Significance of international life cycle data in South African extended producer responsibility

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The South African extended producer's responsibility has made cradle-to-grave life cycle assessments a mandatory requirement for the paper and paper packaging industry. This is an intensive undertaking that requires a lot of data and time if primary data sets were to be created. The aim was to evaluate the applicability of using secondary and modified data sets in the life cycle assessment to speed up the process and reduce the amount of primary data required, with white-lined chipboard as the case study. Four white-lined chipboard data sets were used, a South African data set created from local industry data, a European data set from the Ecoinvent database and two modified European data sets, Scenario 1 and Scenario 2, to better represent the South African landscape. On an inventory level, the results indicated that the goal, scope and objective of the local and European life cycle assessments were similar, with minor differences. On an impact assessment level, the South African data had a much higher impact compared to the European data. This was mainly due to their reliance on fossil fuels for energy and electricity. On an uncertainty level, the uncertainty of the South African data was much higher, but this was due to the uncertainty related to the adjusted pedigree matrix and the cumulative nature of uncertainty in the life cycle inventory tiers. The results indicated that modified data sets with a base data set that has a similar goal and scope to the original South African study, and in which the data entries, data values and uncertainties are adjusted to match the South African process more closely would suffice.

Significance:

- International life cycle inventory data can be used to conduct local life cycle assessments provided that some minor modifications are made.
- In the South African context, the use of coal in the electric grid and boilers has the largest influence on the life cycle assessment outcomes.
- On a life cycle impact assessment (LCIA) level, uncertainty is cumulative, resulting in high uncertainty scores even if the variability of primary data (life cycle inventory level) is low.

Introduction

The South African government implemented the extended producer responsibility (EPR) legislation in 2021, with the intention of improving sustainability and the circular economy of the industries identified in the legislation. One of the ways in which they planned to achieve this is through life cycle assessment (LCA), with three objectives: reducing the volume of materials used, designing for recycling and reuse without compromising product functionality and reducing the environmental toxicity of the product in the final waste stream. The problem is that South Africa, unlike Europe and America, does not have sufficient life cycle inventories (LCIs) or databases, and, secondly, conducting LCAs with primary data collected from industries is both challenging and time consuming, especially considering the number of manufacturers and converters involved in the EPR's identified paper and paper packaging products (219 in the paper and paper packaging industry).

In this study, we aimed to conduct a representative LCA for white-lined chipboard (WLC) by using local, international and modified (both primary and secondary) data and adjusting the uncertainty of each data set to match its representativeness to the South African industry infrastructure. The objective was to compare the accuracy, representativeness and time it took to collect data and conduct the LCAs and to determine whether it is necessary to use 100% local data. The LCAs were conducted using SimaPro v9.3.0.3 simulation software and data from the Ecoinvent database, with the impacts determined using the ReCiPe 2016 v1.1 (H) impact method. The international ISO 14040 and ISO 14044 standards were used to guide the study.

Literature review

The pulp and paper industry is well established in LCA research. Although European countries and America have been using LCA for a long time, it is still an immature practice in South Africa (comparatively speaking). LCAs in South Africa span several industries, but to date, there are no LCA data sets available for the South African pulp, paper and paper packaging industries.[1,2] Therefore, South African researchers have three options available to conduct LCAs: option 1, to create the LCI themselves by approaching local companies; option 2, to use international LCI data; or option 3, to modify the international LCI data to create a mixture of local and international data. Each approach has its limitations and advantages.

Collecting data to create a locally representative LCI is time consuming and resource intensive.[3] The greater the scope of the LCA, the more detail and information will be required, and the longer the study will take.[4] Secondly, approaching local companies for data (especially if the LCA is not their intention) can prove to be a problem as they are reluctant to share sensitive information or refuse site visits, which could result in several data gaps and/or non-representative modelling of the process. However, despite these setbacks, using localised data is much more representative of the current technology, temporal boundary and geographical boundary and, if conducted accurately and correctly, will allow for LCI data that have much lower uncertainty and more reliability.[5]

International data sets are considered secondary because they have been created by previous researchers. By using secondary data, the time spent on creating the LCI is significantly reduced as the data can be extracted from a database such as Ecoinvent and the US Life Cycle Inventory (USLCI). This could allow for a study with a greater scope and cover a larger value chain in a shorter time. Also, using secondary data could give a researcher a generalised idea of the overall impact of a process/product and can help identify potential hotspots. This could guide the goal and scope of a future study, which would then focus on obtaining primary data for those specific hotspots or observed anomalies.[4] Several drawbacks also accompany the use of secondary data[3], such as data gaps, being unrepresentative on a local level and may not conform to the scope of the local study. These factors not only influence the outcome of the LCA but also increase the level of uncertainty of the LCI[3,6,7], which reduces the confidence in the data and the LCA results.

The third option is creating a modified data set. These data sets consist of a mixture of primary and secondary data. It is not possible to conduct an LCA using LCA software without the use of secondary data. For example, when conducting an LCA using the Ecoinvent database, it should be noted that even a South African data set, such as pulp manufacturing, is built with other data sets, such as transport, electricity, machinery, fuels, and chemicals. Although Ecoinvent does contain South African data sets for electricity and transport, it does not contain South African data sets for the chemicals used in pulping, such as sodium hydroxide solution (white liquor), so international data sets are used to represent those chemicals. The only changes that can then be made are to the data values and uncertainty.

