Life Cycle Assessment of Disposable and Reusable Nappies in the UK 2023

Defra project reference: EV0493

Administrative information	
Name:	Life Cycle Assessment (LCA) of Disposable and Reusable Nappies in the UK.
Research Project Reference:	EV0493
Published by:	Defra - Department for Environment, Food and Rural Affairs
Version:	Final
Status:	Complete
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Critical Review	University College London (UCL), AHPMA, Nappy Alliance
Date of last revision:	February 2023
Standard conformance (primary):	Aligned to ISO14040 and ISO 14044:2006
Language:	Developed and available in English. In case of translated versions, the English version takes precedence in case of any discrepancies.

Keywords:
Life Cycle Assessment (LCA), Disposable nappies, Reusable nappies.

Research Consultants: Giraffe Innovation Limited

Giraffe was founded in 1998 and is an award-winning environmental and technical consultancy. Giraffe was described by The Guardian newspaper business pages as 'one of the UK's top green businesses' due to its extensive experience in delivering a wide range of sustainability driven projects to UK and global organisations.

Commissioning Organisation: Defra – Department for Environment, Food and Rural Affairs

Defra is the United Kingdom (UK) Government Department responsible for the environment, food and rural affairs. The Authority's priorities are to secure a healthy natural environment; a sustainable, low-carbon economy; a thriving farming sector and a sustainable, healthy and secure food supply.

Acknowledgements:

Absorbent Hygiene Product Manufacturers Association (AHPMA)
European Disposables and Nonwovens Association (EDANA)
The Nappy Alliance

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Abbreviation

AHPMA	Absorbent Hygiene Product Manufacturers Association
EDANA	Global association of the nonwovens and related industries
FECP	Freshwater ecotoxicity potential
FEP	Freshwater eutrophication potential
FPMFP	Fine particulate matter formation potential
FRSP	Fossil resource scarcity potential
GWP	Global warming potential also knows as the carbon footprint
HCTP	Human carcinogenic toxicity potential
HNCTP	Human non-carcinogenic toxicity potential
IRP	Ionizing radiation potential
LDPE	Low density polyethylene
LLDPE	Linear low-density polyethylene
LUP	Land use potential
MECP	Marine ecotoxicity potential
MEP	Marine eutrophication potential
MRSP	Mineral resource scarcity potential
NA	Nappy Alliance
OFP HH	Ozone formation potential, Human health
OFP TE	Ozone formation potential, Terrestrial ecosystems
PE	Polyethylene
PP	Polypropylene
PU	Polyurethane
SAP	Super absorbent polymer
SODP	Stratospheric ozone depletion potential
TAP	Terrestrial acidification potential
TEP	Terrestrial ecotoxicity potential
WCP	Water consumption potential
WHO	World Health Organisation

1 Executive summary

Nappies play a key role in a child's health and well-being, as well as ensuring convenient hygiene for the whole family. They are considered a necessity for a child in their early years[1] particularly the first 2.5 years of life. After this period, children are generally less dependent due to potty training, with nappies being used mostly at night-time or not at all.

The environmental impacts and economic costs of nappies is an increasingly important factor amongst policy makers, industry and wider society. Published environmental analysis for nappies using Life Cycle Assessment (LCA) methodology is old, dating from 2005[2] and revised in 2008[3]. Since then, there have been advances in the design and materials used in both disposable and reusable nappies, in the efficiency of washing machines and tumble dryers, the grid energy mix at a national level[4] as well as changes to the way the materials are dealt with at end of life.

The previous complete LCA study[5] on disposable and reusable (cloth) nappies showed there is "*little or no difference between the environmental impact of reusable and disposable nappies"*. This updated LCA study now shows there are differences in environmental impact between nappy formats. Furthermore, the disposable nappy results show a ~27% reduction in the carbon footprint (CO_2eq) since the previous report. The reusable nappy carbon footprint shows a ~38.5% reduction compared to a 'flat cloth' (Terrys) modelled in the previous study. However, the study is based on aggregated data sets so comparisons are indicative of a range of products and direct comparisons can't be made on a product-by-product basis. As the previous studies in 2005 and 2008 used different life cycle indicators, LCA system and modelling methodology, direct comparisons with the previous reports should be done with caution.

This report provides the results from an environmental analysis across 18 environmental impact categories (Table 3) using Life Cycle Assessment (LCA) methodology. The goal of this study is to determine the cumulative environmental impact of the use of a disposable and a reusable nappy system for the first 2.5 years of a child's life.

Consumer research[6] has indicated that since the last LCA study, a percentage of children are being potty trained at a later stage in their development. A sensitivity analysis was therefore undertaken to highlight the potential environmental impact of various factors which would impact the overall results:

- Extended use of nappies (delay in potty training).
- Reduced use of nappies (counterfactual – accelerated potty training).
- Energy recovery at end of life.
- Washing and drying of nappies.
- Reuse of nappies for a second child.
- Flushing of faeces off the disposable nappies.
- Retailer and consumer transport.

The results of this study are predicated upon aggregated data sets (2020-2021) for disposable and reusable nappies. Both data sets are based upon data supplied from members of the Absorbent Hygiene Product Manufacturers Association (AHPMA) and the Nappy Alliance. The reusable nappy data set comprises of an average material composition of 8 different reusable nappy systems from 13 different washable / reusable nappies and nappy components. The materials used in each aggregated data set is given below (Table 1 and Table 2).

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[1] Absorbent Hygiene Product Manufacturers Association (AHPMA)
[2] Life Cycle Assessment of Disposable and Reusable Nappies in the UK, ISBN: 1-84-432427-3
[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291130/scho0808boir-e-e.pdf
[4] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting (0.47853kgCO_2e to 0.23314kgCO_2e per kWh[4])
[5] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291130/scho0808boir-e-e.pdf
[6] You Gov – Children Potty Training (unpublished). UK18 sample@ 30th March to 7th April 2021. Commissioned by Bambino Mio. n= 728

Input per nappy	Unit	Amount	%
Fluff pulp	g	8.34	25.66%
Super absorbent polymer (SAP)	g	13.22	39.09%
PP	g	7.49	22.15%
PE	g	1.16	3.43%
LDPE	g	0.39	1.14%
PET	g	0.069	0.20%
Polyester	g	0.26	0.78%
Elastic	g	1.13	3.34%
Glue/Adhesives	g	1.18	3.49%
Calcium carbonate	g	0.19	0.55%
Tape	g	0.37	1.08%
Lotion	g	6.95E-03[7]	0.02%
Other	g	0.02	0.05%
Total weight	**g**	**33.816**	**100%**

Table 1: Material composition of disposable nappies

Input per nappy	Amount (g)	%
Bamboo (viscose)	1089.50	33.40%
Microfibre (polyester)	1301.31	39.90%
Polyurethane	166.83	5.12%
Velcro strip	168.00	5.15%
Elastic	52.00	1.59%
Poppers	51.55	1.58%
Nylon	0.12	<0.01%
Cotton	395.00	12.11%
Polyester	12.25	0.38%
Polypropylene	25.00	0.77%
Packaging		
Carton box for packaging	496.92	
Jute for packaging	18.50	

Table 2: Material composition of reusable nappy system

The results are therefore based upon the following nappy formats:

- **Disposable nappies** - single use nappies with super absorbent polymer (SAP) and cellulose fluff to retain the urine. They are available in a range of sizes from new-born upwards.
- **Reusable nappies (home laundered)** - available in three different designs:
    - 'Pocket nappy' - consist of a waterproof outer and a fleece inner. An opening along the back of the nappy allows an absorbent pad to be inserted and to change soiled pads.
    - 'All-in-one nappy' - incorporates an absorbent inner with an attached waterproof outer layer.
    - 'All in two nappy' - incorporates an inner absorbent pad that attaches to the outer wrap with poppers to form a one-piece nappy. The pads can be removed for washing and reuse.

At the time of the previous LCA study there were no reusable nappy products that were directly comparable to the current products available on the market. The analysis for the reusable nappies is therefore aggregated from material inventories from 13 different reusable nappy formats with their child weight (kg) and age range (months) and the 8 different reusable nappy system combinations that make up each 'nappy system'.

[7] All results have been rounded to 2 decimal places. When the results are less than 0.01 scientific notation has been used as a way of expressing numbers that are too large or too small to conveniently represent in decimal form. For example, Lotion is 6.93E-03g which in decimal (standard) notation is 0.00693g.

For each nappy studied, all key inputs were considered including materials, production, transportation, use (number of changes and flushing of faeces, washing), and end of life treatment. Life cycle impact assessment (LCIA) is a step for evaluating the potential environmental impacts by converting the LCI results into specific impact indicators. The impact categories modelled in this study along with their indicator characterisation factors and units are given below (Table 3). These environmental impacts (Table 3) are given equal significance in this study.

Midpoint impact	Category	Indicator	Unit
Climate change	Infrared radiative forcing increase	Global warming potential (GWP)	kg CO_2-eq to air IPCC 2013
Ozone depletion	Stratospheric ozone decrease	Ozone depletion potential (ODP)	kg CFC-11-eq to air
Ionising radiation	Absorbed dose increase	Ionising radiation potential (IRP)	kBq Co-60-eq to air
Fine particulate matter formation	PM2.5 population intake increase	Particulate matter formation potential (PMFP)	kg PM2.5-eq to air
Photochemical oxidant formation: terrestrial ecosystems	Tropospheric ozone increase	Ozone formation potential: ecosystems (EOFP)	kg NOx-eq to air
Photochemical oxidant formation: human health	Tropospheric ozone population intake increase	Ozone formation potential: humans (HOFP)	kg NOx-eq to air
Terrestrial acidification	Proton increase in natural soils	Terrestrial acidification potential (TAP)	kg SO_2-eq to air
Freshwater eutrophication	Phosphorus increase in freshwater	Freshwater eutrophication potential (FEP)	kg P-eq to freshwater
Marine eutrophication	Nitrogen increase in Marine water	Marine eutrophication potential (MEP)	kg N-eq to marine water
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	Terrestrial ecotoxicity potential (TETP)	kg 1,4-DCB-eq to industrial soil
Freshwater ecotoxicity	Hazard-weighted increase in freshwaters	Freshwater ecotoxicity potential (FETP)	kg 1,4-DCB-eq to freshwater
Marine ecotoxicity	Hazard-weighted increase in marine water	Marine ecotoxicity potential (METP)	kg 1,4-DCB-eq to marine water
Human toxicity: cancer	Risk increase of cancer disease incidence	Human toxicity potential (HTPc)	kg 1,4-DCB-eq to urban air
Human toxicity: non-cancer	Risk increase of non-cancer disease incidence	Human toxicity potential (HTPnc)	kg 1,4-DCB-eq to urban air
Land use	Occupation and time-integrated land transformation	Agricultural land occupation potential (LOP)	m2 × yr. annual cropland-eq
Mineral resource scarcity	Increase of ore extracted	Surplus ore potential (SOP)	kg Cu-eq
Fossil resource scarcity	Upper heating value	Fossil fuel potential (FFP)	kg oil-eq
Water use	Increase of water consumed	Water consumption potential (WCP)	m^3 water-eq consumed

Table 3: ReCiPe Midpoint method and impact categories

More details about these environmental factors can be found in Appendix G.

1.1 Summary Results

Detailed below are the summary results of the disposable and reusable nappies.

1.1.1 Disposable nappy

As an example of the impacts, the Global warming potential (GWP) (carbon footprint) for disposable nappies for the first 2.5 years of a child's life is 456.91kgCO_2eq which is broken down across its life cycle (Figure 1).

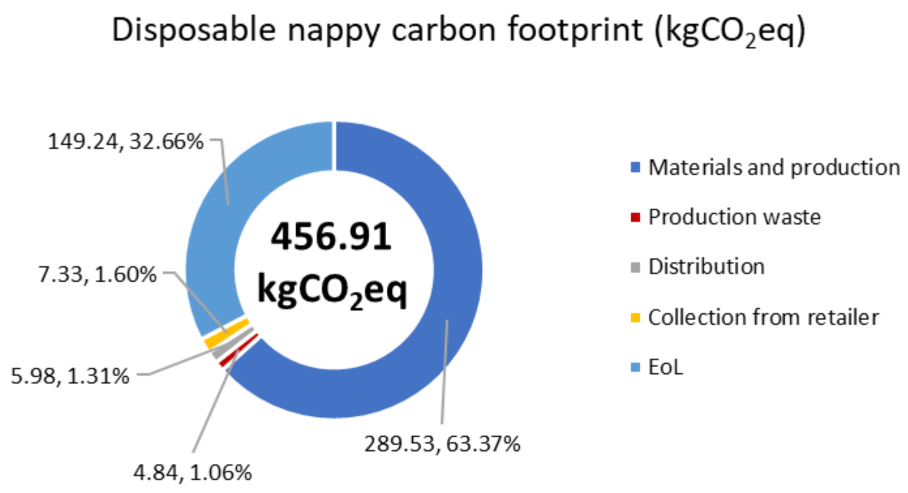

Figure 1: Disposable nappy environmental impact ($KgCO_2eq$)

The largest environmental impact (CO_2eq) is due to the materials and production (~63%) followed by the end of life (EOL) treatment of the nappies, faeces and urine (~33%). Previous research[8] which gives a reliable breakdown of the environmental impact across the lifecycle of disposable nappies shows an overall reduction from 626$kgCO_2eq$ to 456.91$kgCO_2eq$ (~27%) (Table 4).

Product life stage	Current disposable nappy $KgCO_2eq$	2005 disposable nappy $KgCO_2eq$
Nappy production and distribution	294.76	465.00
Packaging and retail	5.58	27.00
Consumer transport home	7.33	40.00
End of life	149.24	94.00
Total	**456.91 $KgCO_2eq$**	**626.00 $KgCO_2eq$**

Table 4: Comparison of the carbon footprint of disposable nappies (2021) against 2005 LCA study

Despite the production of energy from incineration (energy from waste – EfW) the carbon footprint of the end-of-life stage for disposable nappies has increased by over 55$kgCO_2eq$, accounting for ~32.6% of the total disposable nappy life cycle impact. This is due to changes in the end-of-life treatment compared to the previous study. Previously the majority of the nappies were landfilled and now they are incinerated releasing CO_2. In landfill the degradation of the polymers and pulp would be significantly slower and fall outside of the 100-year time horizon used for GWP. This merits further investigation into the potential benefits of nascent technologies and infrastructure for disposable nappy recycling.

1.1.2 Reusable nappy system

As an example of the impacts, the Global warming potential (GWP) (carbon footprint) for the reusable nappies for the 2.5 years of use is 344.57$kgCO_2eq$ which is broken down across its life cycle (Figure 2). This shows the relative impacts of the key stages from raw materials, manufacturing, use (washing and drying) and end of life (EOL) disposal.

