E7240/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Sulphuric acid	Market for sulphuric acid RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/35ED6B7B-3404-4014-BED0-0C40119497D3/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Lubricating oil	market for lubricating oil RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/09D7DA3F-B98F-43B5-9293-D9FA468AD4DA/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Trichloroethylene	Market for trichloroethylene GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/A551E3B3-4A3E-4261-8294-07D2F43BB771/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

5.3.2 PET bottles

Recycled content: Almost entire PET share in India is assumed to be domestically procured and the numerous additives are ignored for the LCA exercise due to lack of availability of specific data.

Background data: Background data have been applied, based on review of literature, TERI internal audit documents, and ecoinvent Database 2020.

Foreground data: Product-specific primary data were collected from beverage- manufacturing company. These data include weight, energy, and water consumption. The losses share while conversion processes were taken from the literature.

Transport: Transport data to filling and distribution was only taken on the basis of consultation carried out with stakeholders. No other data was modelled for transportation.

End-of-life: At end-of-life, PET bottles are collected at 70% for recycling. Based on the literature, reuse at home is taken as 10% (for 600 mL and 750 mL). The credits are given as per substitution approach and switching rate of 1:1 is used.

Table 10: Dataset used to model PET bottle production in India

Material	ecoinvent database	Documentation	Reference year
MEG	Ethylene glycol production RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/6D397C26-952B-4458-A2E6-9D0E2AF48204/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2021
PTA	Purified terephthalic acid production RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/BCB2F78F-6270-43DA-AD18-60C19C6C5115/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2021
PET resin	Polyethylene terephthalate production, granulate, amorphous RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/186B9EC3-05DB-44A3-857D-1654941B6CA9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2021
Bottle: PET granulate	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/133E4154-00EE-4CB8-98F1-560A762E7240/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Bottle: PET blow moulding	HDPE blow moulding, RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/35ED6B7B-3404-4014-BED0-0C40119497D3/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Closure: HDPE granulate	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/09D7DA3F-B98F-43B5-9293-D9FA468AD4DA/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
LDPE granulate	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/BCB2F78F-6270-43DA-AD18-60C19C6C5115/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Label-film extrusion	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/186B9EC3-05DB-44A3-857D-1654941B6CA9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

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Table 10: contd...

Material	ecoinvent database	Documentation	Reference year
Electricity	Market group for electricity, medium voltage IN	https://v35.ecoquery.ecoinvent.org/Details/PDF/8008244D-B9CF-493D-BDB8-1065000E4BDB/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Thermal energy	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/5549CCBA-EC59-4FA8-BD1C-E6FBC927283B/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2021
Secondary packaging: shrink wrap	Carton board sheets, technology mix, production mix, at plant, 46% primary fibre	https://v35.ecoquery.ecoinvent.org/Details/PDF/D9945EE4-B92F-48C7-A020-9A96AAE0F456/06590A66-662A-4885-8494-AD0CF410F956	2018
Secondary packaging: corrugated board	Market for packaging film, low density polyethylene GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/C2E1C0F2-A5A7-4199-B1A5-A512AB8D9748/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

5.3.3 Glass bottles

Recycled content: Glass and glass containers are both domestically manufactured and imported into India. The recycled content for glass in the Indian context is 56% and number of refill rates considered for different volumes are 5, 10, 20 turns.

Background data: The background data for India have been applied from the TERI internal audit reports of glass-manufacturing companies. The India-specific ecoinvent Database was used wherever possible.

Foreground data: The product-specific data have been collected via sample products, and in consultation with stakeholders.

Transport: Transport data to filling and distribution is taken on the basis of consultation with stakeholders. No other data is modelled for transportation.

End-of-life: Glass bottle are collected at 60% for recycling. However, for the reuse rate analysis glass bottles are collected at 97.5% for reuse, while 2.5% are rejected. The credits are given as per substitution approach and switching rate of 1:1 is used.

Table 11: Dataset used to model glass bottle production in India

Material	Ecoinvent database	Documentation	Reference year
Glass, virgin	Oackaging glass production, brown RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/0DF51F91-AAC2-473C-84A8-A53E0F142334/06590A66-662A-4885-8494-AD0CF410F956	2021
Glass, recycled	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/BCB2F78F-6270-43DA-AD18-60C19C6C5115/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Label paper	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/186B9EC3-05DB-44A3-857D-1654941B6CA9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	-
Steel cap	Steel tinplate (Asia)	https://v35.ecoquery.ecoinvent.org/Details/PDF/9C6B7AB8-1FDD-47E6-9478-4C3B2BAE8BE9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2019
Secondary plastic crate	Market for polypropylene, granulate GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/5549CCBA-EC59-4FA8-BD1C-E6FBC927283B/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Electricity for washing	Market for electricity, medium voltage IN-Northern grid	https://v35.ecoquery.ecoinvent.org/Details/PDF/D9945EE4-B92F-48C7-A020-9A96AAE0F456/06590A66-662A-4885-8494-AD0CF410F956	2018

5.3.4 Multilayer packaging cartons

Recycled content: The MLP cartons are domestically manufactured in India and also recycled. There is no recycled content used for manufacturing of MLP and thus 0% recycled content is used to model.

Background data: The background data for India have been applied wherever possible from the EcoInvent Databases, mostly for energy consumption.

Foreground data: The energy, water and waste data for foreground systems are taken from secondary literature on Tetra Brick Asceptic (TBA). Product-specific data of weights have been collected via sample products.

Transport: Transport data to filling and distribution are only taken after consultating stakeholders. No other data are modelled for transportation.

End-of-life: MLP are collected at 54% for recycling, while 45% going for incineration. The credits are given as per substitution approach and switching rate of 1:1 is used.

Table 12: Dataset used to model MLP carton production in India

Material	Ecoinvent database	Documentation	Reference year
Liquid-packaging board	Liquid-packaging board production, production mix, at plant	https://v35.ecoquery.ecoinvent.org/Details/PDF/133E4154-00EE-4CB8-98F1-560A762E7240/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
LDPE granulate	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/35ED6B7B-3404-4014-BED0-0C40119497D3/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2021
Aluminium ingot	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/4D3816AF-91DA-448C-AE65-E5BB5C184F82/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Aluminium foil	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/3575C9B2-777F-44F4-8574-158E2D18520B/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2021
Natural gas	Heat production, natural gas, at boiler- condensing modulating <100kW CH	https://v35.ecoquery.ecoinvent.org/Details/PDF/14AF0C10-EC82-477A-B689-AEC6B6337155/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2021
Waste paper	Treatment of waste paperboard, sorting plant RoW	https://v34.ecoquery.ecoinvent.org/Details/PDF/C96482ED-AE14-4856-BA21-E3EC2DEDAB15/06590A66-662A-4885-8494-AD0CF410F956	2018

5.3.5 Background data of energy and transports applicable for all products

All production processes in India were modelled using the country-specific electricity grid mix (medium voltage) and other thermal energy datasets were modelled for India. Transport models for specified mode of transports have been used. Table 13 summarises the ecoinvent datasets used across all modelled production processes.

Table 13: Datasets used to model energy provision for products manufactured in India

Material	Ecoinvent database	Documentation	Reference year
Electricity	Market group for electricity, medium voltage IN	https://v35.ecoquery.ecoinvent.org/Details/PDF/8008244D-B9CF-493D-BDB8-1065000E4BDB/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Thermal energy from natural gas	Market for heat, central or small-scale, natural gas RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/9C6B7AB8-1FDD-47E6-9478-4C3B2BAE8BE9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Thermal energy from fuel oil	Market for diesel RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/EBDDBD67-8C77-4AAE-91C1-19916FBFDD49/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

Table 14: Datasets used to model transport provision for products manufactured in India

Material	ecoinvent database	Documentation	Reference year
Truck trailer	Market for transport, freight, lorry 7.5–16 metric tonnes, EURO3 RoW	https://v35.ecoquery.ecoinvent.org/Details/PDF/4D673084-F684-4294-9DBF-6A79AA7A0D77/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Lorry	Market for municipal waste collection service by 21 metric tonnes lorry GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/C08933AA-58FD-42AC-8095-250BCA8BB0F4/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
Motor ship (transoceanic ship route)	Transport, freight, sea, transoceanic ship GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/F2DF6DA3-1CF1-4033-AE11-14A740D53E68/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

5.3.6 End-of-life

For each substrate three end-of-life streams were considered—recycling, incineration, and landfill. This information is summarised in Table 15. The statistics on these are sourced from secondary literature and studies conducted in India. The re-use as end-of-life fate for glass bottles is analysed as additional scenario.

Table 15: End-of-life treatment of considered packaging alternatives in India

	EOL stream	EOL share (%)	Recycling yield (%)
Aluminium can	Recycling	85%	98%
	Incineration	1%	–
	Landfill	14%	–
PET bottle	Recycling	70%	85%
	Incineration	10%	–
	Landfill	20%	–
	Reuse (at home)	10%	
Glass bottle	Recycling	60%	90%
	Incineration	5%	–
	Landfill	35%	–
	Reuse	0–20 reuses	–
Beverage cartons	Recycling	54%	75%
	Incineration	45%	–
	Landfill	1%	–

Transport distances to end-of-life-processing facilities are neglected, as these are expected to be within 100 km radius of the disposal sites. The transport distance of processed aluminium scrap is considered as per route used to bring aluminium sheet to India facility at Sri City.

The end-of-life waste streams are split using consistent calculations for all products. Wherever material or energy is recovered from the EOL processes, fixed credits are applied to compensate the burdens created by product life cycles.

Table 16: Datasets used to model end-of-life processes for products manufactured in India

	Material/ process	Ecoinvent database	Documentation	Reference year
Aluminium cans	Aluminium waste to landfill	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/C08933AA-58FD-42AC-8095-250BCA8BB0F4/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	To incineration	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/F2DF6DA3-1CF1-4033-AE11-14A740D53E68/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	To recycling	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	https://v35.ecoquery.ecoinvent.org/Details/PDF/A72F28A5-31A5-491F-BEDB-7142BAA5B9E6/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Aluminium Ingot production (credits)	Aluminium, secondary, ingot, from beverage cans, at plant/ RNA	https://v35.ecoquery.ecoinvent.org/Details/PDF/BCB2F78F-6270-43DA-AD18-60C19C6C5115/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE-	2015
PET	Plastic waste to landfill	Treatment of waste polyethylene terephthalate, unsanitary landfill, dry infiltra	https://v35.ecoquery.ecoinvent.org/Details/PDF/4D3816AF-91DA-448C-AE65-E5BB5C184F82/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	To incineration	Treatment of waste polyethylene terephthalate, municipal incineration	https://v35.ecoquery.ecoinvent.org/Details/PDF/3575C9B2-777F-44F4-8574-158E2D18520B/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	To recycling	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/B5833A9A-CF4D-4270-8FCD-6C19229E4CB9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

Contd..

Table 16: contd...

	Material/ process	Ecoinvent database	Documentation	Reference year
Glass	Glass waste to landfill	Treatment of waste glass, inert material landfill	- https://v35.ecoquery.ecoinvent.org/Details/PDF/229008A6-39C1-48CC-872C-D1ADD37F740E/06590A66-662A-4885-8494-AD0CF410F956	2018
	To incineration	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/35ED6B7B-3404-4014-BED0-0C40119497D3/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Production of glass cullet	-	https://v35.ecoquery.ecoinvent.org/Details/PDF/4D3816AF-91DA-448C-AE65-E5BB5C184F82/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Glass cullet for recycling	Recycling of packaging glass, white GLO	https://v35.ecoquery.ecoinvent.org/Details/PDF/3575C9B2-777F-44F4-8574-158E2D18520B/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2017
MLP	Paper waste for landfill	Treatment of municipal solid waste, sanitary landfill	https://v35.ecoquery.ecoinvent.org/Details/PDF/466B30A0-25D3-4295-8F1C-09EF5CBEBDB8/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	For incineration	Treatment of municipal solid waste, incineration	https://v35.ecoquery.ecoinvent.org/Details/PDF/FC63DB2C-EC34-4583-BB15-8F14CE4CBC39/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	For recycling	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/9C6B7AB8-1FDD-47E6-9478-4C3B2BAE8BE9/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018
	Product with recycled paper content	–	https://v35.ecoquery.ecoinvent.org/Details/PDF/5549CCBA-EC59-4FA8-BD1C-E6FBC927283B/290C1F85-4CC4-4FA1-B0C8-2CB7F4276DCE	2018

5.4 Life Cycle Inventory Analysis Results

ISO 14044 defines life cycle inventory (LCI) analysis results as “outcomes of the life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment.” The complete inventory analysis results obtained post the LCA exercise is given in Annexure.