Based on this, there are three ways of creating a modified data set. One is to switch a process/product/material entry to its local counterpart. The second is to replace the non-local data value (secondary data) with a primary data value representing the local process. The third then is a mixture of both. Creating modified data sets is faster than creating primary data sets, they are more representative than the secondary data option, and sensitive data are indirectly accounted for as the values in the base data set are averaged for that country or region, which could help bridge local data gaps. The downside of using modified data sets is similar to the secondary data set and revolves around the lack of local representativeness, increased uncertainty, lack of reliability, the potential of over/underestimating the LCA results, and lastly, differences in the goal and scope.[8,9]

The aim of this study was therefore to test the applicability and representatives of the three modelling techniques, to indicate which one is more favoured on a time scale and an LCI, life cycle impact assessment (LCIA) and data quality level.

Methods

Data set preparation and alterations

Four data sets were created and evaluated, namely:

1. South African
2. European
3. Scenario 1
4. Scenario 2

South African data for eucalyptus forestry, kraft pulping and WLC manufacturing were collected. The data were collected from local companies and consisted of both primary and generalised South African data. The primary data covered a 3-year temporal boundary from 2018 to 2020.

The European WLC data set, 'White Lined Chipboard Carton Production, RER, 2018–2018', was extracted from the Ecoinvent database and was used as the secondary data set. No changes were made to this data set. The European data set represents 52% of all European mills. Some of the mills were integrated, performing pulping, manufacturing and converting on the same site, and some of them were self-standing manufacturing mills. This means that the European WLC data set includes some data entries only used in pulping (wood chips, pulpwood, sodium hydroxide, sodium sulfate, calcium carbonate, peroxide, etc.); however, this was accounted for by including South African Kraft pulping.

The modified data sets were derived from the European data set. For Scenario 1, all the European data entries with relevant South African counterparts were replaced, but no changes were made to the numerical entries. The data entries changed included coal, electricity, water, effluent, natural gas, transport, diesel, and light fuel oil. The distribution of the data (uncertainty) was also changed based on its representativeness of the South African process via the Ecoinvent pedigree matrix. The matrix was used to adjust the standard deviation by grading the representativeness of the data on a scale of 1 to 5 by considering the data's reliability, completeness, temporal correlations, geographical correlations and technological correlations.

In Scenario 2, the same process as Scenario 1 was followed; however, the numerical values of the replaced data entries (and others) were also substituted with South African primary data and their uncertainty was modelled using the standard deviation of the South African data. These changes were made to virgin fibre, recycled fibre, coal, electricity, water, effluent, natural gas, transport, diesel, light fuel oil, air emissions (CO_2, SO_2, NO_x, CO, PM) and effluent (chemical oxygen demand, suspended solids, biological oxygen demand, total organic carbon) composition, ash, sludge, and landfill waste. Scenario 2 was modified to convert data entries to their respective South African counterparts and to model data that mills are most likely to supply (non-sensitive data). This allowed the European data to account for sensitive data and data gaps, including bills of materials, process chemicals, emissions other than those listed above, vehicle maintenance and process maintenance. Data sets that were not in any way applicable to South Africa were removed. Changes made to the EU data set for Scenario 1 and Scenario 2 can be found in the supplementary material.

Modelling of scenarios

The comparisons for the data sets were conducted using the Ecoinvent allocation cut-off by classification technique. This technique essentially corresponds to the 'polluter pays' approach, thus incentivising the use of recyclable products and increased recycling. This is in line with the EPR, which expects manufacturers to take responsibility for their products in the final waste stream and reduce the number of raw materials used in their products. The LCA was conducted using SimaPro v 9.3.0.3 (2022) and data from EcoInvent[10], with the impact assessment calculated using ReCiPe 2016 v1.1 Midpoint (H).

The goal for the South African WLC LCA

The production of WLC (unconverted) was studied using a cradle-to-gate assessment and included eucalyptus forestry, kraft pulping and WLC manufacturing. The mass and energy flows were used to determine the environmental impact of producing 1 kg of WLC (unconverted). This value was used as the 'functional unit' of the study to which all other flows and co-products were scaled. The comparisons took place in three steps. The first comparison was an inventory comparison between the South African and European data sets. The second comparison was an LCIA comparison for the South African, European, and Scenario 1 and Scenario 2 modified data sets. The last comparison was a Monte Carlo analysis for all four data sets.

The scope for the South African WLC LCA

Forestry

The forestry process was for pulp logs only. The forestry portion of the value chain starts with the planting of eucalyptus seedlings and ends with the logs being transported to the pulping mill (Table 1). Forestry was modelled using economic allocation, and all the weight of forestry was allocated to the debarked logs. The seed germination and nursery process was excluded from the study. For forestry, processes such as pre-planting fertilisation, pre-planting pesticide and herbicide application, pre-planting irrigation, and the continuation of these throughout the rotation period were excluded as the application of these is often small, inconsistent and conditional, making it difficult to track and numerically represent. The transport from the point of harvest to the roadside pick-up was considered negligible.