[8] Life Cycle Assessment of Disposable and Reusable Nappies in the UK, ISBN: 1-84-432427-3

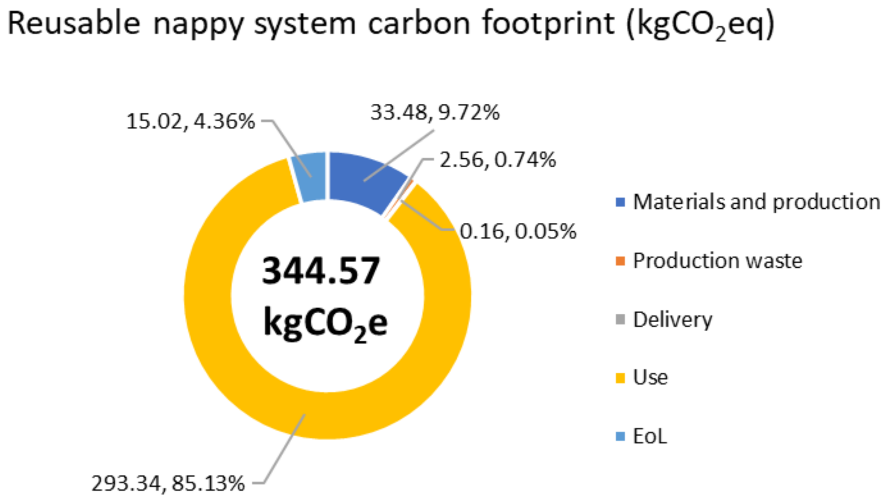

Figure 2: Reusable nappy system - environmental impact (KgCO2eq)

The use phase (energy use in washing and detergent impact) is by far the largest contributory factor to the carbon footprint (~85%). Since the previous LCA study there has been considerable reductions in the material impact of reusable nappies due to the design and configuration of nappy components. For example, a home laundered 'pre folded cotton nappy' indicative to that modelled in the previous LCA study had an overall carbon footprint of 559KgCO2eq compared to 344.57kgCO2eq in this study (~38.4% reduction). The materials and liner impact and production were 93kgCO2eq[9] compared to the current reusable nappy average of 33.65kgCO2eq (~64% reduction).

Product life stage	Current reusable nappy KgCO2eq	2005 reusable (Terry) nappy KgCO2eq
Nappy and liner materials and production	33.65	93.00
Distribution	2.56	38.00
Home washing and drying	293.34	414.00
End of life including faeces and urine disposal	15.02	16.00
Total	**344.57 KgCO2eq**	**559.00 KgCO2eq** [10]

Table 5: Comparison of the carbon footprint of the reusable nappies 2021 and 2005.

Furthermore, the reduction in the GWP of the UK's grid energy mix[11], the efficiency of washing machines and tumble dryers has improved, largely driven by three main factors:

- EU legislation[12] [13] on eco design.
- Update to the energy label requirements for washing machines and tumble dryers.
- Introduction of heat pump tumble dryers which are much more energy efficient.

The overall results are shown for the disposable and reusable nappies below along with 'Unit's difference' and 'Main cause for difference' (Table 6). The highest impact in each category is highlighted in yellow. When the results are less than 0.01 scientific notation has been used.

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[9] Table 8.13 - Life Cycle Assessment of Disposable and Reusable Nappies in the UK, ISBN: 1-84-432427-3
[10] Rounded to nearest whole number in table 8.13
[11] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting (0.47853kgCO2e to 0.23314kgCO2e per kWh)
[12] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/tumble-driers_en
[13] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/washing-machines_en https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/about_en

Impact category	Unit	Disposable nappy	Reusable nappy system	Units difference	% Difference	Main cause for difference
Global warming potential	kg CO_2eq	456.91	344.57	112.34	25%	Nappy materials/EOL
Stratospheric ozone depletion	kg CFC11 eq	2.33E-04	4.13E-04	1.79E-04	77%	Energy, detergent, water use and EOL[a]
Ionizing radiation	kBq Co-60 eq	46.01	88.02	42	91%	Electricity use
Ozone formation, Human health	kg NOx eq	0.85	0.95	0.1	12%	Electricity use
Fine particulate matter formation	kg PM2.5 eq	0.45	0.55	0.1	22%	Electricity use
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.89	0.97	0.08	9%	Electricity use
Terrestrial acidification	kg SO_2 eq	1.04	1.3	0.27	26%	Electricity use
Freshwater eutrophication	kg P eq	0.23	0.17	0.06	26%	SAP/PP[c]/EoL
Marine eutrophication	kg N eq	0.06	0.26	0.2	333%	Wastewater treatment/electricity use
Terrestrial ecotoxicity	kg 1,4-DCB	1903.33	1657.93	245.4	13%	Distribution, SAP[b] and EOL
Freshwater ecotoxicity	kg 1,4-DCB	26.16	28.18	2.02	8%	Energy, detergent and water use
Marine ecotoxicity	kg 1,4-DCB	35.61	46.1	10.49	29%	Electricity use/ EOL
Human carcinogenic toxicity	kg 1,4-DCB	18.82	19.09	0.27	1%	Minimal difference
Human non-carcinogenic toxicity	kg 1,4-DCB	486.54	478.33	8.21	2%	Minimal difference
Land use	m^2 a crop eq	73.06	61.69	11.37	16%	Pulp
Mineral resource scarcity	kg Cu eq	0.74	1.29	0.55	74%	Electricity and detergent use
Fossil resource scarcity	kg oil eq	153.16	112.48	40.68	27%	SAP/PP
Water consumption manufacturing use	m^3	7.8	7.11	0.68	9%	Minimal difference

Note [a] end of life, [b] super absorbent polymer, [c] polypropylene

Table 6: Comparison of disposable and reusable nappies environmental impacts (2.5 years)

Although attention is often given to the Global warming potential (CO_2eq) the LCA methodology highlights variation in results across a number of environmental impact categories. The disposable nappies have a higher environmental impact across 7 of the impact categories: Global warming potential (GWP) (KgCO_2eq), Freshwater eutrophication (kg P eq), Terrestrial ecotoxicity (kg 1,4-DCB), Human non carcinogenic toxicity (kg 1,4-DCB), Land use (m^2 a crop eq), Fossil resource scarcity (kg oil eq), and water use in manufacturing (m^3). The production of the super absorbent polymer (SAP) and EoL treatment were key contributors to the difference, accounting for up to ~69% of these impacts. The weight of disposable nappies (128.36Kg) compared to reusable nappies (3.22Kg), end-of-life incineration and landfilling of the disposable nappies was also a major contributor to these impacts.

Reusable nappies have a higher environmental impact across 11 of the impact categories: Stratospheric ozone depletion (kg CFC11 eq), Ionizing Radiation (kBq Co-60 eq), Ozone formation-human health (kg NOx eq), Fine particulate matter formation (kg PM2.5 eq), Ozone Formation-terrestrial ecosystems (kg NOx eq), Terrestrial acidification (kg SO_2 eq), Marine eutrophication (kg N eq), Freshwater ecotoxicity (kg 1,4-DCB), Marine ecotoxicity (kg 1,4-DCB), human Carcinogenic toxicity (kg 1,4-DCB), Mineral resource scarcity (kg Cu eq) plus Water Consumption (flushing of toilet and washing machine use) (m^3). The main contributing factors (aside from materials) is electricity used in pre-washing, washing and drying operations (~438kWh), detergent use and the treatment of wastewater (toilet flushing and washing machine). Over the course of the 2.5 year period 36.56m^3 of water is used in washing the reusable nappies and disposing flushing faeces down the toilet.

The impact of reusable nappies could be reduced by the consumer using more energy efficient washing machines and tumble dryers or by air drying the nappies. The nappies could also be used for a second child. The impact of disposable nappies could be reduced by disposing of them at sites with energy recovery. Recycling technologies do exist for nappies but are not widely available in the UK and no data was made available for recycling to be included in the modelling to determine any potential environmental savings.

2 Introduction

Nappies play a key role in a child's health and well-being, as well as ensuring convenient hygiene for the whole family. They are considered a necessity for a child in their early years[14] particularly the first 2.5 years of life. After this period, children are generally less dependent due to potty training, with nappies being used mostly at night-time.

The environmental impacts and economic costs of nappies is an increasingly important factor amongst policy makers, industry and wider society. Published environmental analysis for nappies using Life Cycle Assessment (LCA) methodology is old, dating from 2005[15] and revised in 2008[16]. Since then, there have been advances in the design and materials used in both disposable and reusable nappies, in the efficiency of washing machines and tumble dryers, the grid energy mix at a national level[17] as well as changes to the way the materials are dealt with at end of life.

The results of this study are predicated upon aggregated data sets (2020-2021) for disposable nappies from major manufactures and 4 reusable nappy producers combining 8 different reusable nappies from 13 different washable / reusable nappy components (nappy systems).

The LCA study will be used to report the environmental aspects associated with the life cycles of reusable nappy systems and disposable nappies to Defra and to a wider audience. As this study will be used externally, it has undergone critical review by external reviewers aligned with ISO 14040 and 14044.

The study is based on aggregated data sets so comparisons are indicative of a range of products and direct comparisons can't be made on a product-by-product basis. As the previous studies in 2005 and 2008 used different life cycle indicators, LCA system and modelling methodology direct comparisons with the previous reports should be done with caution.

2.1 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a holistic decision support tool that calculates the potential environmental impacts of different products and systems. LCAs can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant material inputs, energy and environmental releases.
- Evaluating the potential impacts associated with identified inputs and releases.
- Interpreting the results to help support for a better integration of environmental sustainability with decision-making.

The modelling in this study follows the international accepted principles, framework, methodology and practices for LCA established by ISO 14040 and ISO 14044 the international standards governing the investigation and evaluation of the environmental impacts of a given product over their life cycle:

- ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework.
- ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines.

These international standards use a four-step LCA framework, which includes:

- Goal and Scope Definition - to ensure that they are fair and robust.
- Inventory Analysis – data collection and LCA model.
- Impact Assessment – environmental impacts calculated.
- Interpretation – conclusions are drawn, and where appropriate recommendations made.

[14] Absorbent Hygiene Product Manufacturers Association (AHPMA)
[15] Life Cycle Assessment of Disposable and Reusable Nappies in the UK, ISBN: 1-84-432427-3
[16] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291130/scho0808boir-e-e.pdf
[17] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting (0.47853kgCO_2e to 0.23314kgCO_2e per kWh[17])

3 Goal of the study

The goal of the study is to determine the cumulative environmental impact of the use of a disposable and a reusable nappy 'system' for the first 2.5 years of a child's life. This is when the majority of the children are potty trained.

The scope of the study addresses the following items:

- Functional unit.
- Product system and boundaries.
- Inventory analysis.
- Data collection procedures.
- Data quality indicators (DQIs).
- Data paucity and epistemic uncertainty.
- Allocation.
- Inclusion /exclusions.
- Temporal, spatial and technological scope
- Disposable nappies.
- Reusable nappies.
- Nappy usage patterns.
- LCA modelling methodology.
- Key assumptions and limitations .
- Limitations of the methodology.
- Results -Impact assessment and interpretation.
- Sensitivity analysis.
- Conclusions.

3.1 Functional unit

The function that is appropriate to the goal of the study is defined as 'the use of nappies during the first 2.5 years of a child's life in the UK'. This is the average age a typical child is no longer dependent upon wearing a nappy.

This functional unit provides a specific quantity of disposable and reusable nappies of different sizes and weight used within the time period of 2.5 years, which has been fully taken onto account for both types of nappies. For both types of nappies an aggregated data set was used based upon the different makes, styles and sizes of nappies used by a child for the first 2.5 years. The data set for disposable nappies is also based upon the percentage of the UK market share using manufacturers data.

3.2 Product system boundaries

The system boundary (Figure 3) shows the unit processes included in the LCA study. This includes all significant processes in the materials, manufacture, distribution, sale, use, disposal and end of life treatment of disposable and reusable nappies. Recycling technologies do exist for nappies but are not widely available in the UK and no data was made available for recycling to be included in the modelling.

The LCA covers the following inputs and outputs through the nappy's life cycle from cradle to grave:

Upstream processes (highlighted green)

- Raw material extraction and production of for all materials and components of the nappies.
- Transportation of raw material.
- Manufacturing process for the materials.
- Impacts due to the production of electricity and fuels used in the upstream production.
- Manufacturing of primary and secondary transit packaging.
- Waste treatment of waste generated during upstream processes.
- Associated emissions to land water and air.

Core processes (highlighted yellow)

- External transportation of the nappy.
- Manufacturing and assembly of the nappies and associated packaging.
- Waste treatment of waste generated during manufacturing.
- Impacts due to the production of electricity and fuels used in the core product(s).
- Transportation of the nappies to the UK retailer.
- Associated emissions to land water and air.

Downstream processes (highlighted blue)

- Transportation of the nappies from the retailer to the consumer.
- Use of the nappy including washing, drying and associated energy, materials and water use.
- End-of-life processing of the product and packaging.
- Associated emissions to land water and air.

The system boundary is shown below (Figure 3). The grey shaded area denotes what is included within scope of the LCA. The energy recovery at end of life, waste bags for disposable nappies and liners and faeces is outside of the system boundary. However, the energy recovery potential is discussed in detail in the sensitivity analysis (Section 12).

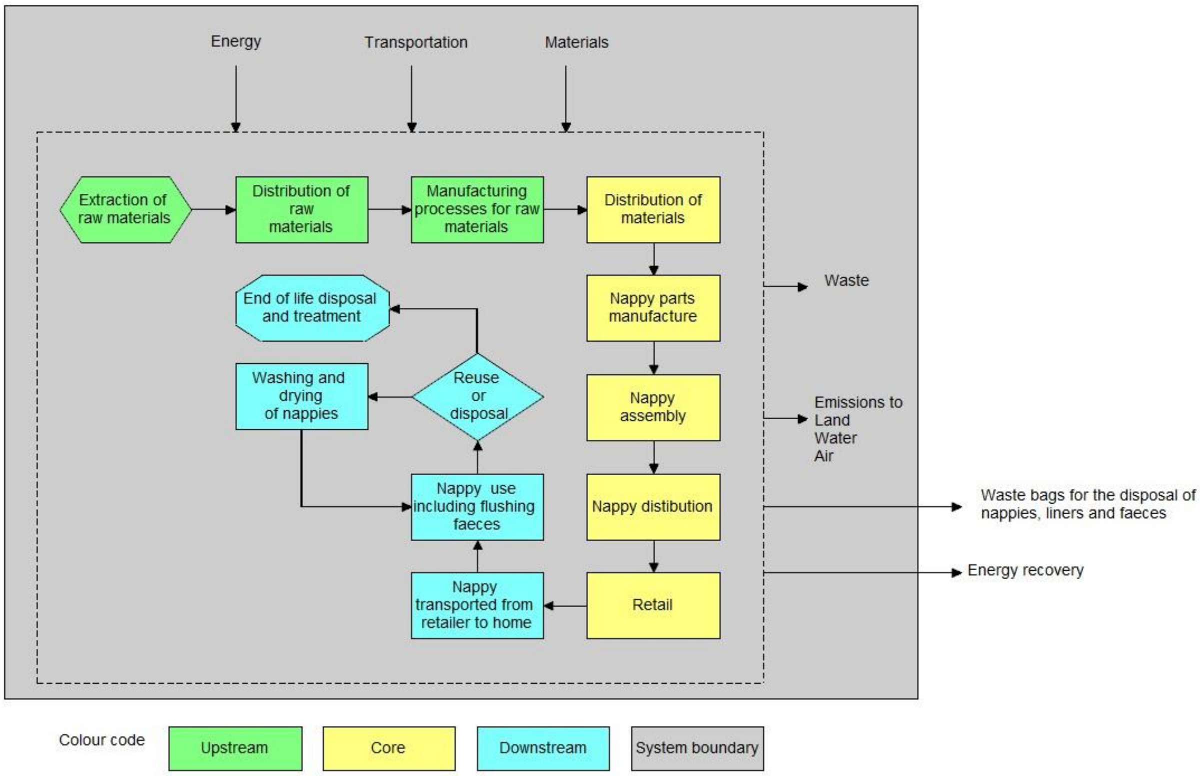

Figure 3: Nappy LCA framework and system boundary

4 Inventory analysis

For each of the nappy systems assessed, a full inventory of the materials used and processed in each of the nappy systems and inventories of environmental flows, and internal material and energy flows, have been produced.

