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

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The environmental impacts of disposable diapers in comparison to reusable diapers have 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 of 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 landfills (26.1%) or burned (18.6%). The production phase contributed the most to the majority of impact categories, excluding freshwater exotoxicity, marine exotoxicity 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 of diapers 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 LCA conducted on diapers in the rural context of Africa.
- The majority of impacts were attributed to the production of disposable diapers.
- The majority of disposable diapers were dumped or sent to unsanitary landfills.
- However, LCA cannot take into consideration improper disposal, giving an incomplete picture of the environmental impacts.

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.[1], in the Mpumalanga Province of South Africa, 80% of respondents reported using disposable diapers. A further study in 2021 estimated that 67 000 to 160 000 tonnes 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 have been a matter of interest in the life cycle assessment (LCA) community for a number of years. The LCA is often conducted from a comparative perspective, that is, reusable versus 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 the development of new materials, studies have been conducted to evaluate their potential impacts.[6-8] Mirabella et al.[8] investigated the environmental impacts of substituting petrochemical-based plastics with bio-based alternatives, finding that while they provide some benefits, it is important to pay attention to their agricultural phase. Mendoza et al.[7] 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 conducted in Brazil[9]. Thus, improper disposal methods have rarely been considered, with landfilling and incineration being the most common methods of waste treatment modelled. 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 the geographical context was identified as one of the critical factors influencing the environmental impacts of diapers.[5] This article is structured according to the generic steps of an LCA:

- Goal and scope definition
- Life cycle inventory
- Life cycle impact assessment (LCIA)
- Interpretation

Data sources and modelling approach

The diaper modelled was based on primary and secondary information. Specifically, the foreground data were informed by primary data provided by a major local diaper manufacturer. The data were provided for the year 2021. This was supplemented by secondary data sourced from the literature. Background data were based on the Ecoinvent v3.9 cut-off system model database. The section on ‘Life cycle inventory’ 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 were based on a series of questionnaires conducted in the Kruger 2 Canyon (K2C) Biosphere Region in South Africa in 2022. The 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 such as diapers, a pressing environmental and health issue. The area presents an ideal context in which to study the environmental impacts of disposable diapers, as most existing 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 diapers, 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. In total, 1575 questionnaires were completed across eight villages in the area.

Goal and scope

The goal of this study was to evaluate the potential environmental impacts of disposable diaper usage in rural areas. It places a particular focus on the end-of-life aspects not yet investigated in previous research.

Functional unit and reference flow

Previous studies have used a number of functional units. For example, several 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.[7] According to the distributed questionnaires, the average number of diapers used per day was 4.47. This figure is similar to those in studies by Hoffmann et al.[9] and Aumónier et al.[3] in which they estimated 5 and 4.16 diapers per day, respectively. Thus, for this study, the figure used for the number of diapers used per day was 4.47.

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

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 composed 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 into contact with the wearer, 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.

Diaper components

There were limited data regarding the production of diaper components. The manufacturer provided information on the types of components, their weights and their primary materials. They also provided the country of origin, as some of the components are imported. However, no information was provided on the manufacturer in the exporting country or the processes employed. Therefore, the modelling of these components was based on data sets 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 that done by Cordella et al.[6] and Mendoza et al.[7]

Diaper manufacture

Data regarding diaper manufacture were provided by a major diaper manufacturer in South Africa. These data included weights of diaper components used, electricity consumption as well as waste generation and disposal.

Use phase

The use phase was not modelled due to the wide variety of transport distances and methods utilised by consumers to reach retailers. The questionnaires indicated that there was a wide variety of retailers available to respondents, which were located at varying distances.