Table 1: South African eucalyptus forestry process flows for 1 m^3 pulp logs harvested

Product	Value	Unit	Source	Note
Wood under bark	1	m^3		Reference product
Resources				
Carbon dioxide	898	kg	Secondary	Absorbed from environment
Energy (biomass)	12 939	MJ	Secondary	
Wood	1	m^3	Primary	Harvested
Forest land occupied	567	m^{2}a	Primary	Land area used for a period of tree growth
Rail/road embankment land occupied	17.0	m^{2}a	Secondary	Land used for rail and road during the period of tree growth
Land transformed into forestry	0.21	m^2	Secondary	Afforestation
Land transformed from forestry	2.5	m^2	Secondary	Deforestation
Land transformed from traffic area, rail/road embankment	0.075	m^2	Secondary	Roads removed during deforestation
Land transformed into a traffic area, rail/road embankment	0.0063	m^2	Secondary	Roads built during afforestation
Materials/fuels				
Harvesting, forestry harvester	0.03	h	Secondary	Machinery used to harvest trees
Forwarding, forwarder	0.038	h	Secondary	
Skidding, skidder	0.077	h	Secondary	
Power sawing, without a catalytic converter	0.25	h	Secondary	
Gravel, crushed	20.0	kg	Secondary	Road construction and maintenance
Lubricating oil	0.3	kg	Secondary	Maintenance
Diesel	78	MJ	Secondary	Fuels used in machinery

Pulping

The pulping portion of the value chain starts with the receipt of debarked logs at the pulping mill and ends with pulp bales transported to the manufacturing mill. The process included wood cutting and chipping, pulping, drying, bleaching, baling, transport, effluent treatment and disposal, steam and electricity generation (from coal, wood yard waste, and chemical recovery), chemical recovery and waste treatment (Table 2). Mass allocation was used. The impact of capital equipment, buildings and their maintenance was considered negligible. On-site transport was not considered. Business travel and employee commutes were considered negligible.

Manufacturing

The manufacturing portion of the value chain starts with the receipt of eucalyptus virgin pulp bales and recycled paper grades and ends with the production of WLC jumbo reels (unconverted). The process of WLC manufacturing includes re-pulping of virgin and recycled pulp, screening and treatment, calendaring, coating, on-site energy generation, drying, water treatment, on-site transport, transport to clients, and cutting and wrapping of WLC jumbo reels. The LCI for WLC is presented in Table 3. Mass allocation was used, and the impact of WLC manufacturing was solely attributed to WLC (no co-products). The same assumptions as for the pulping section were used.

Results

Inventory comparison

In the analysis, the inventory data entries were compared by the number of data entries in both the South African and European data sets and by studying the impact of the processes when energy and electricity data entries were excluded (Figure 1), primarily due to the country-specific influence of fuel sources.

The information in Table 4 indicates a minor difference between the two data sets when considering the number of data entries. Several mills were included because the European data set represented 52% of Europe's WLC production. Because each mill uses different chemicals and raw material sources, there are some flows represented by two or more data entries. For example, the European mill had three water entries (tap, well and lake) compared to the one (tap) in the South African mill. Similarly, because some mills were integrated, the additional pulping chemicals and waste are also part of the LCI (but negligible in mass at $<1\%$ in total). Hence, there are differences in the number of data entries. With this considered, the data coverage for the South African LCI is good compared to the European LCI.

The significant mass balance difference between the two data sets exists because the European mills use and discharge more water. The European mill uses around 18 L of fresh water per kg WLC produced and discharges 15.9 L per kg WLC, whereas the South African mill uses 8.8 L of fresh water per kg WLC and discharges 5.7 L per kg WLC. As the water volumes are scaled to the reference product, the difference in consumption is quite notable. However, their use of water is reasonable, because their process includes pulping, manufacturing and converting; the location of mills in the European countries is in water-abundant regions, unlike South Africa, which is a semi-arid, water-scarce country where water recycling is crucial (up to 80%). Secondly, as the European mills are integrated, there is an additional mass of wood chips, pulping chemicals, pulping wastes (white liquor, bleaching, dreg wastes, lime mud, etc.), inks and converting wastes. However, the greatest reason for the mass balance difference was the volume of fresh water used and effluent discharged.

Two approaches were taken to study the impact of the LCI. In the first approach, the boiler and electricity data sets were excluded from the analysis to solely study the impact of material use, on-site waste

Table 2: South African eucalyptus kraft pulping process flows for 1 kg baled pulp produced