6. Life Cycle Impact Assessment

This chapter contains the description of results for the major impact categories as presented under ReCiPe. These results are presented for various packaging substrates and selected volumes. The method has been given the name ReCiPe as it provides a 'recipe' to calculate life cycle impact category indicators. It is important to mention here that that the reported impact categories represent impact potentials. In other words, they are approximations of environmental impacts that could occur if emissions would follow: (a) the underlying pathway; and (b) meet certain conditions in the receiving environment while doing so.

LCIA results are therefore relative expressions and do not depict actual impacts, the exceeding thresholds, safety margins, and risks.

The results presented in this report also have contribution analyses, which split the numbers according to the life cycle stages: manufacturing, secondary packaging, transportation, and end-of-life. However, the contribution analyses have been presented only for global warming potential (GWP) and that to for a subset of substrates and selected volumes. This will help in understanding the influence on the GWP of each stage on overall environmental impact. This also enables hotspot identification.

This chapter on life cycle assessment is divided into: (i) baseline assessments, (ii) sensitivity analysis, and (iii) comparative analysis of aluminium cans with selected competing beverage packaging substrates.

6.1 Baseline Assessments

This section depicts performance of different product categories with respect to key relevant environmental impact categories. It is to be noted that the substitution approach was taken in assessing these results for aluminium cans and glass bottles while a cut-off approach was followed for PET bottles and MLP cartons as these products do not incorporate any recycled content while manufacturing in the Indian context. As per the existing rules of the Government of India, when the exercise was carried out, due to food safety concerns, use of recycled content in PET bottles was prohibited.

The baseline assessments present impacts for various packaging substrates for: (i) GWP, (ii) water consumption, and (iii) impact of GWP across various life cycle stages. Further additional mid-point impacts of these packaging substrates are also presented. However, the detailed results for all impact categories and their respective units are presented in the Annexure

6.1.1 Global warming potential

GWP is the most used parameter to assess the climate change potential of emissions. The GWP refers to the amount of energy that 1 tonne of gas will absorb over a given period of time, relative to the emissions of carbon dioxide (CO_2). Most common greenhouse gases (GHGs) responsible for climate change are carbon dioxide, methane, and nitric oxide. In this study, all these gases are not marked individually but are represented as CO_2 equivalent.

For the purpose of comparison between various product categories, the GWP impact of 500 mL aluminium can is taken as reference and marked at 100%. The impact of remaining products is depicted in reference to the aluminium can. The best performer in terms of GWP impacts is 500 mL aluminium can. The worst performer is 200 mL glass bottle which has 526% the impacts of the reference. The 200 mL MLP carton which uses corrugated board material also has significantly high eutrophication impact.

PET bottles of 200 mL and all volumes of glass bottles have high GWP impact. PET bottles are derived from fossil-based energy resources and mainly fossil-derived energy is used during production. The impact is less for larger volumes as increased quantity of beverage per container relatively offsets the emissions per functional unit. In case of glass bottles, emissions are high because production of glass is a highly energy intensive process as manufacturing involves very high temperatures. Moreover, glass bottles are 10 times heavier than PET bottles, 15 times heavier than MLP cartons, and 20 times heavier than aluminium cans. MLP cartons have low GWP impacts as around 75% of their mass is made of virgin paperboard which is a bio-material.

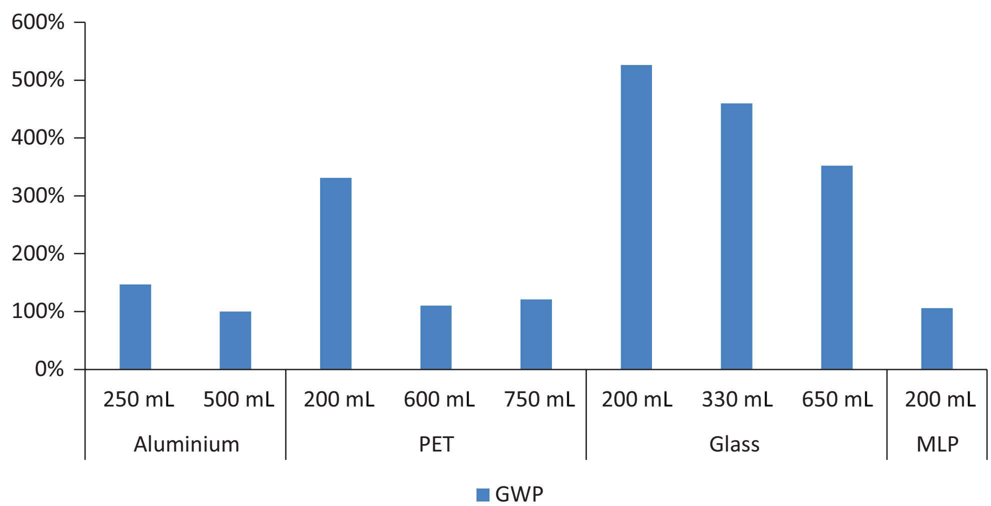

Figure 9: GWP results of product categories in reference to 500 mL aluminium can (scaled to 1 L of fill volume, using the ReCiPe 2016 method)

Most GHG emissions for all product categories are associated to cradle to gate stage. This includes manufacturing and hence maximum energy consumption which is Indian context is largely coal derived. Thus, cradle to gate is identified as a hotspot for GWP impacts.

The contribution analysis shows the manufacturing stage is the dominant contributor to GWP for all products. Cartons show the lowest GWP from this life cycle stage because they are predominantly made from paperboard made from virgin fibres, generating by-products (bark, forestry off cuts, wood chips, black liquor, and others) that serve as renewable fuel for the pulp and papermaking process. Removals and emissions of biogenic carbon dioxide are not shown in these results but will roughly be balanced over the packaging lifetime. Carbon dioxide sequestered during tree growth is re-emitted at end-of-life, resulting in overall zero net emission of GHGs unless the carbon is converted to methane, for example, on a landfill site. Biogenic carbon converted to methane is included in these results.

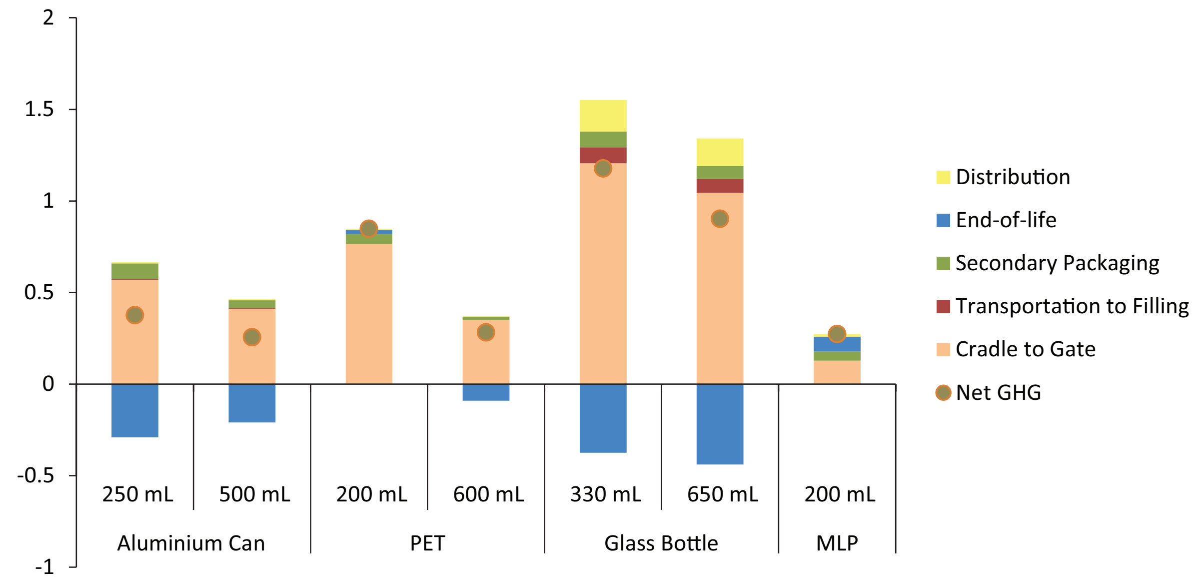

Figure 10: Contribution of different life cycle stages/production processes to the overall global warming potential results, scaled to 1 L of fill volume, using the ReCiPe 2016 method

The results are all scaled to a functional unit of 1 L of fill volume, and this impact category once again demonstrates how product-to-packaging ratios influence environmental performance when normalised per litre. Larger bottles require less packaging to contain a given quantity of beverage compared to smaller bottles.

Aluminium cans also have a relatively high impact associated with manufacturing (primarily due to the burdens associated with scrap input), but this is largely offset by the end-of-life processes due to their very high recycling rate at end-of-life, thus making aluminium the best performer in this category when summing all life cycle stages.

6.1.2 Water consumption

Water being a scarce resource, it is imperative to understand the potential impacts of various packaging substrates on water consumption during their life cycle stages. Such knowledge is especially relevant is a water stressed country like India. Figure 11 presents the water consumption for aluminium can (250 mL and 500 mL), PET (200 mL, 600 mL and 750 mL), glass bottle (200 mL, 330 mL, and 650 mL) and MLP (200 mL). Aluminium can with 500 mL size have the least water consumption estimated to have a water footprint of 0.00058 m^3. This value is taken as reference (100%) and relative performance of other products in terms of percentage in comparison to the reference is depicted in the graph. Aluminium cans consume water in its background processes like ingot making and sheet rolling but due to high-recycled content, the impacts are significantly dimmed, and it performs better than other substrates.

Despite its lightweight and packing efficiency, PET bottles has significant water footprint as it sourced from petroleum, which consumes huge quantities of water during extraction. A major contribution towards water consumption in case of PET bottles also comes from secondary packaging, which is done using corrugated boards in the Indian context. Production of one PET bottle requires 3 times the amount of water it can hold. Glass bottles have the highest water footprint that stands at 954%, 850%, and 815% of the reference product for sizes 200 mL, 330 mL and 650 mL, respectively. Water consumption contribution in case of glass bottles is largely from secondary packaging, which is done through plastic crates in India. Glass filling is another water intensive process. Even during glass manufacturing, huge amounts of water are used for evaporation to provide cooling effect to the furnace.[4]

The water footprint of MLP of 200 mL is 327% of the reference product. Cartons have relatively low manufacturing impact but it has high water footprint because paper manufacturing is a water-intensive process as large amount of water is required to turn fibre pulp into slurry.

