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End of Life Model for Paper and Paper Packaging in South Africa

Guideline 5 in the CSIR's LCA Guideline Series

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June 2026

science, technology & innovation
Department: Science, Technology and Innovation
REPUBLIC OF SOUTH AFRICA

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Degree of Confidentiality:	Public
Title:	End of Life Model for Paper and Paper Packaging in South Africa
Author(s):	de la Rey, J., Botha, E., Goga, T., Harding, K., Nahman, A., Stafford, W., and Russo, V.
Date of Issue:	9th June 2026
Grant Holder:	Valentina Russo
Organization Report Number:	
Prepared by:	CSIR Smart Places Stellenbosch South Africa PAMDEV NPC t/a Fibre Circle Sandton South Africa University of the Witwatersrand Braamfontein South Africa
Prepared for:	Department of Science, Technology and Innovation Circular Innovation South Africa Pretoria South Africa
Contract Number:	CSIR/BEI/CISA/2025/075
Keywords:	LCA, EPR, Paper and Packaging, CSIR LCA Guidelines
Version:	Final draft for submission

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External Reviewer:		

APPROVED BY (On behalf of issuing organisation):		
Name:	Position:	Date:

ACKNOWLEDGMENTS

The development of this Guideline has been possible thanks to funds received from the Department of Science, Technology and Innovation (DSTI) through the Circular Economy STI Strategy.

It has been developed in collaboration with Fibre Circle NPC (Producer Responsibility Organisation representing the paper and paper packaging sector), and LCA experts from Witwatersrand University (Assoc. Prof. K Harding and PhD candidate Mr E. Botha).

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1 Introduction

This Guideline forms part of the **CSIR's Life Cycle Assessment (LCA) Guideline series**.

Guideline 1 is the main guideline, providing information on how to conduct an LCA study in the South African context.

This accompanying guideline, Guideline 5, provides a detailed End of Life (EoL) model for the Paper and Paper Packaging sector for application in LCA studies conducted under the Extended Producer Responsibility (EPR) Regulations in South Africa. The EoL model has been derived using industry data pertaining to the sector.

The Guideline was developed in collaboration with Fibre Circle, the Producer Responsibility Organisation (PRO) for Paper and Paper Packaging in South Africa which includesrecycling companies members of the Paper Manufacturers Association of South Africa (PAMSA) recycling forum, and represent 95% of the volumes recycled locally.

The model and recommendations provided in this Guideline can be considered the best available in terms of data coverage for paper and paper packaging in South Africa.

2 General approach to modelling End of Life and the waste management system in South Africa

A critical aspect of conducting an LCA study to comply with the EPR regulations in South Africa, is to correctly model the EoL of the identified products, given South Africa's current waste management system. This section makes general recommendations to ensure that the EoL of products is accurately and consistently reported in LCA studies. The next section provides more specific recommendations for modelling EoL for paper and paper packaging.

Figure 1 provides a schematic of the main lifecycle stages to consider when modelling product end-of-life. It is important to gather accurate data on material inputs/outputs associated with the product system at the main EoL stages as per Figure 1 and Table 1, to be able to accurately model South Africa's waste management system and current practices. Specifically:

- To correctly account for material collection, recycling and waste management:
    - In South Africa, approximately 71% (by mass) of municipal solid waste generated is collected ($W_{collection}$ as per Figure 1), while 29% is not collected or treated via formal waste management systems (Rodseth et al., 2020).
    - The uncollected waste should be treated as contributing to open dumping (W_{open_dump}), and ultimately contributing to environmental pollution.
    - It is recommended that waste-stream specific splits between collected and uncollected waste be used if available; alternatively, the values for mixed waste (71% collected / 29% uncollected) should be used as a default.

- The municipal solid waste collected via formal waste management can further be broken down into approximately 13% collected from rural areas and 87% collected from urban areas (including metropolitan areas) (Rodseth et al., 2020).