Product/process	Value	Standard deviation	Unit	Source	Notes
Materials/fuels					
Delignification and bleaching	0.011	0.0039	kg	Primary	Chemicals
pH control	0.008	0.0002	kg	Primary	Chemicals
Heavy fuel oil	0.14	0.071	MJ	Primary	Used for drying and electricity production
Heat (biomass)	0.77	0.028	MJ	Primary	Used for drying and electricity production
Disinfectant	9.3×10^{-5}	2.1×10^{-5}	kg	Primary	Chemicals
Starch	0.0019	6.8×10^{-4}	kg	Primary	Chemicals
Other fillers and additives	0.019	0.0057	kg	Primary	Chemicals
Sizing agent	0.00014	3.0×10^{-5}	kg	Primary	Chemicals
Pitch control	0.00022	8.4×10^{-5}	kg	Primary	Chemicals
Eucalyptus (wood under bark)	0.0031	–	m^3	Primary	From forests
Water	25	1.3	kg	Primary	Surface water source
Electricity/heat					
Electricity, natural gas	0.11	0.008	kWh	Primary	On-site
Electricity, wood bark	0.039	0.0028	kWh	Primary	On-site
Electricity, coal	0.19	0.014	kWh	Primary	On-site
Electricity, coal	0.034	0.0053	kWh	Primary	Municipality
Heat, black liquor	6.1	0.32	MJ	Primary	On-site
Transport from forests (40- ton truck)	100	–	kgkm	Primary	
Emissions to water					
Chemical oxygen demand	0.00068	2.9×10^{-4}	kg	Primary	To the ocean, after treatment
Suspended solids	0.00020	8.6×10^{-5}	kg	Primary	
Nitrogen	7.9×10^{-7}	2.8×10^{-7}	kg	Primary	
Phosphorus	1.1×10^{-6}	7.3×10^{-7}	kg	Primary	
Waste to treatment					
Wood ash mixture	0.00011	5.3×10^{-5}	kg	Primary	Landfill
Hard coal ash	0.00055	2.6×10^{-4}	kg	Primary	Landfill
Municipal solid waste	0.001	3.7×10^{-4}	kg	Primary	Landfill
Hazardous waste	2.3×10^{-5}	2.1×10^{-5}	kg	Primary	Incineration
Green liquor dregs	0.00077	2.2×10^{-4}	kg	Primary	Landfill
Sludge	0.004	–	kg	Primary	Landfill

generation and transport. The boiler and electricity data sets were excluded because both mills used different fuel sources, the electric grids for both regions were considerably different, and they were the two processes with the most significant influence.

Comparing the LCI for the two processes, excluding electricity and boiler data sets, the results showed that the impact on the rest of the inventory was quite similar (Figure 1). The European impact was slightly higher due to additional data entries; nevertheless, the results from Figure 1 show that if a secondary data source was well modelled and included a similar goal and scope, the impact of process-specific data would be similar. This is especially true for the pulp and paper industry, where many processes follow the same pulping and manufacturing processes and use similar chemicals, even though they are from different regions. The only significant differences were for freshwater ecotoxicity and eutrophication, but this was because the European mills discharged their effluent into surface water sources, their water balances were higher (larger mass of contaminants), and they reported more contaminants.

In the second scenario, the inclusion of the boiler and electricity processes completely changed the results (Figure 2). The environmental impact of using coal in the South African scenario has caused the environmental impact of the South African data set to increase and surpass that of the European mill's impact for all impact categories. The electricity generation process is country-specific and can vary extensively. In Europe, 15% of fossil fuels are used to supply electricity to the grid, whereas in South Africa, 85% of fossil fuels are used to supply their electric grid. The same applies to boilers because the boiler's fuel source depends on the most

Table 3: South African white-lined chipboard (WLC) production process flows for 1 kg WLC produced

Product	Value	Standard deviation	Unit
Raw materials			
Virgin kraft fibre	0.19	0.0052	kg
Virgin mechanical fibre	0.06	0.0017	kg
Recycled fibre	0.85	0.0096	kg
Fresh water	8.8	0.27	L
Energy			
Electricity	1.1	0.065	kWh
Natural gas	0.76	0.12	MJ
Diesel	0.13	–	MJ
Coal	0.36	0.026	kg
Chemicals			
Polymers	0.25	0.013	kg
Salts	0.048	0.0013	kg
Starches	0.018	0.00028	kg
Amines	0.00013	1.2×10^{-5}	kg
Sodium hydroxide	0.0011	3.3×10^{-5}	kg
Defoamers	2.8×10^{-4}	7.8×10^{-6}	kg
Sizing agents	0.0004	0.00016	kg
Minerals	0.026	0.002	kg
Optical brighteners	0.00015	4.2×10^{-6}	kg
Biocide	0.0011	2.6×10^{-5}	kg
Water treatment	0.00023	3.0×10^{-4}	kg
Boiler water softening	4.0×10^{-4}	5.4×10^{-5}	kg
Transport			
By ship	849	24	kg.km
Transport to mill	290	13	kg.km
Transport from mill	420	40	kg.km
Solid wastes			
Screened waste	0.076	0.016	kg
Effluent	5.7	0.41	L
Sludge	0.048	0.0083	kg
Ash	0.085	0.018	kg
Emissions			
Water lost as steam during drying	1.5	–	L
Carbon dioxide, fossil	0.6	0.021	kg
Carbon monoxide, fossil	0.0015	5.7×10^{-4}	kg
Methane, fossil	1.0×10^{-4}	–	kg
Nitrogen oxides	0.0012	1.7×10^{-4}	kg
Particulate matter	0.001	1.0×10^{-4}	kg
NMVOC	1.8×10^{-5}	–	kg
Sulfur dioxide	0.0019	0.00032	kg
Metals	0.0027	–	kg
Inorganics	4.2×10^{-4}	–	kg
Organics	1.7×10^{-4}	–	kg

Table 4: Differences between the South African and European white-lined chipboard data entries

Data entries	Unit	South African	European
Inputs	–	32	40
Outputs (including emissions)	–	83	98
Outputs (excluding emissions)	–	13	18
Chemical inputs (potentially sensitive data)	–	20	18
Recycled fibre	–	3	2
Virgin fibre	–	2	3
Energy sources (all)	–	3	5
Energy sources (fossil fuel)	–	3	3
Mass in	kg	10.69	19.5
Mass out	kg	10.65	20.22
Mass in (excluding water)	kg	1.89	1.5
Mass out (excluding effluent)	kg	4.95	4.32

abundant fuel in that region or country. The integrated European WLC mills used a mix of coal and biomass, but biomass was the most used fuel, whereas the South African WLC mill used 100% coal because it was the closest, most abundant and most affordable fuel source. The results indicate that when using secondary data, it is important to consider country- or region-specific processes and processes that result in significant changes from one region or country to another.

