Peer review history for:

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HOW TO CITE:
A critical view of applying life cycle assessment on disposable diapers in a rural context [peer review history]. S Afr J Sci. 2025;121(3/4), Art. #18211. https://doi.org/10.17159/sajs.2025/18211/peerreview

Reviewer 2: Round 1
Date completed: 01 July 2024
Recommendation: Accept / Revisions required / **Resubmit for review** / Resubmit elsewhere / Decline / See comments
Conflicts of interest: None

Does the manuscript fall within the scope of SAJS?
Yes/No
Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone?
Yes/No
Does the manuscript contain sufficient novel and significant information to justify publication?
Yes/No
Do the Title and Abstract clearly and accurately reflect the content of the manuscript?
Yes/No
Is the research problem significant and concisely stated?
Yes/No
Are the methods described comprehensively?
Yes/No
Is the statistical treatment appropriate?
Yes/**No**/Not applicable/Not qualified to judge
Are the interpretations and conclusions justified by the research results?
Yes/**Partly**/No
Please rate the manuscript on overall contribution to the field
Excellent/Good/**Average**/Below average/Poor
Please rate the manuscript on language, grammar and tone
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Is the manuscript succinct and free of repetition and redundancies?
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The number of tables in the manuscript is
Too few/**Adequate**/Too many/Not applicable
The number of figures in the manuscript is
Too few/**Adequate**/Too many/Not applicable
Is the supplementary material relevant and separated appropriately from the main document?
Yes/No/**Not applicable**
Please rate the manuscript on overall quality
Excellent/Good/Average/**Below average**/Poor
Is appropriate and adequate reference made to other work in the field?

Yes/No
Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates?
Yes/No/Not applicable
If accepted, would you recommend that the article receives priority publication?
Yes/**No**
Are you willing to review a revision of this manuscript?
Yes/No
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.
Yes/No

Comments to the Author:

Please give details on which of the ecoinvent modules contributed to the LCA. Particularly since the SA database is near non-existent. So how was the SA scenario modelled if (if!) international data was used?

Goal and scope: When was this study performed - impact of COVID?

Line 129: "The questionnaires found there are a wide variety of retailers available to respondents which are at varying distances" then why not use an average? [Although i imagine the overall contribution would be minimal]

"Section 2.2 details the cases in which the different types of information sources are used" - there is no section 2.2.

Section 4. Heading number returns to 1.

What does this mean: line 146 "Waste residues from the diaper production process reportedly only accounted for 3 % of materials"?

Table 3: It would be beneficial (here or elsewhere) to understand the breakdown of impacts at the production stage eg electricity vs impacts from other areas. This is even more important when we see Fig 2 giving such high impacts from the diaper production stage.

Page 10: Page numbers restarted.

Fig 3: Please use a secondary axis, or split y-axis, new graph, or some other means to show the impacts of all the other categories. While they might seem insignificant, which ones are higher or lower (graphically) relative to each other in remaining categories?

Line 217: "As mentioned in section 2.3.5' - there is no 2.3.5. Is there a huge section missing?? Section 6 does not make sense as thre is nothing to refer back to to understand the scenarios.

Again: The whole of section 6 is difficult to follow without being able to find teh sections in p[art 2 that seem to be missing?

Line 264: "Electricity was consistently a top contributor". Please show this in results. And again when you tell us taht the core was a contributor - line 270.

Line 280: "renewable energy..." A scenario analysis showing examples of how much the impact could be reduced with , e.g. wind would be good.

Line 283: "This was demonstrated by the featuring of locally produced PP components" AS mentioned

sevral times, showing the process contributions earlier (Fig 2) would help prove your argument here. It would be good to add the numbers from other studies to both validate the scale of your results, but also compare to other studies and scenarios. A more convincing conclusion could be written, including numbers. As it stands the conclusions feels rushed and do not cover all aspects of the project, or what the objectives were and how they were addressed.

Author response to Reviewer 2: Round 1
Please give details on which of the ecoinvent modules contributed to the LCA. Particularly since the SA database is near non-existent. So how was the SA scenario modelled if (if!) international data was used?
Author: It is specified that ecoinvent v3.9 was used which includes South African inventory models for key production inputs such as electricity and polypropylene. Further, it is specified that the ecoinvent datasets were modified as far as possible to reflect the local context in section 4.1.
Goal and scope: When was this study performed - impact of COVID?
Author: In section 2, it has been specified that the diaper production data was based on 2021 values and the questionnaires were conducted in 2022.
Line 129: "The questionnaires found there are a wide variety of retailers available to respondents which are at varying distances" then why not use an average? [Although i imagine the overall contribution would be minimal]
Author: It is further explained in section 4.3.1 that the diapers could pass through several points before reaching consumers thus it would be difficult to get an average distance travelled. Further, participants use a variety of transport modes which would have been difficult to model.
"Section 2.2 details the cases in which the different types of information sources are used" - there is no section 2.2.
Author: The correct section has been referenced.
Section 4. Heading number returns to 1.
Author: This has been rectified.
What does this mean: line 146 "Waste residues from the diaper production process reportedly only accounted for 3 % of materials"?
Author: It has been clarified that this refers to the waste produced during diaper production.
Table 3: It would be beneficial (here or elsewhere) to understand the breakdown of impacts at the production stage eg electricity vs impacts from other areas. This is even more important when we see Fig 2 giving such high impacts from the diaper production stage.
Author: The results have been expanded to include a breakdown of the contributions to each of the impact categories.
Page 10: Page numbers restarted.
Author: This has been rectified.
Fig 3: Please use a secondary axis, or split y-axis, new graph, or some other means to show the impacts of all the other categories. While they might seem insignificant, which ones are higher or lower (graphically) relative to each other in remaining categories?
Author: The figure has been replaced with a table showing the numerical values.
Line 217: "As mentioned in section 2.3.5' - there is no 2.3.5. Is there a huge section missing?? Section 6 does not make sense as thre is nothing to refer back to to understand the scenarios.
Author: The sections referenced have been corrected.
Again: The whole of section 6 is difficult to follow without being able to find teh sections in p[art 2 that seem to be missing?
Author: The sections referenced have been corrected.
Line 264: "Electricity was consistently a top contributor". Please show this in results. And again when you tell us taht the core was a contributor - line 270.

Author: The results have been expanded to include a breakdown of the contributions to each of the impact categories.
Line 280: "renewable energy..." A scenario analysis showing examples of how much the impact could be reduced with , e.g. wind would be good.
Author: Whilst we agree that such a scenario analysis would be of value the datasets for medium voltage electricity (supplied to industries) produced from renewable sources are not available.
Line 283: "This was demonstrated by the featuring of locally produced PP components" AS mentioned several times, showing the process contributions earlier (Fig 2) would help prove your argument here.
Author: The results have been expanded to include a breakdown of the contributions to each of the impact categories.
It would be good to add the numbers from other studies to both validate the scale of your results, but also compare to other studies and scenarios.
Author: The numbers have been added where appropriate to provide further information.
A more convincing conclusion could be written, including numbers. As it stands the conclusions feels rushed and do not cover all aspects of the project, or what the objectives were and how they were addressed.
Author: The conclusions have been strengthened including increased coverage of the results supported by numbers.

Reviewer 3: Round 1
Date completed: 14 August 2024
Recommendation: Accept / **Revisions required** / Resubmit for review / Resubmit elsewhere / Decline / See comments
Conflicts of interest: None

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Yes/No
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Is the statistical treatment appropriate?
Yes/No/Not applicable/Not qualified to judge
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If accepted, would you recommend that the article receives priority publication?
Yes/**No**
Are you willing to review a revision of this manuscript?
Yes/No
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.
Yes/No
Comments to the Author: The research addressed a gap in the body of knowledge in waste management and will make a contribution to the field. It is a welcome change to read research conducted in a rural setting. The management of disposal nappies is becoming a serious issue in waste management and thus more research is needed that propose workable solutions. Title - also see my comment in document. I do object to the use of the word diaper; a word that is only used in North America. Introduction and methodology - these sections are extremely cryptic (maybe to adhere to the 6 000 word count?). Methodology – lacking is a motivation of the study area. It is mentioned that the questionnaires were part of a larger study in the area but this does not constitute a motivation why this particular rural area was chosen. Reference is made to primary and secondary data but nowhere is it clearly stated what the primary and secondary data are that was used. Also, clearly state in the methodology the three waste scenarios. Under transport distances were approximated but the choice of the Durban Harbour needs to be motivated. E.g., is this the closest harbour to the SA manufacturer? Also, explain to the reader why Hoedspruit (is it the biggest town in the study area?) was used to calculate distances. In general - the methodology section needs rewriting and a more logical flow. Discussion - references are made to numbered sections that do not exist. This makes for a confusing read as the reader has to take an educated guess to which section the authors refer to. Figure 4 - do not use the default colours of Excel – change to match the colours of previous figures. The font is also different from the one in the content. Some minor technical and language issues and these are indicated in the document.
[See Appendix 1 for Reviewer 3's comments made directly on the manuscript]

Author response to Reviewer 3: Round 1

The research addressed a gap in the body of knowledge in waste management and will make a contribution to the field. It is a welcome change to read research conducted in a rural setting. The management of disposal nappies is becoming a serious issue in waste management and thus more research is needed that propose workable solutions.

Title - also see my comment in document. I do object to the use of the word diaper; a word that is only used in North America.
Author: Thank you for your insightful feedback regarding the terminology used in the manuscript. We appreciate your suggestion to use the term "nappies" instead of "diapers," recognising that "nappies" is the terminology commonly used in South Africa and other regions outside North America/Canada. However, we have chosen to use the term "diapers" in this manuscript for several reasons: 1. The term "diapers" is more commonly used in the global academic discourse, particularly in peer-reviewed journals. As much of the research on disposable diaper waste and related topics originates from North American sources, the use of "diapers" aligns with the terminology that the broader academic community is accustomed to. 2. While our research is conducted in South Africa, it is intended for an international audience, including readers from regions where "diapers" is the standard term. Using a term that is widely recognised helps ensure that the research is accessible and understandable to a diverse readership.
Methodology – lacking is a motivation of the study area. It is mentioned that the questionnaires were part of a larger study in the area but this does not constitute a motivation why this particular rural area was chosen.
Author: The motivation has been included as follows: The Kruger 2 Canyon (K2C) Biosphere Region was chosen for this study due to its unique combination of rural settings, high population density, and limited waste management infrastructure. This region also has a significant human-wildlife interface, making waste management, particularly the improper disposal of absorbent hygiene products like nappies, a pressing environmental and health issue. The area presents an ideal context to study the environmental impacts of disposable nappies, as most existing life cycle assessments (LCAs) have focused on urban or more developed regions with well-established waste management systems. By focusing on a rural area with diverse and inadequate waste disposal practices, this study fills a critical gap in understanding how geographical context affects the environmental impacts of nappies, particularly in areas lacking formal waste collection services.
Reference is made to primary and secondary data but nowhere is it clearly stated what the primary and secondary data are that was used
Author: Such details are provided in the inventory (section 4) which specifies the sources of data for each production stage.
Also, clearly state in the methodology the three waste scenarios.
Author: The waste scenarios are explained as part of the inventory in section 4.3.2. This is in line with the reporting of life cycle assessments.
Under transport distances were approximated but the choice of the Durban Harbour needs to be motivated. E.g., is this the closest harbour to the SA manufacturer? Also, explain to the reader why Hoedspruit (is it the biggest town in the study area?) was used to calculate distances. In general - the methodology section needs rewriting and a more logical flow.
Author: The paper has been written according to the steps in a life cycle assessment. Thus, what might be traditionally considered methodology steps are reported as part of the inventory (section 4). Thus, there is no traditional methodology section and we are unsure what section the reviewer is referring to specifically for a rewrite.
Discussion - references are made to numbered sections that do not exist. This makes for a confusing read as the reader has to take an educated guess to which section the authors refer to.
Author: The referenced section numbers have been corrected.
Figure 4 - do not use the default colours of Excel – change to match the colours of previous figures. The font is also different from the one in the content.
Author: The figures are generated by different softwares hence the differences in colours. However, we do not believe this detracts from the message of the graphs. The font has been changed.
Some minor technical and language issues and these are indicated in the document.
Author: These have been addressed.
Line 72: Source for population number
Author: The source has been added.