Secondary data on the use phase has been used for all of the material and processes as well as additional primary data was collected for each reusable nappy systems. Secondary data was used for the energy and water use in washing and drying the reusable nappies. Secondary data was also used for material transport to the manufacturers and product distribution.

4.1 Data collection

The key sources of data used for the LCA modelling are given in the table below:

Description	Data source	Assumptions
Disposable nappy materials and manufacturing data	AHPMA	The data was accurate and representative of the current UK market.
Reusable nappy materials and manufacturing data	Nappy Alliance	The data was accurate and representative of the current UK market.
Nappy usage - changes per day	AHPMA Nappy Alliance	The data was accurate and representative of the current UK market.
Faeces and urine	Published literature describing the faeces and urine produced by the child·· Geigy scientific tables: Volume 1: Units of measurement, body fluids, composition of the body, nutrition.	That faeces and urine production has not changed significantly since the report was published.
Life cycle and usage of nappies	Questionnaires and interviews with nappy producers and other experts regarding the main life cycle stages of the nappy. The Great Cloth Nappy Census 2020, hosted by www.thenappygurus.com (n=3218).	The data was accurate.
Non-woven Polypropylene (PP) production data and LCA data	EDANA, the international association for the nonwovens and related industries.	The data was accurate.
Nappy liner usage	Great cloth nappy census.	The data was accurate and captured a representative sample of reusable nappies.
Energy and water use of washing machines	EU directive on eco design for washing machines[18] and survey of 20 current washing machines from 6 leading manufacturers.[19]	Using eco design directive data is based upon an average of 3 full washes at 60°C, 2 half full washes at 60°C and 2 full washes at 40°C.
Washing machine detergent production and use	Product Environmental Footprint (PEF) Category Rules (PEFCRs) Household Heavy Duty Liquid Laundry Detergents (HDLLD) for machine wash.	Assumes normal dosage of detergent used at all times.
Tumble dryer electricity use[20]	A review of the energy labels of 20 tumble dryers available from 12 manufacturers design for tumble dryers.[21]	Survey identified an average of 2.65kWh per full load and 1.25kWh for a cool drying load as recommended by the manufacturers of the nappies.
Disposal and treatment of nappies at end of life	Defra and Environment Agency. Defra Incineration of Municipal Solid Waste. February 2013.	All nappies are disposed of in the domestic non-recyclable bin.
Secondary data source used for LCI	Ecoinvent v3.7.1 database (2021), standard data sets on energy, environmental impacts of materials,	That datasets for the EU are representative of UK waste disposal and recycling.

[18] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1575536811417&uri=CELEX:32019R2014
[19] Giraffe Innovation data based upon survey of best sellers at Dixons
[20] Very limited data was available on heater airers, therefore only tumble dryer data was used.
[21] https://www.statista.com/statistics/437669/leading-brands-of-tumble-dryers-in-the-uk/

	material processing and production, waste disposal and recycling.	
Potty training	You Gov – Children Potty Training. UK18 sample@ 30th March to 7th April 2021. Commissioned by Bambino Mio. n=728	The data was accurate and captured a representative sample of potty training.
Electricity generation	Ecoinvent grid electricity[22]	The data for UK grid electricity was accurate
Washing and drying of nappies and use of nappy liner	Bambino Mio[23] survey and The Great Cloth Nappy Census 2020	Usage behaviour was assumed to be common for all reusable nappies. 6 nappies prewashed together with the liners and then washed in main wash with other items. This will allow at least 6 nappies to be in use per day, 6 drying and 2 in reserve. 24% of the nappies are tumble or heated airer dried in a mixed load.
Water treatment and sewage treatment	Ecoinvent sewage treatment[24] based upon weight faeces and 5 litres of water[25] used per flush for reusables.	Flushing of toilet for 57% of faeces disposal, 2 flushes a day.
Waste management	Taken from UK statistics on waste.[26]	Reusable nappy materials will eventually be disposed of as general waste.

Table 7: Data requirements, sources and assumptions

A list of selected reference papers is given in section 14.

4.1.1 Data for disposable nappy materials

Data was collected from 4 manufacturers by AHPMA, and an aggregated data set was produced that covered the 2.5 years of use. This included the following:

- Materials including packaging.
- Manufacturing processes.
- Production Energy, water use and yield rate.
- Distribution.

The non-woven PP production data and LCA data was supplied by the European Disposables and Nonwovens Association (EDANA), the international association for the nonwovens and related industries. The SAP data was modelled based upon the information in JRC report on Revision of EU Ecolabel criteria for Absorbent Hygiene Products. Preliminary report 2021.

4.1.2 Data for the home laundered reusable nappy materials

Data was collected from 4 manufacturers which included the following:

- Materials including packaging.
- Manufacturing processes.
- Suppliers.
- Production Energy and water use and yield rate.
- Distribution.
- Usage rates of the nappies.

[22] https://ecoinvent.org/
[23] Bambino Mio YouGov survey April 2021. Nappy usage behaviour study and The Great Cloth Nappy Census 2020, hosted by www.thenappygurus.com
[24] https://ecoinvent.org/
[25]https://www.nidirect.gov.uk/articles/saving-water-home
[26] https://www.gov.uk/government/statistics/uk-waste-data

4.1.3 Data on urine and faeces

For disposable nappies, the faeces and urine are typically retained in the nappy and placed in the general waste bin which will effectively arrive as raw sewage at a landfill site or energy from waste (EfW) plant. For reusable nappies, after the child is 6 months old the faeces are either washed down a toilet (57%) or put in a general waste bin (43%). The urine will be washed off in the washing machine (prewash and main wash). The volume of water used by the toilet and washing machine will significantly dilute this effluent and be released as 'general wastewater from residence'.

The Geigy (Lentner 1981) data set[27] is considered the reference point for units of body fluid measurement and provides a comprehensive breakdown of both human urine and faeces. Over the first 2.5 years a child will excrete 254.3 litres of urine (Table 8). Over the same time period a child will excrete 97.9kg of faeces (Table 9).

Age of child	Urinary volume rate (mld-1kg-1)	Total volume for period*(litres)
0-6 months	34.00	32.40
6–12 months	29.00	45.60
12-24 months	25.00	100.50
24-30 months	33.00	75.80
TOTAL		**254.30**

Table 8: Urine production per child from Geigy (Source: Lenter, 1981)

Age of child	Faeces mass rate (gd-1)	Total mass for period (kg)
0-3 months	83.00	7.60
3 months to 2.5 years	110.00	90.30
TOTAL		**97.90**

Table 9: Faeces production per child from Geigy (Source: Lenter, 1981)

5 Data quality

The analysis aligns to ISO14040 and ISO14044 standards which acknowledges the Life Cycle Assessment requirements of key phases beginning with goal and scope definition, inventory, analysis, impact assessment, and interpretation. Each of these phases, along with their associated databases and models, can have associated uncertainties.

Each piece of data supplied for the LCA was assessed using the data quality indicators to ensure the reliability of the source and that it was representative, less than 3-year-old and represented the UK market and the material data supplied was relevant to the study.

5.1 Data quality indicators (DQIs)

To ensure data quality, checks were completed on key data parameters using data quality indicators (DQIs) which are applied to key data parameters to ensure fit for purpose. Key data parameters are assessed against a data quality matrix and assigned scores between 1 (very good) and 5 (very poor). The data quality matrix used in this study (Table 10) and the scoring for the overall data is highlighted in light blue. Data quality was further assured through sensitivity and uncertainty analyses.

[27] Geigy scientific tables: Volume 1: Units of measurement, body fluids, composition of the body, nutrition

Score	Very good	Good	Fair	Poor	Very poor
Reliability of the source	Verified data based on measurements	Verified data partly based on assumptions or unverified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g., by industrial expert)	Non-qualified estimate
Representative	Representative data from sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal correlation	Less than three years of difference to year of study	Less than six years of difference	Less than 10 years of difference	Less than 15 years of difference	Age of data unknown or more than 15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Table 10: Data Quality Indicator (DQI) Matrix

The quality of the data with regard to reusable nappy materials, use of the nappy including washing, drying and disposal is very good. However, there is a wide variation in the energy consumption of washing machines and tumble dryers, due to their age and capacity, which presents a higher level of uncertainty but still good data.

The data used was considered to be of an adequate period and representative of what was required. The main data on nappy materials, use and disposal was all less than 3 years old and was based upon products sold in the UK. Full scoring of the data quality is given in Appendix H.

5.2 Data paucity and epistemic uncertainty

Epistemic uncertainty is also known as systematic uncertainty and is due to things one could in principle know but does not in practice, due to limited data and knowledge. This may be because a measurement is not accurate, because the model neglects certain effects, or because particular data have been deliberately hidden.

The following is a list of any data paucity or epistemic uncertainty and how this was managed.

- There was some data paucity in the energy used on one of the reusable nappy systems (BB4) and this was covered by using the average of the 8 nappy systems.
- In the absence of recent primary data on shopping habits of consumers with babies, consumer transport to and from the retailer was modelled based upon the same percentage of the total weekly shopping in the previous LCA study. The same physical distance was applied but a more accurate way of measuring the impact on fuel use was used.
- No primary material inventory data was available on a range of specific disposable nappies only on an aggregated dataset across 4 major producers. The authors of this report did not have sight of the raw data that was used to calculate the generic dataset. It was however, signed off by AHPMA contributing members so the authors of this report have assumed its accuracy.

- Transport distances from the producer to retailer were not available from either type of nappies, so a generic set of transport distances were used for both types of nappies.
- Assumptions: No data was available on how the waste generated in the manufacture of the reusable nappies in China was treated. Therefore, it was assumed to be treated the same as in the UK.

The material, processes and transport inventories for each of the different nappies is set out in each section on the different nappies and also in Appendix A for disposable nappies and Appendix E for disposable nappies.

5.3 Allocation

For cases where there is more than one product in the system being studied, ISO 14040/ISO4044 prescribes a procedure for the allocation of material and energy flows and environmental emissions. For compliance with these ISO standards, allocation procedures must be defined, and, in this study, there were no multi-product processes.

5.4 Inclusions/exclusions

When building a life cycle inventory (LCI), it is typical to exclude items considered to have a negligible contribution to results. To do this in a robust manner there must be confidence that the exclusion is fair and reasonable. Therefore, cut-off criteria are defined, which allow items to be neglected if they meet the criteria. In this study exclusions could be made if they were expected to be within the below criteria:

- Mass: if a flow is anticipated to be less than 1% of the mass of the product it may be neglected.
- Energy: if a flow is anticipated to be less than 1% of the cumulative energy it may be neglected.
- Environmental significance: if a flow is anticipated to be less than 1% of the key impact categories it may be excluded.
- If an item meets one of the criteria but is expected to be significant to one of the other criteria it may not be neglected. For example, if a chemical is small in mass but is expected to have a notable contribution to the environmental results then it may not be excluded.

The following are included in this LCA study:

5.4.1 Excreta and urine

Excreta and urine have been included within the scope of this study and its disposal for both disposable and reusable nappy systems. Unlike the previous LCA study which focused on 'Terry – flat cloth' reusable nappies, the current nappy designs are not soaked in sterilisers. The practice of commercial laundry for reusable nappies is not indicative of current user behaviour and therefore excluded from the scope of this study.

5.4.2 Material transport

Raw material transport was assumed to be 1000km by road and 100km by oceanic freight. This is consistent with assumptions calculated in the previous LCA studies[28].

5.4.3 Retailer distribution

Retail distribution by road haulage in a 32-tonne articulated lorry, was assumed to be 500km by road. For reusable nappies, the majority of these are purchased online, as confirmed by the manufacturers and survey results and a figure of 500km was allocated to the distribution of these nappies direct to the consumer via 7.5-16 metric tonne lorry.

[28] Life Cycle Assessment of Disposable and Reusable Nappies in the UK, ISBN: 1-84-432427-3

5.4.4 Collection from retailer

Based upon the previous 2005[26] report the average distance to the supermarket was 5 miles (8km) each way, once per week.

The following are excluded from the LCA:

5.4.5 Capital equipment

Due to the longevity of the capital equipment such as manufacturing equipment, washing machines, tumble dryers, lorries and cars used in this LCA compared to the amount of material used in both nappy systems, they have been excluded from the analysis.

5.4.6 Retailer energy use

The energy use at the retailer is well below the cut off requirement for an LCA and is highly variable and therefore not included in this analysis.

5.4.7 Workforce burdens

Human labour is outside the scope and resources of this project.

5.4.8 Nappy materials

For the disposable nappies the 'lotion', was 0.007g and accounts for less than 0.1% of the weight of the nappy and would be below the 1% by weight cut off and therefore was excluded.

5.5 Temporal, spatial and technological scope

The geographical coverage is defined as the use of nappies in the UK in 2020-2021. However, raw material production and some processing occurs outside of the UK. The disposable nappies were manufactured in Europe and the reusables in China, Taiwan, Turkey and the UK.

The technologies being assessed are representative of the product systems. The geographic, temporal and technological scope of the data has been recorded.

6 Disposable nappies

Disposable nappies are single use products incorporating super absorbent polymer (SAP) and cellulose fluff to retain the urine. They are available in a range of sizes from new-born (2Kg) up to 15kg in child weight. The disposable nappies are manufactured in Europe, imported into the UK and typically sold at retailers and collected by the buyer.

Primary data for disposable nappies was supplied by 4 major manufacturers representing the vast majority of disposable nappies on the UK market. This provides an aggregated data set for a disposable nappy covering the full 2.5 years of the child's life. This took onto account following:

- Nappy materials.
- Different sizes of nappies.
- Length of time a child will be in each nappy size.
- Manufacturing.
- Distribution.
- Use.
- End of life collection of nappies by a municipal vehicle.
- End of life treatment 78% of nappies incinerated and 22% landfilled.

6.1 Disposable nappy material composition

A comparison of the current nappy composition with that in the original LCA report is given (Table 11). The super absorbent polymer (SAP) was modelled in this LCA study using secondary data[29] based upon sodium polyacrylate. The material inventory shows the indicative weight reduction of disposable nappies.