Life cycle impact assessment

The results of the LCIA for the South African WLC, European WLC, and Scenarios 1 and 2 are presented in Figure 3. Scenario 1 was modelled by changing data entries in the European data set with available South African SimaPro data entries and adjusting the uncertainty of the data entries. Scenario 2 was modelled the same as Scenario 1, but the data values were also changed based on the likelihood that a company would be willing to supply that kind of information (non-sensitive data).

The results for Scenario 2 indicated that the modified data set could be used to represent the South African process. Even though Scenario 2 had the closest representation of the South African WLC manufacturing process, it still overestimated the impact in all categories, particularly for eutrophication and freshwater ecotoxicity. This overestimation was anticipated as the base data set was European, and, as observed in Figures 1 and 2, the impact of eutrophication and freshwater ecotoxicity was fairly high for the European data set, even when the electricity and boiler data were included.

Apart from the eutrophication impact outlier, Scenario 2 could be used instead of creating an entirely new primary LCI. However, Scenario 2 should be applied cautiously, as the goal, scope and inventory completeness of the base data sets should be the same or very similar to the goal and scope of the South African LCA; otherwise, the results from the LCIA would be non-representative and futile.

Regarding Scenario 1, it was beginning to show a closer resemblance to the South African data set. Even though the differences were still large, it does indicate that even small changes, such as converting data entries to their respective South African equivalents, can already start shaping the data set and the LCIA to be more locally representative.

The results for the European data set indicate that using an international data set without some way of linking it or adjusting it to match South African processes, as with Scenario 2, is not acceptable. There is a large difference between the European and South African data sets,

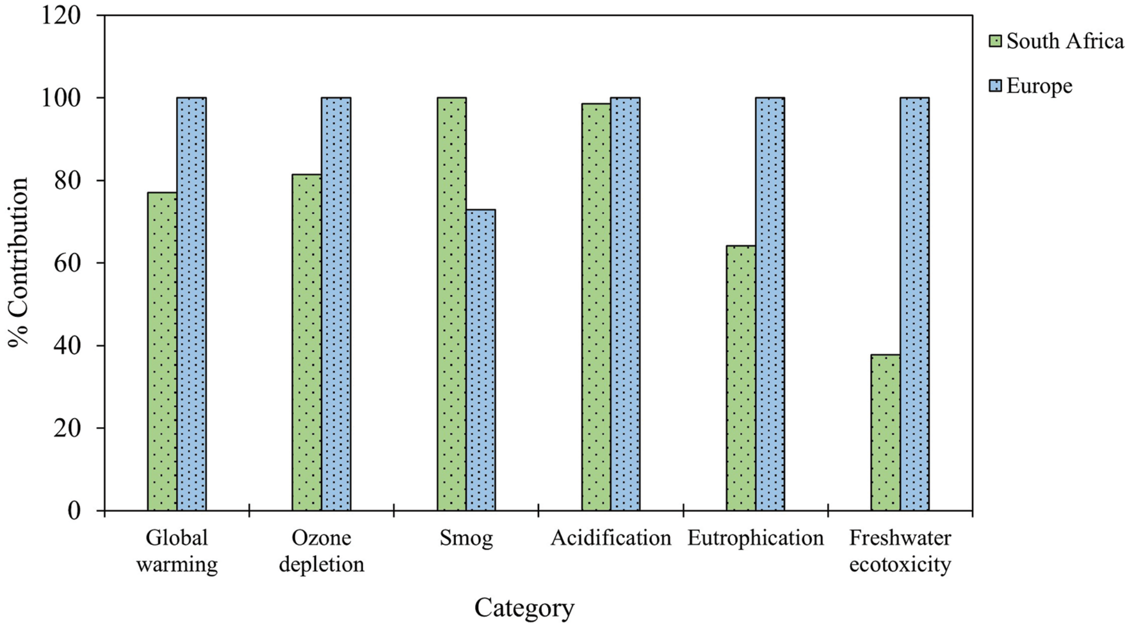

Figure 1: Life cycle impact assessment of white-lined chipboard manufacturing with the electricity and boiler data sets excluded, indicating the influence of process-specific data.