Reviewer 3: Round 2
Date completed: 14 August 2024
Recommendation: Accept / Revisions required / Resubmit for review / Resubmit elsewhere / Decline / See comments
Conflicts of interest: None

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Yes/No/Not applicable
If accepted, would you recommend that the article receives priority publication?
Yes/**No**
Are you willing to review a revision of this manuscript?
Yes/No
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.
Yes/No

Comments to the Author:
Correct language in line 161. The 'are' should be changed to 'as'. Currently it is "Only skip bins were collected by the municipality and taken to an unsanitary landfill whereas, the respondents used dustbins are a temporary waste retainer till they could dump the waste".

Author response to Reviewer 3: Round 2

Correct language in line 161. The 'are' should be changed to 'as'. Currently it is "Only skip bins were collected by the municipality and taken to an unsanitary landfill whereas, the respondents used dustbins are a temporary waste retainer till they could dump the waste"

Author: The language has been corrected.

Reviewer 4: Round 2
Date completed: 19 December 2024
Recommendation: Accept / **Revisions required** / Resubmit for review / Resubmit elsewhere / Decline / See comments
Conflicts of interest: None

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Yes/No
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.
Yes/No

Comments to the Author:

The comments from round one of the review was adequately addressed in the revised manuscript. There are various data limitations in this study, but the author highlights and acknowledges these limitations and what their impact could be. Understanding the impact of disposal methods is important, as this is a growing issue in many rural communities. I would have liked to see a bit more attention to the impact that the increased freshwater ecotoxicity could have on the biodiversity in protected areas in the K2C region (e.g. Kruger National Park), but this is not the main aim of the paper, so it is just a suggestion. This was an interesting read! See a few other comments below:

- Line 144: Change "the diapers were shipped" to "the diaper components were shipped" to avoid confusion.
- Line 222: There is a word missing, see highlighted text on manuscript.
- Line 276: Since human carcinogenic toxicity is mostly attributed to landfilling, it would add value to be more specific about the gases referred to in the statement "This may be attributed to the emission of carcinogenic gases from the landfill. " This is very vague and should be expanded and substantiated from literature.
- Line 290: A brief discussion of the normalization process and its purpose would add value to this section. Specifically to readers who are not very familiar with modeling.
- Line 368: Pulp:SAP ratio is reported as 1:0.92 - please correct.

[See Appendix 2 for Reviewer 4's comments made directly on the revised manuscript]

Author response to Reviewer 4: Round 2

Line 144: Change "the diapers were shipped" to "the diaper components were shipped" to avoid confusion
Author: The change has been made.
Line 222: There is a word missing, see highlighted text on manuscript.
Author: The text has been corrected.
Line 276: Since human carcinogenic toxicity is mostly attributed to landfilling, it would add value to be more specific about the gases referred to in the statement "This may be attributed to the emission of carcinogenic gases from the landfill. " This is very vague and should be expanded and substantiated from literature.
Author: The discussion has been expanded and substantiated with literature.
Line 290: A brief discussion of the normalization process and its purpose would add value to this section. Specifically to readers who are not very familiar with modeling
Author: The purpose of normalization has been described.
Line 368: Pulp:SAP ratio is reported as 1:0.92 - please correct.
Author: It has been corrected.
Line 50: This sentence reads a bit "clumsy". Perhaps consider rephrasing to something like "Thus, common improper disposal methods such as landfilling and incineration have rarely been included in LCAs"
Author: The suggestion has not been adopted as it changes the meaning of the sentence however, the sentence has been edited for clarity.

Line 87: Consider rephrasing. “It places particular focus on the end-of-life aspects not yet investigated in previous research.
Author: The suggestion has been adopted.
Line 96: Check sentence construction and punctuation.
Author: The sentence has been reviewed and edited.

Appendix 1: Reviewer 3's comments on manuscript (round 1)

A critical view of applying life cycle assessment on disposable diapers in a rural context

Abstract

The environmental impacts of disposable diapers in comparison to reusable diapers has been a matter of interest within the life cycle assessment (LCA) community for many years. However, the majority of LCAs have been conducted in developed countries with well-developed waste management infrastructure. This study takes a critical view on the application of LCA to evaluate the environmental impacts of disposable diapers in rural areas. In the study area, the majority of diapers were dumped (43.8 %), sent to unsanitary landfill (26.1 %) or burned (18.6 %). The production phase contributed the most to the majority of impact categories excluding freshwater ecotoxicity marine ecotoxicity and human carcinogenic toxicity. These impacts were instead dominated by end-of-life impacts and also had the highest relative significance when normalisation was conducted. The lack of and/or poor waste management has resulted in the end-of-life being a significant environmental risk. However, current life cycle impact methodologies are not able to fully cover the scope of impacts presented by mismanaged diaper waste. This study demonstrates the importance of geographical contexts when conducting diaper LCAs wherein, in some scenarios it may be necessary to include impacts beyond the scope of a traditional LCA.

Significance

- This is the first Life Cycle Assessment conducted on diapers in the rural contexts of Africa.
- The majority of impacts were attributed to the production of diapers.
- The majority of diapers were dumped or sent to unsanitary landfill.
- However, LCA cannot take into consideration improper disposal giving an incomplete picture of the environmental impacts.

1 Introduction

Since their invention, disposable diapers have become increasingly popular around the world. There is limited information on diaper usage in South Africa. According to a study conducted by Berrian *et al.* (2016)(1), in the Mpumalanga Province of South Africa, 80 % of respondents reported utilising disposable diapers. A further study in 2021 estimated that 67 000 – 160 000 tons of absorbent hygiene products were generated in metropoles depending on their size (2). Whilst diapers have aided in increasing sanitation in developing countries, they have presented a further challenge in terms of the waste created.

The environmental impacts associated with diapers has been a matter of interest in the life cycle assessment (LCA) community for a number of years. This is often conducted from a comparative perspective i.e. reusable vs disposable diapers (3–5). A meta-analysis conducted in 2021 found that reusable diapers are the better choice in the majority of scenarios (5). However, this depends on a number of factors including the reusable diaper laundering process and diaper disposal practices.

With the evolution of technology and development of new materials, studies have been conducted to evaluate their potential impacts (6–8). Mirabella *et al.* (2013)(8) investigated the environmental impacts of substituting petrochemical based plastics with biobased alternatives, finding that while they provide some benefits it is important to pay attention to their agricultural phase. Mendoza *et al.* (2019) found that substituting adhesives with a novel bonding technique reduced raw material consumption, primary energy demand and greenhouse gas emissions.

The majority of diaper LCA studies have been conducted in developed countries (5), with one having been conducted in Brazil (9). Thus, improper disposal methods have been rarely considered with landfilling and incineration being the most common methods of waste treatment. Furthermore, there are limited insights into scenarios in which there is limited access to water, sanitation, and waste management infrastructure.

This study contributes to the lack of studies in developing countries. Furthermore, it investigates the rural context. This is of particular importance as geographical context was identified as one of the critical factors influencing the environmental impacts of diapers (5). The article is structured according to the generic steps of a life cycle assessment:

- Goal and scope definition
- Life cycle inventory
- Life cycle impact assessment
- Interpretation

2 Data sources and Modelling approach

The diaper modelled was based on primary and secondary information. Specifically, the foreground data was informed by primary data provided by a major local diaper manufacturer. This was supplemented by secondary data sourced from literature. Background data was based on the Ecoinvent v3.9 cut-off system model database. Section 2.2 details the cases in which the different types of information sources are used. The LCA was modelled on SimaPro LCA Software v9.4.0.1.

Primary data for the waste scenario was based on a series of questionnaires conducted in the Kruger 2 Canyon (K2C) Biosphere Region in South Africa. The boundaries of the biosphere extend to the Kruger National Park and two catchment areas and is inhabited by 1.5 million people. The questionnaires were part of a larger study investigating diaper usage and disposal practices in the area. 1 575 questionnaires were conducted across eight villages in the area.

3 Goal and scope

The goal of this study is to evaluate the potential environmental impacts of disposable diaper usage in rural areas. It places a particular focus on the end-of-life, aspects of which have yet to be investigated in previous research.

3.1 Functional unit and reference flow

Previous studies have used a number of functional units. For example, a number of studies have utilised the average number of children's diapers used over 2.5 years (3,9,10). In some cases the functional unit seems arbitrarily chosen such as the 1000 units used by (7). According to the distributed questionnaires, the average number of diapers used per day was 4.47. This is similar to studies by Hoffmann, de Simone Morais and Teodoro (2020) and Aumónier, Collins and Garrett (2008) where they estimated 5 and 4.16 diapers per day respectively. Thus, this study will be utilising the number of diapers required in one day which, equate to 4.47 diapers.

3.2 System boundaries

A cradle-to-grave LCA was conducted, from raw material extraction to disposal. Both informal and formal disposal methods were taken into consideration. Transport and distribution were partly included and use phases were excluded (further discussed in the following sections). The system under consideration is depicted in Figure 1.