		2021		2001-2002	
Input per nappy	**Unit**	**Amount**	**%**	**Amount**	**%**
Fluff pulp	g	8.34	24.66%	19.09	42.8%
Super absorbent polymer (SAP)	g	13.22	39.09%	12.3	27.63%
PP	g	7.49	22.15%	6.81	15.25%
PE	g	1.16	3.43%	0	0%
LDPE	g	0.387	1.14%	3.46	7.74%
PET	g	0.07	0.20%	0	0%
Polyester	g	0.26	0.78%	0	0%
Elastic	g	1.13	3.34%	0.24	0.53%
Glue/Adhesives	g	1.18	3.49%	1.34	2.99%
Calcium carbonate	g	0.19	0.55%	0	0%
Tape	g	0.37	1.08%	0	0%
Lotion	g	6.93E-03[30]	0.02%	0	0%
Other	g	0.02	0.05%	1.38	3.09%
Total weight	**g**	**33.82**	**100%**	**44.64**	**100.0%**

Table 11: Material composition of disposable nappies 2021 and 2001 (AHPMA)

There has been a significant reduction of ~24% (44.64g to 33.816g) in the weight of the nappy and associated packaging. This is based upon a theoretical nappy based upon a weighted average, taking into account different sizes used up to 2.5 years.

The production of disposable nappies shows the average factory energy use largely derived from renewable technologies (78%) renewables (solar PV/wind) with the remaining energy sourced using EU grid average[31,32]: (Table 12).

Energy used	Total energy used %
Electricity, medium voltage {Europe without Switzerland}| market group for | Cut-off, S	13%
Electricity, high voltage {NO}| electricity production, hydro, reservoir, alpine region | Cut-off, S	42%
Electricity, high voltage {RoW}| electricity production, wind, >3MW turbine, onshore | Cut-off, S	37%
Electricity, low voltage {RoW}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, S	8%

Table 12: Energy mix for disposable nappy manufacturing (AHPMA)

6.2 Transport to retail outlet

It was assumed that for disposable nappies the distance from the producer to the retail outlet was 500km by 32 tonne articulated lorry. This impact is based upon the weight of the nappy and distance

[29] JRC technical report. Revision of EU Ecolabel criteria for Absorbent Hygiene Products Preliminary report. Sept 2021
[30] When the results are less than 0.01 scientific notation has been used as a way of expressing numbers that are too large or too small to conveniently represent in decimal form. For example, Lotion is 6.93E-03g which in decimal (standard) notation is 0.00693g.
[31] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics
[32] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210416-1

travelled (Tkm) to the retailer, as a single journey and that the lorry will make deliveries onward to other retailers.

6.3 Retail outlet

The energy use allocated to a nappy at the retail outlet was insignificant (0.004kWh) and well below the 1% cut off. This is also highly variable and therefore has been excluded from the study.

6.4 Transport home

It was assumed that the average disposable nappy consumer travelled once a week to the supermarket. The average distance to the supermarket was ~5 miles (8km) consistent with the previous LCA study. Therefore, total distance = 52*2.5*8*2=2080km. The addition of 1.0162kg of nappies per shop (132.112kg /130 weeks) will increase the fuel consumption by at least 0.011%[33,34]. Based upon this data the full impact of collecting the nappies is equivalent to driving an additional 22.88km (2080*0.011).

6.5 Disposal of nappies at end of life

Once used, it is assumed that nappies are put in the non-recyclable municipal waste bin. In 2005/6, 86% of residual waste was sent to landfill and 14% to energy from waste (EfW). Since then, this has changed to 78% incinerated and 22% landfilled. This change is due to the revised Waste Framework Directive (rWFD2) which sets out the waste hierarchy incorporating the broad options for waste management, with energy recovery from waste being a preferred option to landfill/disposal[35].

It was assumed that the faeces remained in the disposable nappy when they were disposed of. As there is no evidence of how many users would flush the faeces down the toilet a sensitivity analysis was carried out to show how this would affect the environmental impact of the disposable nappies.

The analysis also assumed that all of the nappies are disposed of in the general waste and transported 20km by municipal vehicles and treated. The LCA emissions at end-of-life accounts for 78% of the nappies being incinerated and 22% landfilled in the UK.

As there was no robust data on the use of nappy sacks used when disposing of the nappies these have been considered to be out of scope of the modelling.

According to the Product Category Rules (PCRs) on Absorbent Hygiene Products (PCR 2011:14 Absorbent hygiene products (3.01)) [36], there is potential to recover an average of 7.2MJ/kg from the incineration of nappies at end of life. The PCR also states that in the event of incineration without energy recovery the product system generating the waste shall include all of the environmental impacts from incineration. If the incineration is with energy recovery, 50% of the impacts of the waste incineration plant may be attributed to waste treatment and 50% to the energy recovery. The impacts related to making use of the thermal energy shall be attributed to the next product life cycle.

Based upon the above, in 2020 there were 53 energy from waste (EfW) plants but only 28 (52.8%) met the R1 rating of 0.6 in the UK (a performance indicator for the level of recovery of energy from waste in a plant dedicated to the incineration of municipal solid waste (MSWI)). Therefore, for the incineration of disposable nappies 26.4% (50% of the 52.85% of the impact of the waste plant) was attributed to energy recovery. According to the PCRs as well as the fact that the 'Cut off' model was used during this analysis there is no credit to the system for the generation of energy during incineration as it is outside of the system boundary. However, the sensitivity analysis includes the results for inclusion of this energy recovery at end of life.

[33] https://www.fueleconomy.gov/feg/driveHabits.jsp
[34] https://www.racfoundation.org/assets/rac_foundation/content/downloadables/eco-driving.pdf
[35] Defra Incineration of Municipal Solid Waste. February 2013
[36] https://www.environdec.com/pcr-library

7 Reusable nappies

The analysis is based on data from 4 reusable nappy producers[37] combining into 8 different reusable nappy system from 13 different washable / reusable nappies and nappy components. This accounts for nappy size based upon child weight (Kg) and age range (up to 2.5 years) all currently available on the market in the UK. The majority of the reusable nappies are manufactured in China, Turkey, India and Taiwan with one brand being manufactured in the UK. Over 97% are sold online and delivered direct to the customer. Due to commercial confidentiality respective company data is anonymised and assigned an initialism (RA, RB, RC and RD) within the report.

Reusable nappies (home laundered) covered in this study are available in three different designs:

- 'Pocket nappy' - consist of a waterproof outer and a fleece inner. An opening along the back of the nappy allows an absorbent pad to be inserted and to change soiled pads.
- 'All-in-one nappy' - incorporates an absorbent inner ('core') with an attached waterproof outer layer sewn together and can be used without additions as a complete nappy system.
- 'All in two nappy' - incorporates an inner absorbent pad ('insert') that attaches to the outer waterproof layer ('wrap') with poppers to form a one-piece nappy. The pads can be removed for washing independently of each other and reuse. Both the absorbent inner and waterproof outer must be used together to comprise a complete nappy system.

These 'nappy systems' are made up from the following component:

- **Core:** The absorbent inner of an all-in-one nappy.
- **Insert:** The absorbent inner of a two-part/pocket nappy.
- **Wrap**: The waterproof outer of a two-part/pocket nappy
- **Booster:** An optional additional insert that can be added to any nappy type in order to boost absorbency**.**

The different nappies and nappy components supplied by manufactures (RA to RD) are listed below (Table 13).

Nappy	Weight range (kg)	Months	Comments
RA1	2-8	0-6	All-in-one newborn nappy
RA2	2-16	2-30	Pocket nappy
RB1	4+	0-30	All -in-one nappy
RB2	<9	0-12	Wrap small size
RB3	>9	12-30	Wrap large size
RB4	0-16	0-30	Insert
RC1	2-5.5	0-3	Two-part newborn nappy with additional inserts
RC2	3-16	0-30	Two-part nappy
RC3	3-16	0-30	Two-part nappy
RD1	2-16	0-30	All-in-one nappy
RD2	3.5-16	0-30	Insert - night use
RD3	3.5-16	0-30	Outer wrap
RD4	3.5-16	0-30	Insert

Table 13: Reusable nappies and nappy components evaluated (Nappy Alliance)

The 8 different 'nappy systems' and combination of nappies and nappy components in each system, produces a total of 20 nappies to be used over the 2.5 years is given below. A breakdown of each system is given below. (Table 14).

[37] These account for an estimated 35-40% of reusable nappies sold in the UK

Nappy system	Nappy combinations	Number of items
1	RA1, RA2	20 of each
2	RB1	20
3	RB2, RB3, RB4	RB2 10, RB3 10 RB4 20
4	RC1, RC2	RC1 12 & 20 inserts, RC2 20
5	RC1, RC3	RC1 12 & 20 inserts, RC3 20
6	RD1	20
7	RD3, RD4	RD3 8, RD4 12
8	RD2, RD3, RD4	RD2 4, RD3 8, RD4 8

Table 14: Reusable nappies systems

Using primary data an aggregated 'nappy system' for each manufacturer was produced. As each nappy system varied in design and material content (all in ones, poppers, new-born, night pads) each system was modelled individually, and aggregated impacts calculated. The reusable 'nappy system' analysis includes the following:

- Nappy materials.
- Manufacturing.
- Distribution.
- Use including- washing, drying and use of disposable and reusable nappy liners.
- End of life disposal including - collection of nappies by a municipal vehicle collecting household waste on behalf of the council landfill and incineration with energy from waste (EfW).

7.1 Reusable nappy material composition

The average material composition based upon the 8 different 'nappy systems' is given below (Table 15). This is based upon a 'theoretical nappy' and weighted average, taking into account different sizes.

Material	Amount (g)	%
Bamboo (viscose)	1089.50	33.40%
Microfibre (polyester)	1301.31	39.90%
Polyurethane	166.83	5.12%
Velcro strip	168.00	5.15%
Elastic	52.00	1.59%
Poppers	51.55	1.58%
Nylon	0.12	<0.01%
Cotton	395.00	12.11%
Polyester	12.25	0.38%
Polypropylene	25.00	0.77%
Packaging		
Carton box for packaging	496.92	
Jute for packaging	18.50	

Table 15: Average reusable nappy system composition

7.2 Nappy liners

To easily remove faeces from the nappy most parents (89.28%) use additional nappy liners. These are available in disposable (single use) and reusable formats. A majority of those chose reusable nappy liners (62.34%). These are typically made from micro absorbent cloth such as polyester and typically these weigh 10g each. The remainder of parents (26.94%) that use liners chose disposable versions with an average weight of 1.16g viscose per liner.

Due to recommendations from the different water boards to not flush liners down the toilet it is assumed that 100% of them are put in the household municipal waste bin. However, it is acknowledged this might not reflect all behaviours. Liners collected at the water treatment facility will be incinerated or land filled in the same way as those collected in the non-recyclable household waste. The main issue with flushing liners down the toilet is that they can cause blockage in the sewage network. This is outside the scope of this LCA.

7.3 Retail and direct to the consumer

Most (97%) of the reusable nappies are purchased online and a figure of 500km was allocated to the distribution of these nappies direct to the consumer via a 7.5-16 metric ton lorry. The collection of the laundry detergent is captured in the detergent data set.

7.4 Faeces – disposal

After use, the faeces are either flushed down the toilet (57%) or put in the bin (43%)[38]. A typical toilet flush uses five litres of water[39] (domestic wastewater effluent). During the first 6 months, due to the non-solid, sticky nature of the faeces, the nappy typically goes into the prewash cycle. For the remaining 2 years the faeces flushing typically occurs twice a day (2 flushes), based upon the average number of times a child will defecate per day.

For each nappy system, the faeces disposed of via the general household waste bin or flushed down the toilet have been treated as raw sewage (57% toilet, 43% bin). Urine is washed off in the washing machine and treated as household water waste. The sensitivity analysis includes the effect of the faeces being flushed of disposable nappies prior to disposal. Due to the significant dilution of the urine and faeces the wastewater from toilet flushing was modelled as 'wastewater from residence'.

The 43% of the faeces disposed in the general waste and were transported 20km by municipal vehicles and treated whereby 78% will be incinerated and 22% will end up as landfill in the UK**.** As there was no robust data on the use of bags for the disposal of the faeces, these have been considered to be out of scope of the modelling.

7.5 Nappy washing and drying

Industry surveys[40] [41], highlighted prewashing the soiled nappy pads or all in one nappy prior to the main wash was common practice. The manufacturer recommendation is to air dry, or tumble dry the nappies on a cool setting. Industry surveys[42] reported advice given by the nappy manufactures on washing and drying nappies (Table 16) with 24% of respondents claiming the nappies were tumble dried. Washing temperatures are also given (Table 17).

Description	Quantity	Comment	Source
Nappies used per day	Up to 10 per day for newborn		Nappy Alliance members
Liner	89.28% of the nappies used liners.	26.94% disposable and 62.34% reusable. Waste disposal of these items were taken into account.	Great cloth nappy census.
Faeces disposal	57% toilet, 43% bin.		Environment Agency 2005.
Nappy washing	Washing machine used 100% of the time.	For two-part nappies pads are washed after each use, and the outer washed after 2 uses.	Nappy Alliance members.

[38] The Great Cloth Nappy Census 2020, hosted by www.thenappygurus.com (n=3218)
[39] https://www.nidirect.gov.uk/articles/saving-water-home
[40] Usage behaviour survey 2021
[41] The Great Cloth Nappy Census
[42] Bambino Mio YouGov survey April 2021. Nappy usage behaviour study and The Great Cloth Nappy Census 2020, hosted by www.thenappygurus.com

Reusable nappy liners	Washing machine used 100% of the time.	Washed with each nappy.	Nappy Alliance.
Nappy washing behaviour	See tables 17-18.		Bambino Mio usage behaviours study.
Drying behaviour	24% tumble or heated airer dried.		Nappy Alliance survey.

Table 16: Reusable nappy washing and drying

Temperature	% of responses	No. of responses
30	3.40	120
40	43.60	1544
60	52.90	1872
90	<0.01	2
Total	**100.00%**	**3538**

Table 17: Washing machine temperature

This research shows nappies and reusable liners are predominantly washed at either 40ºC (43.6%) or 60ºC (52.9%). Therefore, a weighted kWh per wash was used for the washing of the nappies as set out in the EU directive on eco design for washing machines[43]. This is based upon an average of 3 full washes at 60ºC, 2 half full washes at 60ºC and 2 full washes at 40ºC. This takes any deviation from these results into account and aligns with typical usage patterns for washing machines. The majority of washing machines last 5 to 9 years[44,45] and it was assumed that the washing machine was purchased within the past 5 years, based upon the average life expectancy of washing machines[46] [47].

Since the previous LCA studies[48,49] not only has the design of reusable nappies changed significantly but there also been a reduction in carbon footprint of grid electricity emissions[50] due to investment in renewables at a national level in the UK. There has also been a significant increase in energy efficiency of washing machines and tumble dryers due to the implementation of the eco-design of energy using products directives[51,52,53,54] and the introduction of more efficient heat pump tumble dryers. The washing machines and tumble dryers used in the previous LCA study are likely to have been replaced with more energy efficient products, as the majority are unlikely to last over 12 years[55,56,57]. A review of the energy in use of these products as well as a survey on different nappy drying methods used by parents has also been included in the modelling[58].