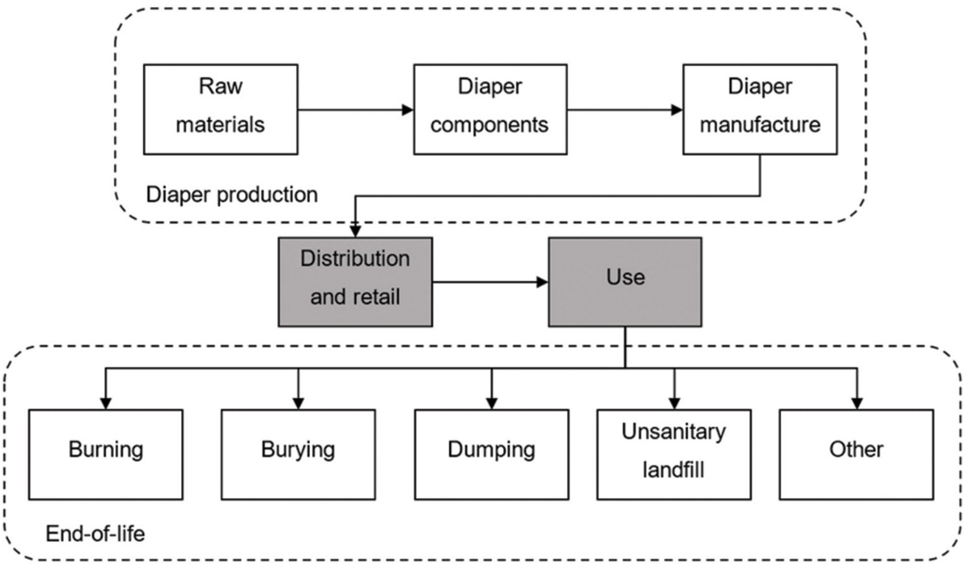

Figure 1: Diaper life-cycle stages.

Table 1: Primary raw materials used in diaper manufacturing and their contribution to diaper weight

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

Source: South African manufacturer

Furthermore, different transport methods were used to reach the retailer, including public transport, private transport or walking.

Transport

Transportation of the imported diaper components was included in the model. The diaper components are 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 1880 km was used for transport to distributors and retailers in the town of Hoedspruit, within the K2C Biosphere. This distance represented the distance from the factory to the Hoedspruit area and was obtained using Google Maps. Further details could not be modelled, however, as the diapers could have passed through several hands before they were retailed to consumers, for example, distributors to wholesalers to spaza shops.

End of life

Waste resulting from the diaper production process accounted for only 3% of materials, as reported by the diaper manufacturer. This figure is higher than that in the study by Mendoza et al.[7] 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 diapers. They did not necessarily adhere to one method and might have used 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 a temporary waste retainer until they could dump the waste. Dumping took place in 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 involved 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[12]: open burning, open dumps and unsanitary landfills. The underlying data were 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' were modelled using a dummy waste treatment; thus, the impacts are not reflected in the life cycle impact assessment (LCIA). The impacts of this modelling choice are explored in the section on 'Pit latrine modelling choice'.

The impacts of the disposal of urine and faeces were not modelled. Instead, the potential impacts are discussed under 'Improper diaper disposal'. This includes impacts that cannot be accounted for in LCAs, such as ingestion by animals and dumping in rivers.

Table 2: Waste scenario

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

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 to assess 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.

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 (Figure 2). The impacts were then normalised, using default ReCiPe values, to enable the determination of the relative significance of the different impact categories.

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 highest 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 impact categories was a locally made polypropylene (PP)-based component. Similar to the electricity mix, PP is fossil fuel based in South Africa; propylene in South Africa is produced as a by-product of the coal gasification process.

Global warming potential

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. In addition, locally, the precursor for PP, propylene, is produced from coal via the Fischer–Tropsch process and 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.

Stratospheric ozone depletion

Electricity consumption during diaper manufacturing was a top individual contributor to stratospheric ozone depletion at 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%).