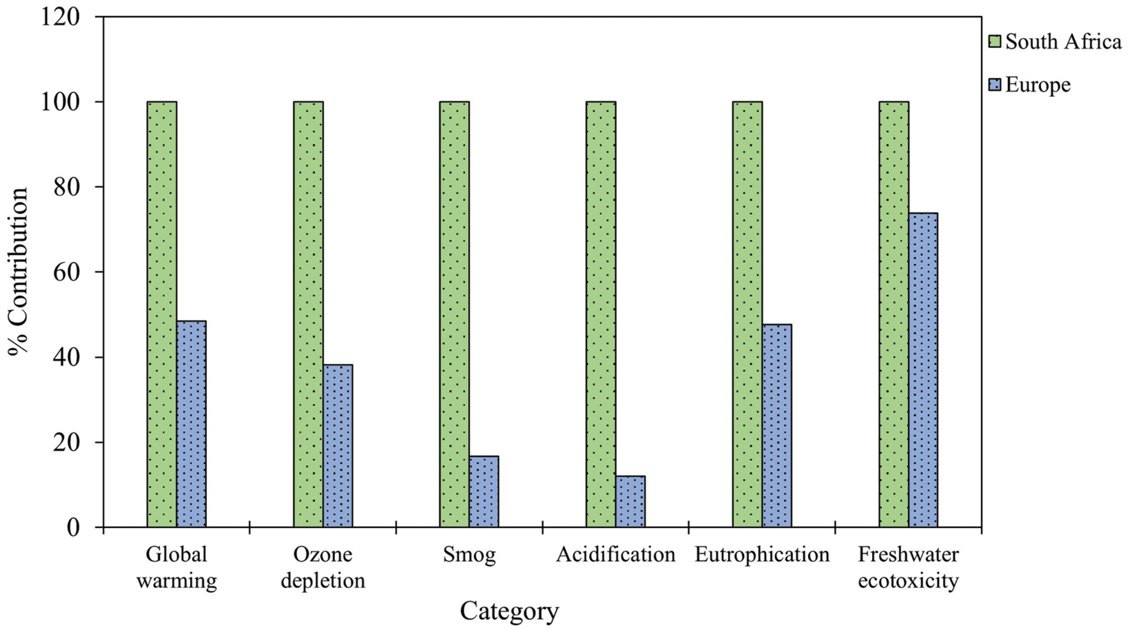

Figure 2: Life cycle impact assessment of white-lined chipboard manufacturing with the electricity and boiler data sets included indicating the influence of country/region-specific data.

which shows that using international data to represent local processes could lead to large over- or underestimations that are inaccurate and not representative of the local process.

Uncertainty tests

In building the LCI for a study, two aspects of data collection need to be considered: the data type and data quality. Data type was covered in the previous two sections by observing the influence of primary data, secondary and hybrid (mixed) data on the LCIA results. Data quality refers to the data uncertainty (representativeness), variability and model assumptions.[11]

Data variability was addressed in SimaPro using standard deviation and the Ecoinvent pedigree matrix. The results from the Monte Carlo analysis for each of the data sets are presented in Figure 4, showing the impact of uncertainty on the outcome of the data and the level of variability.

Considering the South African data set, two observations relating to the uncertainty of the data sets could be made. Firstly, the uncertainty for the South African data set was higher in comparison to the European data set. Secondly, the uncertainty for the two water impact categories, eutrophication and freshwater ecotoxicity, was considerably higher compared to the other impact categories.

Concerning the first observation. One of the problems with the South African process is the lack of data sets in Ecoinvent (and the lack of South African data sets in general). SimaPro data sets are then built using non-South African data entries. This increases the uncertainty as the representativeness of the data set is lower, which increases the pedigree matrix score, which in turn increases the standard deviation value. Even though the standard deviation (variability) of the collected primary data in the LCI was low, the uncertainty is higher via the simulation results.

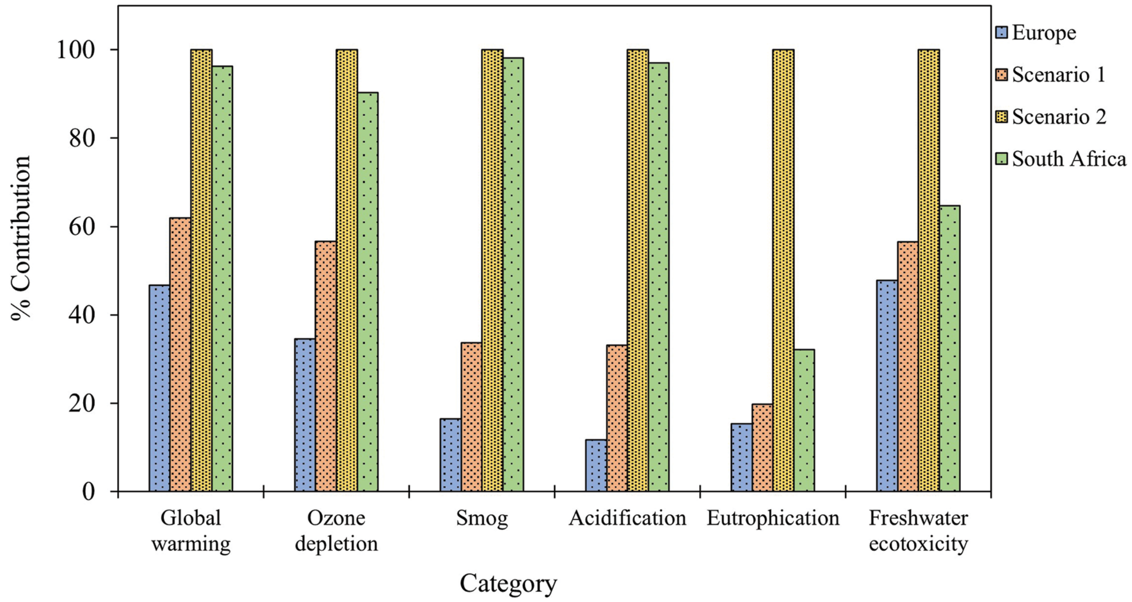

Figure 3: Life cycle impact assessment results for the comparison of South African white-lined chipboard, European white-lined chipboard and the two modified data sets, Scenario 1 and Scenario 2.