[43] https://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2010/c_2010_7607_en.pdf (Appendix II)
[44] Understanding lifetimes and failure modes of defective washing. machines and dishwashers Paolo Tecchio*, Fulvio Ardente, Fabrice Mathieux. 2019
[45] An empirical survey on the obsolescence of appliances in German Households Laura Hennies, Rainer Stamminger 2016
[46] JRC report 2018. Durability assessment of products: analysis and testing of washing machines. Final report for Task 3
[47] An empirical survey on the obsolescence of appliances in German households Laura Hennies, Rainer Stamminger 2016
[48] Life Cycle Assessment of Disposable and Reusable Nappies in the UK. EA 2005
[49] An updated lifecycle assessment study for disposable and reusable nappies Science Report C010018/SR2. EA 2008
[50] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2005
[51] https://www.gov.uk/guidance/placing-energy-related-products-on-the-uk-market
[52] https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2017/7-appliances-products-lighting-and-ict/electricity-consumption-of-cold-appliances-washing-machines-dish-washers-tumble-driers-and-air-conditioners-on-site-monitoring-campaign-in-100-households-analysis-of-the-evolution-of-the-consumption-over-the-last-20-years/2017/7-019-17_Dupret.pdf/
[53] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109033/jrc109033_20171117_wash_prepstudy%287%29.pdf
[54] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109033/jrc109033_20171117_wash_prepstudy%287%29.pdf
[55] An empirical survey on the obsolescence of appliances in German households. Laura Hennies, Rainer Stamminger, 2016
[56] Understanding lifetimes and failure modes of defective washing machines and dishwashers. Paolo Tecchio*, Fulvio Ardente, Fabrice Mathieux 2018
[57] JRC report: Study for the development of an endurance testing method for washing machines.2017
[58] Usage Behaviour study 2020 (n=273) Bambino Mio You Gov 2021

In order to evaluate the energy and water use of washing machines the following research was carried out.

1. The best-in-class benchmark in 2019 according to the EU directive on eco-design requirements for household washing machines and household washer-dryer[59] Appendix V, the energy in use for an 8kg washing machine was 0.54kWh and water use of 36.82 litres.
2. A report on changes in electricity consumption of washing machines from 2008 to 2021 showed a drop from 0.658 to 0.569kWh per cycle[60].
3. A review of the current energy labelling requirement for 8kg washing machines, as these are the most popular size[61] [62] [63] and analysis of the energy and water use of 20 current washing machines retailer from 6 leading manufacturers[64], all available from a leading UK retailer. The average energy use was 0.5kWh and 30 litres of water for the pre-wash and 0.62kWh and 47 litres of water per main wash (worse than the benchmark in 2019).

The percentage of the different washing machine energy ratings was used to model the energy in use phase (Figure 4).

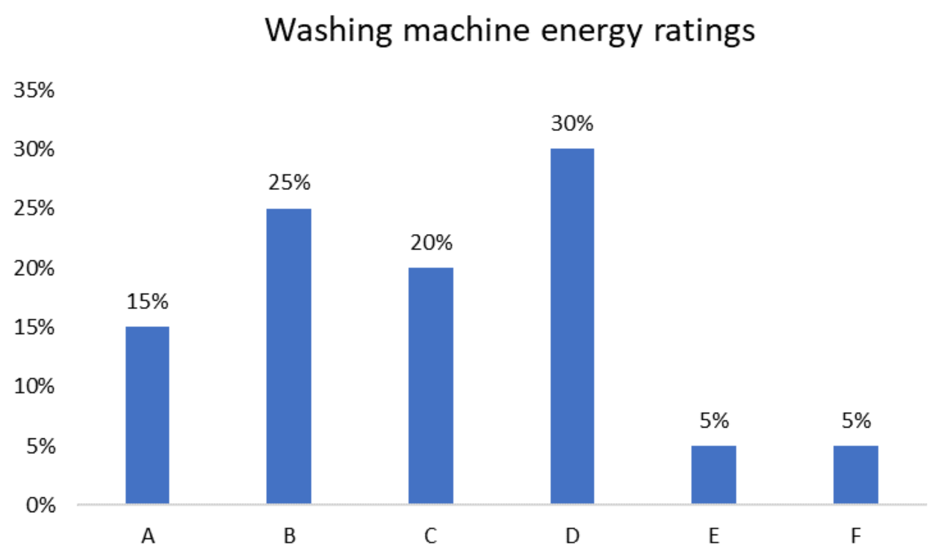

Figure 4: Range of energy ratings for the washing machines.

Data on energy use from the current washing machines on sale in the UK was used as this was higher than the best in class[65] as detailed in the Eco design requirements, and within the range of energy use in the second piece of research[66]. The size of washing load per wash of nappies is based upon Bambino Mio usage behaviours study n=685 (Table 18).

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[59] Ecodesign requirements for household washing machines and household washer-dryer
[60] https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2017/7-appliances-products-lighting-and-ict/electricity-consumption-of-cold-appliances-washing-machines-dish-washers-tumble-driers-and-air-conditioners-on-site-monitoring-campaign-in-100-households-analysis-of-the-evolution-of-the-consumption-over-the-last-20-years/2017/7-019-17_Dupret.pdf/
[61] This is the most common size according to - https://www.currys.co.uk/gbuk/techtalk/washing-machine-capacity-guide/#:~:text=The%20most%20common%20sizes%20are,often%20you're%20washing%20it
[62] https://www.whitegoodshelp.co.uk/difference-drum-capacities/
[63] https://www.madeformums.com/reviews/best-large-washing-machines-families/
[64] https://www.statista.com/forecasts/997870/washing-machine-ownership-by-brand-in-the-uk
[65] Ecodesign requirements for household washing machines and household washer-dryer
[66] https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2017/7-appliances-products-lighting-and-ict/electricity-consumption-of-cold-appliances-washing-machines-dish-washers-tumble-driers-and-air-conditioners-on-site-monitoring-campaign-in-100-households-analysis-of-the-evolution-of-the-consumption-over-the-last-20-years/2017/7-019-17_Dupret.pdf/

Washing machine loads	% responses	No. responses
Full load	19.85%	136
Three quarter load	42.63%	292
Half load	30.95%	212
Less than a half load	6.57%	45
Grand Total	**100.00%**	**685**

Table 18: Washing machine loads

Based upon the information supplied by the Nappy Alliance, the majority of reusable nappy owners have 20 complete nappies, which can be broken down into three groups - ready to use (8 - 6 for use plus 2 spare), a day's worth washing and drying (6) and a day's worth being used during the day (6).

It was assumed that 6 nappies (a minimum of 1 days' worth) are washed together in pre-wash without any other items and then in a general mixed wash and the machine is three quarters filled with other items. The sensitivity analysis reviews the impact of washing more nappies together in a wash load.

The environmental impact of the detergent takes into account the detergents packaging, distribution, retailer's impacts and collected from the retailer by the consumer. For detergents, this report uses formulation data supplied by - the International Association for Soaps, Detergents and Maintenance Products (AISE) [67] and the analysis of Product Environmental Footprint (PEF) Category Rules (PEFCRs) Household Heavy Duty Liquid Laundry Detergents (HDLLD) for machine wash, 2019[68]. A standard dose of detergent (76g) was therefore applied for the prewash and main wash.

The representative 'product' is a 'model' of concentrated liquid detergent products at one dose per washing machine cycle sold in the EU market in 2014[69]. The use of this type of detergent could be considered to be a worst-case scenario as it is typically used on heavily soiled items.

7.6 Nappy drying

The different methods used for drying nappies is based upon Bambino Mio usage behaviours study n=677 (Table 19).

Drying method	% Of responses	No. of responses
100% heated airer or dehumidifier	7.24%	49
100% line or traditional airer	65.44%	443
100% tumble dryer	7.98%	54
Tumble dryer + heated airer	0.74%	5
Tumble dryer + traditional airer	10.34%	70
Heated airer + traditional airer	6.50%	44
All	1.77%	12
Grand Total	**100%**	**677**

Table 19: Nappy drying methods

Using industry data, 24% of the users use accelerated heating such as tumble dryers or heated airers. There was very limited data available on heated airers, so tumble dryers were used as a proxy within the modelling. A review of the energy labels of 20 tumble dryers available from 12 manufacturers[70] (Figure 5) identified an average of 2.65kWh per full load and 1.25kWh for a cool drying load as recommended by the manufacturers of the nappies.

[67] A.I.S.E., the International Association for Soaps, Detergents and Maintenance Products
[68] https://ec.europa.eu/environment/eussd/smgp/documents/2019_09_16_AISE_PEFCR_Detergents_v1.2.pdf
[69] Product Environmental Footprint Category Rules (PEFCR) Household Heavy Duty Liquid Laundry Detergents (HDLLD) for machine wash
[70] https://www.statista.com/statistics/437669/leading-brands-of-tumble-dryers-in-the-uk/

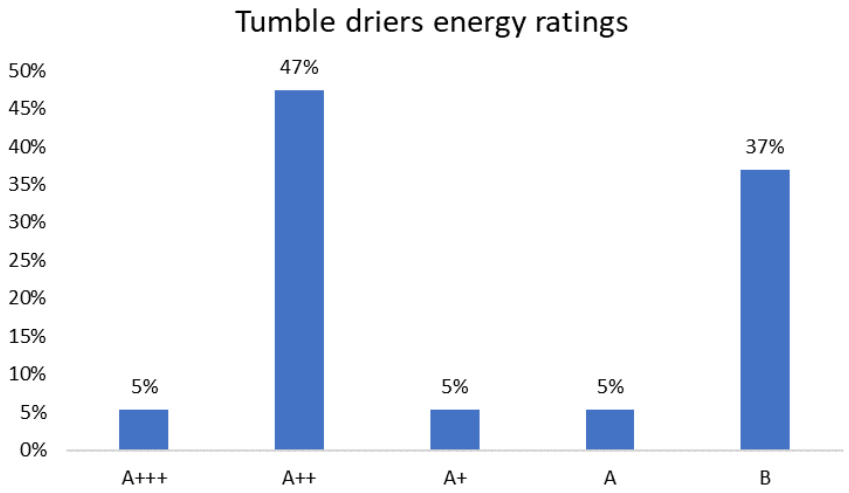

Figure 5: Range of energy ratings for tumble dryers.

7.7 Ironing

Industry survey data indicates consumers adhere to manufacturers recommendation not to iron reusable nappies. This activity has therefore been excluded from the study.

7.8 Disposal of nappies at end of life

This was modelled using the same approach outlined for disposable nappies. At end of life the 2.5 years some nappies may be suitable for reuse (e.g., for a second child) and this is modelled in the sensitivity analysis.

8 Nappy usage patterns

Children are gradually weaned off nappies as they age with the number of nappies used per day decreasing. By 2.5 years of age the majority of children are no longer in nappies.

The indicative numbers of nappies used over a day (24 hours), for each of the age groups (0-3 months up to 2.5 years) and the percentage of children wearing nappies is based upon data supplied by both the disposable and reusable nappy manufacturers[71].

The nappies used per age group is calculated as follows: [number of days* average number of nappies * % of children wearing nappies]. The usage patterns (up to 2.5 years) for disposable nappies are shown below (Table 20) and shows an average of 4.16 nappies per day and a total of 3,796 disposable nappies used over the 2.5 years. This is based upon the data supplied and confirmed by AHPMA.

[71] The NHS estimate 10 changes per day in first 3 month for a new-born baby https://www.nhs.uk/conditions/baby/caring-for-a-newborn/how-to-change-your-babys-nappy/#:~:text=Young%20babies%20need%20changing%20as,least%206%20to%208%20times .

Disposable Nappies			
Age	**Average nappies per day**	**Children wearing nappies**	**Nappies used**
0 to 3 months	7	100%	639
3 months to 6 months	7	100%	639
6 to 12 months	6	95%	1048
12 to 18 months	6	83%	907
18 months to 24 months	5	46%	416
24 months to 30 months	5	18%	148
Total			**3796**
Average nappies per day			**4.160**

Table 20: Disposable nappy use over 2.5 years (rounded to nearest whole nappy)

The use of reusable nappies, along with washing and drying frequency is based upon usage data supplied by the Nappy Alliance members. On average the parents purchase 20 reusable nappies[72]. This showed that children use an average of 4.8 nappy uses per day (Table 21). This gives a total of 4,373 reusable nappies uses over the first 2.5 years. This is based upon the data supplied and confirmed by members of the Nappy Alliance.

Reusable Nappies			
Age	**Average nappies per day**	**Children wearing nappies**	**Nappies used**
0 to 3 months	9	100%	821
3 months to 6 months	8	100%	730
6 to 12 months	7	96%	1223
12 to 18 months	6	83%	907
18 months to 24 months	6	46%	499
24 months to 30 months	6	18%	193
Total			**4373**
Average nappies per day			**4.8**

Table 21: Reusable nappy use over 2.5 years

For this study based upon information supplied by the Nappy Alliance it was assumed that the reusable nappies will last the full 2.5 years.

Consumer research[73] has indicated that since the last LCA study, children are being potty trained at a later stage in their development. A sensitivity analysis was therefore undertaken to include the potential environmental impact of extended use of nappies (delay in potty training) and the reduced use of nappies (counterfactual – accelerated potty training) and the overall environmental impact for the first 2.5 years of a child's life. This is still the point where the majority of children are out of nappies, and this also allows comparison of data with the previous LCAs.

9 LCA modelling methodology

The modelling in this study is aligned to the international accepted principles, framework, methodology and practices for LCA established by ISO 14040 and ISO 14044 the international standards governing the investigation and evaluation of the environmental impacts of a given product over their life cycle:

- ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework.

[72] Bambino Mio YouGov survey April 2021 (unpublished). Nappy usage behaviour study and The Great Cloth Nappy Census 2020, hosted by www.thenappygurus.com

[73] You Gov – Children Potty Training (unpublished). UK18 sample@ 30th March to 7th April 2021. Commissioned by Bambino Mio. n= 728

- ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines.

The impact assessment method used for this study was ReCiPe 2016 v1.1 midpoint method, Hierarchist version. This is the default ReCiPe midpoint[74]. Life cycle impact assessment (LCIA) translates emissions and resource extractions into a number of environmental impact data points by means of characterisation factors. The ReCiPe mid-point method used in this study and impact categories along with their indicator characterisation factors and units at the midpoint level are given below (Table 22). The environmental impacts are given equal significance in this study.