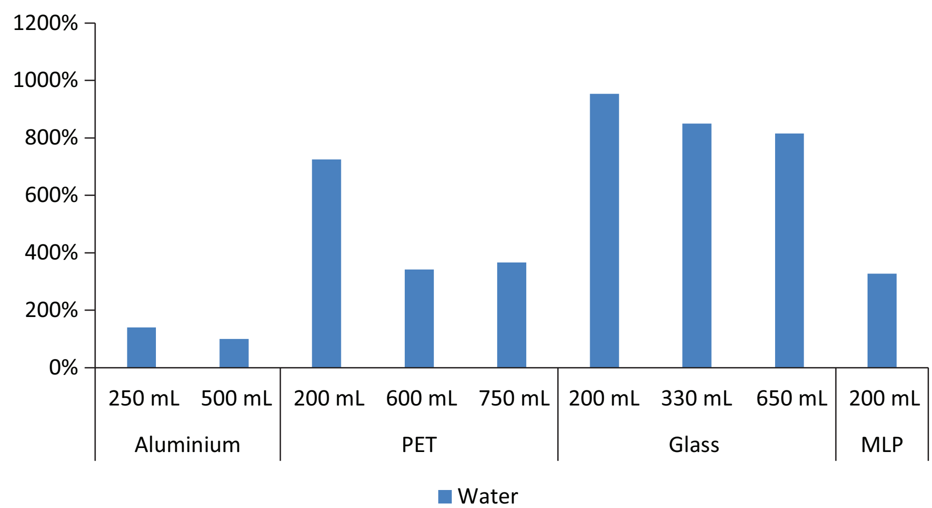

Figure 11: Water consumption of product categories in reference to 500 mL aluminium can (scaled to 1 L of fill volume, using the ReCiPe 2016 method)

6.1.3 Acidification (terrestrial)

Acidification of soils and water mainly occurs through conversion of air pollutants like SO_2, NO_2 into acids such as H2SO4, HNO_3. These acids change the soil and water's chemical properties, cause ecosystem nutrient imbalance and increase solubility of metals into soils and corrode calcium carbonate rocks like limestone. These air pollutants are commonly associated with combustion of fossil fuels during electricity generation and transportation.

For the purpose of comparison between various product categories, the acidification impact of 500 mL aluminium can is taken as reference and marked at 100%. The impact of remaining products is depicted with reference to aluminium can. The best performer in terms of acidification impacts is 600 mL PET bottle, which only has 71% of the impacts of the reference while the worst performer is

[4] Varshneya, Arun (1994). *Fundamentals of Inorganic Glasses*. San Diego, CA: Harcourt Brace & Company. p. 518. ISBN 0-12-714970-8

200 mL glass bottle, which has 454% the impacts of the reference. High acidification burden of glass can be explained through the large amount of sulphur dioxide emissions during the glass melting process. Also the high mass of glass bottles compared to other packaging substrates and the energy intensive glass manufacturing process involves emissions of large quantities of nitric oxide into the air. PET bottles show best performance when it comes to acidification as maximum burden for PET bottles comes from the manufacturing stage where SO_x emissions in case of PET manufacture is relatively less. Similar is the case for MLP cartons.[5] Aluminium cans show significant burden of terrestrial acidification during manufacturing of virgin aluminium, however, high recycled content of aluminium helps to cut down the burden significantly.

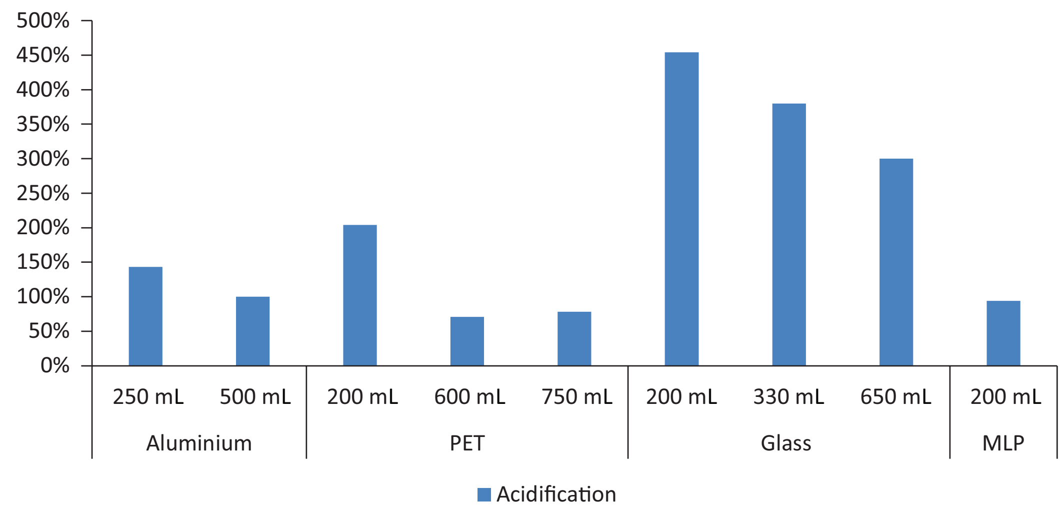

Figure 12: Acidification results of product categories in reference to 500 mL aluminium can (scaled to 1 L of fill volume, using the ReCiPe 2016 method)

6.1.4 Eutrophication (freshwater)

Eutrophication is progressive enrichment of water bodies with minerals and nutrients particularly nitrogen and phosphorus. These usually reach waterbodies through methods of leaching into groundwater or by direct runoff from agriculture (due to fertiliser use). This can unbalance the ecosystem by excessive algal production starving fish and other aquatic life of precious dissolved oxygen.

For the purpose of comparison between various product categories, the eutrophication impact of 500 mL aluminium can is taken as reference and marked at 100%. The impact of remaining products is depicted with reference to the aluminium can. The best performer in terms of eutrophication impacts is the aluminium can. The eutrophication burden can be correlated to water consumption of products primarily during secondary packaging. More water intensive is the product's secondary packaging, more is the wastewater generated which in turns flows into fresh waterbodies. In India, corrugated paperboards are used as secondary packaging for PET bottles and MLP cartons which is associated with high eutrophication. The

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5 Varshneya, Arun. 1994. *Fundamentals of Inorganic Glasses*. San Diego, CA: Harcourt Brace & Company. p. 518. ISBN 0-12-714970-8

worst performer is 200 mL PET bottle that has 3622% the impacts of the reference. The 200 mL MLP carton that uses corrugated board material also has a significantly high eutrophication impact. Glass has high water intensity but its eutrophication burden is low in India probably because of plastic crates for secondary packaging instead of cardboards. The water used during glass melting is processed by many companies on site, thereby reducing its eutrophication potential.[6]

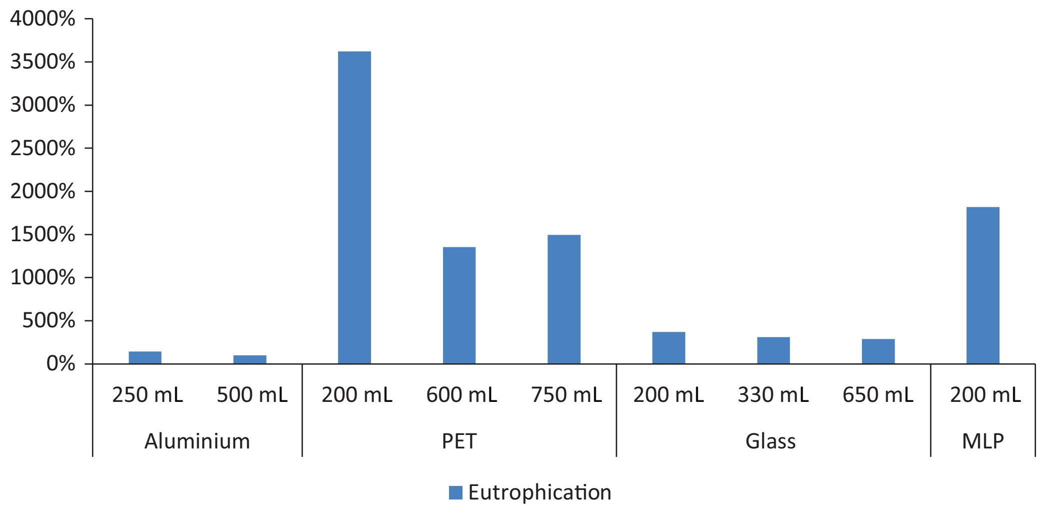

Figure 13: Eutrophication results of product categories in reference to 500 mL aluminium can (scaled to 1 L of fill volume, using the ReCiPe 2016 method)

Impacts associated with other mid-point environmental criterion were also calculated for ecotoxicity, ozone formation, particulate matter ($PM_{2.5}$) and ionising radiation for and the results are presented in the Annexure

6.1.5 End-point impact categories' results

The end-point impact categories in the ReCiPe methodology serve as a composite score for all mid-point impact categories and present them in a format most relevant to humans. The impacts can be understood by referring to the damage pathways as per ReCiPe given in Figure 4. Figure 14 demonstrates the impacts of selected product categories across parameters of human health, ecosystem, and resource utilisation. The damage pathway to high-resource usage has impact categories of mineral and fossil resource utilisation (refer to Figure 4). Glass bottles show high-resource burden because glass is one of the highest energy-intensive industries due to which its fossil depletion potential is very high. Glass manufacturing also includes use of numerous additional materials, causing a high-mineral depletion potential as well. On the contrary; manufacture of aluminium sheets, paper boards relatively originates from single material. However, 200 mL PET also shows high-resource burden as PET is directly obtained from fossil fuels.

6 Varshneya, Arun. 1994. *Fundamentals of Inorganic Glasses*. San Diego, CA: Harcourt Brace & Company. p. 518. ISBN 0-12-714970-8

The category of ecosystems is assessed based on the damage done to freshwater, terrestrial and marine species which in turn is based on impact categories such as GWP, water consumption, ozone, ecotoxicity, acidification, eutrophication (refer to Figure 4). Glass bottles have the largest mass and show high burden in many of these categories, resulting in high burden on the ecosystem.

The burden on human health is assessed based on damage pathways of respiratory and other diseases, cancer formation, and increase in malnutrition. The release in particulate matter, ozone formation, ionising radiation are categories which contribute to the above damage pathways (refer to Figure 4). Owing to impacts caused by glass bottles and their high mass show high burden in many of these categories, results in high burden on human health.

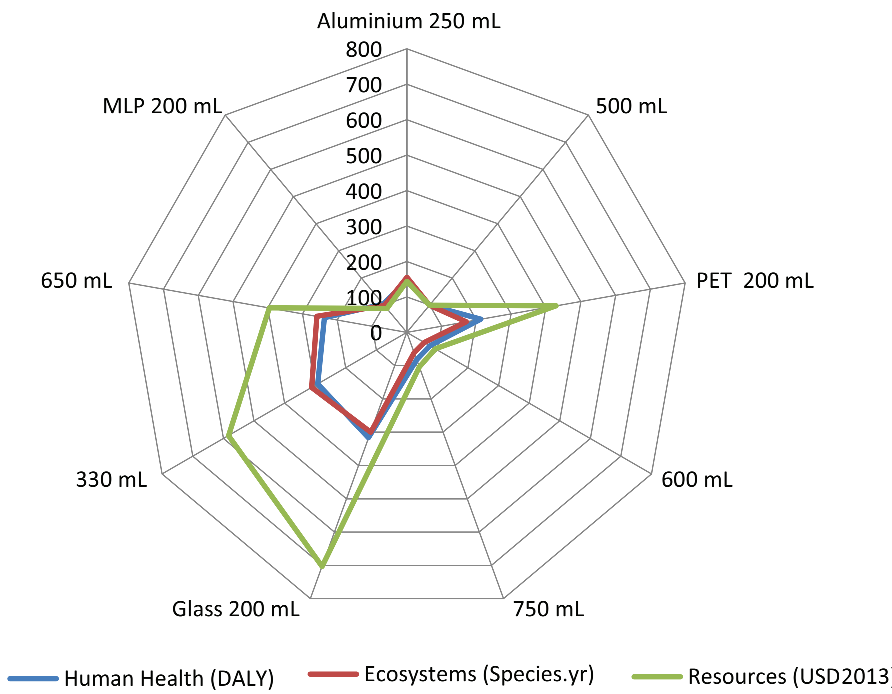

Figure 14: End-point impacts of selected product categories

6.1.6 Material circularity indicator results

Material circularity indicator (MCI) tool helps to identify additional, circular value from the products and materials, and thus mitigates risks from material price volatility and material supply.

Three main aspects of a products life cycle that influence the MCI score are:

(i) Proportion of input material flows that are from reused or recycled sources or sustainably sourced biological material.

(ii) Proportion of waste flows that are reused or recycled at the end-of-life.

(iii) Product utility measured in terms of number of reuse cycles compared to the average situation (single use).