- The split between waste going to "sanitary" and "unsanitary" landfill must also be specified ($W_{sanitary}$ and $W_{unsanitary}$ in Figure 1), as this will determine the extent to which the waste will be contained.
  - The best available data for municipal solid waste in SA, which was applied for Upper Middle Income countries in the Global Breaking the Plastic Wave study (Lau et al. 2020a, 2020b), as well as in the South African Pathways study (Stafford et al. 2022) following consultation with local experts, suggests that:
    - In urban areas, 53% of waste is disposed of in sanitary landfill ($W_{sanitary}$ as per Figure 1), and 47% in unsanitary landfill ($W_{unsanitary}$)
    - In rural areas, 28% of waste is disposed of in sanitary landfill landfill ($W_{sanitary}$), and 72% in unsanitary landfill ($W_{unsanitary}$).
  - It is recommended that the best available estimates of the splits between sanitary vs. unsanitary landfill for the waste stream in question be used, where available.

- Open-burning of waste is prevalent in South Africa, but there is no official country specific data available.
  - Based on Wiedinmyer et al. (2014), the Breaking the Plastics Wave study assumed that open burning of collected plastic waste globally is 13%, while the open burning of uncollected waste in residential areas is 60% (Lau et al., 2020b).
  - To correctly account for open burning, the best available estimates for the waste stream in question should be used. Alternatively, 60% (by mass) of the flow named W_{open_dump} and 13% of the flow named $W_{unsanitary}$ (as per Figure 1) should be used as a default.

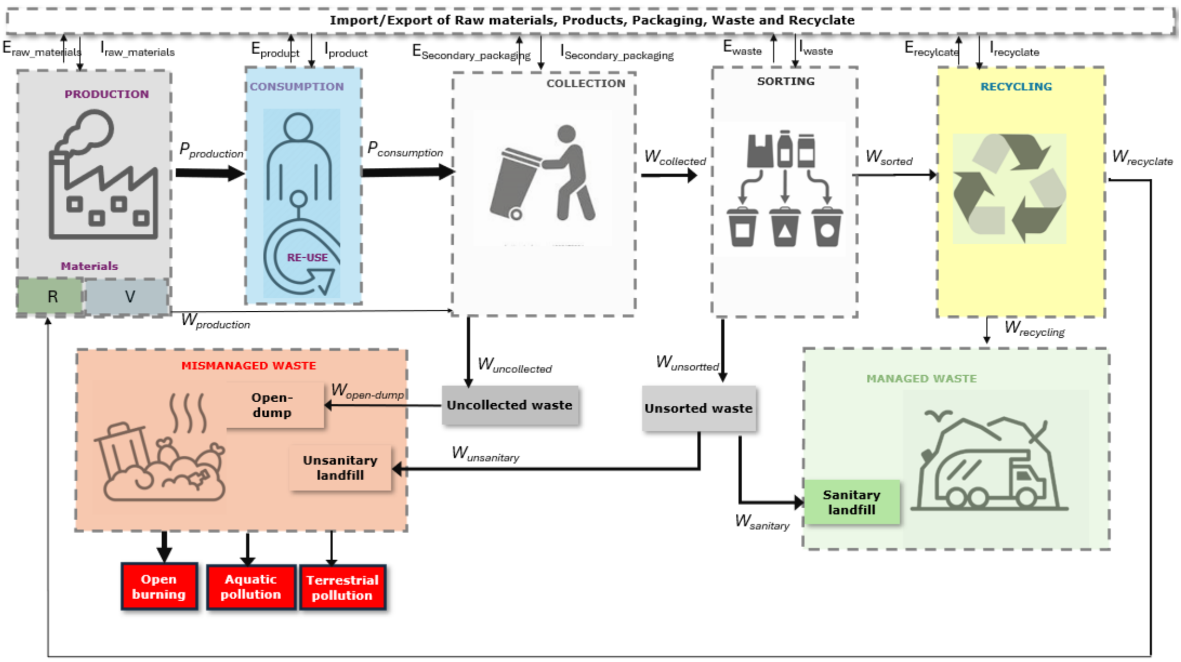

Figure 1: Schematic of main End of Life stages. 'P' refers to the product stream, 'W' refers to the waste stream, 'E' refers to exports and 'I' refers to Imports (source: Authors)