Midpoint impact	Category	Indicator	Unit
Climate change	Infrared radiative forcing increase	Global warming potential (GWP)	kg CO_2-eq to air IPCC 2013
Ozone depletion	Stratospheric ozone decrease	Ozone depletion potential (ODP)	kg CFC-11-eq to air
Ionising radiation	Absorbed dose increase	Ionising radiation potential (IRP)	kBq Co-60-eq to air
Fine particulate matter formation	PM2.5 population intake increase	Particulate matter formation potential (PMFP)	kg PM2.5-eq to air
Photochemical oxidant formation: terrestrial ecosystems	Tropospheric ozone increase	Ozone formation potential: ecosystems (EOFP)	kg NOx-eq to air
Photochemical oxidant formation: human health	Tropospheric ozone population intake increase	Ozone formation potential: humans (HOFP)	kg NOx-eq to air
Terrestrial acidification	Proton increase in natural soils	Terrestrial acidification potential (TAP)	kg SO_2-eq to air
Freshwater eutrophication	Phosphorus increase in freshwater	Freshwater eutrophication potential (FEP)	kg P-eq to freshwater
Marine eutrophication	Nitrogen increase in Marine water	Marine eutrophication potential (MEP)	kg N-eq to marine water
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	Terrestrial ecotoxicity potential (TETP)	kg 1,4-DCB-eq to industrial soil
Freshwater ecotoxicity	Hazard-weighted increase in freshwaters	Freshwater ecotoxicity potential (FETP)	kg 1,4-DCB-eq to freshwater
Marine ecotoxicity	Hazard-weighted increase in marine water	Marine ecotoxicity potential (METP)	kg 1,4-DCB-eq to marine water
Human toxicity: cancer	Risk increase of cancer disease incidence	Human toxicity potential (HTPc)	kg 1,4-DCB-eq to urban air
Human toxicity: non-cancer	Risk increase of non-cancer disease incidence	Human toxicity potential (HTPnc)	kg 1,4-DCB-eq to urban air
Land use	Occupation and time-integrated land transformation	Agricultural land occupation potential (LOP)	m2 × yr. annual cropland-eq
Mineral resource scarcity	Increase of ore extracted	Surplus ore potential (SOP)	kg Cu-eq
Fossil resource scarcity	Upper heating value	Fossil fuel potential (FFP)	kg oil-eq
Water use	Increase of water consumed	Water consumption potential (WCP)	m^3 water-eq consumed

Table 22: ReCiPe Midpoint method and impact categories

[74] https://www.rivm.nl/en/life-cycle-assessment-lca/recipe

10 Key assumptions and limitations

All key assumptions have been detailed in this report in the sections on the two nappy types. The following assumptions are also used as part of the sensitivity analysis ((Table 23):

- Number of reusable nappies and pads prewashed and washed together in the washing machine.
- Reuse of nappies e.g., for siblings (second child).
- Tumble dryer use.
- Age at which children starts potty training and therefore prolonged nappy usage.
- Counterfactual – reduced use.

Activity	Reusable Nappy	Disposable Nappy
Nappy manufacturing	Normal manufacturing process were used.	Normal manufacturing process were used.
Delivery to retailer	500km by road 32t articulated lorry.	500km by road 32t articulated lorry.
Collection of disposable nappies from retailer	97% online purchased and delivered 500km in 7.5-16 metric ton lorry[75].	8km by car as part of weekly shopping.
Nappy Liner	89.28% use nappy liners. Of which 26.94% are disposable liners and 62.34% reusable liners. Disposable liners are 1.16g viscose and reusable liners 10g polyester[76].	NA
Disposable nappy liners	Modelled for 100% of disposable nappies being put in the non-recyclable bin and reusables washed and reused[75].	
Faeces disposal	57% toilet, 43% bin for reusables and 100% in bin for disposables. 7 litres of water used per flush[77].	All faeces disposed of in the nappy. Sensitivity analysis on 57% toilet, 43% bin the same as reusable nappies.
Nappy washing	100% of time for all in ones, pocket nappy and 2-part inserts. Every other for 2-part nappy outer. It was assumed that the washing machine was purchased within the past 5 years. 6 nappies were prewashed together with no other items and then received fully as part of a mixed load[75].	NA
Washing behaviour	See tables 17-18[78]	NA
Drying behaviour	24% tumble or heated airer dried (Table 19).	NA
Nappy production waste	It was assumed that the waste generated in China was treated the same was as in the UK.	Nappy waste was treated in Europe.
Faeces	Sewage treatment based upon weight faeces and 5 litres of water. Flushing of toilet for 57% of faeces disposal, 2 flushes a day[79].	100% disposed of with the nappy.
End of life	Nappies retained for reuse or given to relatives or friends. Pads not reused. Final disposal in non-recyclable bin. Collected by 21t municipal truck and driven 20km.	Nappy disposed of in non-recyclable bin. Collected by 21 t municipal truck and driven 20km.

Table 23: Activities and key assumptions

[75] Nappy Alliance
[76] INDA - Association of the Nonwoven Fabrics Industry
[77] Environment Agency 2005
[78] Nappy Alliance
[79] Environment Agency 2005

10.1 Limitations of the methodology

The LCA is modelled using aggregated data sets. Therefore, direct and specific individual product to product comparisons should not be made based upon this report. The data of both the disposable and reusable nappies was critically reviewed for accuracy by Giraffe Innovation Ltd.

As the LCA is based upon aggregated data sets and assumes typical manufacturing, use and disposal routes it does not take into account atypical behaviour such as flushing disposable nappies down the toilet or putting used nappies in the recycling bin. For reusable nappies the limitation is based around the use stage and that the nappies are washed, dried and not ironed as per the manufacturers' guidance. As the energy used for washing and drying reusables is by far the highest impact, using a low energy rated washing machine may have a significant impact up the results.

There are other limitations in the methodology used due to a number of factors. The scope of nappy use was limited to 2.5 years as this is where the majority of babies are out of nappies, but usage of nappies is very dependent upon each child and this LCA takes a limited data set of usage patterns for both reusable and disposable nappies.

No data was available on how the waste generated in the manufacture of the reusable nappies in China was treated and a UK scenario was applied.

11 Results - Impact assessment

Detailed in this section are the results of the Life Cycle Assessment for the disposable and reusable nappies.

11.1 Disposable nappy

The environmental impact results for a disposable nappy across for the first 2.5 years of a child's life are given below (Table 24).

Impact category	Unit	Average
Global warming potential	kg CO_2 eq	456.91
Stratospheric ozone depletion	kg CFC11 eq	2.29E-04
Ionizing radiation	kBq Co-60 eq	42.74
Ozone formation, Human health	kg NOx eq	0.84
Fine particulate matter formation	kg PM2.5 eq	0.44
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.87
Terrestrial acidification	kg SO_2 eq	1.00
Freshwater eutrophication	kg P eq	0.22
Marine eutrophication	kg N eq	0.06
Terrestrial ecotoxicity	kg 1,4-DCB	1879.16
Freshwater ecotoxicity	kg 1,4-DCB	23.91
Marine ecotoxicity	kg 1,4-DCB	32.84
Human carcinogenic toxicity	kg 1,4-DCB	17.38
Human non-carcinogenic toxicity	kg 1,4-DCB	469.62
Land use	m^2 a crop eq	72.21
Mineral resource scarcity	kg Cu eq	0.68
Fossil resource scarcity	kg oil eq	150.50
Water consumption	m^3	6.70
Weight of nappies (2.5 years)	kg	128.36

Table 24: Disposable nappy environmental impacts

As an example of the impacts, the Global warming potential (GWP) (carbon footprint) for disposable nappies for the first 2.5 years of a child's life is 456.91kgCO_2eq which is broken down across its life cycle (Figure 6).

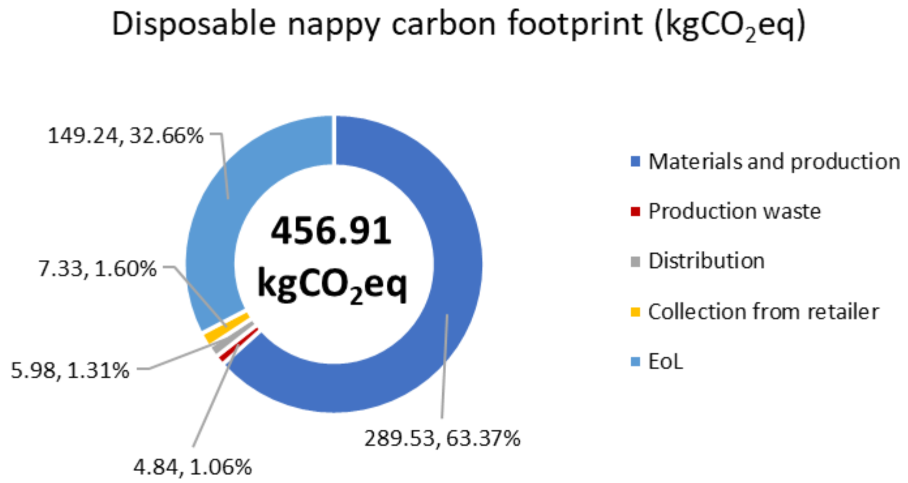

Figure 6: Disposable nappy environmental impact (KgCO_2eq)

The largest environmental impact (CO_2eq) is due to the materials and manufacturing (~63%) followed by the end of life (EOL) treatment (incineration/landfill) of the nappies, faeces and urine (~33%). Previous research[80] which gives a reliable breakdown of the environmental impact across the lifecycle of disposable nappies shows an overall reduction from 626kgCO_2eq to 451.08kgCO_2eq (~28%) (Table 25).

Product life stage	Current disposable nappy KgCO_2eq	2005 disposable nappy KgCO_2eq
Nappy production and distribution	294.76	465.00
Packaging and retail	5.58	27.00
Consumer transport home	7.33	40.00
End of life	149.24	94.00
Total	**456.91 KgCO_2eq**	**626.00 KgCO_2eq**

Table 25: Comparison of the carbon footprint of disposable nappies (2021) against 2005 LCA study

Despite the production of energy from incineration (energy from waste – EfW) the carbon footprint of the end-of-life stage for disposable nappies has increased by over 55kgCO_2eq, accounting for ~32.6% of the total disposable nappy life cycle impact. This is due to an increase in the amount of waste being incinerated in the UK. This merits further investigation into the potential benefits of nascent technologies and infrastructure for disposable nappy recycling.

11.2 Reusable nappy system

The environmental impact results for a reusable nappy system across for the first 2.5 years of a child's life are given below (Table 26).

[80] Life Cycle Assessment of Disposable and Reusable Nappies in the UK, ISBN: 1-84-432427-3

Impact category	Unit	Average
Global warming potential	kg CO_2 eq	344.57
Stratospheric ozone depletion	kg CFC11 eq	4.13E-04
Ionizing radiation	kBq Co-60 eq	88.02
Ozone formation, Human health	kg NOx eq	0.95
Fine particulate matter formation	kg PM2.5 eq	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.97
Terrestrial acidification	kg SO_2 eq	1.30
Freshwater eutrophication	kg P eq	0.17
Marine eutrophication	kg N eq	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	1657.93
Freshwater ecotoxicity	kg 1,4-DCB	28.18
Marine ecotoxicity	kg 1,4-DCB	46.10
Human carcinogenic toxicity	kg 1,4-DCB	19.09
Human non-carcinogenic toxicity	kg 1,4-DCB	478.33
Land use	m^2 a crop eq	61.69
Mineral resource scarcity	kg Cu eq	1.29
Fossil resource scarcity	kg oil eq	112.48
Water consumption	m^3	7.11
Nappy weight	kg	3.22
Water used for washing and flushing	m^3	36.65

Table 26: Reusable nappy system environmental impacts

As an example of the impacts, the Global warming potential (GWP) (carbon footprint) for the reusable nappies for the 2.5 years of use is 344.57kgCO_2eq which is broken down across its life cycle (Figure 7). This shows the relative impacts of the key stages from raw materials, manufacturing, use (washing and drying) and end of life (EOL) disposal.

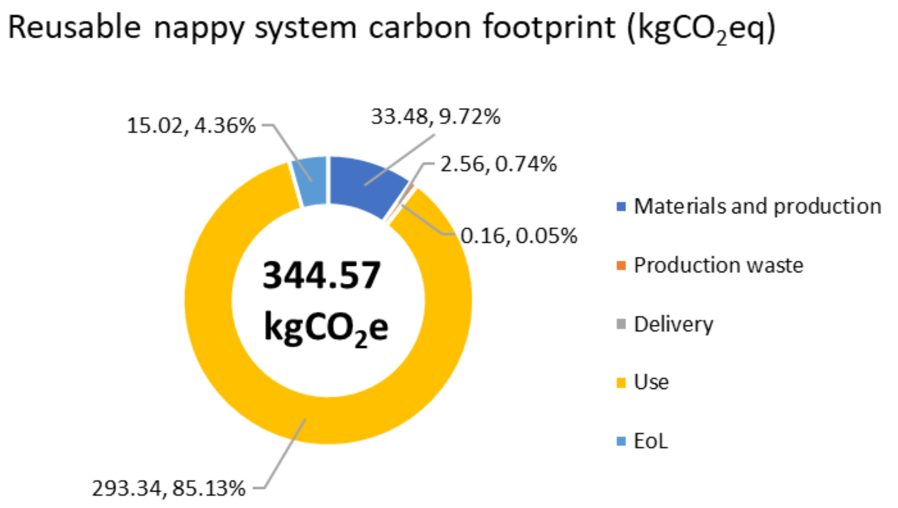

Figure 7: Reusable nappy system - environmental impact (KgCO_2e)

The use phase (energy use in washing and detergent impact) is by far the largest contributory factor to the carbon footprint (~85%). Since the previous LCA study there has been considerable reductions in the material impact of reusable nappies due to the design and configuration of nappy components. For example, a home laundered 'pre folded cotton nappy' indicative to that modelled in the previous LCA study had an overall carbon footprint of 559KgCO_2eq compared to 343.85KgCO_2eq in this study (~38.5% reduction). The materials and liner impact and production were 93kgCO_2eq[81] compared to the current reusable nappy average of 32.91kgCO_2eq (~64% reduction). Furthermore, the reduction in the GWP of the UK's grid energy mix[82], the efficiency of washing machines and tumble dryers has improved, largely driven by three main factors:

- EU legislation[83] [84] on eco design.
- Update to the energy label requirements for washing machines and tumble dryers.
- Introduction of heat pump tumble dryers which are much more energy efficient.

The results clearly show that the washing of the nappies has by far the highest contributing factor to the carbon footprint of the reusable nappy system. Using the 2005 nappy data set (Table 8.13) as a comparison, where there is an overall reduction from 559 kgCO_2e to 344.57kgCO_2e (Table 27).

Product life stage	Current reusable nappy	2005 reusable (Terry) nappy
Nappy and liner materials and production	33.65	93.00
Distribution	2.56	38.00
Home washing and drying	293.34	414.00
End of life including faeces and urine disposal	15.02	16.00
Total	**344.57 KgCO_2eq**	**559.00 KgCO_2eq**

Table 27: Comparison of the carbon footprint of the reusable nappies 2021 and 2005.

11.3 Differences in environmental impact of the nappies

The overall results are shown for the disposable and reusable nappies below along with 'Unit's difference' and 'Main cause for difference' (Table 28). There was minimal difference (less than 10%) between the two nappy systems for 3 of the impact categories. When the results are less than 0.01 scientific notation has been used.