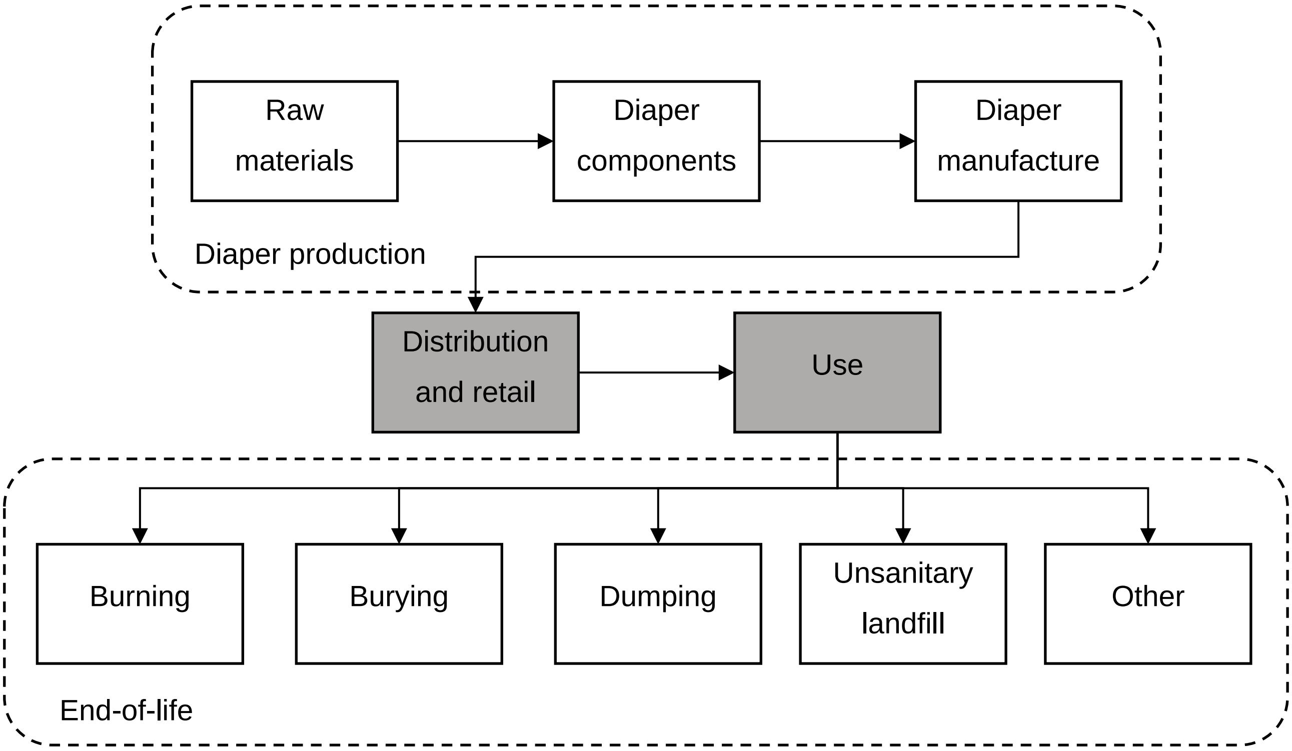

Figure 1: Diaper life cycle stages

The packaging for the diapers was not included in the model. This is supported by the results of the LCA conducted by Cordella *et al.* (2015)(6) wherein they found the impacts of packaging across the life cycle to be negligible.

4 Life Cycle Inventory

Diapers are constructed from a large variety of components, including tapes, elastics and adhesives. The primary raw materials used are similar with differences in their construction and additives employed. Table 1, shows the primary materials used. The most important part of the diaper, the absorbent core, is comprised of pulp and super absorbent material (sodium polyacrylate) and accounts for the majority of the mass of a diaper at 65.2 % (according to a South African manufacturer of disposable diapers). This is to be expected as its primary function is the absorption and retention of excreta. The liner, which comes in contact with the baby, is often made from a polymer mix which allows the passage of fluids to the absorbent core. The outer cover is made of a breathable material which is also polymer based. Adhesives are used to secure the different diaper components.

Table 1: Primary raw materials used in diaper manufacturing and their contribution to diaper weight (source: South African manufacturer)

Material Type	Percentage Contribution

Pulp	33.9%
Sodium polyacrylate (SAP)	31.2%
Polypropylene (PP)	20.8%
Polyethylene (PE)	9.8%
Elastics	1.0%
Adhesive	3.2%

1.1 Diaper components

There was limited data regarding the production of diaper components. The manufacturer provided the types of components, their weights and their primary materials. Further, they provided the country of origin as some of the components are imported. However, there was no information provided on the manufacturer in the exporting country or the processes employed. Therefore, the modelling of these components was based on datasets available in Ecoinvent and modified as far as possible to reflect the conditions in the country of origin. For example, substituting the electricity for the local electricity mix from the Ecoinvent database.

Many of the diaper components are composed of composite materials. However, in this study only the primary materials were modelled per component, similar to Cordella *et al.* (2015) and Mendoza *et al.* (2019).

1.2 Diaper manufacture

Data regarding diaper manufacture was provided by a major diaper manufacturer in South Africa. This includes weights of diaper components used, electricity consumption and waste generation and disposal.

1.3 Use phase

The use phase was not modelled due to the wide variety of transport distances and methods that would be used by consumers to the retailer. The questionnaires found there are a wide variety of retailers available to respondents which are at varying distances. Further, they would use differing transport methods to reach the retailer including public transport, private transport or walking.

4.1.1 Transport

Transportation of the imported diaper components was included in the model. The diapers were shipped from the originating country to South Africa. The distances were approximated using a major port in the country of origin as the source and Durban Harbour, on the east coast of South Africa, as the destination. The components are then transported by road to the factory.

An average distance of 1 880 km was utilised for transport to distributors and retailers in the town of Hoedspruit, within the K2C Biosphere. The distance represented the distance from the factory to the Hoedspruit area and was obtained using google maps. However further details could not be modelled as the diapers could pass through several hands before they are retailed to consumers e.g. distributors to wholesalers to spaza shops.

4.1.2 End-of-life

Waste residues from the diaper production process reportedly only accounted for 3 % of materials. This is higher than the study by Mendoza et al., (2019) which utilised 1%. These residues are reportedly sent for further beneficiation by other value chain members. However, we were not privy to the nature of these beneficiation methods therefore, it was not possible to model the waste scenario in this case.

Based on the interviews, respondents used a variety of methods for the disposal of nappies. They do not necessarily stick with one method and might use different options based on convenience. Only skip bins were collected by the municipality and taken to an unsanitary landfill whereas, the respondents used dustbins are a temporary waste retainer till they could dump the waste. Dumping included multiple environments: riverbeds, bush/veld and next to roads. The most popular method was dumping in the bush/veld followed by burning. Other disposal methods consisted of dumping in pit latrines or other methods not specified in the questionnaire.

Three waste treatments (Table 2) were modelled using the models developed by Doka (2021) (11): open burning, open dump and unsanitary landfill. The underlying data was modified to reflect the region using the available information. Burying was modelled as an unsanitary landfill however, it is acknowledged that this does not fully represent the method. Disposal in pit latrines and "other" was modelled using a dummy waste treatment thus the impacts are not reflected in the LCIA. The impacts of this modelling choice are explored in section 4.1.

Table 2: Waste scenario

Open dump	43.8%
Unsanitary landfill	26.1%
Burning	18.6%
Other	11.5%

The impacts of the disposal of urine and faeces was not modelled. Instead, the potential impacts are discussed in section 4.2. This includes impacts that cannot be accounted for in LCA such as, ingestion by animals and dumping in rivers.

5 Life Cycle Impact Assessment

Previous studies have used the CML 2001 or ReCiPe methods for calculating the potential environmental impacts (5). In this study, a long-term approach was taken for the environmental impacts. Thus, the impact assessment was conducted using the ReCiPe Midpoint (H) method which, uses global models to evaluate environmental impacts. The method also provides a comprehensive set of indicators.

5.1 Contribution analysis

The results of the characterisation phase are presented in Table 3. A contribution analysis was performed on each indicator so as to highlight the major contributors. The impacts were then normalised, using default ReCiPe values, to enable the determination of the relative significance of the different impact categories.

Table 3: LCIA characterisation results

Impact category	Unit	Total	Diaper production	Transport to distributors	Waste scenario
Global warming	kg CO_2 eq	6.10E-01	5.59E-01	2.44E-02	2.61E-02
Stratospheric ozone depletion	kg CFC11 eq	3.19E-07	2.81E-07	1.04E-08	2.78E-08
Ionizing radiation	kBq Co-60 eq	1.52E-02	1.47E-02	5.07E-04	0.00E+00
Ozone formation, Human health	kg NOx eq	2.35E-03	2.10E-03	2.20E-04	3.41E-05
Fine particulate matter formation	kg $PM_{2.5}$ eq	1.27E-03	1.11E-03	5.33E-05	1.06E-04
Ozone formation, Terrestrial ecosystems	kg NOx eq	2.39E-03	2.13E-03	2.24E-04	3.83E-05
Terrestrial acidification	kg SO_2 eq	3.38E-03	3.25E-03	1.27E-04	1.15E-05

Freshwater eutrophication	kg P eq	5.50E-04	3.60E-04	8.25E-06	1.82E-04
Marine eutrophication	kg N eq	3.07E-05	2.18E-05	4.06E-07	8.48E-06
Terrestrial ecotoxicity	kg 1,4-DCB	1.74E+00	1.29E+00	4.51E-01	2.87E-03
Freshwater ecotoxicity	kg 1,4-DCB	2.34E-01	1.80E-02	6.89E-04	2.15E-01
Marine ecotoxicity	kg 1,4-DCB	3.49E-01	2.45E-02	1.16E-03	3.23E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.85E+01	3.72E-02	1.52E-03	1.84E+01
Human non-carcinogenic toxicity	kg 1,4-DCB	8.16E-01	6.02E-01	2.40E-02	1.91E-01
Land use	m^2a crop eq	9.17E-02	8.91E-02	2.60E-03	5.20E-05
Mineral resource scarcity	kg Cu eq	1.49E-03	1.41E-03	7.59E-05	0.00E+00
Fossil resource scarcity	kg oil eq	2.19E-01	2.11E-01	8.30E-03	0.00E+00
Water consumption	m^3	5.23E-03	5.14E-03	8.70E-05	0.00E+00

As can be seen in Figure 2, diaper production, from cradle-to-gate, accounted for the majority of impacts on average (> 65 %) except for freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. In these cases, the disposal of diapers was the higher contributor accounting for 96 % or more.

The absorbent core was a notable contributor across all impact categories during diaper production. In particular, it accounted for 92 % of land use impacts; this can be attributed to the land needed to grow the trees from which pulp fluff is made. South African generated electricity used in diaper production was also a significant contributor to a number of categories including global warming potential, stratospheric ozone depletion, particulate matter formation and terrestrial acidification. This can be attributed to the fact that most of the electricity in South Africa is coal based. Another notable contributor across all impacts was a locally made PP based component. Like the electricity mix, polypropylene is fossil fuel based in South Africa; propylene in South Africa is produced as a by-product of the coal gasification process.