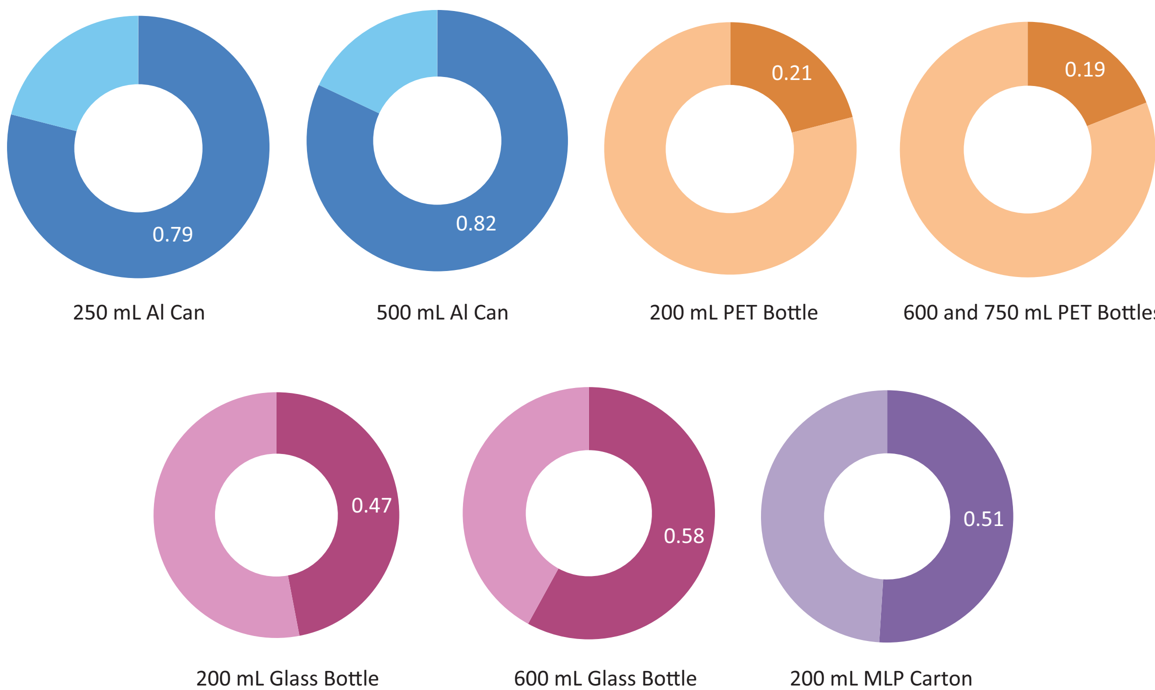

Figure 15: MCI scores of different product categories

Aluminium cans have relatively high MCI scores of 0.79–0.82, which reflects the highest average recycled content of 76% with an end-of-life recycling rate of 85%.

MCI score for 200 mL MLP cartons is intermediate of 0.51 as they have low-collection rate of 54% and only paper fraction of the entire carton is assumed to be recycled. However, cartons are composed of 70% paperboard which even though use 100% virgin material for manufacturing but because they are sustainably sourced, hence the process is considered completely restorative by MCI methodology. This greatly benefits the MCI score. Conversely to the basic principles of LCAs, material efficiency and waste treatment, the use of additional material in this case is rewarded in the MCI score purely because of its renewable origins. If a scenario is considered where the primary material for cartons is sourced unsustainably, MCI score will drop significantly, however, such consideration is not a part of this study. Therefore, MCI scores must be interpreted with caution as they may not automatically translate into degree of recyclability.

Glass bottles also have intermediate MCI scores of 0.58 and 0.47 because they are reused several times before discarding. The MCI scores of glass bottles can reach a perfect 1 with nearly 20 refills.

The PET bottles have low MCI scores of 0.19 and 0.21 which indicates that they have negligible recycled content and are not reused. While PET bottles are reused at the household level in India, such consideration is not taken as consumer behaviour is not a component of this study and also there is no such data available.

6.2 Comparative Analysis

To make the study more relevant for the Indian market, competing products of different substrates selling specific beverages are identified and compared for their impacts across a range of impact categories. Comparative analysis helps better and quick identification of shortcomings in product design and marketing and allows development of specific strategies in response.

Beverage-specific comparison is undertaken, as it will allow targeted product packaging improvement and efficiency. The chosen products are as suggested by Ball Corporation and according to relevance of the Indian market.

6.2.1 Beer

The value of Indian beer industry was INR 371 billion in 2020 and estimated to rise to INR 662 billion by 2028. With a high compound annual growth rate (CAGR) of around 9%, it is important to assess the most efficient and sustainable way of making beer available to consumers. Glass bottles are preferred only due to reduced cost to product of around 20%. However, glass has several environmental disadvantages over cans in terms of energy requirement and end-of-life usage. The comparison of the 500 mL aluminium can with 650 mL glass bottle across various environmental impact categories reveals the importance of support and incentivisation required for cans (Figure 16).

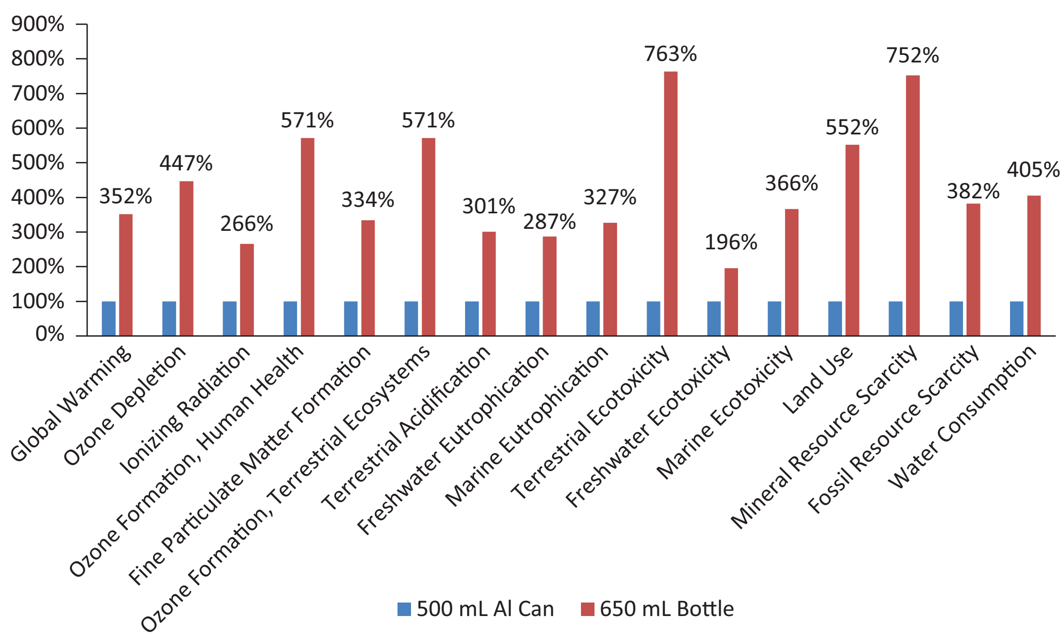

Figure 16: Comparison of 550 mL Al can and 650 mL glass bottle across several mid-point impact categories

The value of the 500 mL aluminium cans in each impact category given in the x-axis is taken as reference (100%). The performance of 650 mL glass bottle in corresponding impact categories is compared in terms of percentage with respect to the reference, that is, 500 mL aluminium can.

Aluminium can performs significantly better than glass bottle across all the assessed impact categories. The global warming potential (GWP) intensity of 650 mL beer glass bottle is 3.5 times than that of 500 mL can. The impact of glass bottle is highest in parameters of terrestrial ecotoxicity and mineral resource scarcity.

Another set of product category relevant to the Indian market is of the 330 mL can and the 330 mL glass bottle. Cans have added advantage in chilling, convenience, improved beer protection from light, oxygen and heat; over and above other environmental advantages. However, pricing remains a major setback for cans in India.

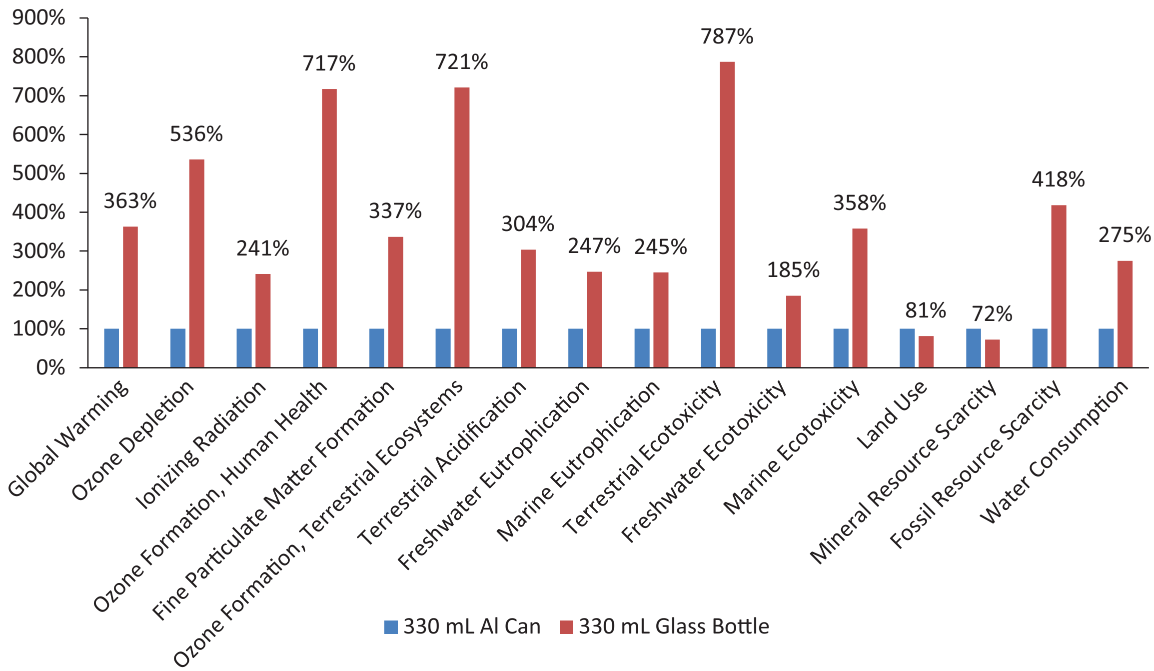

Figure 17: Comparison of 330 mL Al can
and 330 mL glass bottle across several mid-point impact categories

The value of 330 mL aluminium cans in each impact category, given in x-axis, is taken as reference (100%). The performance of 330 mL glass bottle in corresponding impact categories is compared in terms of percentage with respect to the reference, that is, 330 mL aluminium can.

The environmental impacts associated with 330 mL aluminium can is better than 330 mL glass bottle across most impact categories except land use and mineral resource scarcity. However, the difference is not much. This is due to the can's lightweight, energy and space-use efficiency. The impact for can has significantly improved in categories of ozone formation and terrestrial ecotoxicity.

6.2.2 Carbonated soft drinks

A. Carbonated soft drinks (250 mL can versus 185 mL can versus 200 mL PET)

The value of 250 mL aluminium can in each impact category, given in the x-axis, is taken as reference (100%). The performance of 185 mL aluminium can and 200 mL PET bottle is depicted in terms of percentage with respect to the reference, that is, 250 mL aluminium can.