Ionising radiation

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

Table 3: Life cycle impact assessment 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
Ionising radiation	kBq Co-60 eq	1.52E-02	1.47E-02	5.07E-04	0.00E+00
Ozone formation, human health	kg NO*x* 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 NO*x* 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

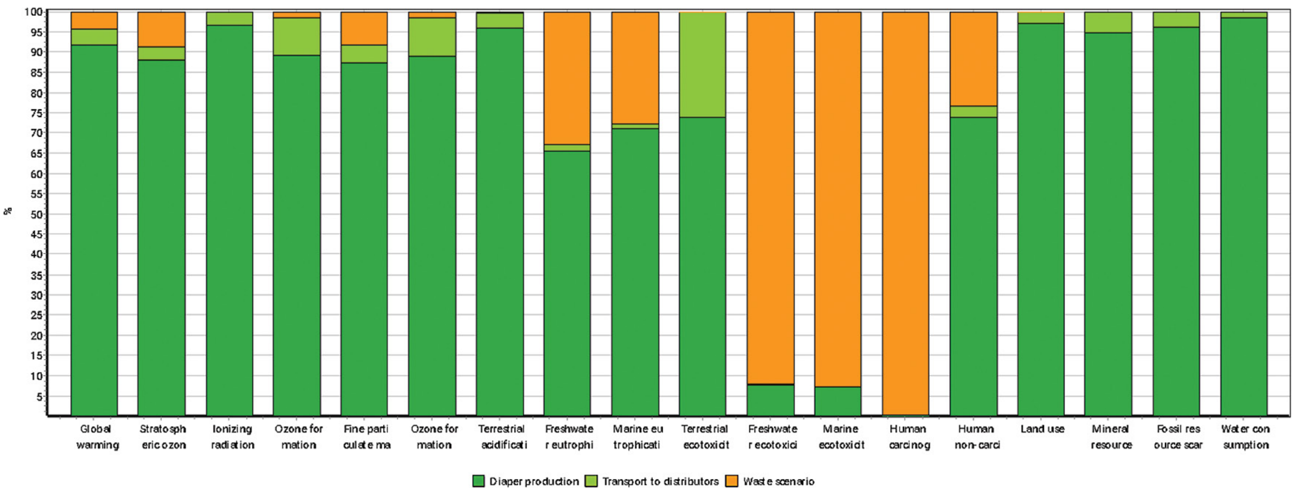

Figure 2: Relative contribution of life-cycle stages to different impacts.

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.

Fine particulate matter formation

Diaper production contributed 87.4% to particulate matter formation. Local electricity produces particulate matter when the coal is combusted to produce steam for the generation of 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%.

Ozone formation, terrestrial

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

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. Sodium polyacrylate (SAP) and PP component A were also notable contributors at 12.9% and 15.1%, respectively.

Freshwater eutrophication

Diaper end of life was a notable contributor to freshwater eutrophication, accounting for 33.1% of the impact. 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%).

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 at 54.3%.

Terrestrial ecotoxicity

The waste scenario was a minuscule contributor to terrestrial ecotoxicity (1.74 kg 1,4-DCB) at 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.

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.

Marine ecotoxicity

Once again, unsanitary landfilling was the major contributor to marine ecotoxicity at 92.7%. This may be attributed to the uncontrolled release of leachate that is formed in the landfill.

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 in the form of volatile and semi-volatile organic compounds which are characteristic of landfill gases.[13]

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.

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.

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.

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.

Water consumption

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

Table 4: Life cycle impact assessment normalisation results

Impact category	Total
Global warming	7.62E-05
Stratospheric ozone depletion	5.32E-06
Ionising 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

Normalisation

Normalisation calculates the magnitude of an impact relative to a reference value. In this case, global reference values were used. 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 waste disposal was not a major contributor across all the impact categories, it had the largest impact when translated into real-world terms. The waste scenario was also a major contributor to freshwater and marine exotoxicity, which also had relatively significant impacts upon the 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 completely ignored; instead, the normalisation highlights hot spots for improvement.