Ideally, a standard use of these parameters in accounting for the EoL stage of a product is needed to ensure transparency and improve the consistency of efficiency and performance indicators. It is important to clearly state the parameters used (as per Figure 1) when calculating the Collection rate, Recycling rate, Recycling efficiency, Recyclate content, and Sanitary landfill treatment**.** Finally, it is important to model the corresponding dataset for materials collection and recycling in the LCA study to evaluate the associated burdens.

Table 1: Definition of variables as per Figure 1

Variable	Description
R	Recycled material input to production
V	Virgin material input to production
E_raw_materials	Export of raw materials
I_raw_materials	Import of raw materials
P_production	Product flow from production to consumption
W_production	Waste or production residuals leaving production
E_product	Export of product
I_product	Import of product
P_consumption	Post-consumption product/waste flow to collection
E_secondary_packaging	Export of secondary packaging
I_secondary_packaging	Import of secondary packaging
W_collected	Waste collected and sent to sorting
W_uncollected	Waste not collected
E_waste	Export of waste
I_waste	Import of waste
W_sorted	Sorted waste sent to recycling
W_unsorted	Unsorted waste leaving sorting
E_recyclate	Export of recyclate
I_recyclate	Import of recyclate
W_recyclate	Recyclate output from recycling
W_recycling	Recycling rejects/residuals sent to managed waste
W_open-dump	Waste sent to open dump
W_unsanitary	Waste sent to unsanitary landfill
W_sanitary	Waste sent to sanitary landfill

3 End of Life modelling for Paper and Paper Packaging

This section describes the EoL model derived for the paper and paper packaging sector, and provides recommendations for implementing the modelling in LCA studies.

3.1 Background to Paper and Paper Packaging

Fibre Circle is a Producer Responsibility Organisation (PRO) for paper and paper-based packaging under the Extended Producer Responsibility (EPR) Regulations of 2021 (DFFE, 2021). Fibre Circle's members collectively place 95%-96% of the locally consumed packaging papers in South Africa on the market.

The definition of packaging papers is limited to *Kraft and Box Board* for the purposes of the EPR scheme for paper packaging. This definition therefore also applies to the requirements for LCA studies, and the associated EoL modelling for paper packaging. Other formats of paper-based packaging; such as liquid board packaging, labels, non-recyclable paper sacks and multilayered packaging; should be addressed separately.

The apparent consumption of packaging papers is defined as total local production volumes plus imported or unused packaging volumes, less exported unused packaging volumes. A correction to the apparent consumption was made to remove the volumes of the other EPR categories listed above, and to account for the packaging involved in the net trade of packaged goods (imports less exports).

The reported South African recycling volumes for *packaging papers* were determined from reported volumes of defined grades of wastepaper as received at the factory gates (weighbridge records) of recyclers, as well as the legally required reporting of wastepaper imports and exports by licenced operators.

The industry-reported conversion rate of wastepaper is 1 tonne of recyclate reused in new products for every 1.1 tonnes of wastepaper bales received at the mill gates. This includes a moisture factor, and after correcting for moisture, the conversion rate is 1 tonne per 1.048 tonnes of wastepaper.
The 0.048 fraction consists of water-soluble waste material (starches, inks and glues) as well as solid waste material or throw outs (adhesive tape, staples and labels). This is made up of non-fibre elements used in the converting step, such as starch glue for corrugating, inks and dyes; and material applied during the use phase, such as labels, staples and adhesive tapes. These materials are therefore inherent to the use of the corrugated case, box board or kraft papers; and must be included in the EoL modelling.