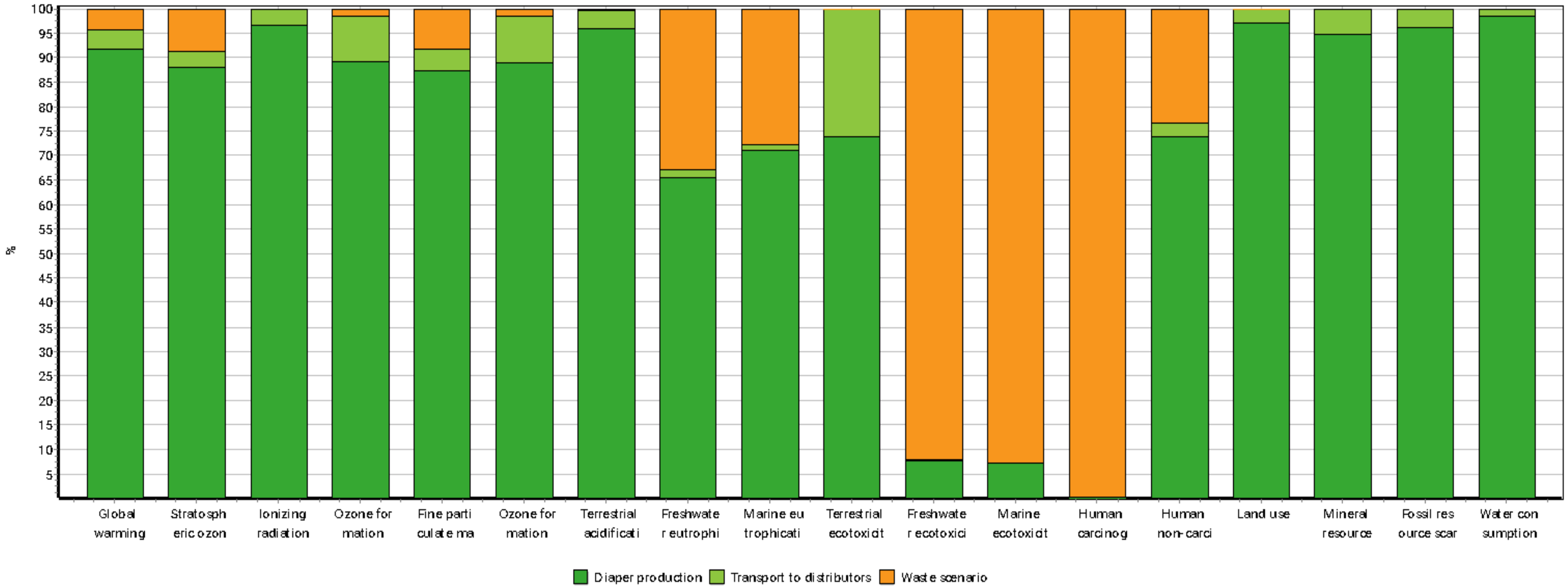

Figure 2: Relative contribution of life cycle stages to different impacts

5.2 Normalisation

The results of the normalisation can be seen in Figure 3. From this, the most significant impact is human carcinogenic toxicity. Unsanitary landfilling of diapers was virtually the only contributor to human carcinogenic toxicity contributing 99.8 %. Thus, whilst the waste disposal wasn’t a major contributor across all the impact categories, it has the largest impact when translated into real world terms. The waste scenario was also a major contributor to freshwater and marine ecotoxicity which also had relatively significant impacts upon exclusion of human carcinogenic toxicity. Once again, these were dominated by unsanitary landfilling of diapers accounting for 92.0 % and 92.7 % respectively. However, this does not mean that the other categories should be totally ignored, instead the normalisation highlights hotspots for improvement.

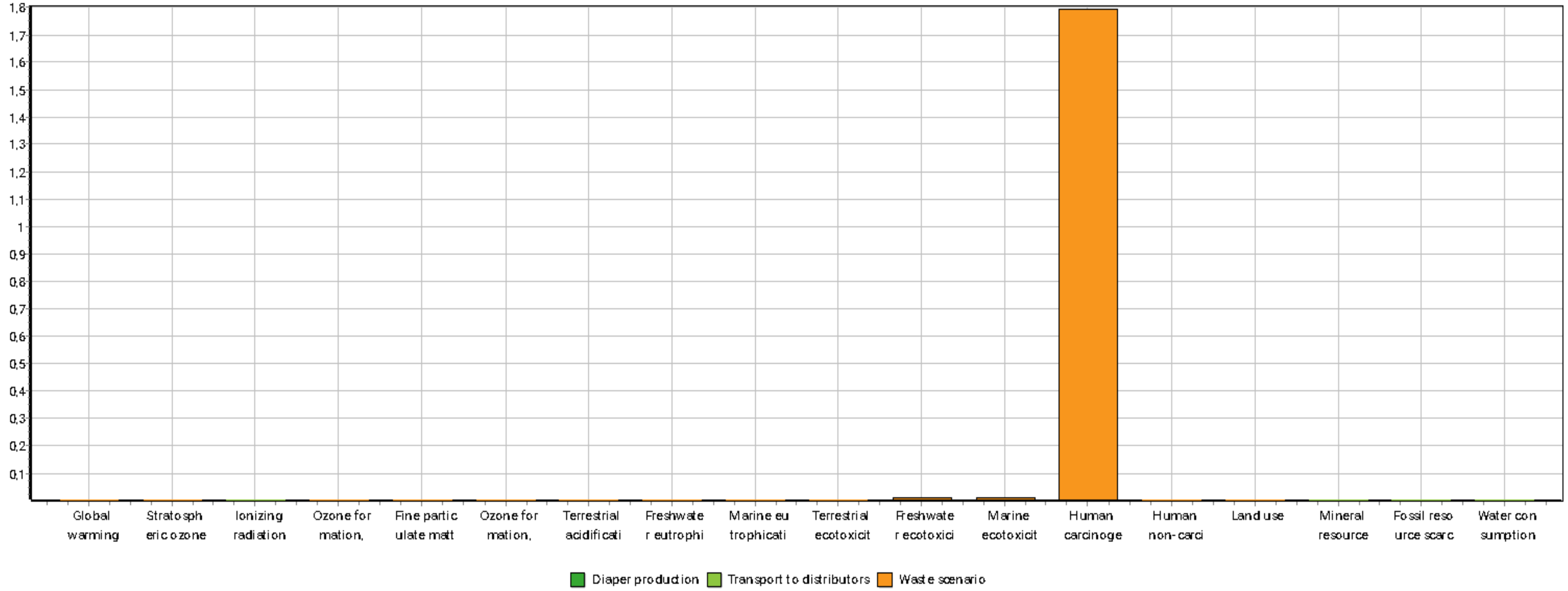

Figure 3: LCIA normalisation results

6 Further Results

6.1 Pit latrine modelling choice

Pit latrines are essentially a pit that is dug for the purpose of human defecation. A shelter is often built around the hole which may include an air vent. Once the pit is almost full, the waste is buried and another pit is dug.

As mentioned in section 2.3.5, in the base case waste scenario disposal in pit latrines was modelled as a dummy treatment. The consequences of these choices are investigating by modelling pit latrines as open dumping and unsanitary landfill as waste scenarios 2 and 3 respectively.

As can be seen in Figure 4, no changes in impacts are observed for some of the impact categories including ozone formation, fine particulate matter formation and ionizing radiation. In the cases where changes were observed, waste scenario 3 had the highest increases in impacts. Waste scenario 3 was particularly significant for human toxicity and ecotoxicity. Thus, the modelling choice for pit latrines is significant when it comes to the waste scenario emissions.

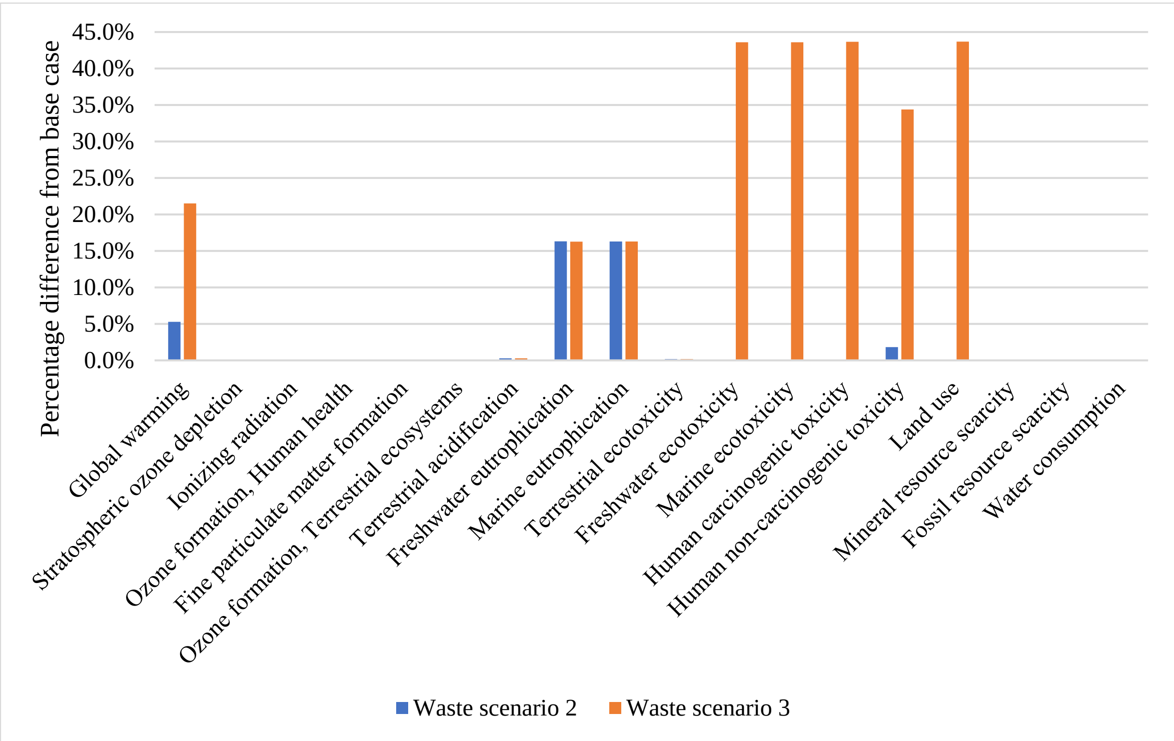

Figure 4: Comparing modelling choices for pit latrine

6.2 *Improper diaper disposal*

As mentioned in section 2.2.3, it was not possible to accurately portray the end-of-life impacts within LCA. In particular, the impacts of improper disposal of excreta in the environment was not addressed. In K2C, only 12.8 % of the respondents reported emptying the stool before diaper disposal, meaning the bulk of diapers are disposed with stool in them. This is a danger to the environment and human and animal health. Used diapers carry viruses and diseases and their proper disposal is essential to limit human exposure to these (12–14). Excreta has been associated with many diseases including cholera, typhoid and hepatitis.

Burning diapers releases a variety of pollutants including carcinogens such as dioxins and greenhouse gasses (13). It is a difficult process due to the wetness of the excreta. This may result in a residue that may be ingested by dogs or other animals such as goats and cows. Further, the ash created can leach pathogens into surface and groundwater sources as it rains (14).

Burying, whilst it puts the waste out of sight and less available to humans and animals, has the potential to contaminate ground water sources with pathogens (12,14). This is similar to unsanitary landfilling and open dumping where there is no leachate control, so it is free to absorb into the soil and potentially contaminate ground water. Furthermore, gases that permeate through the landfill and are released into the air may contain harmful pollutants.

Open dumping leaves diapers out in the open which may attract dogs and small children. This results in exposure to disease as described earlier and additionally risk of ingestion by animals. Another route for potential risk to health is the dumping of diapers next to rivers or onto dry riverbeds. This has the potential to directly contaminate the river water, when the river starts to flow again. This is a significant risk to community members which rely on the river as a water source. Dumping in rivers also has the potential to damage infrastructure such as bridges as reported by municipal officials. This was attributed to flash floods which occur when the waste dams a river and the water eventually breaks through.

A pit latrine has the potential to leach into underground water sources contaminating them. Further, the depositing of diapers in the pit latrine result in the pit filling up quickly requiring more to be dug.

7 Interpretation

Across the life-cycle, the production phase was the majority contributor to impacts with the exception of freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity, which were also the impacts with the highest relative importance. Aumónier, Collins and Garrett,

(2008) also found the production of diapers to contribute the most to environmental impacts. During the production phase, manufacturing electricity was consistently a top contributor across the majority of impacts. This raised the contribution of the diaper manufacturing phase which is the opposite of what Mendoza *et al.* (2019) found in their study. The electricity impacts can be attributed to the South African energy source wherein the majority of energy is sourced from local coal deposits. Thus, it stands to reason that the standing of electricity as a top contributor is a situation unique to the South African context.