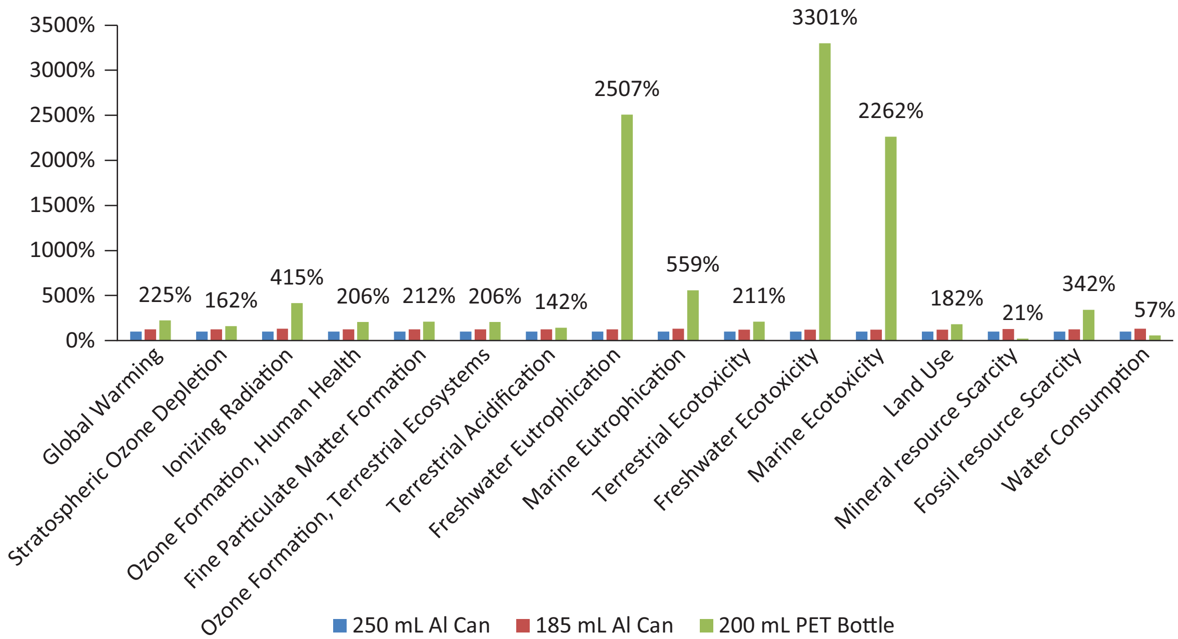

Figure 18: Comparison of 250 mL Al can, 185 mL Al can, and 200 mL PET bottle across several mid-point impact categories

The performance of 185 mL aluminium can is close to 250 mL can; however the former has slight better performance due to improved product to packaging ratio. The performance of both types of cans is significantly better than 200 mL PET bottle. The environmental impact of PET, in comparison to cans, is extremely high, in categories of freshwater eutrophication and ecotoxicity (marine and freshwater). Production of PET bottles is an energy-intensive process and is based on non-renewable raw materials. In relation to aluminium, which has high recycled content, PET has 0% recycled content in India; also PET bottles are amongst the most callously disposed items that end up in our waterbodies (fresh water and marine) which is probably the reason for its high ecotoxicity.

Another set of comparison is between 185 mL can and 250 mL PET bottle.

B. Carbonated soft drinks (185 mL can versus 250 mL glass bottle)

The value of 185 mL aluminium can in each impact category, given in the x-axis, is taken as reference (100%). The performance of 250 mL glass bottle is depicted in terms of percentage with respect to the reference, that is, 185 mL aluminium can.

The performance of 185 ml aluminium can is significantly better than 250 mL glass bottle in most impact categories except for ionising radiation, marine eutrophication, and fossil resource scarcity. The 250 mL glass bottle serving carbonated soft drinks is 5.4 times worse than 185 mL cans when it comes to land usage. This is probably because the end-of-life usage of aluminium cans is manifold better than eend-of-life of PET bottles in India.

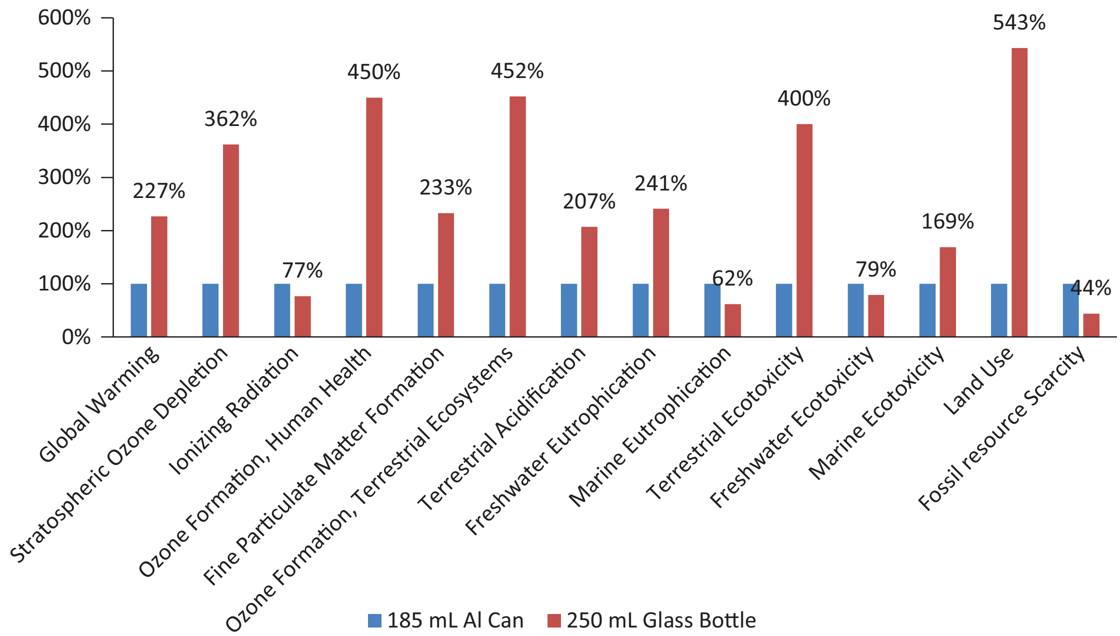

Figure 19: Comparison of 185 mL can and 250 mL glass bottle across several mid-point impact categories

6.2.3 Spirits

Spirits are one of the highest selling alcohols in India with a market size of INR 2.36 trillion. Glass bottles have traditionally dominated the spirits packaging industry, however, gradually environmental consciousness of consumers has made them accept spirits in cans. The comparative assessment points out the environmental impacts of 185 mL aluminium can with 180 mL glass bottle selling spirits (Figure 20).

The value of 185 mL aluminium can in each impact category, given in the x-axis, is taken as reference (100%). The performance of 180 mL glass bottle in corresponding impact categories is compared in terms of percentage with respect to the reference (that is, 185 mL aluminium can).

The performance of 185 mL can is better than 180 mL glass bottle across almost all impact categories except freshwater ecotoxicity and fossil resource scarcity. This is due to the can's lightweight and energy and space-use efficiency.

6.2.4 Juice

Non-carbonated soft drinks market in India was valued at INR 153 billion INR in 2020 and is estimated to reach INR 782 billion by 2027 with a CAGR of around 20%. Its high growth rate is attributed to increased rejection to carbonated and artificially sweetened beverages, thereby creating more space for fruit juices.

A comparison between product categories relevant to Indian market—250 mL aluminium can versus 200 mL MLP carton is given in Figure 21.

A. Spirits (185 mL can versus 180 mL glass bottle)

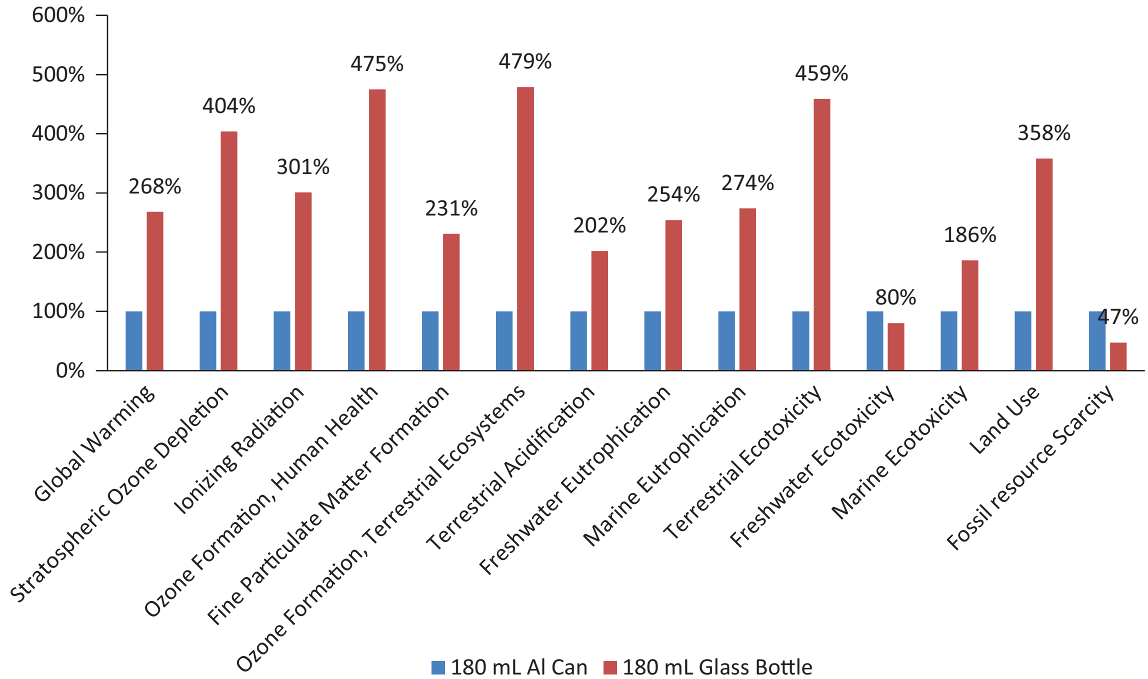

Figure 20: Comparison of 185 mL can and 180 mL glass bottle across several mid-point impact categories

A. Juice (250 mL can versus 200 mL MLP carton)

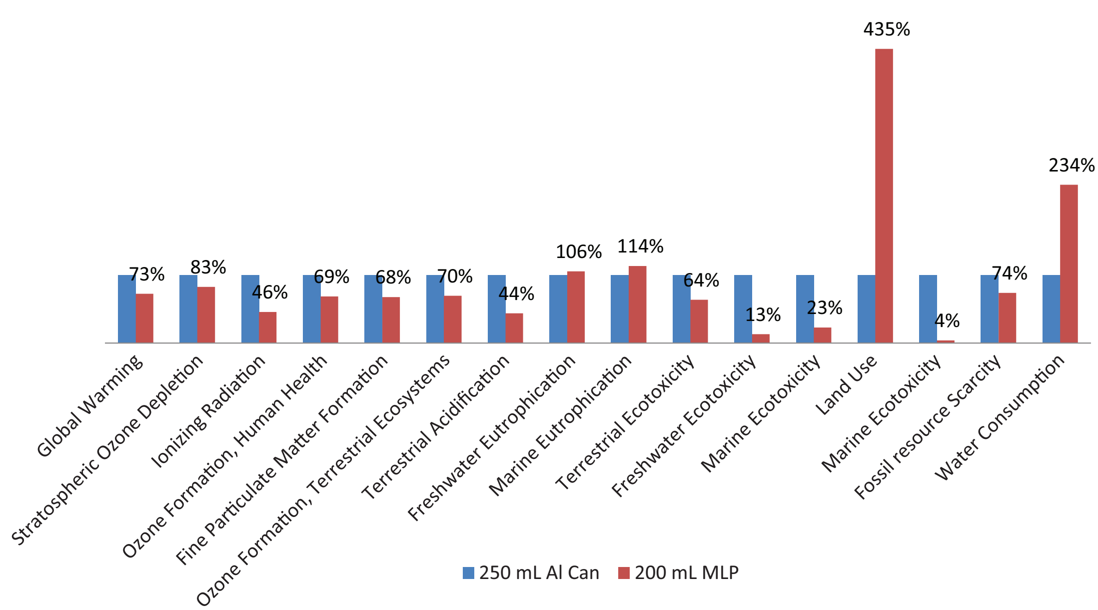

Figure 21: Comparison of 250 mL can and 200 mL MLP carton across several mid-point impact categories

The value of the 250 mL aluminium can in each impact category, given in the x-axis, is taken as reference (100%). The performance of 200 mL MLP carton is depicted in terms of percentage with respect to the reference, that is, 250 mL aluminium can.

The 200 mL MLP carton performance is better than 250 mL can across several impact categories, however, the difference is not extremely high. This is particularly due to less manufacturing impacts of the carton. It is also based on the preferred choice of customers. However, MLP cartons are not very efficient at protecting the juice against material and biological contamination. Aluminium cans also increase shelf life of juices much more than the cartons. The MLP carton has poor performance in comparison to can in category of land use due to higher recyclability of cans in India.