[81] Table 8.13 Life Cycle Assessment of Disposable and Reusable Nappies in the UK, ISBN: 1-84-432427-3
[82] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting (0.47853kgCO_2e to 0.23314kgCO_2e per kWh)
[83] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/tumble-driers_en
[84] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/washing-machines_en https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/about_en

Impact category	Unit	Disposable nappy	Reusable nappy system	Units difference	% Difference	Main cause for difference
Global warming potential	kg CO_2eq	456.91	344.57	112.34	25%	Nappy materials/EOL
Stratospheric ozone depletion	kg CFC11 eq	2.33E-04	4.13E-04	1.79E-04	77%	Energy, detergent, water use and EOL[a]
Ionizing radiation	kBq Co-60 eq	46.01	88.02	42	91%	Electricity use
Ozone formation, Human health	kg NOx eq	0.85	0.95	0.1	12%	Electricity use
Fine particulate matter formation	kg PM2.5 eq	0.45	0.55	0.1	22%	Electricity use
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.89	0.97	0.08	9%	Electricity use
Terrestrial acidification	kg SO_2 eq	1.04	1.3	0.27	26%	Electricity use
Freshwater eutrophication	kg P eq	0.23	0.17	0.06	26%	SAP/PP[c]/EoL
Marine eutrophication	kg N eq	0.06	0.26	0.2	333%	Wastewater treatment/electricity use
Terrestrial ecotoxicity	kg 1,4-DCB	1903.33	1657.93	245.4	13%	Distribution, SAP[b] and EOL
Freshwater ecotoxicity	kg 1,4-DCB	26.16	28.18	2.02	8%	Energy, detergent and water use
Marine ecotoxicity	kg 1,4-DCB	35.61	46.1	10.49	29%	Electricity use/ EOL
Human carcinogenic toxicity	kg 1,4-DCB	18.82	19.09	0.27	1%	Minimal difference
Human non-carcinogenic toxicity	kg 1,4-DCB	486.54	478.33	8.21	2%	Minimal difference
Land use	m^2 a crop eq	73.06	61.69	11.37	16%	Pulp
Mineral resource scarcity	kg Cu eq	0.74	1.29	0.55	74%	Electricity and detergent use
Fossil resource scarcity	kg oil eq	153.16	112.48	40.68	27%	SAP/PP
Water consumption manufacturing use	m^3	7.8	7.11	0.68	9%	Minimal difference

Note [a] end of life, [b] super absorbent polymer, [C] polypropylene

Table 28: Comparison of disposable and reusable nappies environmental impacts (2.5 years)

Although attention is often given to the Global warming potential (CO_2eq) the LCA methodology highlights variation in results across a number of environmental impact categories, given equal significance in this study. The disposable nappies have a higher environmental impact across 7 of the impact categories: Global warming potential (GWP) (KgCO_2eq), Freshwater eutrophication (kg P eq), Terrestrial ecotoxicity (kg 1,4-DCB), Human non carcinogenic toxicity (kg 1,4-DCB), Land use (m^2 a crop eq), Fossil resource scarcity (kg oil eq), and water use in manufacturing (m^3). The production of the super absorbent polymer (SAP) and EoL treatment were key contributors to the difference, accounting for up to ~69% of these impacts. The weight of disposable nappies (128.36Kg) compared to reusable nappies (3.22Kg), end-of-life incineration and landfilling of the disposable nappies was also a major contributor to these impacts.

Reusable nappies have a higher environmental impact across 11 of the impact categories: Stratospheric ozone depletion (kg CFC11 eq), Ionizing Radiation (kBq Co-60 eq), Ozone formation-human health (kg NOx eq), Fine particulate matter formation (kg PM2.5 eq), Ozone Formation-terrestrial ecosystems (kg NOx eq), Terrestrial acidification (kg SO_2 eq), Marine eutrophication (kg N eq), Freshwater ecotoxicity (kg 1,4-DCB), Marine ecotoxicity (kg 1,4-DCB), human Carcinogenic toxicity (kg 1,4-DCB), Mineral resource scarcity (kg Cu eq) plus Water Consumption (flushing of toilet and washing machine use) (m^3). The main contributing factors (aside from materials) is electricity used in pre-washing, washing and drying operations (~438kWh), detergent use and the treatment of wastewater (toilet flushing and washing machine). Over the course of the 2.5 year period 36.56m^3 of water is used in washing the reusable nappies and disposing flushing faeces down the toilet.

12 Sensitivity analysis

This section describes the sensitivity analysis carried out on variables that will impact on the total environmental impacts of the results. Sensitivity analysis is a significant tool for studying the robustness of results and their sensitivity to uncertainty factors in Life Cycle Assessment (LCA). It highlights the most important set of model parameters to enhance interpretation of results.

Key variables and assumptions have been tested to determine their influence on the results of the inventory analysis and impact assessment. Due to the behavioural differences in the use of nappies such as extended potty training as well as end of life treatment the following have been evaluated:

- Different usage models based upon extended potty training.
- Reduced nappy use due to earlier potty training (counterfactual).
- Potential energy recovery from incineration (energy from waste) of the nappies at end of life.
- Methane generation from landfill – disposable nappies.
- The effect of the faeces being flushed of disposable nappies prior to disposal.
- The reuse of the nappies is modelled for an additional child's use.
- Washing and drying off nappies.

12.1 Extended nappy use scenario

The goal of this study is to determine the cumulative environmental impact of the use of a disposable and a reusable nappy system for the first 2.5 years of a child's life. Consumer research[85] has indicated that since the last LCA study, children are being potty trained at a later stage in their development. A sensitivity analysis was therefore undertaken to include the potential environmental impact of extended use of nappies (delay in potty training).

In order to take into account, the theory that children are taking longer to be potty trained a YouGov survey was carried out in 2021. This showed that children are slower at potty training than in the early 2000s. It also highlighted a larger difference between reusable and disposable nappy use. The results also showed that at 2.5 years 37% of babies using disposables and 35% of babies using reusable nappies were still in nappies. This is an increase of 19.4% and 17.4% respectively over the previous LCA studies. The sensitivity analysis shows the impact this has on the nappy usage up to 2.5 years for disposable (Table 29) and reusable nappies (Table 30). This shows an increase in nappy usage up to 2.5 years.

Age	Average nappies per day	Children wearing nappies	Nappies used
0 to 3 months	7	100%	638.80
3 months to 6 months	7	99%	632.40
6 to 12 months	6	96.%	1051.20
12 to 18 months	6	84%	919.80
18 months to 24 months	5	66%	602.30
24 months to 30 months	5	37%	310.60
Total			**4155**
Average nappies per day			**4.553**

Table 29: Changes to disposable nappy use

[85] You Gov – Children Potty Training (unpublished). UK18 sample@ 30th March to 7th April 2021. Commissioned by Bambino Mio. n= 728

Age	Average nappies per day	Children wearing nappies	Nappies used
0 to 3 months	9	100%	821.26
3 months to 6 months	8	93%	678.91
6 to 12 months	7	86%	1098.66
12 to 18 months	6	77%	843.16
18 months to 24 months	6	63%	689.86
24 months to 30 months	6	35%	383.25
Total			**4515.10**
Average nappies per day			**4.95**

Table 30: Changes to reusable nappy use

This shows the Global warming potential (CO_2eq) would increase by 9% for disposable nappies and 3% for reusable nappies. The updated environmental impacts at 2.5 years are given below (Table 31). The highest impact in each category is highlighted in yellow.

Impact category	Unit	Current disposable average	Extended use scenario	Current reusable average	Extended use scenario
Global warming potential	kg CO_2 eq	456.91	500.12	344.57	354.62
Stratospheric ozone depletion	kg CFC11 eq	2.33E-04	2.55E-04	4.13E-04	4.24E-04
Ionizing radiation	kBq Co-60 eq	46.01	50.37	88.02	90.82
Ozone formation, Human health	kg NOx eq	0.85	0.94	0.95	0.98
Fine particulate matter formation	kg PM2.5 eq	0.45	0.49	0.55	0.57
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.89	0.97	0.97	1.00
Terrestrial acidification	kg SO_2 eq	1.04	1.13	1.30	1.34
Freshwater eutrophication	kg P eq	0.23	0.25	0.17	0.18
Marine eutrophication	kg N eq	0.06	0.07	0.26	0.27
Terrestrial ecotoxicity	kg 1,4-DCB	1903.33	2083.33	1657.93	1708.39
Freshwater ecotoxicity	kg 1,4-DCB	26.16	28.63	28.18	29.05
Marine ecotoxicity	kg 1,4-DCB	35.61	38.98	46.10	47.22
Human carcinogenic toxicity	kg 1,4-DCB	18.82	20.60	19.09	19.63
Human non-carcinogenic toxicity	kg 1,4-DCB	486.54	532.56	478.33	492.83
Land use	m^2 a crop eq	73.06	79.96	61.69	63.15
Mineral resource scarcity	kg Cu eq	0.74	0.81	1.29	1.32
Fossil resource scarcity	kg oil eq	153.16	167.64	112.48	115.81
Water consumption (manufacturing)	m^3	7.80	8.53	7.11	7.24
Water consumption (Washing nappies and flushing faeces)	M^3			3.22	3.32
Weight	kg	128.36	140.51	36.65	37.84

Table 31: Environmental impact of extended use.

The results show that for the extended use scenario, the disposable nappies have a higher Global warming potential (CO_2e), but reusable nappies have a higher impact in 10 areas. This are mainly due to the electricity, water and detergent use. The main causes for the differences between the two types of nappies are:

- The amount of materials used in the disposable materials compared to the reusables.
- Electricity used for prewashing, washing and tumble drying the reusable nappies.
- Water used by the washing machine and toilet flushing.
- The treatment of the wastewater and detergent.

12.2 Reduced nappy use scenario

Although, consumer research[86] has indicated that since the last LCA study, children are being potty trained at a later stage in their development the sensitivity also shows the impact should a change in behaviour also lead to a reduced use of nappies (counterfactual – accelerated potty training) and the overall environmental impact for the first 2.5 years of a child's life.

In order to evaluate if a reduction in the reliance on nappies at 2.5 years by the same overall amount that it was increased by in the extended use scenario. The following usage patterns were modelled (Tables 32 and 33).

Age	Average nappies per day	Percentage of children wearing nappies	Nappies used
0 to 3 months	7	100.0%	638.80
3 months to 6 months	7	100.0%	638.80
6 to 12 months	6	95.7%	1047.90
12 to 18 months	6	82.8%	906.70
18 months to 24 months	5	43.8%	399.70
24 months to 30 months	5	0.0%	0.0
Total			**3632**
Average nappies per day			**3.980**

Table 32: Changes to disposable nappy use

Child age	Average nappies per day	Percentage of children wearing nappies	Nappies used
0 to 3 months	9	100.0%	821.30
3 months to 6 months	8	100.0%	730.00
6 to 12 months	7	95.7%	1222.60
12 to 18 months	6	82.8%	906.70
18 months to 24 months	6	45.6%	499.30
24 months to 30 months	6	0.2%	2.20
Total			**4182**
Average nappies per day			**4.583**

Table 33: Changes to reusable nappy use

The result of this analysis is given in given below (Table 34). The highest impact in each category in the reduced scenario is highlighted in yellow.

Impact category	Unit	Current disposable average	Reduced disposable use scenario	Current reusable average	Reduced reusable use scenario
Global warming potential	kg CO_2 eq	456.91	437.14	344.57	334.51
Stratospheric ozone depletion	kg CFC11 eq	2.33E-04	2.23E-04	4.13E-04	4.01E-04
Ionizing radiation	kBq Co-60 eq	46.01	44.02	88.02	85.21
Ozone formation, Human health	kg NOx eq	0.85	0.82	0.95	0.92
Fine particulate matter formation	kg PM2.5 eq	0.45	0.43	0.55	0.54
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.89	0.85	0.97	0.94
Terrestrial acidification	kg SO_2 eq	1.04	0.99	1.30	1.27
Freshwater eutrophication	kg P eq	0.23	0.22	0.17	0.17

[86] You Gov – Children Potty Training (unpublished). UK18 sample@ 30th March to 7th April 2021. Commissioned by Bambino Mio. n= 728

Marine eutrophication	kg N eq	0.06	0.06	0.26	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	1903.33	1821.01	1657.93	1607.47
Freshwater ecotoxicity	kg 1,4-DCB	26.16	25.03	28.18	27.32
Marine ecotoxicity	kg 1,4-DCB	35.61	34.07	46.10	44.98
Human carcinogenic toxicity	kg 1,4-DCB	18.82	18.01	19.09	18.56
Human non-carcinogenic toxicity	kg 1,4-DCB	486.54	465.50	478.33	463.84
Land use	m^2 a crop eq	73.06	69.90	61.69	60.23
Mineral resource scarcity	kg Cu eq	0.74	0.70	1.29	1.25
Fossil resource scarcity	kg oil eq	153.16	146.53	112.48	109.15
Water consumption (manufacturing)	m^3	7.80	7.46	7.11	6.99
Water consumption (Washing nappies and flushing faeces)	m^3			3.22	3.11
Weight	kg	128.36	126.41	36.65	35.45

Table 34: Reduce use scenario results

The results show that for the reduced use scenario, the disposable nappies have a higher Global warming potential, Freshwater eutrophication, Terrestrial ecotoxicity, Human carcinogenic and non-carcinogenic toxicity, Fossil resource scarcity and Water use during manufacturing. Reusable nappies have a higher impact in all of the other 12 other areas (highlighted yellow). This are mainly due to the electricity use, detergent and water use.

12.3 Energy recovery at end of life

A sensitivity analysis was undertaken on the potential energy recovery from incineration (energy from waste) of the nappies at end of life. As the LCA modelling is carried out using the 'Cut off' model the energy recovered is not attributed to the nappies as they are outside of the boundary system. However, as part of a sensitivity analysis the potential environmental benefits of the energy recovered have been calculated.

12.3.1 Disposable nappies

Based upon the data outlined in the LCA the weight of nappies incinerated with energy recovery (based upon percentage of incinerators meeting the R1 rating of 0.6) in the UK was 34.88kg (26.4% of 132.12kg). The potential energy recovered = 34.88*7.2MJ=251.137MJ = 69.76kWh. The potential reduction in environmental impact taking into account the energy produced from incineration is shown below (Table 35). The highest impact in each category is highlighted in yellow.

Impact category	Unit	Reduction due to energy recovery from incineration	Revised total impact of disposable nappies	Current reusable Nappy average
Global warming potential	kg CO_2 eq	23.55	433.36	344.57
Stratospheric ozone depletion	kg CFC11 eq	1.21E-05	2.21E-04	4.13E-04
Ionizing radiation	kBq Co-60 eq	14.90	31.11	88.02
Ozone formation, Human health	kg NOx eq	0.04	0.81	0.95
Fine particulate matter formation	kg PM2.5 eq	0.02	0.43	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.04	0.85	0.97
Terrestrial acidification	kg SO_2 eq	0.05	0.99	1.30
Freshwater eutrophication	kg P eq	4.23E-03	0.22	0.17
Marine eutrophication	kg N eq	5.42E-04	0.06	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	15.94	1887.39	1657.93
Freshwater ecotoxicity	kg 1,4-DCB	0.59	25.57	28.18
Marine ecotoxicity	kg 1,4-DCB	0.81	34.80	46.10
Human carcinogenic toxicity	kg 1,4-DCB	0.89	17.93	19.09
Human non-carcinogenic toxicity	kg 1,4-DCB	12.42	474.12	478.33
Land use	m2a crop eq	1.71	71.35	61.69
Mineral resource scarcity	kg Cu eq	0.03	0.71	1.29

Fossil resource scarcity	kg oil eq	8.13	145.03	112.48
Water consumption	m^3	0.11	7.69	7.11

Table 35: Disposable nappies potential reduction for energy recovery from incineration at EoL

The results of energy recovery for the disposable nappies shows that they still have a higher Global warming potential and are also higher in a further 5 impact categories. However, the overall Global warming potential is reduced from 456.91KgCO_2eq to 433.36KgCO_2eq.

12.3.2 Reusable nappies

Based upon the data the weight of nappies incinerated with energy recovery at end of life in the UK for nappies is 0.78kg (26.4% of 2.95kg). The potential energy recovered would be 0.78*7.2 =5.607MJ=1.56kWh, assuming that the nappies are disposed of when soiled and wet. The potential reduction in environmental impact is shown below (Table 36). The highest impact in each category is highlighted in yellow.