The absorbent core was also found to be a top contributor to impacts. In the case of SAP, it's production could be traced as the primary contributor to impacts. This is similar to results obtained by Mendoza *et al.* (2019). The pulp also played a notable role in impacts associated with the ecosystem. Pulp was found to be the top contributor across the majority of impacts by Cordella *et al.* (2015) with, SAP being the second most significant. The contributions of SAP and pulp can be influenced by the ratios of the in the absorbent core. In this case, the pulp: SAP ratio is 1:0.92. Whereas Mendoza *et al.* (2019) reported a ratio of 1:4. Some studies have been conducted on the efficacy of changing the ratio of SAP: pulp in diapers finding that a reduction in materials leads to a reduction in environmental impacts (6,7).

The emergence of these processes highlights potential hotspots for improvement. In terms of electricity, the diaper manufacturing factory can look towards using renewable energy sources and reduce reliance on the national grid which is already strained (15).

Whilst there is a national push for the use of locally produced materials it is important to note the potential impacts associated with such a shift. This was demonstrated by the featuring of locally produced PP components e.g. flap material, as a notable contributor in many impact categories. This can be attributed to the fact that the precursor for PP is a by-product of coal processing via the Fischer-Tropsche process. Chitaka, Russo and von Blottnitz (2020) (16) found that polypropylene produced in South Africa had higher GWP than the production of the same material in the United States and Europe. Thus, the push for localisation comes with additional environmental burdens.

Diaper disposal was only dominant in three impact categories: freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. However, the importance of these categories was shown to be significant after normalisation. It is important to note that diapers can take up to 500 years to decompose, thus they are largely inert in landfills and dumps (17). Furthermore, the impact assessment methodology chosen only has a 100year time frame.

Diaper disposal presents a greater scope of impacts than can be assessed by current LCA models and research is required to address this limitation. As discussed in section 4, improper diaper disposal presents a real threat to the health and safety of humans and animals. Thus, when developing interventions to reduce the environmental impacts of disposable diaper, emphasis should be placed on waste disposal. Cordella *et al.* (2015) recommend better disposal methods such as recycling to reduce end-of-life impacts however, developing countries have much further to go. Improvements need to be made to service delivery wherein the waste is actually collected before treatment options can be discussed.

8 Conclusions

According to the normalisation, the most significant impacts from the disposable nappies are those contributing to human and ecological toxicity; the majority contributor of which was improper disposal of used diapers. It is important to address these impacts. In order to do this, there needs to be proper waste management of the diaper waste. Thus, interventions to address the impacts of diapers should be focused on the proper management of used diapers. For example, improvement in waste management service delivery to the villages and improved landfill conditions before more high-tech solutions can be considered.

Local electricity used in the manufacture of diapers is a top contributor to the majority of impact categories. This indicates the need for increased energy efficiency and a shift towards renewable sources of energy.

The absorbent core is also another area that can be earmarked for improvement. This may be in the form of material reduction or substitution of materials.

In the rural areas, the impacts of disposable diapers extend beyond what can be captured by LCA. Thus, there needs to be further research as to how these impacts can be integrated in LCIA methodology. Further, it is important to consider the wider consequences of the use and disposal of diapers in different geographical contexts.

Ethical approval was received from [anonymised], reference number [anonymised].

References

1. Berrian AM, van Rooyen J, Martínez-López B, Knobel D, Simpson GJG, Wilkes MS, et al. One Health profile of a community at the wildlife-domestic animal interface, Mpumalanga, South Africa. Prev Vet Med [Internet]. 2016;130:119–28. Available from: http://dx.doi.org/10.1016/j.prevetmed.2016.06.007

2. Govender R, Whyte C, Govender T. Detailed Feasibility Study and Business Case/s for the Establishment of Refuse Derived Fuel Plants to Address Absorbent Hygiene Products and other Residual Materials. Cape Town, South Africa: Department of Environment, Forestry and Fisheries; 2021.

3. Aumónier S, Collins M, Garrett P. Using science to create a better place: An updated lifecycle assessment study for disposable and reusable nappies. Bristol: Environmental Agency; 2008. 33 p.

4. Ng FSF, Muthu SS, Li Y, Hui PCL. A critical review on life cycle assessment studies of diapers. Crit Rev Environ Sci Technol. 2013;43(16):1795–822.

5. Notten P, Gower A, Lewis Y. Single-use nappies and their alternatives. Recommendations from from Life Cycle Assessments. United Nations Environ Program. 2021;1–45.

6. Cordella M, Bauer I, Lehmann A, Schulz M, Wolf O. Evolution of disposable baby diapers in Europe: Life cycle assessment of environmental impacts and identification of key areas of improvement. J Clean Prod [Internet]. 2015;95:322–31. Available from: http://dx.doi.org/10.1016/j.jclepro.2015.02.040

7. Mendoza JMF, Popa SA, D'Aponte F, Gualtieri D, Azapagic A. Improving resource efficiency and environmental impacts through novel design and manufacturing of disposable baby diapers. J Clean Prod [Internet]. 2019;210:916–28. Available from: https://doi.org/10.1016/j.jclepro.2018.11.046

8. Mirabella N, Castellani V, Sala S. Life cycle assessment of bio-based products: A disposable diaper case study. Int J Life Cycle Assess. 2013;18(5):1036–47.

9. Hoffmann BS, de Simone Morais J, Teodoro PF. Life cycle assessment of innovative circular business models for modern cloth diapers. J Clean Prod [Internet]. 2020;249:119364. Available from: https://doi.org/10.1016/j.jclepro.2019.119364

10. Brien KO, Olive R, Hsu Y chieh, Morris L, Bell R. Life cycle assessment: Reusable and disposable nappies in Australia. ALCAS--Australian Life Cycle Assess Soc. 2009;1–14.

11. Doka G. A model for waste-specific and climate-specific life cycle inventories of open dumps and unsanitary landfilling of waste. Zürich, Switzerland: Doka Life Cycle Assessments; 2016.

12. Kordecki H, Antrobus-Wuth R, Uys MT, van Wyk I, Root ED, Berrian AM. Disposable diaper waste accumulation at the human-livestock-wildlife interface: A one health approach. Environ Challenges [Internet]. 2022;8(June):100589. Available from: https://doi.org/10.1016/j.envc.2022.100589

13. Meseldzija J, Poznanovic D, Frank R. Assessment of the differing environmental impacts between reusable and disposable diapers. Dufferin Res. 2013;(November).

14. Ntekpe ME, Mbong EO, Edem EN, Hussain S. Disposable diapers: Impact of disposal methods on public health and the environment. Am J Med Public Heal. 2020;1(2):1–7.

15. Trenner R. CNN. 2023 [cited 2023 Feb 5]. p. 1–10 Dead chickens and decomposing bodies: Inside South Africa’s power blackout ‘pandemic.’ Available from: https://edition.cnn.com/2023/01/31/africa/south-africa-power-blackouts-intl-cmd/index.html

16. Chitaka TY, Russo V, von Blottnitz H. In pursuit of environmentally friendly straws : a comparative life cycle assessment of five straw material options in South Africa. Int J Life Cycle Assess. 2020;

17. Płotka-Wasylka J, Makoś-Chełstowska P, Kurowska-Susdorf A, Treviño MJS, Guzmán SZ, Mostafa H, et al. End-of-life management of single-use baby diapers: Analysis of technical, health and environment aspects. Sci Total Environ. 2022;836(April).

A critical view of applying life cycle assessment on disposable diapers in a rural context

Abstract

The environmental impacts of disposable diapers in comparison to reusable diapers has been a matter of interest within the life cycle assessment (LCA) community for many years. However, the majority of LCAs have been conducted in developed countries with well-developed waste management infrastructure. This study takes a critical view on the application of LCA to evaluate the environmental impacts of disposable diapers in rural areas.

In the study area, the majority of diapers were openly dumped (43.8 %), sent to unsanitary landfill (26.1 %) or burned (18.6 %). The production phase contributed the most to the majority of impact categories excluding freshwater ecotoxicity marine ecotoxicity and human carcinogenic toxicity. These impacts were instead dominated by end-of-life impacts and also had the highest relative significance when normalisation was conducted.

The lack of and/or poor waste management has resulted in the end-of-life being a significant environmental risk. However, current life cycle impact methodologies are not able to fully cover the scope of impacts presented by mismanaged diaper waste. This study demonstrates the importance of geographical contexts when conducting diaper LCAs wherein, in some scenarios it may be necessary to include impacts beyond the scope of a traditional LCA.

Significance

- This is the first Life Cycle Assessment conducted on diapers in the rural contexts of Africa.
- The majority of impacts were attributed to the production of diapers.
- The majority of diapers were dumped or sent to unsanitary landfill.
- However, LCA cannot take into consideration improper disposal giving an incomplete picture of the environmental impacts.

1 Introduction

Since their invention, disposable diapers have become increasingly popular around the world. There is limited information on diaper usage in South Africa. According to a study conducted by Berrian *et al.* (2016)(1), in the Mpumalanga Province of South Africa, 80 % of respondents reported utilising disposable diapers. A further study in 2021 estimated that 67 000 – 160 000 tons of absorbent hygiene products were generated in metropoles depending on their size (2).

Whilst diapers have aided in increasing sanitation in developing countries, they have presented a further challenge in terms of the waste created.

The environmental impacts associated with diapers has been a matter of interest in the life cycle assessment (LCA) community for a number of years. This is often conducted from a comparative perspective i.e. reusable vs disposable diapers (3–5). A meta-analysis conducted in 2021 found that reusable diapers are the better choice in the majority of scenarios (5). However, this depends on a number of factors including the reusable diaper laundering process and diaper disposal practices.

With the evolution of technology and development of new materials, studies have been conducted to evaluate their potential impacts (6–8). Mirabella *et al.* (2013)(8) investigated the environmental impacts of substituting petrochemical based plastics with biobased alternatives, finding that while they provide some benefits it is important to pay attention to their agricultural phase. Mendoza *et al.* (2019) found that substituting adhesives with a novel bonding technique reduced raw material consumption, primary energy demand and greenhouse gas emissions.

The majority of diaper LCA studies have been conducted in developed countries (5), with one having been conducted in Brazil (9). Thus, improper disposal methods have been rarely considered with landfilling and incineration being the most common methods of waste treatment. Furthermore, there are limited insights into scenarios in which there is limited access to water, sanitation, and waste management infrastructure.

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This study contributes to the lack of studies in developing countries. Furthermore, it investigates the rural context. This is of particular importance as geographical context was identified as one of the critical factors influencing the environmental impacts of diapers (5).

The article is structured according to the generic steps of a life cycle assessment:

- Goal and scope definition
- Life cycle inventory
- Life cycle impact assessment
- Interpretation

2 Data sources and Modelling approach

The diaper modelled was based on primary and secondary information. Specifically, the foreground data was informed by primary data provided by a major local diaper manufacturer. The data was provided for the year 2021.This was supplemented by secondary data sourced from literature. Background data was based on the Ecoinvent v3.9 cut-off system model database. Section 4 details the cases in which the different types of information sources are used. The LCA was modelled on SimaPro LCA Software v9.4.0.1.