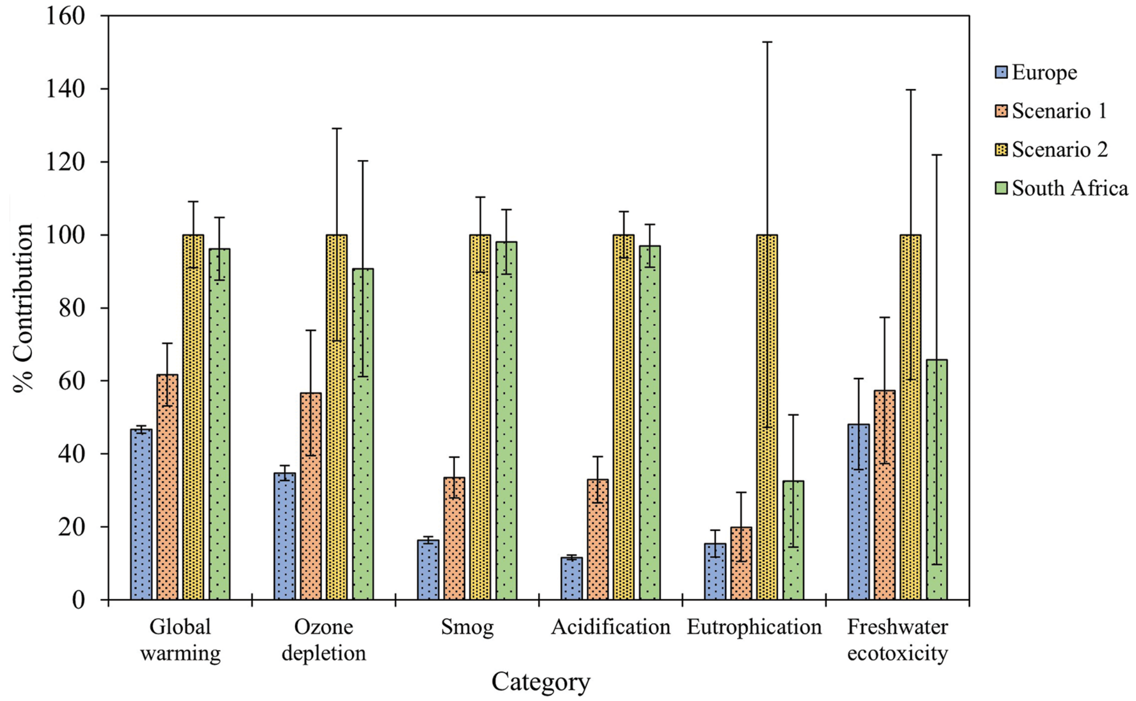

Figure 4: Uncertainty of environmental impacts scaled to one, with the error bars representing the standard deviation.

Additionally, the data set in SimaPro consists of tiers (process tree). For example, the WLC manufacturing data set consists of data sets (second tier), and those data sets are built using more data sets (third tier) and so on. The final uncertainty generated by the Monte Carlo analysis is not the uncertainty of the WLC data set itself, but a cumulative value of all the uncertainties across all the tiers.[12] This means that a South African data entry, such as electricity, becomes a second-tier data entry in the WLC data set. This data entry is also built with South African and non-South African data, which means the standard deviation will be higher for the non-South African data values. This then cumulatively adds to the WLC data set's uncertainty as well. Hence, the increased uncertainty via the pedigree matrix for non-South African data entries and the tiered nature of the data sets results in the higher uncertainty observed in Figure 4.

As for the second observation, the uncertainty for all the data sets was highest for freshwater ecotoxicity and highest for the South African and Scenario 2 eutrophication relative to the other impact categories, especially considering the significant differences among the different data sets. A study by Chen et al.[13] indicated that uncertainties can be caused by the LCI, substance coverage by the different impact methods (impact method inventory) and differences in the characterisation factor values of the substances. Therefore, the reason for this observation could be uncertainty in the inventory for the ReCiPe 2016 impact method. This indicates that the uncertainty in an LCA is linked to both the uncertainty in the LCI and the uncertainty in the impact method. Similar conclusions were made by Alyaseri and Zhou[14] and by Barahmand and Eikeland[7]. Therefore, the greater uncertainty for these two impact categories could be associated with the inventory of the ReCiPe 2016 impact method and not the inventory or the uncertainty of the LCIs.

However, the European data set had the smallest overall uncertainty associated with the impact values, as the tiered data sets used were

European data sets, which meant that its representativeness was good, and the associated uncertainty and the cumulative uncertainty values were low. For Scenario 1, a similar observation could be made, where the overall uncertainty remained small. In Scenario 2, the uncertainty became more like the South African data set because the data set entries were changed, the pedigree matrix was updated, and the data values were also changed, allowing Scenario 2 to become more South African, hence the larger impacts and greater uncertainty.