Further results

Pit latrine modelling choice

Pit latrines are essentially pits that are 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 covered with soil and another pit is dug.

As mentioned in ‘End of life’, in the base case, waste scenario disposal in pit latrines was modelled as a dummy treatment. The consequences of these choices were investigated by modelling pit latrines as open dumping and unsanitary landfill and thus 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 ionising radiation. In the cases in which changes

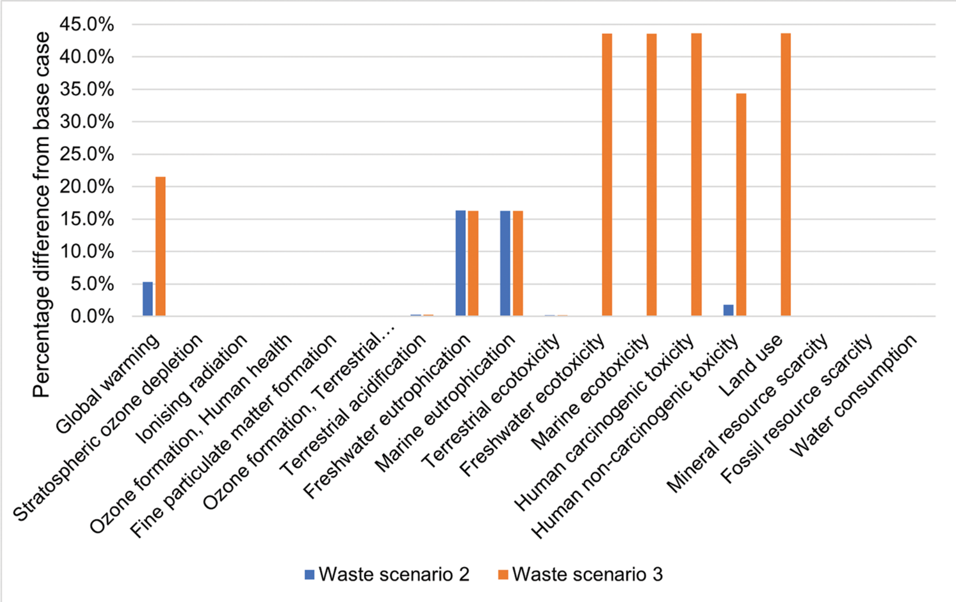

Figure 3: Comparing modelling choices for pit latrines.

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 waste scenario emissions.

Improper diaper disposal

As mentioned in ‘End of life’, it was not possible to accurately portray the end-of-life impacts within the LCA. In particular, the impacts of improper disposal of excreta in the environment were not addressed. In K2C, only 12.8% of the respondents reported emptying the stool before diaper disposal, meaning the bulk of diapers were disposed of with stool in them. This is a danger to the environment as well as to human and animal health. Used diapers carry viruses and diseases, and their proper disposal is essential to limit human exposure to these.[14-16] 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 gases.[15] 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. Furthermore, the ash created can leach pathogens into surface and groundwater sources when it rains.[16]

Burying, whilst it puts the waste out of sight and less available to humans and animals, has the potential to contaminate groundwater sources with pathogens.[14,16] 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 groundwater. 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 diseases as described earlier and, additionally, creates the 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 who 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 damage was attributed to flash floods that occur when the waste dam blocks a river and the water eventually breaks through.

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

Interpretation

Across the life cycle of diapers, the production phase was the main contributor to impacts, except for freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity, which were also the impacts with the highest relative importance. Aumónier et al.[3] 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.[7] found in their study. The electricity impacts can be attributed to the fact that South Africa’s generation of energy is predominantly based on local coal deposits. Consequently, electricity being 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, its production could be traced as the primary contributor to impacts. This is similar to the results obtained by Mendoza et al.[7], who found pulp and SAP together contributed 44% to 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.[6] (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 absorbent core. In this case, the pulp:SAP ratio is 1:0.92, whereas Mendoza et al.[7] 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 hot spots for improvement. In terms of electricity, the diaper manufacturing factory can look towards using renewable energy sources and, thus, reducing reliance on the national grid, which is already strained.[17]

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 features of locally produced PP components, for example, 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–Tropsch process. Chitaka et al.[18] found that PP produced in South Africa had higher global warming potential than the production of the same material in the USA and Europe. Thus, the push for localisation comes with additional environmental burdens.