Primary data for the waste scenario was based on a series of questionnaires conducted in the Kruger 2 Canyon (K2C) Biosphere Region in South Africa in 2022. The Kruger 2 Canyon (K2C)

Biosphere Region was chosen for this study due to its unique combination of rural settings, high population density of 1.5 million people (10), and limited waste management infrastructure. This region also has a significant human-wildlife interface, making waste management, particularly the improper disposal of absorbent hygiene products like nappies, a pressing environmental and health issue. The area presents an ideal context to study the environmental impacts of disposable nappies, as most existing life cycle assessments (LCAs) have focused on urban or more developed regions with well-established waste management systems. By focusing on a rural area with diverse and inadequate waste disposal practices, this study fills a critical gap in understanding how geographical context affects the environmental impacts of nappies, particularly in areas lacking formal waste collection services.

The questionnaires were part of a larger study investigating diaper usage and disposal practices in the area. 1 575 questionnaires were conducted across eight villages in the area.

3 Goal and scope

The goal of this study is to evaluate the potential environmental impacts of disposable diaper usage in rural areas. It places a particular focus on the end-of-life, aspects of which have yet to be investigated in previous research.

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3.1 Functional unit and reference flow

Previous studies have used a number of functional units. For example, a number of studies have utilised the average number of children's diapers used over 2.5 years (3,9,11). In some cases the functional unit seems arbitrarily chosen such as the 1000 units used by Mendoza et al. (2019) (7). According to the distributed questionnaires, the average number of diapers used per day was 4.47. This is similar to studies by Hoffmann, de Simone Morais and Teodoro (2020) and Aumónier, Collins and Garrett (2008) where they estimated 5 and 4.16 diapers per day respectively. Thus, this study will be utilising the number of diapers required in one day which, equate to 4.47 diapers.

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3.2 System boundaries

A cradle-to-grave LCA was conducted, from raw material extraction to disposal. Both informal and formal disposal methods were taken into consideration. Transport and distribution were partly included and use phases were excluded (further discussed in the following sections). The system under consideration is depicted in Figure 1.

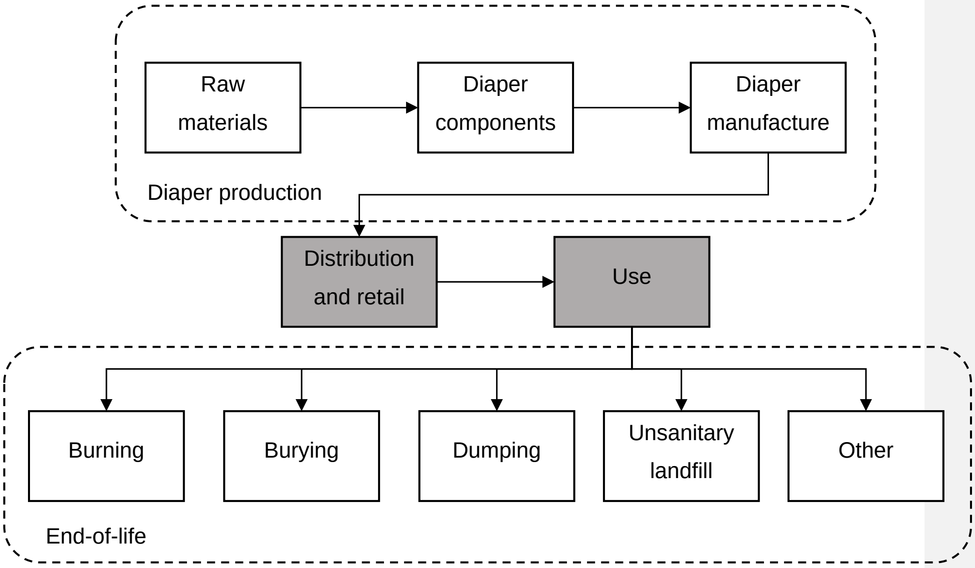

Figure 1: Diaper life cycle stages

The packaging for the diapers was not included in the model. This is supported by the results of the LCA conducted by Cordella *et al.* (2015)(6) wherein they found the impacts of packaging across the life cycle to be negligible.

4 Life Cycle Inventory

Diapers are constructed from a large variety of components, including tapes, elastics and adhesives. The primary raw materials used are similar with differences in their construction and additives employed. Table 1 shows the primary materials used. The most important part of the diaper, the absorbent core, is comprised of pulp and super absorbent material (sodium polyacrylate) and accounts for the majority of the mass of a diaper at 65.2 % (according to a South African manufacturer of disposable diapers). This is to be expected as its primary function is the absorption and retention of excreta. The liner, which comes in contact with the baby, is often made from a polymer mix which allows the passage of fluids to the absorbent core. The outer cover is made of a breathable material which is also polymer based. Adhesives are used to secure the different diaper components.

Table 1: Primary raw materials used in diaper manufacturing and their contribution to diaper weight (source: South African manufacturer)

Material Type	**Percentage Contribution**
Pulp	33.9%
Sodium polyacrylate (SAP)	31.2%
Polypropylene (PP)	20.8%

Polyethylene (PE)	9.8%
Elastics	1.0%
Adhesive	3.2%

4.1 Diaper components

There was limited data regarding the production of diaper components. The manufacturer provided the types of components, their weights and their primary materials. Further, they provided the country of origin as some of the components are imported. However, there was no information provided on the manufacturer in the exporting country or the processes employed. Therefore, the modelling of these components was based on datasets available in Ecoinvent and modified as far as possible to reflect the conditions in the country of origin. For example, substituting the electricity for the local electricity mix from the Ecoinvent database.

Many of the diaper components are composed of composite materials. However, in this study only the primary materials were modelled per component, similar to Cordella *et al.* (2015) and Mendoza *et al.* (2019).

4.2 Diaper manufacture

Data regarding diaper manufacture (DM) was provided by a major diaper manufacturer in South Africa. This includes weights of diaper components used, electricity consumption and waste generation and disposal.

4.3 Use phase

The use phase was not modelled due to the wide variety of transport distances and methods that would be used by consumers to the retailer. The questionnaires found there are a wide variety of retailers available to respondents which are at varying distances. Further, they would use differing transport methods to reach the retailer including public transport, private transport or walking.

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4.3.2 End-of-life

Waste produced from the diaper production process reportedly only accounted for 3 % of materials. This is higher than the study by Mendoza et al., (2019) which utilised 1%. These residues are reportedly sent for further beneficiation by other value chain members. However, we were not privy to the nature of these beneficiation methods therefore, it was not possible to model the waste scenario in this case.

Based on the interviews, respondents used a variety of methods for the disposal of nappies. They do not necessarily stick with one method and might use different options based on convenience. Only skip bins were collected by the municipality and taken to an unsanitary landfill whereas, the respondents used dustbins as~~re~~ a temporary waste retainer till they could dump the waste. Dumping included multiple environments: riverbeds, bush/veld and next to roads. The most popular method was dumping in the bush/veld followed by burning. Other disposal methods consisted of dumping in pit latrines or other methods not specified in the questionnaire.

Three waste treatments (Table 2) were modelled using the models developed by Doka (2021) (12): open burning, open dump and unsanitary landfill. The underlying data was modified to reflect the region using the available information. Burying was modelled as an unsanitary landfill however, it is acknowledged that this does not fully represent the method. Disposal in pit latrines and "other" was modelled using a dummy waste treatment thus the impacts are not reflected in the LCIA. The impacts of this modelling choice are explored in section 6.1.

Table 2: Waste scenario

Open dump	43.8%
Unsanitary landfill	26.1%
Burning	18.6%
Other	11.5%

The impacts of the disposal of urine and faeces was not modelled. Instead, the potential impacts are discussed in section 6.2. This includes impacts that cannot be accounted for in LCA such as, ingestion by animals and dumping in rivers.

5 Life Cycle Impact Assessment

Previous studies have used the CML 2001 or ReCiPe methods for calculating the potential environmental impacts (5). In this study, a long-term approach was taken for the environmental impacts. Thus, the impact assessment was conducted using the ReCiPe Midpoint (H) method which, uses global models to evaluate environmental impacts. The method also provides a comprehensive set of indicators.

5.1 Contribution analysis

The results of the characterisation phase are presented in Table 3. A contribution analysis was performed on each indicator so as to highlight the major contributors. The impacts were then normalised, using default ReCiPe values, to enable the determination of the relative significance of the different impact categories.

Table 3: LCIA characterisation results

Impact category	Unit	Total	Diaper production	Transport to distributors	Waste scenario
Global warming	kg CO_2 eq	6.10E-01	5.59E-01	2.44E-02	2.61E-02
Stratospheric ozone depletion	kg CFC11 eq	3.19E-07	2.81E-07	1.04E-08	2.78E-08
Ionizing radiation	kBq Co-60 eq	1.52E-02	1.47E-02	5.07E-04	0.00E+00
Ozone formation, Human health	kg NOx eq	2.35E-03	2.10E-03	2.20E-04	3.41E-05
Fine particulate matter formation	kg $PM_{2.5}$ eq	1.27E-03	1.11E-03	5.33E-05	1.06E-04
Ozone formation, Terrestrial ecosystems	kg NOx eq	2.39E-03	2.13E-03	2.24E-04	3.83E-05
Terrestrial acidification	kg SO_2 eq	3.38E-03	3.25E-03	1.27E-04	1.15E-05
Freshwater eutrophication	kg P eq	5.50E-04	3.60E-04	8.25E-06	1.82E-04
Marine eutrophication	kg N eq	3.07E-05	2.18E-05	4.06E-07	8.48E-06
Terrestrial ecotoxicity	kg 1,4-DCB	1.74E+00	1.29E+00	4.51E-01	2.87E-03
Freshwater ecotoxicity	kg 1,4-DCB	2.34E-01	1.80E-02	6.89E-04	2.15E-01
Marine ecotoxicity	kg 1,4-DCB	3.49E-01	2.45E-02	1.16E-03	3.23E-01

Human carcinogenic toxicity	kg 1,4-DCB	1.85E+01	3.72E-02	1.52E-03	1.84E+01
Human non-carcinogenic toxicity	kg 1,4-DCB	8.16E-01	6.02E-01	2.40E-02	1.91E-01
Land use	m^2a crop eq	9.17E-02	8.91E-02	2.60E-03	5.20E-05
Mineral resource scarcity	kg Cu eq	1.49E-03	1.41E-03	7.59E-05	0.00E+00
Fossil resource scarcity	kg oil eq	2.19E-01	2.11E-01	8.30E-03	0.00E+00
Water consumption	m^3	5.23E-03	5.14E-03	8.70E-05	0.00E+00

As can be seen in Table 3, diaper production, from cradle-to-gate, accounted for the majority of impacts on average (> 65 %) except for freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. In these cases, the disposal of diapers was the higher contributor accounting for 96 % or more.

The absorbent core was a notable contributor across all impact categories during diaper production. In particular, it accounted for 92 % of land use impacts; this can be attributed to the land needed to grow the trees from which pulp fluff is made. South African generated electricity used in diaper production was also a significant contributor to a number of categories including global warming potential, stratospheric ozone depletion, particulate matter formation and terrestrial acidification. This can be attributed to the fact that most of the electricity in South Africa is coal based. Another notable contributor across all impacts was a locally made PP based component. Like the electricity mix, polypropylene is fossil fuel based in South Africa; propylene in South Africa is produced as a by-product of the coal gasification process.