3.2 Paper packaging Life Cycle model and definitions

Figure 2 presents a schematic of the main life cycle stages for the Paper Packaging sector. The model has been derived from three years of industry data (2022, 2023 and 2024) on Packaging Paper (PP), which refers to Corrugated Cases and Kraft Papers for the purposes of EPR (relevant data sources are reported in Table 2).

A combination of reported, estimated and calculated data was used to derive a weighted average across the 3 years, applying a 20/30/50 weighting rule (i.e. 20% to 2022, 30% to 2023, and 50% to 2024; thereby assigning a higher weighting to the most recent years). The weighted average was then normalised to 1 tonne of locally consumed PP after correction for net import and export of packaging with products (see Figure 2, which represents an adaptation of the general schematic for the EoL stages for municipal solid waste (Figure 1) for the paper packaging sector).

All figures are reported inclusive of their respective moisture contents. The pre-consumed material is assumed to have 8% moisture content on average, and the post consumed material or waste paper is assumed to have 12% moisture content on average. A detailed description of the PP recycling process mass balance is further provided in Figure 3.

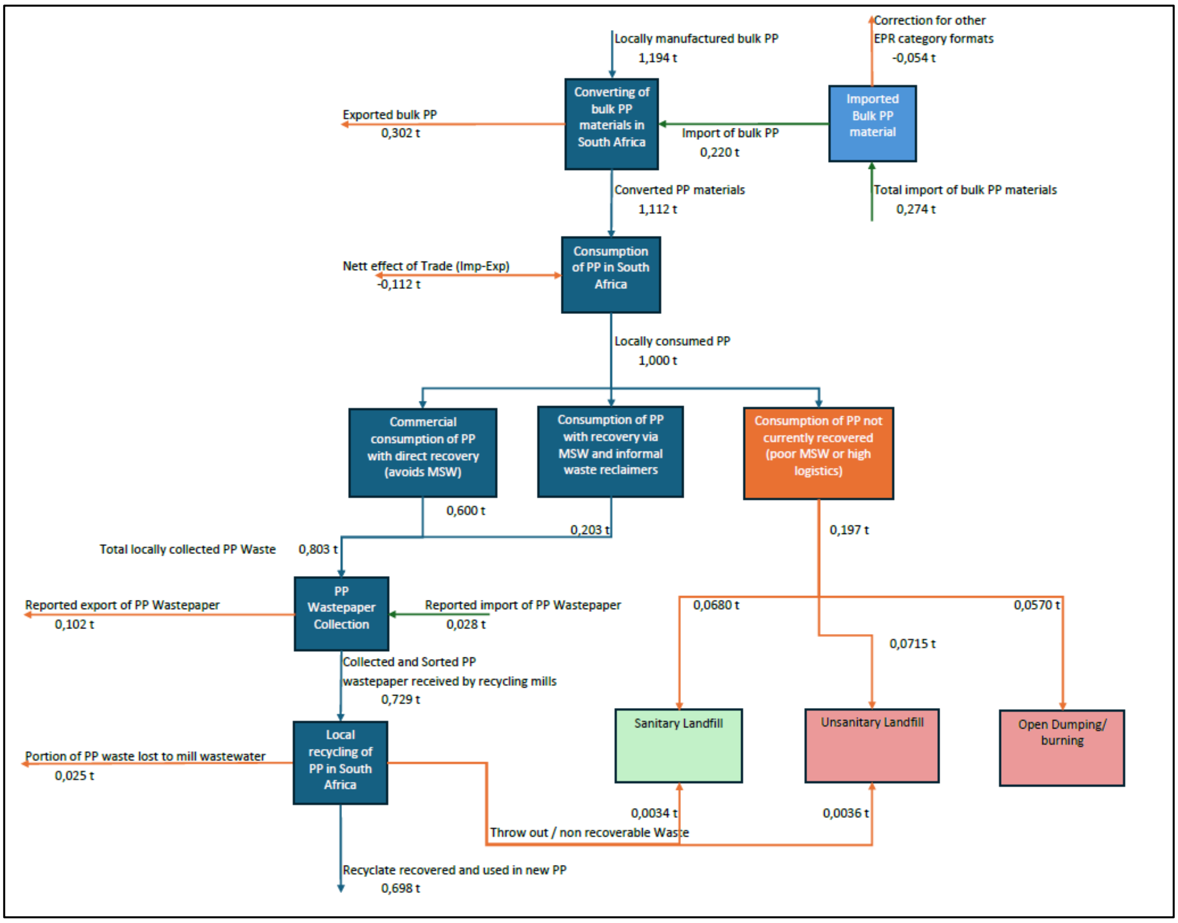