6.3 Sensitivity Analysis

Sensitivity analysis is a model that assesses how target variables are affected based on changes in other variables known as input variables. It helps to predict outcome of a decision within a certain range of variables. Thus, sensitivity analysis can help to make predictions about future course of action needed in order to promote a particular product or service over others.

Sensitivity analysis serves a viable tool for studying the robustness of results and their sensitivity to uncertainty factors in life cycle assessment (LCA). It also highlights important set of model parameters to determine whether data quality needs to be improved, and to enhance interpretation of results. For the purpose of this study, sensitivity analysis has been done with respect to five parameters: 1. methodology used, 2. use of renewable energy in manufacturing phase, 3. varying product weights, 4. recycling rates and 5. varied number of refills for glass bottles (330 mL) and non-returnable 650 mL. The ensuing section demonstrates the impact of slight change introduced to the mentioned parameters on GWP intensity of different substrates.

6.3.1 Sensitivity to methodology used: substitution versus cut-off

In order to assess how methodology affects results, alternative scenario using cut-off methodology had been set up where end-of-life credits are unconnected to results. Additional scenario with cut-off approach was adopted for aluminium cans and glass bottles only. PET bottles and MLP cartons have 0% recycled content in their products because Food Standard and Safety Authority of India (FSSAI) guidelines require usage of 100% virgin material in PET and MLP packaging in India. Hence, a cut-off scenario is relevant in case of PET and MLP packaging. Figure 22 shows the change in GWP intensity for aluminium cans and glass bottles with both methodologies.

6.3.2 Sensitivity to use of renewable energy in the manufacturing phase

Ball Corporation has committed to source all its all energy requirements through renewable means by 2030. This scenario is therefore a future projection of how manufacturing and accordingly the total life cycle impacts will change when this shift is realised considering the level of technology remains the same.

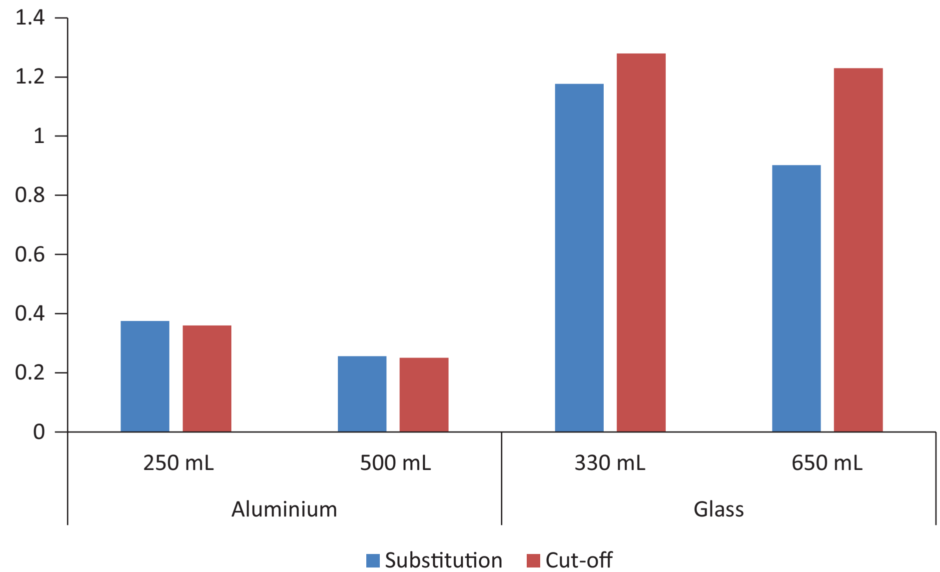

Figure 22: GWP intensity with methodology

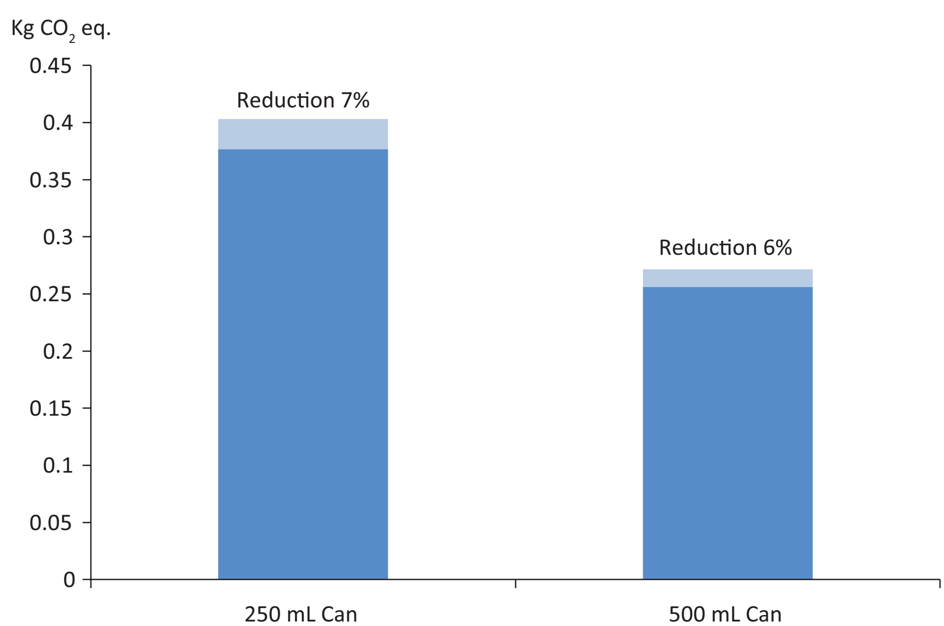

Figure 23: Reduction in GWP intensity with use of renewable energy

The graph given in Figure 23 shows that the GWP intensity reduces by 7% and 6% for 250 mL and 500 mL aluminium cans, respectively by use of renewable in the manufacturing stage which constitutes the can-making process. Thus, investments for energy transition by Ball Corporation must be suitably considered, as it will further bring the aluminium can a step closer to being a highly sustainable beverage option than present.

6.3.3 Sensitivity to product weight

It is evident from Figure 24 that GWP intensity of different product categories reduces with decreased container weight. Table 17 gives the numbers for percentage decrease of GWP intensity for 5% and 10% reduction of container weights, respectively.

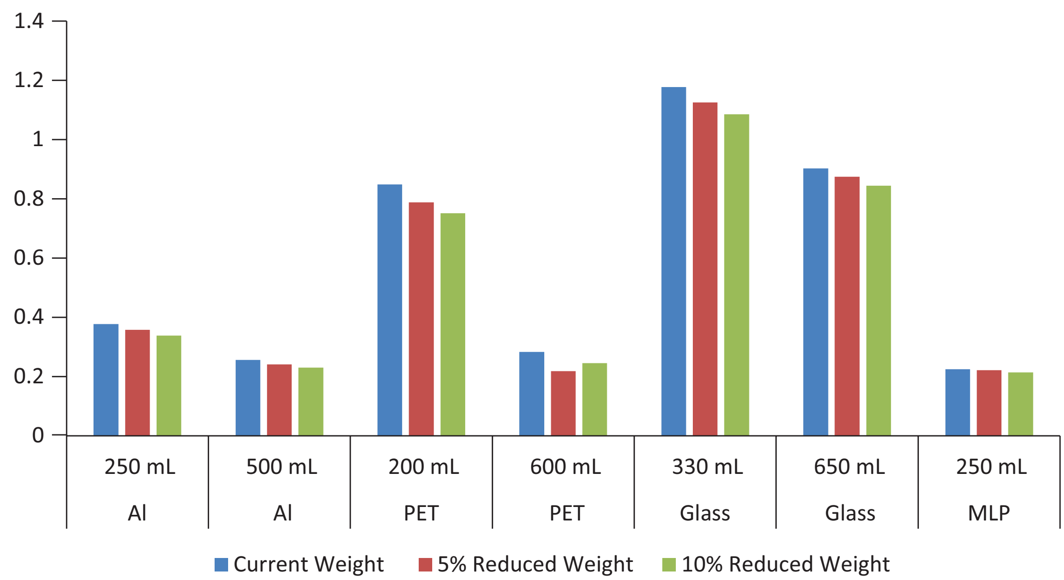

Figure 24: Reduction of GWP intensity with reduction in container weights

Table 17: Percentage reduction of GWP intensity with decreased container weights

Product category	Weight reduction (5%)	Weight reduction (10%)
Aluminium can 250 mL	5.2%	10.2%
Aluminium can 500 mL	5.8%	10.2%
PET 200 mL	7.1%	11.5%
PET 600 mL	8.75%	13.3%
Glass 330 mL	4.4%	7.8%
Glass 650 mL	3.1%	6.5%
MLP 200 mL	1.7%	4.9%

PET 600 mL has maximum reduction of GWP intensity with decrease in container weights, while aluminium cans also show significant reduction in GWP intensity with decreased weight. Thus, switching over to sleek cans may be a relevant step towards further improving eco-friendliness of cans.

6.3.4 Sensitivity to recycling rates 0–100%

For each packaging substrate material, one product (the most optimal according to the climate change profile) was tested with 0% and 100% recycling rates. The trend lines demonstrate that different substrates have different optimisation potential when it comes to real recycling rates.

The maximum reduction in GWP intensity is of glass, however due to its low real recycling rate, this potential has not been realised fully. Aluminium also shows significant drop in GWP intensity and with its high recycling rates close to 90%, it presents the opportunity of closing the material loop and applying the post-consumer scrap directly as a new material input.

PET bottles and MLP cartons do not show any significant improvement with increased recycling rates. LCA methodology does not give any benefit to recycled paper, either as recycled content or as end-of-life credits (Figure 25).

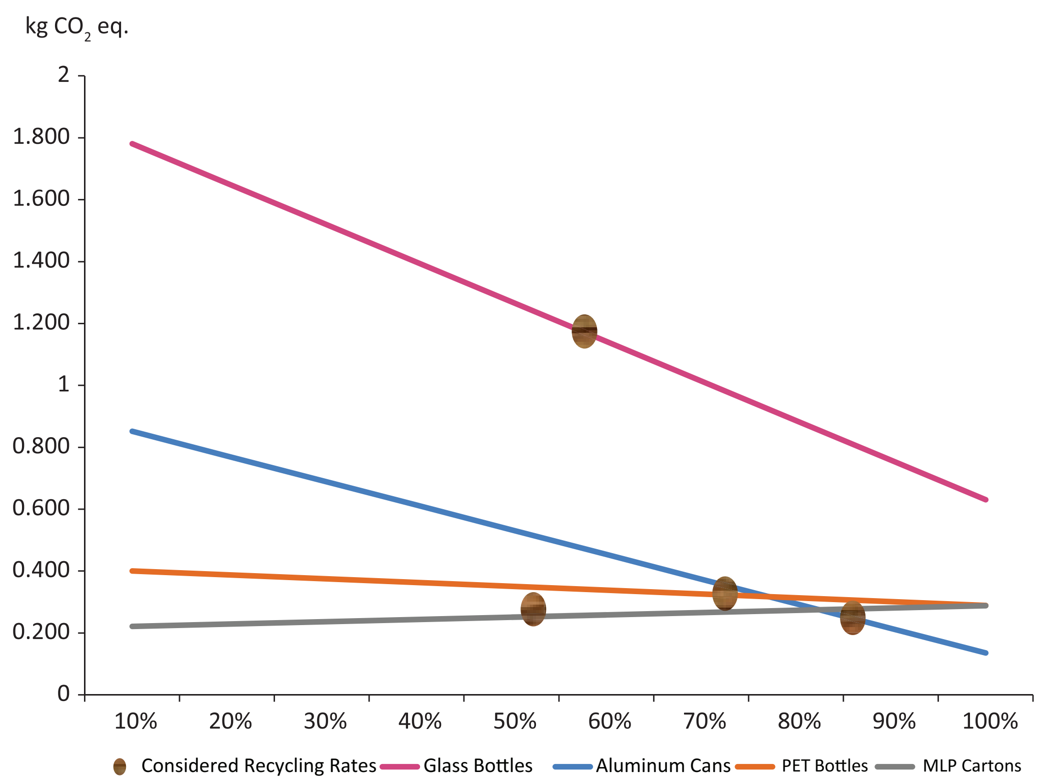

Figure 25: GWP intensity with different recycling rates

6.3.5 Sensitivity to refill of glass bottles for 330 mL and 650 mL (non- returnable and returnable)

For the case of measuring impacts of refill of glass bottle, 330 mL bottles carrying alcoholic beverages was considered. For refills of glass bottles, transportation from point of return to washing infrastructure and refilling station was considered. Despite this increase in transportation, the decrease in manufacturing impacts and end-of-life burden significantly brought down the GWP intensity with five refills. The percentage decrease is 64.2% for 330 mL and 72.7% for 650 returnable bottles with five turns. This makes glass bottles with five refills competitive with cans. However, with increasing number of refills the GWP intensity does not show any significant reduction in case of 330 mL bottles, however, the MCI score of glass bottles with 20 refills touches a near perfect 1, indicating equivalence to complete circularity.