5.1.1 Global warming potential (GWP)

The total global warming potential was 0.610 $CO_{2\,eq}$ with diaper production accounting for 0.559 kg $CO_{2\,eq}$. The major contributors were diaper manufacturing (DM) electricity (0.148 kg $CO_{2\,eq}$), the super absorbent material (0.112 kg $CO_{2\,eq}$) and the locally produced PP component A (0.0935 kg $CO_{2\,eq}$). The electricity contribution is not surprising as South Africa's electricity is mostly coal-based. Furthermore, locally, the precursor for PP, propylene, is produced from coal via the Fischer-Tropsch process. In addition, it is processed using coal-based electricity as an energy source. Transportation to distributors and the waste scenario make minor contributions of 4.0 % and 4.3 % respectively.

5.1.2 Stratospheric ozone depletion

Electricity consumption during diaper manufacturing was a top individual contributor with 34.8 %. This can be traced back to the use of coal as an energy source. Open burning of diapers contributed a relatively small amount in comparison to diaper production (8.7 %).

5.1.3 Ionizing radiation

Diaper production contributed 96.7 % to ionizing radiation with transportation making up the balance. DM electricity consumption was once again a top contributor accounting for 33.9 % whilst the contributed 26.4 %. The electricity contribution can be attributed to the presence of nuclear energy in the national energy mix.

5.1.4 Ozone formation, Human health

Again, DM electricity consumption was a top contributor to ozone formation, accounting for 27.7 %. This is due to the use of coal to generate electricity; the combustion of coal leads to the release of many pollutants including nitrogen oxides. The absorbent core of diapers contributed almost the same percentage (27.0 %) to ozone formation. This can be attributed to the use of heavy fuel oil and marine diesel oil to provide energy to freight ships for shipping.

5.1.5 Fine particular matter formation

Diaper production contributed 87.4 % to particulate matter formation. Local electricity produces particulate matter when the coal is combusted to generate steam for the electricity. Thus, it contributed 33.5 % to the total emissions. The absorbent core was a notable contributor as well accounting for 22.9 %. Open burning also releases particulate matter which accounted for 8.4 %.

5.1.6 Ozone formation, Terrestrial

The results for terrestrial ozone formation (0.000239 kg $NO_{x\,eq}$) were similar to those for ozone formation, Human health (0.00235 kg $NO_{x\,eq}$). So, unsurprisingly, the top contributors were the same: DM electricity (27.3 %) and absorbent core (27.0 %). Transport contributed 9.4 %.

5.1.7 Terrestrial acidification

Diaper production accounted for 95.9 % of terrestrial acidification impacts. Electricity contributed 41.7 %; this can be traced back to the use of coal for energy production. SAP and PP component A were also notable contributors with 12.9 % and 15.1 % respectively.

5.1.8 Freshwater eutrophication

Diaper end-of-life was a notable contributor to freshwater eutrophication, accounting for 33.1 % of impacts. This was due to leachate produced in open dumps and unsanitary landfills. The treatment of spoil from coal mining was also a contributor to emissions (49.6 %).

5.1.9 Marine eutrophication

Similar to freshwater eutrophication, diaper dumping and unsanitary landfills contributed to marine eutrophication (27.6 %). Treatment of coal spoil in the electricity production process was a major contributor with 54.3 %.

5.1.10 Terrestrial ecotoxicity

The waste scenario was a miniscule contributor to terrestrial ecotoxicity (1.74 kg 1,4-DCB) with 0.17 %. Diaper production and transport to distributors contributed 73.9 % and 25.9 % respectively. Emissions were from a variety of sources including SAP production, SAP and pulp transportation from the Durban Harbour to the factory, DM electricity consumption and locally made PP.

5.1.11 Freshwater ecotoxicity

Unsanitary landfilling of diaper waste accounted for the majority (92.0 %) of freshwater ecotoxicity impacts (0.234 kg ,4-DCB). Diaper production and transport accounted for 7.69 % and 0.29 % respectively.

5.1.12 Marine ecotoxicity

Once again, unsanitary landfilling contributed the most to marine ecotoxicity with 92.7 %. This may be attributed to the uncontrolled release of leachate that is formed in the landfill.

5.1.13 Human carcinogenic toxicity

Unsanitary landfilling of diapers was virtually the only contributor to human carcinogenic toxicity contributing 99.8 %. This may be attributed to the emission of carcinogenic gases from the landfill.

5.1.14 Human non-carcinogenic toxicity

Diaper production contributed 73.7 % to human non-carcinogenic toxicity whilst the waste scenario contributed 23.4 % to the total emissions. A variety of contributors arising from the diaper production stage, including DM electricity, PP components and SAP, were identified.

5.1.15 Land use

Pulp was the major contributor (97.1 %) to land use. This is to be expected as the production of pulp is dependent on the growing and harvesting of softwood trees.

5.1.16 Mineral resource scarcity

Diaper production was the only contributor to mineral resource scarcity. PP components manufactured in South Africa were significant contributors accounting for 55.6 %. The waste scenario was not a contributor. This can be attributed to the fact that the diaper disposal methods do not require any mineral resources to be executed.

5.1.17 Fossil resource scarcity

The total fossil resource scarcity emissions were 0.211 kg oil $_{eq}$. A variety of DM production materials and processes contributed to this impact category including plastic polymer production, DM electricity and SAP. Transport to distributors was a minor contributor.

5.1.18 Water consumption

As was to be expected, the top contributor was pulp (33.9 %) due to the water consumption during farming and pulp production. This was followed by SAP which contributed 18.9 %.

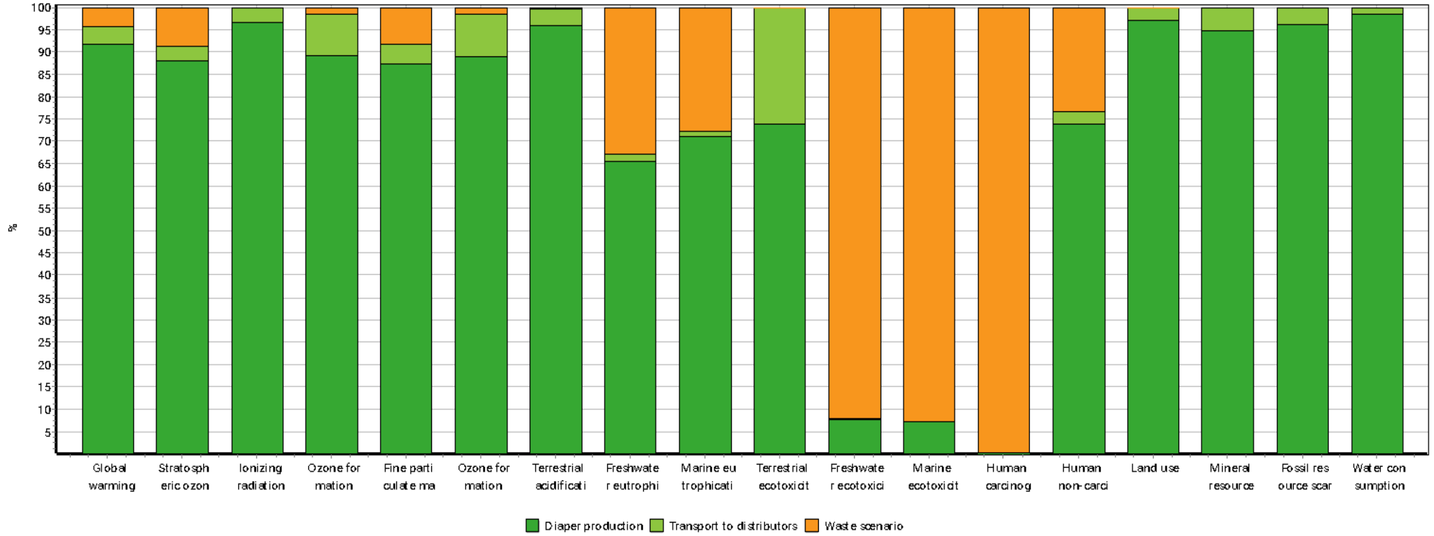

Figure 2: Relative contribution of life cycle stages to different impacts

5.2 Normalisation

The results of the normalisation can be seen in Table 4. From this, the most significant impact is human carcinogenic toxicity. Unsanitary landfilling of diapers was virtually the only contributor to human carcinogenic toxicity contributing 99.8 %. Thus, whilst the waste disposal was not a major contributor across all the impact categories, it has the largest impact when translated into real world terms. The waste scenario was also a major contributor to freshwater and marine ecotoxicity which also had relatively significant impacts upon exclusion of human carcinogenic toxicity. Once again, these were dominated by unsanitary landfilling of diapers accounting for 92.0 % and 92.7 % respectively. However, this does not mean that the other categories should be totally ignored, instead the normalisation highlights hotspots for improvement.

Table 4: LCIA normalisation results

Impact category	Total
Global warming	7,62E-05
Stratospheric ozone depletion	5,32E-06
Ionizing radiation	3,17E-05
Ozone formation, Human health	1,14E-04
Fine particulate matter formation	4,96E-05
Ozone formation, Terrestrial ecosystems	1,35E-04
Terrestrial acidification	8,26E-05
Freshwater eutrophication	8,48E-04
Marine eutrophication	6,67E-06
Terrestrial ecotoxicity	1,14E-04
Freshwater ecotoxicity	9,29E-03
Marine ecotoxicity	8,02E-03
Human carcinogenic toxicity	1,79E+00
Human non-carcinogenic toxicity	2,61E-05
Land use	1,49E-05
Mineral resource scarcity	1,24E-08
Fossil resource scarcity	2,23E-04
Water consumption	1,96E-05

6 Further Results

6.1 Pit latrine modelling choice

Pit latrines are essentially a pit that is dug for the purpose of human defecation. A shelter is often built around the hole which may include an air vent. Once the pit is almost full, the waste is buried and another pit is dug.

As mentioned in section 4.3.2, in the base case waste scenario disposal in pit latrines was modelled as a dummy treatment. The consequences of these choices are investigating by modelling pit latrines as open dumping and unsanitary landfill as waste scenarios 2 and 3 respectively.

As can be seen in Figure 3, no changes in impacts are observed for some of the impact categories including ozone formation, fine particulate matter formation and ionizing radiation. In the cases where changes were observed, waste scenario 3 had the highest increases in impacts. Waste scenario 3 was particularly significant for human toxicity and ecotoxicity. Thus, the modelling choice for pit latrines is significant when it comes to the waste scenario emissions.