Figure 2: Schematic of Packaging Paper flows from local production to End of Life (source: developed by Fibre Circle NPC)

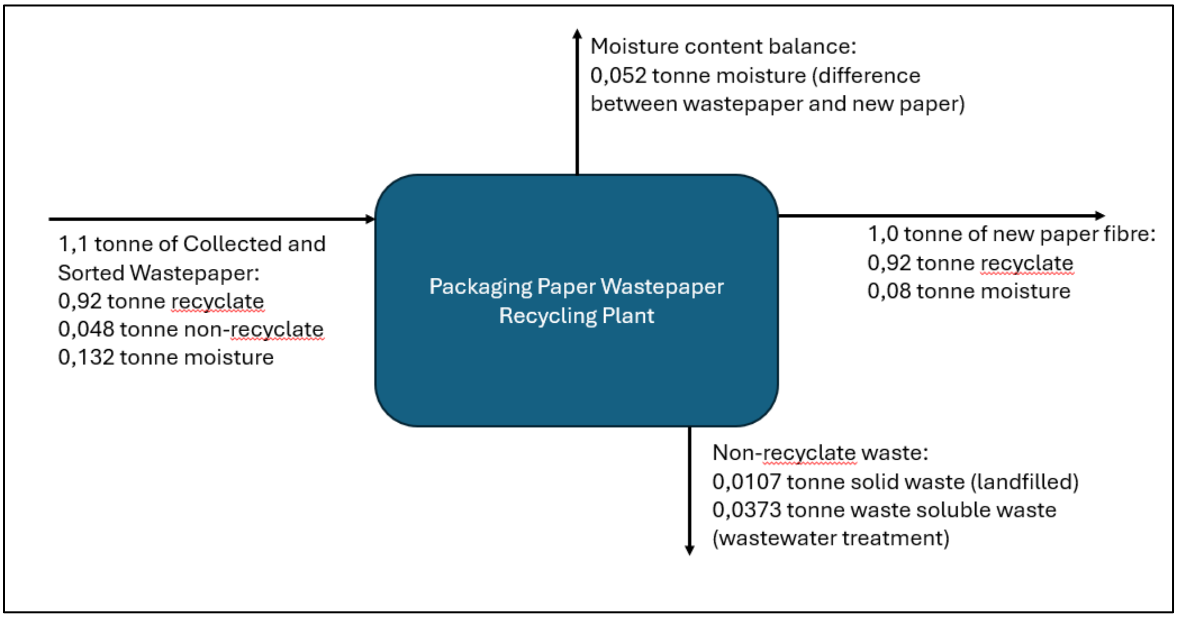

Figure 3: Schematic of Packaging Paper recycling process mass balance (source: developed by Fibre Circle NPC)

Lastly, Table 2 (overleaf) provides definitions of the flows modelled in Figure 2, details regarding data sources, and linkages to the general EoL model of Figure 1, where possible. The following flows were omitted, for the following reasons:

- *E_raw_materials* and *I_raw_materials*: The starting point of the model in Figure 2 is the conversion stage, hence the input is the bulk PP material from the manufacturing stage;
- *W_unsorted*: Not represented in the model in Figure 2. This because reporting is done after sorting takes place, hence it not possible to calculate or estimate this flow. The collections network for waste paper is complex, with many role players and material changing ownership multiple times before it reaches a recycling mill or waste paper exporter. This means that losses at collection cannot be quantified, as there is no way of performing the balance across the collections system without possible double counting.
- *E_recyclate* and *I_recyclate*: there was no reporting of these flows.