A. 330 mL glass bottle

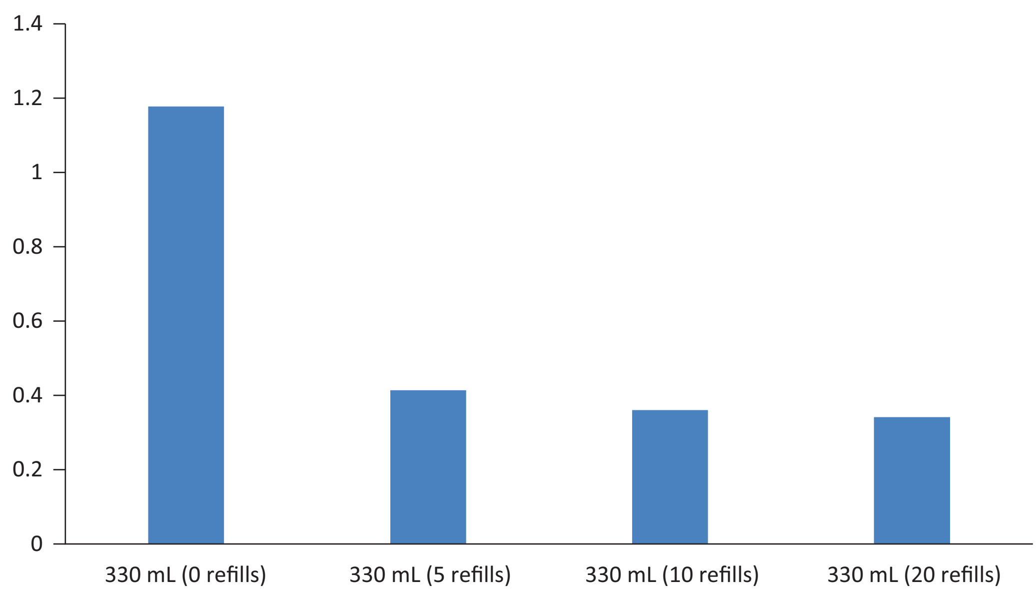

Figure 26: GWP intensity of 330 mL glass bottles with different refill rates

B. 650 mL glass bottle (returnable and non-returnable with 5 turns)

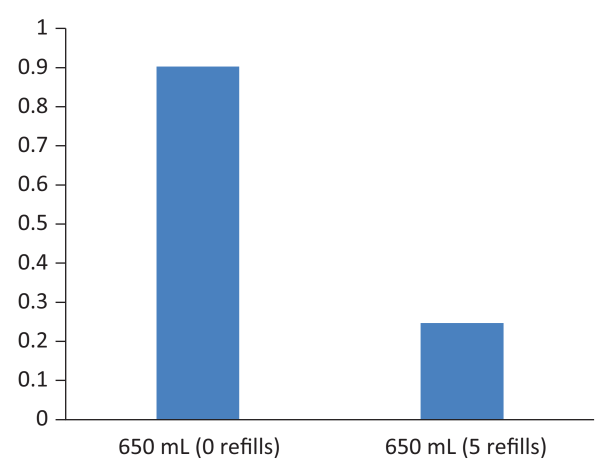

Figure 27: GWP intensity of 650 mL non-returnable and returnable glass bottles

6.4 Uncertainty Analysis

This section summarises the variability of GWP impact based on various sensitivity analyses performed to assess potential change in the future. Together the results are intended to show maximum potential improvements and worst-case outcomes identified for a representative volume of each packaging substrate. The uncertainty analysis presented in Figure 28 considers the following scenario and sensitivity analyses:

- Recycling rates of substrates from 0–100%
- Weight reduction of substrates by 5% and 10%
- Glass bottles without reuse and with reuse of 5, 10, and 20 refills
- Methodology used for assessment (substitution versus cut-off)

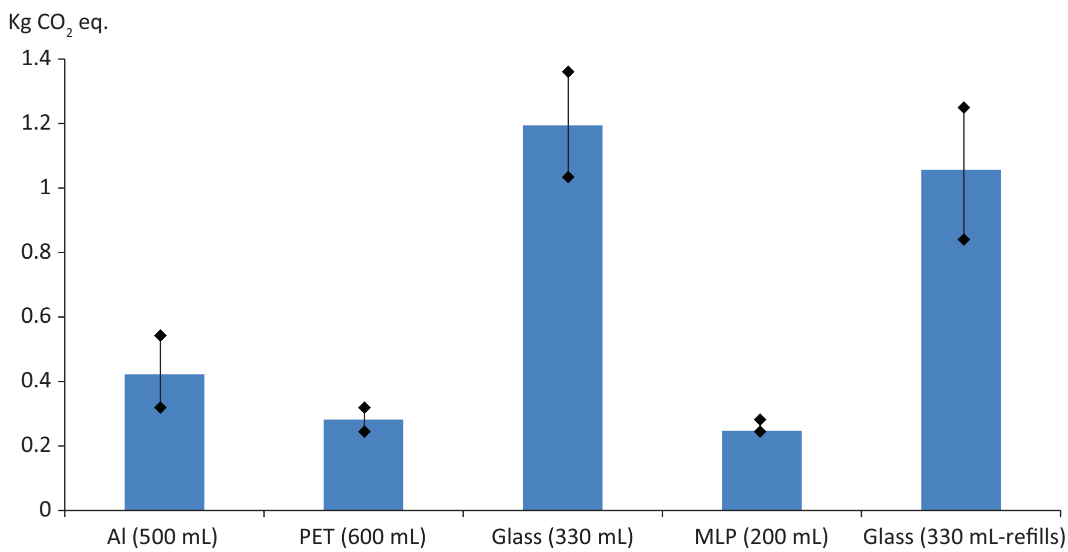

Figure 28: Uncertainty analysis of GWP impact (kg CO_2 eq.)

From Figure 28 it is evident that both MLP cartons and PET bottles have very little recorded uncertainty and therefore will show no significant improvement potential in future. This is because cartons and PET bottles are very slightly affected by change in recycling rates. However, PET shows a little higher uncertainty than MLP cartons due to its sensitivity to weight reduction in relation to cartons.

The glass bottles with and without refills show highest uncertainty and hence have a shown a marked potential for improvement if parameters are changed in future. The glass bottles are significantly sensitive to weights' reduction and the methodology of assessment. The glass bottles with refills even show a higher uncertainty due to significant reduction of impact in the first five refills.

Aluminium cans also show some uncertainty due to sensitivity to weight reduction and recycling rate. This proves that cans have high potential for improvement through refinement in these parameters.

7. Interpretation

7.1 Overall Relevant Findings from Baseline Scenarios

- The overall best performer for carbonated beverage in the assessed impact categories is the 500 mL aluminium can, due to its lightweight and highly reduced end-of-life burden as a result of its infinite recyclability.
- The 600 mL PET bottle is a close competitor of the 500 mL aluminium can in terms of impacts and also due to its favourable packaging-to-product ratio.
- PET bottles fare well despite zero usage of recycled materials. This is because of the relatively low virgin material impacts and manufacturing-related impacts.
- The 200 mL MLP carton performs best in several impact categories and thus is the overall best performer for non-carbonated beverages.
- The strong performance of MLP carton is primarily due to its main raw material, paperboard that typically constitutes 70% of the carton weight and has low manufacturing impacts. If paperboard is produced in an integrated pulp and paper mill, most the energy usage comes from biomass such as wood offcuts from forestry, bark and wood chips and from black liquor produced from wood during pulp production.
- Aluminium cans are lightweight compared to most other packaging options, this helps to reduce impacts. The potential for further reduction of GWP intensity with aluminium is also significant with average of 5.5% and 10.2% with 5% and 10% reduction of container weights, respectively.
- The maximum reduction of GWP intensity is seen in case of PET bottles, particularly 600 mL PET with reduction potential of 8.75% and 13.3% with 5% and 10% reduction of container weights, respectively.
- Glass bottles and aluminium cans have significant potential of improving GWP intensity with increased recycling rates. This potential is realised in case of cans due to their high recycling rate at 90% while the real cycling rate of glass bottles is low at around 40%.
- The potential decrease in GWP intensity for MLP is low because paper recycling facilities unlike virgin paper production rely on external energy sources. Thus, high recycling of paper does not necessarily decrease GWP of cartons.
- Collected PET bottles are usually down cycled in India and hence high recycling rates do not improve GWP intensity of PET bottles. This finding demonstrates that environmental benefits of driving up recycling rates further at end-of-life, implying for aluminium cans, circular economy enhancements and climate protection go hand in hand.
- For glass bottles, a 64.2% drop in GWP intensity is seen with five refills due to decrease in manufacturing impacts and end-of-life burden. This is despite the increase in transportation distance from collection centres to washing stations and refilling stations.

- 250 mL and 500 mL aluminium cans also show a reduction of GWP intensity by 7% and 6%, respectively with use of renewable energy in the manufacturing stage.
- Certainly other packaging substrates are also likely to benefit from full reliance on renewable energy, most notably PET bottles and to some extent glass bottles. However, MLP cartons are less likely to show significant reduction as they are already benefitting from renewable energy usage considered in virgin pulp production.

7.2 Assumptions

The following conservative assumptions were made based on goal and scope of the study:

- The transportation distance from collection to end-of-life treatment is assumed to be 200 km for other substrates except aluminium, as the recycled aluminium is transported back to South Korea facility for sheet manufacturing.
- The recycling rates were taken as average for India, however, the end-of-life practices may differ from region to region within the country.
- The recycled content (for cut-off analysis) may vary for different producers or clusters, however, it is taken as average for aluminium and glass production based on inputs from Ball India and All India Glass Manufacturing Federation (AIGMF).
- The switching rate is assumed to be 1:1 for the recycled material due to lack of circular footprint methodology within Indian context. However, it may happen that recycled material from MLP and PET bottle is used in other less competitive industries. The aluminium and glass however don't lose their properties and quality to be recycled in closed loop.
- The energy requirement for chilling of beverage containers at point of sale is excluded from the study, however, it is expected that aluminium will have least energy requirement due to least specific heat capacity.
- The best available datasets were used wherever the geography or technology-specific datasets were not available. The injection moulding for HDPE granulate to preform manufacturing is assumed in place of PET. While the global average datasets were assumed for the used chemicals and lubricants.

7.3 Limitations

- A key limitation of this study is data quality difference between different subjects of comparison. Most data for aluminium cans is primary while secondary data is used for other substrates.
- The results described in this report are valid only within specified scope of the study, focusing on aluminium cans, cartons, glass and PET bottles for specific sizes and scenarios assessed. Results may vary in comparing different products.
- The assumption related to switching rate of 1:1 is key the limitation of the study, results might vary if the recycled material is used in other industries. This is more relevant to PET and MLP as aluminium and glass can be recycled in a closed loop system.
- The use of proxy datasets might vary the results, however chemical or other production process are standardised across the world. It is the source of energy which generally results in embodied impacts. The regional energy datasets were used in the study.