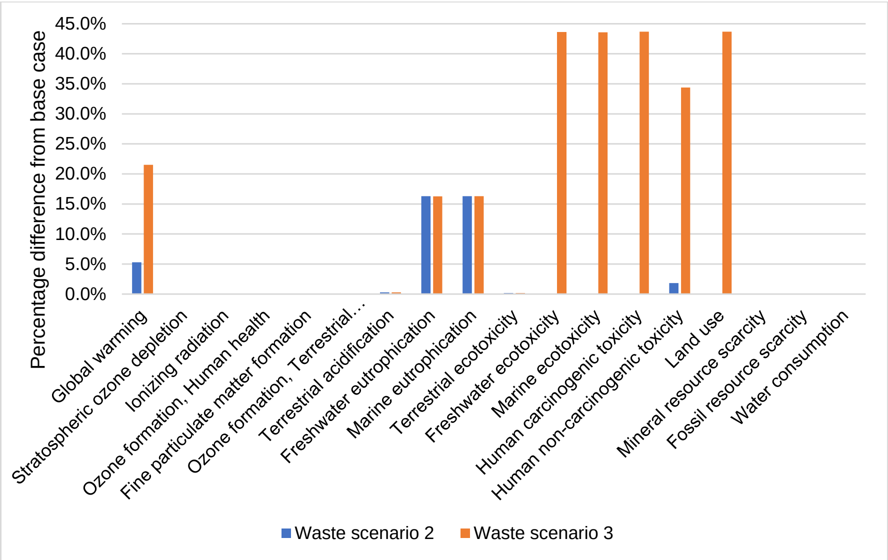

Figure 3: Comparing modelling choices for pit latrine

6.2 Improper diaper disposal

As mentioned in section 4.3.2, it was not possible to accurately portray the end-of-life impacts within LCA. In particular, the impacts of improper disposal of excreta in the environment was not addressed. In K2C, only 12.8 % of the respondents reported emptying the stool before diaper disposal, meaning the bulk of diapers are disposed with stool in them. This is a danger to the environment and human and animal health. Used diapers carry viruses and diseases and their proper disposal is essential to limit human exposure to these (13–15). Excreta has been associated with many diseases including cholera, typhoid and hepatitis.

Burning diapers releases a variety of pollutants including carcinogens such as dioxins and greenhouse gasses (14). It is a difficult process due to the wetness of the excreta. This may result in a residue that may be ingested by dogs or other animals such as goats and cows. Further, the ash created can leach pathogens into surface and groundwater sources as it rains (15).

Burying, whilst it puts the waste out of sight and less available to humans and animals, has the potential to contaminate ground water sources with pathogens (13,15). This is similar to unsanitary landfilling and open dumping where there is no leachate control, so it is free to absorb into the soil and potentially contaminate ground water. Furthermore, gases that permeate through the landfill and are released into the air may contain harmful pollutants.

Open dumping leaves diapers out in the open which may attract dogs and small children. This results in exposure to disease as described earlier and additionally risk of ingestion by animals. Another route for potential risk to health is the dumping of diapers next to rivers or onto dry riverbeds. This has the potential to directly contaminate the river water, when the river starts to flow again. This is a significant risk to community members which rely on the river as a water source. Dumping in rivers also has the potential to damage infrastructure such as bridges as reported by municipal officials. This was attributed to flash floods which occur when the waste dams a river and the water eventually breaks through.

A pit latrine has the potential to leach into underground water sources contaminating them. Further, the depositing of diapers in the pit latrine result in the pit filling up quickly requiring more to be dug.

7 Interpretation

Across the life-cycle, the production phase was the main~~majority~~ contributor to impacts with the exception of freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity, which were also the impacts with the highest relative importance. Aumónier, Collins and Garrett, (2008) also found the production of diapers to contribute the most to environmental impacts. During the production phase, manufacturing electricity was consistently a top contributor across the majority of impacts. This raised the contribution of the diaper manufacturing phase which is the opposite of what Mendoza *et al.* (2019) found in their study. The electricity impacts can be attributed to the South African energy source wherein the majority of energy is sourced from local coal deposits. Thus, it stands to reason that the standing of electricity as a top contributor is a situation unique to the South African context.

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The absorbent core was also found to be a top contributor to impacts. In the case of SAP, it's production could be traced as the primary contributor to impacts. This is similar to results obtained by Mendoza *et al.* (2019) which found pulp and SAP together contributed 44 - 88 % of impacts. The pulp also played a notable role in impacts associated with the ecosystem. Pulp was found to be the top contributor across the majority of impacts by Cordella *et al.* (2015) (from 29 % for global warming potential to 96 % for cumulative energy demand renewable) with, SAP being the second most significant. The contributions of SAP and pulp can be influenced by the ratios of the in the absorbent core. In this case, the pulp: SAP ratio is 1:0.92. Whereas Mendoza *et al.* (2019) reported a ratio of 1:4. Some studies have been conducted on the efficacy of changing the ratio of SAP: pulp in diapers finding that a reduction in materials leads to a reduction in environmental impacts (6,7).

The emergence of these processes highlights potential hotspots for improvement. In terms of electricity, the diaper manufacturing factory can look towards using renewable energy sources and reduce reliance on the national grid which is already strained (16).

Whilst there is a national push for the use of locally produced materials it is important to note the potential impacts associated with such a shift. This was demonstrated by the featuring of locally produced PP components e.g. flap material, as a notable contributor in many impact categories. This can be attributed to the fact that the precursor for PP is a by-product of coal processing via the Fischer-Tropsche process. Chitaka, Russo and von Blottnitz (2020) (17) found that polypropylene produced in South Africa had higher GWP than the production of the same material in the United States and Europe. Thus, the push for localisation comes with additional environmental burdens.

Diaper disposal was only dominant in three impact categories: freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. However, the importance of these categories was shown to be significant after normalisation. It is important to note that diapers can take up to 500 years to decompose, thus they are largely inert in landfills and dumps (18). Furthermore, the impact assessment methodology chosen only has a 100-year time frame.

Diaper disposal presents a greater scope of impacts than can be assessed by current LCA models and research is required to address this limitation. As discussed in section 6, improper diaper disposal presents a real threat to the health and safety of humans and animals. Thus, when developing interventions to reduce the environmental impacts of disposable diaper, emphasis should be placed on waste disposal. Cordella *et al.* (2015) recommend better disposal methods such as recycling to reduce end-of-life impacts however, developing countries have much further to go. Improvements need to be made to service delivery wherein the waste is actually collected before treatment options can be discussed.

8 Conclusions

Diaper production, from cradle-to-gate, accounted for the majority of impacts on average (> 65 %) except for freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. In these cases, the disposal of diapers was the higher contributor accounting for 92.0 – 99.8 %. Further, according to the normalisation, the most significant impacts from the disposable nappies are those contributing to human and ecological toxicity. Thus, it is important to address these impacts. In order to do this, there needs to be proper waste management of the diaper waste. Thus, interventions to address the impacts of diapers should be focused on the proper management of used diapers. For example, improvement in waste management service delivery to the villages and improved landfill conditions before more high-tech solutions can be considered.

Local electricity used in the manufacture of diapers is a top contributor to the majority of impact categories including global warming potential (24.3 %), stratospheric ozone depletion (34.8 %), fine particulate matter formation (33.5 %) and terrestrial acidification (41.7 %). This indicates the need for increased energy efficiency and a shift towards renewable sources of energy.

The absorbent core is also another area that can be earmarked for improvement. This may be in the form of material reduction or substitution of materials; the potential impact reduction results which have been demonstrated by previous studies (6,7).

In the rural areas, the impacts of disposable diapers extend beyond what can be captured by LCA. Thus, there needs to be further research as to how these impacts can be integrated in LCIA methodology. Further, it is important to consider the wider consequences of the use and disposal of diapers in different geographical contexts.

Declarations

Ethical approval was received from [anonymised], reference number [anonymised].

References

1. Berrian AM, van Rooyen J, Martínez-López B, Knobel D, Simpson GJG, Wilkes MS, et al. One Health profile of a community at the wildlife-domestic animal interface, Mpumalanga, South Africa. Prev Vet Med [Internet]. 2016;130:119–28. Available from: http://dx.doi.org/10.1016/j.prevetmed.2016.06.007
2. Govender R, Whyte C, Govender T. Detailed Feasibility Study and Business Case/s for the Establishment of Refuse Derived Fuel Plants to Address Absorbent Hygiene Products and other Residual Materials. Cape Town, South Africa: Department of Environment, Forestry and Fisheries; 2021.

3. Aumónier S, Collins M, Garrett P. Using science to create a better place: An updated lifecycle assessment study for disposable and reusable nappies. Bristol: Environmental Agency; 2008. 33 p.
4. Ng FSF, Muthu SS, Li Y, Hui PCL. A critical review on life cycle assessment studies of diapers. Crit Rev Environ Sci Technol. 2013;43(16):1795–822.
5. Notten P, Gower A, Lewis Y. Single-use nappies and their alternatives. Recommendations from from Life Cycle Assessments. United Nations Environ Program. 2021;1–45.
6. Cordella M, Bauer I, Lehmann A, Schulz M, Wolf O. Evolution of disposable baby diapers in Europe: Life cycle assessment of environmental impacts and identification of key areas of improvement. J Clean Prod [Internet]. 2015;95:322–31. Available from: http://dx.doi.org/10.1016/j.jclepro.2015.02.040
7. Mendoza JMF, Popa SA, D'Aponte F, Gualtieri D, Azapagic A. Improving resource efficiency and environmental impacts through novel design and manufacturing of disposable baby diapers. J Clean Prod [Internet]. 2019;210:916–28. Available from: https://doi.org/10.1016/j.jclepro.2018.11.046
8. Mirabella N, Castellani V, Sala S. Life cycle assessment of bio-based products: A disposable diaper case study. Int J Life Cycle Assess. 2013;18(5):1036–47.
9. Hoffmann BS, de Simone Morais J, Teodoro PF. Life cycle assessment of innovative circular business models for modern cloth diapers. J Clean Prod [Internet]. 2020;249:119364. Available from: https://doi.org/10.1016/j.jclepro.2019.119364
10. K2C. Kruger to Canyons. Kruger to Canyons Biosphere Region.
11. Brien KO, Olive R, Hsu Y chieh, Morris L, Bell R. Life cycle assessment: Reusable and disposable nappies in Australia. ALCAS--Australian Life Cycle Assess Soc. 2009;1–14.
12. Doka G. A model for waste-specific and climate-specific life cycle inventories of open dumps and unsanitary landfilling of waste. Zürich, Switzerland: Doka Life Cycle Assessments; 2016.
13. Kordecki H, Antrobus-Wuth R, Uys MT, van Wyk I, Root ED, Berrian AM. Disposable diaper waste accumulation at the human-livestock-wildlife interface: A one health approach. Environ Challenges [Internet]. 2022;8(June):100589. Available from: https://doi.org/10.1016/j.envc.2022.100589
14. Meseldzija J, Poznanovic D, Frank R. Assessment of the differing environmental impacts between reusable and disposable diapers. Dufferin Res. 2013;(November).
15. Ntekpe ME, Mbong EO, Edem EN, Hussain S. Disposable diapers: Impact of disposal methods on public health and the environment. Am J Med Public Heal. 2020;1(2):1–7.
16. Trenner R. CNN. 2023 [cited 2023 Feb 5]. p. 1–10 Dead chickens and decomposing bodies: Inside South Africa's power blackout 'pandemic.' Available from:

https://edition.cnn.com/2023/01/31/africa/south-africa-power-blackouts-intl-cmd/index.html

17. Chitaka TY, Russo V, von Blottnitz H. In pursuit of environmentally friendly straws : a comparative life cycle assessment of five straw material options in South Africa. Int J Life Cycle Assess. 2020;

18. Płotka-Wasylka J, Makoś-Chełstowska P, Kurowska-Susdorf A, Treviño MJS, Guzmán SZ, Mostafa H, et al. End-of-life management of single-use baby diapers: Analysis of technical, health and environment aspects. Sci Total Environ. 2022;836(April).