Table 2: Definitions and data sources illustrated in Figure 2 for Packaging Paper (PP) and the corresponding flows in Figure 1

Flow as per Figure 1	Term as per Figure 2	Definition as per Figure 2	Value (t)	Source
$P_{production}$	**Locally manufactured bulk PP**	Locally manufactured bulk PP used as input to converting process (as sold ex mill gate, typically 8% moisture).	1.194	Reported data to Paper Manufacturers Association of South Africa (PAMSA) recycling forum (https://thepaperstory.co.za/statistics/) (PAMSA, 2022; 2023, 2024)
$I_{product}$	**Import of bulk PP**	Unconverted bulk materials that will be consumed during the local converting of PP, correct for the non PP category as per EPR classification.	0.220	Reported data (SARS Import and Export data https://tools.sars.gov.za/tradestatsportal/data_download.aspx)
$E_{product}$	**Exported bulk PP**	Unconverted bulk PP materials that are sold and used outside of South Africa and do not become relevant for collections.	0.302	Reported data (SARS Import and Export data https://tools.sars.gov.za/tradestatsportal/data_download.aspx) (PAMSA, 2022; 2023, 2024)
$P_{Production} + I_{Product} - E_{Product}$	**Converted PP materials**	Locally converted PP products from locally manufactured and imported bulk PP materials. Less exported bulk PP materials.	1.112	Calculated data from reported and estimated data
$P_{consumption}$	**Locally consumed PP**	Total locally consumed PP products, calculated from locally converted PP products corrected for the PP used in imported and exported packaged goods.	1.000	Calculated data
$E_{secondary\ packaging} + I_{secondary\ packaging}$	**Net effect of trade**	Net effect of the PP consumed in imported and exported packaged goods (Imp – Exp)	-0.112	Calculated
$W_{collection}$	**Total locally collected PP waste**	Calculated from the reported tonnages of waste paper imports, exports and received volumes as reported by recycling mills. This already includes Sorting.	0.803	Calculated

$W_{uncollected}$	**Consumption PP not currently recovered**	Refers to tonnage of waste paper locally consumed but and not currently collected, due to lack of municipal services or high cost of logistics.	0.197	Calculated
$W_{sorted} = W_{collection} + I_{Waste} - E_{Waste}$	**Collected and sorted PP waste paper received by recycling mills**	Refers to reported tonnages of waste paper received at recyclers (net collection) as input.	0.729	Reported data (PAMSA) (PAMSA, 2022; 2023, 2024) Reported value
I_{waste}	**Reported Import of PP waste paper**	Refers to reported tonnages of waste paper received at recyclers as input from imports.	0.028	
E_{waste}	**Reported Export of PP waste paper**	Refers to reported tonnages of waste paper exported from at recyclers	0.102	
$W_{recyclate}$	**Recyclate recovered and used in new paper product**	Refers to recovered fibre from PP waste processed by recycling mills and used in new bulk PP material.	0.698	Calculated data
$W_{recycling,}$	**Throw Outs / non recoverable waste**	Defined as the non-fibre elements removed during the recycling of waste paper and is made up of adhesive tapes, metals staples and non-recyclable labels. This has been reported as 1 tonne of reusable recyclate recovered from 1,1 tonnes of received waste paper. This can be corrected for moisture difference (0,052t/t) and therefore waste material (water soluble and throw outs) is 0,048 tonne per tonne of waste paper.	0.007=0.0034+ 0.0036	Further split into $W_{sanitary}$ and $W_{unsanitary}$ Calculated data = Throw outs + Water soluble waste + moisture difference between new paper and waste paper (8% vs. 12%) based on industry reported conversion rate from waste paper to new bulk PP material (see Figure 3).
N.A.	**Proportion of PP waste lost to mill wastewater**	Percentage of $W_{recycling}$ that is not landfilled, rather biologically treated. There is no corresponding flow in the general model of Figure 1.This consists of organic and inorganic chemicals used during the converting of the bulk material to use case ready materials. It is predominantly made up of starch glues, inks and dyes and other adhesives or non-plastic coatings.	0.025	Calculated data, based on lab measurements done by a local recycler and reported to Fibre Circle