- The transportation distances to filling site and then to point of sale are assumed to be consistent. However, it will depend on the market share of substrate, consumption patterns, and distribution infrastructure developed.
- Results depend on supply chains that are modelled in this study. Any change in transportation distance, location, and so on will affect the results.
- As stated by ISO 14040, LCA shall not be the sole basis of comparative assertions. Other social, economic, and environmental aspects should also be considered. One such aspect is of circularity captured by MCI score, which has gained enormous social and political traction.

7.4 Material Circularity Indicator

The MCI score provides a reliable understanding of the circularity of each packaging option rewarding the use of recycled/reused content and renewable) sustainably sourced materials and waste treatment through reuse and recycling. However, the score does not include the factors of material and energy efficiency. Together with the results of the main LCA study, it can help to derive meaningful and effective means to achieve circular economy with low environmental impacts.

- Aluminium cans have high MCI score of 0.79 (250 mL can) and 0.82 (500 mL can), indicating a high degree of circularity because recycling rates are high and aluminium has extremely low yield losses during the recycling process.
- MLP cartons and single-use glass bottles have intermediate MCI score. MLP cartons have high amounts of renewable content but low collection rate and almost negligible recycled content in Indian context.
- Glass bottles are recycled but have low recycling rates compared to aluminium cans. However, increased number of refills increases its MCI score.
- PET bottles perform poorly in MCI score because PET in India is not really recycled but is down cycled. The modelled PET bottles in this exercise completely use 100% virgin granulate during production.

Other means of improving MCI score is increasing number of reuse, applicable to PET and glass bottles (but such data could not be captured). Secondary packaging made from cardboard also increases circularity because it is sourced from renewable biomass material. This implies that one must apply caution while interpreting MCI scores as it gives benefit to product using higher paper-based secondary packaging. Therefore, MCI should always be read in conjunction with main LCA results.

7.5 Results from Sensitivity Analysis

Sensitivity analysis was performed to test the influence of results of changes in parameter values that are based on assumptions or are otherwise uncertain.

The first case of sensitivity analysis considered in this study is the methodology applied. While substitution methodology was applied for baseline scenarios, a cut-off approach was taken for aluminium cans and glass bottles in the sensitivity analysis. The results associated with 330 mL and 650 mL glass bottles show significant change while the results do not vary much for aluminium cans.

Another analysis was done in which the influence of the usage of renewable energy was tested for GWP intensity. The results showed that a shift to renewable energy in the manufacturing stage causes a reduction of GWP intensity by 7% and 6% for 250 mL and 500 mL aluminium cans, respectively.

The analysis showed that results based on the substitution approach are sensitive to recycling/collection rates at the end-of-life. The drop in GWP intensity is significant for aluminium cans and glass bottles but is negligible for MLP cartons as value of recycled paper and virgin paper is not very different in terms of their climate change burdens. It is to be noted that the end-of-life treatment of several products has major potential in offsetting some of the manufacturing-related impacts.

Also as part of end-of-life treatment, GWP intensity was tested over a range of 0–20 refills off glass bottles to demonstrate the effect of bottle refilling on environmental performance. The system was sensitive to these changes and there was a huge drop of 64.2% in GWP intensity of 330 mL glass bottles with 5 refills. In the case of 650 mL glass bottles the GWP intensity dropped by 72.7% with 5 refills. This is to be noted that similar facilities have also been installed for PET bottles too and these are expected to decrease the impacts of PET to similar degrees as glass but since these systems are still not prevalent in most markets, hence were not analysed in this study.

7.6 Conclusion and Recommendations

With rising consumerism arising largely from higher disposable income and changing lifestyles, there has been a growing demand for packaging solutions globally and India is no different. This is further accentuated by increase in the rapid expansion of organised retail, e-commerce and exports further facilitating the growth of the market.

The beverage packaging sector largely uses four major substrates: (i) aluminium, (ii) plastics, (iii) glass, and (iv) multi-layered packets. While the functionality of these products is largely the same, that is, of the products is to contain beverages, enabling transportation, and protecting beverages against mechanical stress and material loss, however the potential environmental impacts associated with mismanaged packaging materials are not uniform. It is only in recent years that there has been greater acknowledgment of possible environmental challenges associated with mismanaged packaging materials, leading to introduction of various rules and regulations.

While these regulations are indeed a welcome move, consumers, too, have a larger role to play in supporting brand owners by making choices and thereby creating markets for sustainable packaging solutions. As observed from the extensive LCA, choice of packaging materials does play a significant role in addressing environmental burdens, not to mention the imperative the proper end-of-life management. This is possible when there is greater awareness amongst consumers about the potential environmental threats arising from mismanaged (uncollected beverage packaging wastes).

Form the LCA, it is observed that the best performance for non-carbonated beverages is exhibited by MLP cartons largely due to being lightweight and use of environmentally benign raw materials. This is an intrinsic advantage of cartons. However, a key limitation of MLPs is that they hardly find application for carbonated beverages.

Aluminium cans are close behind again due to being lightweight, indicating less material is required during their manufacturing. Among carbonated beverages, aluminium cans perform best across most impact categories while PET bottles are close behind due to their thin wall designs. Along with lightweight, an important reason for good performance of aluminium cans is because of the high average levels of recycled content used during manufacturing and high recycling rates at end-of-life.

The study findings indicate the paramount importance of enhancing circular systems through:

- Increasing recycled content as far as technologically feasible
- Increasing collection rates at end-of-life
- Maximising refill cycles of bottles designed for reuse
- Supporting the logistics of closing the loop, that is, providing the scrap input in required quantity and quality
- Sourcing renewable for manufacturing sites is another action that can improve environment profile of cans

Each packaging option has a valid justification for use from an environmental perspective, as each option exhibits different environmental strengths and weaknesses. Maintaining diversity in the consumption of materials by using a range of packaging option is required for sustainable resilience, because each option exerts a different burden on the planet.

Hotspot analysis of substrates for GWP intensity shows that most significant impacts are during the phase of cradle to gate which includes the manufacturing phase. Glass bottles show the worse environmental performance across several impact categories and the impact is significantly high in case of single-use glass. The glass bottles that are inherently designed for reuse and are extensively reused, thus outperform single-use bottles. Reuse is the single most important future improvement potential for glass.

Cartons have less potential to improve their performance by recycling as there is no significant difference between recycled and virgin paper in terms of environmental burdens.

The aim of the report has been to provide deeper insights about beverage packaging choices. It provides sustainability implications of various beverage packaging solutions based on which various stakeholders along the production consumption chain can make informed and judicious choices in lowering environmental impacts, thereby supporting circularity for the economy.

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The following URLs were also accessed for carrying out the study:

- https://www.researchandmarkets.com/reports/5190308/india-beverage-packaging-market-2020-2026
- https://www.globenewswire.com/news-release/2021/12/14/2351554/0/en/The-Future-of-Beverage-Packaging-Market-Economy-Size-Expected-a-Growth-of-190-Billion-by-2028-According-to-Vantage-Market-Research.html
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Annexure

Mid-point Impact Categories

		Aluminium		PET			Glass (with zero refills)		Glass (with refills)					MLP
Impact category	Unit	250 mL	500 mL	200 mL	600 mL	750 mL	200 mL (CSD)	330 mL (Beer)	650 mL (Beer)	330 mL (5 refills)	330 mL (10 refills)	330 mL (20 refills)	650 mL (5 refills)	200 mL
Global warming	kg CO2 eq.	0.37663742	0.25615618	0.84835318	0.28261778	0.31029956	1.3481048	1.1771067	0.90261407	0.41357853	0.36027057	0.34141961	0.24656685	0.42497775
Stratospheric ozone depletion	kg CFC11 eq.	1.10E-07	7.41858E-08	1.78E-07	7.20E-08	7.73E-08	5.65E-07	5.05E-07	3.32E-07	1.35E-07	1.85E-07	1.76E-07	9.78E-08	1.43E-07
Ionising radiation	kBq Co-60 eq.	0.004181585	0.002391401	0.017378867	0.006524499	0.006808707	0.005309445	0.008040421	0.006364327	0.00472046	0.003720052	0.00365067	0.002678038	0.008514729
Ozone formation, Human health	kg NOx eq.	0.000832558	0.000604025	0.001716134	0.000627792	0.000688258	0.006131908	0.005229103	0.003451547	0.001098616	0.001556801	0.001471876	0.00093994	0.000865122
Fine particulate matter formation	kg PM2.5 eq.	0.000753086	0.000530398	0.001598141	0.000589501	0.000649416	0.002662548	0.002225372	0.001771936	0.000758778	0.000544595	0.000505928	0.00037175	0.000795961
Terrestrial acidification	kg SO2 eq	0.001748155	0.001225092	0.002493507	0.000866327	0.000950804	0.005560116	0.004656173	0.003694743	0.001709779	0.001113679	0.001032235	0.000774001	0.001154023
Freshwater eutrophication	kg P eq.	1.20886E-05	8.36889E-06	0.000303166	0.000113449	0.000125249	3.10E-05	2.61E-05	2.41E-05	1.08E-05	6.54E-06	6.10E-06	5.26E-06	0.000152146
Marine eutrophication	kg N eq.	3.77E-06	2.11301E-06	2.11E-05	2.62E-05	2.72E-05	5.34E-06	7.33E-06	6.91E-06	5.48E-06	2.54E-06	2.47E-06	2.09E-06	1.45E-05
Terrestrial ecotoxicity	kg 1,4-DCB	0.527209332	0.40320626	1.1150718	0.33081388	0.36616071	4.139383	3.5563943	3.0772623	1.0343953	1.5689378	1.5324521	1.7664594	0.61813759
Freshwater ecotoxicity	kg 1,4-DCB	0.000625507	0.000450852	0.020648386	0.009999132	0.010807182	0.001221045	0.001019428	0.000888161	0.000337412	0.000374162	0.000359685	0.000360198	0.013506021
Marine ecotoxicity	kg 1,4-DCB	0.001221462	0.000890779	0.027631664	0.013515884	0.014597924	0.004477956	0.003823998	0.003268544	0.001086936	0.001420703	0.001371661	0.001501149	0.01844826
Land use	m2a crop eq.	0.005174836	0.003674994	0.009434538	0.004010542	0.004279311	0.011808768	0.003671491	0.00203117	0.017455422	0.005491685	0.005374956	0.002352279	0.023738317
Mineral resource scarcity	kg Cu eq.	0.004093822	0.002942943	0.000870594	0.000210673	0.000235708	0.003463243	0.002662757	0.002214643	0.001141834	0.001129198	0.001090666	0.000622252	0.000203032
Fossil resource scarcity	kg oil eq.	0.089706605	0.062689969	0.30748037	0.084774175	0.09451324	0.39750277	0.32489306	0.23950067	0.093071242	0.10547316	0.10002814	0.067725951	0.096614535
Water consumption	m3	0.000811861	0.000581227	0.004216083	0.001987266	0.002128325	0.005545161	0.004944648	0.004736711	0.001461685	0.001655877	0.00161223	0.006451619	0.001900369

End-point Impact Categories

Impact category	Unit	Aluminium		PET			Glass (with zero refills)			Glass (with refills)			MLP
		250 mL	500 mL	200 mL	600 mL	750 mL	200 mL (CSD)	330 mL (Beer)	650 mL (Beer)	330 mL (5 refills)	330 mL (10 refills)	330 mL (20 refills)	200 mL
Human health	DALY	1.4972E-06	1.01882E-06	2.17E-06	7.75E-07	8.44E-07	3.24E-06	2.97E-06	2.42E-06	5.91E-07	8.19E-07	7.73E-07	1.06E-06
Ecosystems	Species.yr	3.6711E-09	2.36578E-09	4.06E-09	1.37E-09	1.45E-09	7.10E-09	7.38E-09	6.13E-09	1.64E-09	2.11E-09	2.01E-09	2.36E-09
Resources	USD2013	0.027097	0.018812052	0.08070445	0.017584348	0.019707153	0.13229797	0.10974677	0.074350056	0.023545618	0.040327266	0.038510207	0.016692159