Concerning the application of uncertainty in the EPR, if the variability of the primary data in the LCI is low and the information gathered is representative of the local geography, infrastructure, technology and temporal correlation, then uncertainty should not be an influence and only considered on an LCI level.

Conclusion

Based on the EPR objectives, international LCI data can be used to conduct local LCAs for the paper industry, provided that the base data set used has a similar goal, scope and modelling choices and that, as a minimum, the electricity, boiler fuel and emissions are replaced by its South African data entry counterpart and primary data.

The tiered nature of LCA causes uncertainty to be cumulative and therefore much more significant on the LCIA level; however, if the variability of primary data used is low, uncertainty should be considered on an LCI level and not the LCIA level.

Generally, it is assumed that the processes of the paper and paper packaging industry have little variation from one country to another, and as a result, these findings could potentially apply to other paper and paper packaging products defined by the EPR. This will only be possible if the base data set is appropriately modified and has the same or similar goal and scope as its South African counterpart.

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Data availability

All the data supporting the results of this study are included in the article itself and the supplementary material. The data tables presented in the main text are the South African inventory for forest, pulping and manufacturing. The supplementary material includes the modifications to the RER WLC data set for Scenario 1 and Scenario 2, which includes changes in uncertainty and data values.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

E.E.B.: Conceptualisation, data collection, data analysis, writing – the initial draft. K.G.H.: Student supervision, writing revisions. Both authors read and approved the final manuscript.

References

1. Harding KG, Friedrich E, Jordaan H, le Roux B, Notten P, Russo V, et al. Status and prospects of life cycle assessments and carbon and water footprinting studies in South Africa. Int J Life Cycle Assess. 2021;26(1):26–49. https://doi.org/10.1007/s11367-020-01839-0
2. Karkour S, Rachid S, Maaoui M, Lin CC, Itsubo N. Status of life cycle assessment (LCA) in Africa. Environments. 2021;8(2):10–56. https://doi.org/10.3390/environments8020010
3. Ciroth A, Di Noi C, Burhan SS, Srocka M. LCA database creation: Current challenges and the way forward. Int J Life Cycle Assess. 2019;3(2):41–51. https://doi.org/10.52394/ijolcas.v3i2.105
4. Quist Z. Primary vs. secondary data – What's the best in LCA? [webpage on the Internet]. c2022 [cited 2023 Jan 25]. Available from: https://ecochain.com/knowledge/primary-vs-secondary-data-in-lca/
5. Kalverkamp M, Helmers E, Pehlken A. Impacts of life cycle inventory databases on life cycle assessments: A review by means of a drivetrain case study. J Clean Prod. 2020;269, Art. #121329. https://doi.org/10.1016/j.jclepro.2020.121329
6. Bamber N, Turner I, Arulnathan V, Li Y, Zargar Ershadi S, Smart A, et al. Comparing sources and analysis of uncertainty in consequential and attributional life cycle assessment: Review of current practice and recommendations. Int J Life Cycle Assess. 2020;25:168–180. https://doi.org/10.1007/s11367-019-01663-1
7. Barahmand Z, Eikeland MS. Life cycle assessment under uncertainty: A scoping review. World. 2022;3:692–717. https://doi.org/10.3390/world3030039
8. Canals LMI, Azapagic A, Doka G, Jefferies D, King H, Mutel C, et al. Approaches for addressing life cycle assessment data gaps for bio-based products. J Ind Ecol. 2011;15(5):707–725. https://doi.org/10.1111/j.1530-9290.2011.00369.x
9. Ossés de Eicker M, Hischier R, Kulay LA, Lehmann M, Zah R, Hurni H. The applicability of non-local LCI data for LCA. Environ Impact Assess Rev. 2010;30(3):192–199. https://doi.org/10.1016/j.eiar.2009.08.007
10. Wernet G, Bauer C, Steubing B, Reinhard J, Moreno-Ruiz E, Weidema B. The ecoinvent database version 3 (part I): Overview and methodology. Int J Life Cycle Assess. 2016;21(9):1218–1230. https://doi.org/10.1007/s11367-016-1087-8
11. Soares SR, Finotti AR, Prudêncio da Silva V, Alvarenga RAF. Applications of life cycle assessment and cost analysis in health care waste management. Waste Manag. 2013;33(1):175–183. https://doi.org/10.1016/j.wasman.2012.09.021
12. Goedkoop M, Oele M, Leijting L, Ponsioen T, Meijer E. Introduction to LCA with SimaPro [webpage on the Internet]. c2016 [cited 2023 Jan 25]. p. 69. Available from: https://support.simapro.com/s/article/Introduction-to-LCA
13. Chen X, Matthews HS, Griffin WM. Uncertainty caused by life cycle impact assessment methods: Case studies in process-based LCI databases. Resour Conserv Recycl. 2021;172, Art. #105678. https://doi.org/10.1016/j.resconrec.2021.105678
14. Alyaseri I, Zhou J. Handling uncertainties inherited in life cycle inventory and life cycle impact assessment method for improved life cycle assessment of wastewater sludge treatment. Heliyon. 2019;5(11), e02793. https://doi.org/10.1016/j.heliyon.2019.e02793