Diaper disposal was dominant in only 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.[19] Furthermore, the impact assessment methodology chosen has only 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 under 'Further results', 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 diapers, emphasis should be placed on waste disposal. Cordella et al.[6] 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 in service delivery, where the waste is actually collected before treatment options can be discussed.

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 three cases, the disposal of diapers was the highest contributor, accounting for 92.0% to 99.8%. Based on the normalisation, the most significant impacts from disposable diapers 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 diaper waste. Therefore, 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 another area that can be earmarked for improvement. This may be in the form of material reduction or substitution of materials, which may lead to the potential impact reduction results that have been demonstrated by previous studies.[6,7]

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

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Data availability

The data supporting the results of this study are confidential and are not available in any format.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Ethical approval was received from the Humanities and Social Science Research Ethics Committee of the University of the Western Cape (HSSREC Reference Number: HS22/1/2).

Authors' contributions

T.Y.C.: Conceptualisation, methodology, data collection, data analysis, writing – original draft, writing – revisions. C.N.: Conceptualisation, data collection, project management, writing – revisions. C.S.: Conceptualisation, funding acquisition, supervision, writing – revisions, project leadership. All authors read and approved the final manuscript.

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. 2016;130:119–128. https://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: 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. p. 33

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):1795–1822. https://doi.org/10.1080/10643389.2012.671746

5. Notten P, Gower A, Lewis Y. Single-use nappies and their alternatives: Recommendations from life cycle assessments. Nairobi: United Nations Environment Programme; 2021. p. 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. 2015;95:322–331. https://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. 2019;210:916–928. 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):1036–1047. https://doi.org/10.1007/s11367-013-0556-6

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

10. Kruger to Canyons. Kruger to Canyons Biosphere Region [homepage on the Internet]. No date [cited 2024 Dec 24]. Available from: https://kruger2canyons.org

11. O'Brien KR, Olive R, Hus Y-C, Bell R, Morris L, Kendall N. Life cycle assessment: Reusable and disposable nappies in Australia. 6th Australian Conference on Life Cycle Assessment, 2009 February 17–19 February; Melbourne, Australia. Melbourne: Australian Life Cycle Assessment Society; 2009. p. 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: Doka Life Cycle Assessments; 2016.

13. Pan Q, Liu QY, Zheng J, Li YH, Xiang S, Sun XJ, et al. Volatile and semi-volatile organic compounds in landfill gas: Composition characteristics and health risks. Environ Int. 2023;174: Art. #107886. https://doi.org/10.1016/j.envint.2023.107886

14. 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. 2022;8, Art. #100589. https://doi.org/10.1016/j.envc.2022.100589

15. Meseldzija J, Poznanovic D, Frank R. Assessment of the differing environmental impacts between reusable and disposable diapers [document on the Internet]. c2013 [cited 2023 Feb 05]. Available from: https://www.dufferinresearch.com/images/sampledata/documents/Environmental%20Impact%20Report%20-%20Cloth%20vs%20Disposible.pdf

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

17. Trenner R. Dead chickens and decomposing bodies: Inside South Africa's power blackout 'pandemic.' CNN. 2023 January 31 [cited 2023 Feb 05]. Available from: https://edition.cnn.com/2023/01/31/africa/south-africa-power-blackouts-intl-cmd/index.html

18. 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;25(9):1818–1832. https://doi.org/10.1007/s11367-020-01786-w

19. 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, Art. #155339. https://doi.org/10.1016/j.scitotenv.2022.155339