3.3 End of Life model for paper and paper packaging

Table 3 reports on the fractions of packaging paper waste to be used when modelling the EoL stage in an LCA study. It is normalised to 1 tonne of locally consumed PP. The import and export of bulk PP materials as well as the net effect of the PP consumed in imported and exported packaged goods are not included (see Figure 2).

Table 3: Percentage of waste PP allocation at EoL based on 1 tonne of locally consumed PP

Suggested EoL allocations for LCA studies, based on 1t of locally consumed PP	1.000
Recovered and reused Fibre (recyclate)	0.698
Water soluble waste material via wastewater treatment	0.025
Sanitary landfill of PP waste paper and throw out from recyclers	0.071
Unsanitary landfill of PP waste paper	0.075
Uncollected PP waste paper – Open Dumping	0.057
Net trade effect of PP Waste paper (positive is export, including throw outs)	0.074

3.3.1 Modelling of Landfill emissions for Paper and Paper Packaging in South Africa

Some landfills in South Africa employ gas-to-energy systems, in which landfill gas (methane) is collected and combusted to produce electricity or flared.

Currently, around nine landfill sites in South Africa actively produce electricity from landfill gas. These are all from well-managed landfill sites (i.e. sanitary landfills). From Figure 2, the total amount of paper waste sent to sanitary landfills is approximately 34.5%. Collectively, these landfills can potentially generate around 19 MW of electricity per year, consuming around 50,000 tonnes of methane.

Currently, on average, paper waste makes up 14% of domestic and business waste sent to landfill (Ayeleru et al., 2018; Lepota et al., 2025; Nell et al., 2022; Tsheleza et al., 2022). Packaging grades make up the largest fraction of paper-based products placed onto the market; however, despite the high recycling rates, a significant volume is still sent to landfill. Relative to the other paper categories, packaging grades make up about 53% of the paper waste sent to landfills. Furthermore, according to Skog & Nicholson (1998), packaging paper does not fully degrade in sanitary landfills, with the highest degradation rate achieved being 32%, producing a mixture of carbon dioxide and methane. The split of the emitted gases from the degradation of packaging papers between methane and carbon dioxide remains undetermined, as this is greatly affected by the landfills' management, weather patterns, capping frequency and material, organic load, and many other factors. As a result, the most used assumption is a 50/50 split (EPA, 2024).

As a result, the total methane produced from the paper packaging waste in landfills is approximately 1.2%; calculated as the product of the 14% paper fraction in landfills, the 53% proportion made up by packaging grades, the 32% degradation volume, and the 50% methane emission.

3.3.2 Modelling of the Recyclate and Recycling for sharing of the benefits

Since paper packaging grades are recycled, the recycled amount that is not treated via the standard South African landfill site at EoL is considered as an avoided landfill impact, and can be deducted from the environmental impact of the recycled fibre value chain. However, this applies to climate change emissions only[1].

By avoiding landfilling, a certain amount of carbon remains stored in the recycled fibres, which are then used to produce new products. This prevents their disintegration in landfill and combustion emission in open burning, thereby preventing the release of biogenic carbon dioxide and methane. However, these avoided emissions cannot be attributed solely to recycled products. With fibres being recycled up to seven times (max) in South Africa, this means that virgin fibres remain important, as they supply fresh fibres that can be used by the recycling value chains. As a result, the avoided emissions cannot be deducted only from the recycled value chains.

The objective, therefore, is to continue diverting waste from landfill, but also to encourage greater recycled fibre content in locally produced and consumed products. For this reason, the avoided landfill emissions should be deducted based on the recycled fibre content of the packaging grades placed onto the South African market. Currently, approximately 62% of locally consumed packaging grades contain recycled fibres, and the remainder is virgin fibres (38%).

The following formula can be used to calculate the net avoided emissions of CO_2 at EoL:

$$\mathrm{Net}_{CO_2 EoL-Avoided} = E_{Landfill} \times D_{Usable-Fibre} \times C_{Local-Content} \tag{1}$$
$$\mathrm{Net}_{CO_2 EoL-Avoided} = E_{Landfill} \times 69.3\% \times 62.3\%$$

Where:

- $\mathrm{Net}_{CO_2 EoL-Avoided}$ = Net EoL climate change emissions avoided by recycled content used on the local market
- $E_{Landfill}$ = Climate change impact of treating waste packaging papers in the standard South African landfill site at EoL
- $D_{Usable-Fibre}$ = Usable fibre from recycled (collected and sorted) waste packaging papers, currently at 69.3%
- $C_{Local-Content}$ = Usable recycled fibre used in paper packaging products consumed in the local market, currently at 62.3%

Once the "Net EoL climate change emissions avoided by recycled content used on the local market" has been calculated, its value can be deducted from the net climate change emission associated with the recycled paper and paper packaging products, as per Equation (2)

$$\mathrm{Net}_{CO_2-Recycling-Avoided} = \mathrm{Net}_{CO_2-Recycling} - \mathrm{Net}_{CO_2 EoL-Avoided} \tag{2}$$

[1] This because under the EF method used in the LCA study, carbon sequestration from forestry is reported exclusively within the biogenic sub-category of climate change. Since the avoided landfill benefit mirrors the same biogenic carbon accounting framework, it is also restricted to climate change only. The recycling process retains a measurable environmental footprint in other impact categories (water use, eutrophication, etc.) and there is no equivalent offset mechanism for those categories.

Where:

- $\text{Net}_{CO_2-Recycling-Avoided}$ = The net climate change emission after avoided landfill impact has been deducted
- $\text{Net}_{CO_2-Recycling}$ = Net climate change emissions associated with recycling paper and paper packaging products
- $\text{Net}_{CO_2EoL-Avoided}$ = Net EoL climate change emissions avoided by recycled content used on the local market.

3.3.3 Best practice to follow

- When conducting an LCA from a consumption point of view, values provided in Table 3 (based on a functional unit of 1 tonne of locally consumed PP) should be used for modelling the EoL
- When modelling the disposal of waste, the following should be considered:
  - In South Africa, the total amount of paper waste sent to sanitary landfills is approximately 34.5%, and around nine of these landfill sites actively produce electricity from landfill gas. Further information can be found in the accompanying description of Life Cycle Inventory (LCI) datasets that model sanitary landfill in LCA software / modelling environments.
  - Unsanitary landfills lack methane capturing (100% of methane gas produced during waste degradation is emitted to air) and leachate collection. The accompanying description of LCI datasets that model unsanitary landfill in LCA software / modelling environments should provide detailed information.
  - Open dumping refers to uncontrolled waste dumps from which waste is highly likely to leak into the environment and contribute to pollution.
  - Wastewater treatment should be included in the EoL modelling for PP to correctly account for the water-soluble waste.
  - Benefits of paper and packaging paper recycling should be accounted for as avoided landfill emissions (climate change emissions only); and should be deducted based on the recycled fibre content of the packaging grades placed onto the South African market (see Equations (1) and (2)). Currently, approximately 62% of locally consumed packaging grades contain recycled fibres, and the remainder is virgin fibres (38%). Should those percentages change, the corresponding values in equation (1) should be adjusted accordingly.

3.3.4 Recommendation on how to use the EoL model for the paper sector

The EoL model developed and presented in this Guideline is intended to be applied for paper and paper packaging only.

By applying the same methodology described in Section 3.2 and using available industry data for the other paper categories, it should be possible to similarly derive the EoL percentages to be used in LCA studies for those products (analogous to those presented in Table 3).

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