Impact category	Unit	Reduction due to energy recovery from incineration	Revised total impact of reusable nappies	Current disposable nappy average
Global warming potential	kg CO_2 eq	0.53	344.04	456.91
Stratospheric ozone depletion	kg CFC11 eq	2.71E-07	4.12E-04	2.33E-04
Ionizing radiation	kBq Co-60 eq	0.33	87.69	46.01
Ozone formation, Human health	kg NOx eq	8.98E-04	0.95	0.85
Fine particulate matter formation	kg PM2.5 eq	3.76E-04	0.55	0.45
Ozone formation, Terrestrial ecosystems	kg NOx eq	9.08E-04	0.97	0.89
Terrestrial acidification	kg SO_2 eq	1.10E-03	1.30	1.04
Freshwater eutrophication	kg P eq	9.45E-05	0.17	0.23
Marine eutrophication	kg N eq	1.21E-05	0.26	0.06
Terrestrial ecotoxicity	kg 1,4-DCB	0.36	1657.57	1903.33
Freshwater ecotoxicity	kg 1,4-DCB	0.01	28.17	26.16
Marine ecotoxicity	kg 1,4-DCB	0.02	46.08	35.61
Human carcinogenic toxicity	kg 1,4-DCB	0.02	19.07	18.82
Human non-carcinogenic toxicity	kg 1,4-DCB	0.28	478.05	486.54
Land use	m2a crop eq	0.04	61.65	73.06
Mineral resource scarcity	kg Cu eq	6.63E-04	1.29	0.74
Fossil resource scarcity	kg oil eq	0.18	112.30	153.16
Water consumption	m^3	2.3E-3	7.11	7.80

Table 36: Reusable nappies potential reduction from energy recovery due to incineration at EoL

The results of energy recovery for the reusable nappies shows that they still have a lower Global warming potential but are higher 12 other areas. The results of energy recovery for the reusable nappies shows a reduction in Global warming potential from 344.57KgCO_2eq to 344.04KgCO_2eq. The two sets of results are compared below (Table 37).

Impact category	Unit	Revised disposable nappy impacts	Revised reusable nappy impacts
Global warming potential	kg CO_2 eq	433.36	344.04
Stratospheric ozone depletion	kg CFC11 eq	2.21E-04	4.12E-04
Ionizing radiation	kBq Co-60 eq	31.11	87.69
Ozone formation, Human health	kg NOx eq	0.81	0.95

Fine particulate matter formation	kg PM2.5 eq	0.43	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.85	0.97
Terrestrial acidification	kg SO_2 eq	0.99	1.30
Freshwater eutrophication	kg P eq	0.22	0.17
Marine eutrophication	kg N eq	0.06	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	1887.39	1657.57
Freshwater ecotoxicity	kg 1,4-DCB	25.57	28.17
Marine ecotoxicity	kg 1,4-DCB	34.80	46.08
Human carcinogenic toxicity	kg 1,4-DCB	17.93	19.07
Human non-carcinogenic toxicity	kg 1,4-DCB	474.12	478.05
Land use	m2a crop eq	71.35	61.65
Mineral resource scarcity	kg Cu eq	0.71	1.29
Fossil resource scarcity	kg oil eq	145.03	112.30
Water consumption	m^3	7.69	7.11

Table 37: Disposable and reusable nappies potential reduction from energy recovery due to incineration at EoL

Comparing the results of energy recovery shows that reusable nappies still have a lower Global warming potential but are higher 12 environmental impact categories.

12.4 Methane generation from landfill - disposable nappies

There is potential for the biodegradable fluff, faeces and urine to degrade in landfill and produce methane which if captured could be used for energy production. As the LCA modelling is carried out using the 'Cut off' model the energy recovered from methane capture is not attributed to the nappies as they are outside of the boundary system. However, as part of a sensitivity analysis the potential environmental benefits of the energy recovered have been calculated. There is also high level of uncertainty in these results as not all methane release will be captured, and the results present in this section assume 100% of the captured methane is converted to energy.

A report[87] on landfill gasses calculate that 112m^3 of methane could be released in landfill per tonne of disposable nappies. There is potential to generate a maximum of 3.163m^3 of methane on the 28.24kg of nappies going to landfill (22% of 132.12kg of nappies going to landfill). Based upon a capture and power usage rate of 51%[88], this would generate 16.13kWh (10kWh per m^3 of methane). However, burning methane also release CO_2 to the atmosphere and 44% of the remaining methane (1.39m^3) is either flared or not captured.

The LCA modelling has already accounted for the methane in landfill without capture and utilisation. Therefore, the difference in results in this sensitivity analysis includes methane recovery and combustion to generate energy. An adjustment for the end-of-life impact is the energy generated minus methane combustion impact minus released to air impact.

Based upon this data, the environmental impact of the disposable nappies would reduce by the equivalent of 16.13kWh of grid electricity as given below (Table 38). The highest impact in each category is highlighted in yellow.

Impact category	Unit	Reduction due to methane capture from landfill	Revised total impact (disposable)	Current reusable average
Global warming potential	kg CO_2 eq	3.10	453.81	344.57

[87] Max J. Krause, Giles W. Chickering & Timothy G. Townsend (2016)
Translating landfill methane generation parameters among first-order decay models, Journal of the Air & Waste Management Association, 66:11, 1084-1097

[88] Table A 3.5.4 of the national inventory annex -https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2106091119_ukghgi-90-19_Annex_Issue_2.pdf

Stratospheric ozone depletion	kg CFC11 eq	2.73E-07	2.33E-04	4.13E-04
Ionizing radiation	kBq Co-60 eq	3.19	42.82	88.02
Ozone formation, Human health	kg NOx eq	2.88E-03	0.85	0.95
Fine particulate matter formation	kg PM2.5 eq	2.04E-03	0.45	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	2.91E-03	0.89	0.97
Terrestrial acidification	kg SO_2 eq	5.95E-03	1.03	1.30
Freshwater eutrophication	kg P eq	7.27E-04	0.23	0.17
Marine eutrophication	kg N eq	8.28E-05	0.06	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	1.99	1901.34	1657.93
Freshwater ecotoxicity	kg 1,4-DCB	0.07	26.09	28.18
Marine ecotoxicity	kg 1,4-DCB	0.10	35.51	46.10
Human carcinogenic toxicity	kg 1,4-DCB	0.03	18.79	19.09
Human non-carcinogenic toxicity	kg 1,4-DCB	1.69	484.85	478.33
Land use	m2a crop eq	0.19	72.87	61.69
Mineral resource scarcity	kg Cu eq	7.5E-03	0.73	1.29
Fossil resource scarcity	kg oil eq	1.56	151.60	112.48
Water consumption	m^3	0.01	7.79	7.11

Table 38: Landfill energy from methane capture and utilisation

The results shows that the disposable nappies still have a higher Global warming potential, and it is higher than the reusable nappies in a further 5 impact categories.

12.5 Washing of nappies

The highest impact of the reusable nappies is the washing phase. The current model uses 6 nappy items being prewashed and then washed together in a mixed load. This sensitivity analysis reviews the changes in impact if 12 nappy items were washed together. This would halve the number of washing and drying loads but double the room taken up in the washing machine and tumble dryer resulting in the same energy and water use as the 6 nappy items.

The same can be applied to 15 nappy items being washed together. The number of washing and drying loads would be reduced by 60% but the capacity used by the items would increase by same amount resulting in the same energy and water use per nappy as the 6 nappy items being washed together.

The only way to decrease the energy and water use would be to increase the overall load in the prewash or main wash in the washing machine and therefore the nappies would be a smaller fraction of this load. The prewashing of 12 items together will decrease the carbon footprint by between 2% and 3% of the of the reusable nappy systems, but this could potentially leave the parent short of clean dry nappies to use.

12.6 Drying of nappies

There is some uncertainty in the use of tumble dryers as the analyses is based upon a survey of only 677 reusable nappy users and the type/model of tumble dryer was not reported on.

The tumble dryers with heat pump technology use less than 50% of the energy of a conventional condensing dryer and are increasingly popular due to their energy savings but are significantly more expensive than condensing and vented tumble dryers[89]. The LCA uses a split of 50:50 of condensing and heat pump type tumble dryers. Tumble drying currently only accounts for less than 6% of the total impact. If the use of a tumble dryer was doubled the total carbon footprint would increase by ~1.2%. The highest increase in environmental impact will be ionising radiation at ~8%, due to the increase in electricity use (Figure 8).

[89] Review of retail prices by Giraffe innovation (February/March 2021).

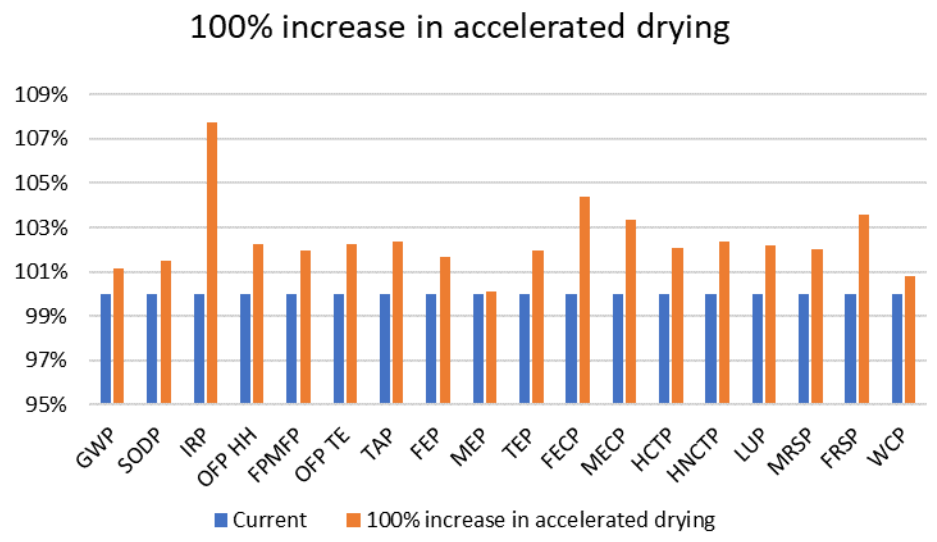

Figure 8: Environmental impact of reusable nappy increase in tumble dryer usage

The results (Table 39) show the highest impact in each category highlighted in yellow.

Impact category	**Unit**	**Current disposable nappy average**	**Current reusable nappy average**	**Increased drying scenario (reusable nappies)**
Global warming potential	kg CO_2 eq	456.91	344.57	348.61
Stratospheric ozone depletion	kg CFC11 eq	2.33E-04	4.13E-04	4.19E-04
Ionizing radiation	kBq Co-60 eq	46.01	88.02	94.82
Ozone formation, Human health	kg NOx eq	0.85	0.95	0.97
Fine particulate matter formation	kg PM2.5 eq	0.45	0.55	0.56
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.89	0.97	0.99
Terrestrial acidification	kg SO_2 eq	1.04	1.30	1.33
Freshwater eutrophication	kg P eq	0.23	0.17	0.18
Marine eutrophication	kg N eq	0.06	0.26	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	1903.33	1657.93	1690.84
Freshwater ecotoxicity	kg 1,4-DCB	26.16	28.18	29.42
Marine ecotoxicity	kg 1,4-DCB	35.61	46.10	47.65
Human carcinogenic toxicity	kg 1,4-DCB	18.82	19.09	19.48
Human non-carcinogenic toxicity	kg 1,4-DCB	486.54	478.33	489.55
Land use	m^2 a crop eq	73.06	61.69	63.04
Mineral resource scarcity	kg Cu eq	0.74	1.29	1.31
Fossil resource scarcity	kg oil eq	153.16	112.48	116.52
Water consumption (manufacturing)	m^3	7.80	7.11	7.17

Table 39: Drying of nappies scenario results

The results of doubling the number of reusable nappies being tumble dried will increase the overall impact, but they still have a lower Global warming potential but remain higher 12 other impact categories.

12.7 Reuse of nappies for second child

The reusable nappies should be suitable for reuse by a second child. This will extend the use of the liners for a further 2.5 years before needing replacement[90]. The following (Figure 9) (Table 40) shows the reduction in the impact of the materials if they were allocated over second child's use cycle. This would, however, need further validation based on actual behaviour as there is likely to be some attrition in the products due to wear in the first use cycle. The highest impact in each category for second child use is highlighted in yellow (Table 40).

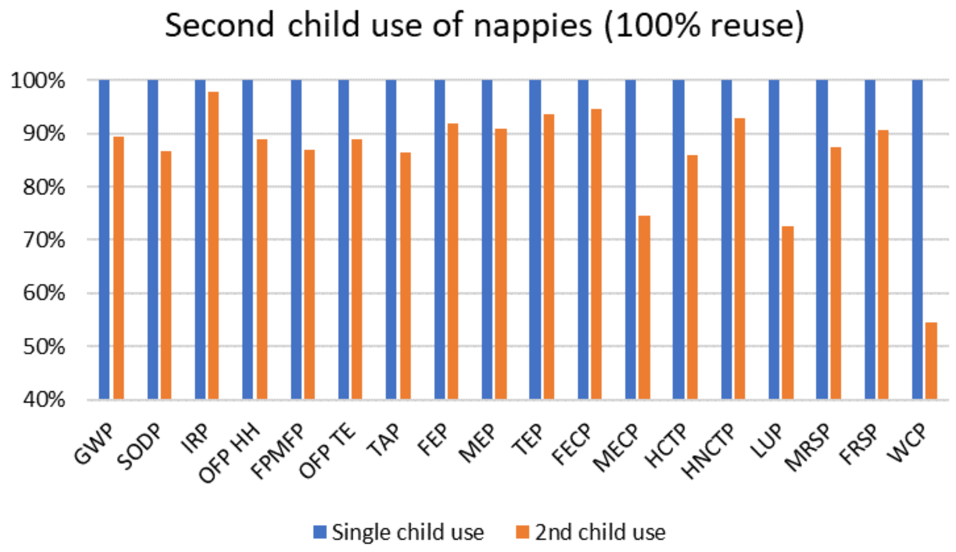

Figure 9: Environmental impacts of Reusable nappy second child use of nappies

Impact category	Unit	Current disposable nappy average	Current reusable nappy average	2nd child 100% reuse scenario
Global warming potential	kg CO_2 eq	456.91	344.57	308.52
Stratospheric ozone depletion	kg CFC11 eq	2.33E-04	4.13E-04	3.58E-04
Ionizing radiation	kBq Co-60 eq	46.01	88.02	86.04
Ozone formation, Human health	kg NOx eq	0.85	0.95	0.84
Fine particulate matter formation	kg PM2.5 eq	0.45	0.55	0.48
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.89	0.97	0.86
Terrestrial acidification	kg SO_2 eq	1.04	1.30	1.13
Freshwater eutrophication	kg P eq	0.23	0.17	0.16
Marine eutrophication	kg N eq	0.06	0.26	0.24
Terrestrial ecotoxicity	kg 1,4-DCB	1903.33	1657.93	1551.77
Freshwater ecotoxicity	kg 1,4-DCB	26.16	28.18	26.65
Marine ecotoxicity	kg 1,4-DCB	35.61	46.10	34.32
Human carcinogenic toxicity	kg 1,4-DCB	18.82	19.09	16.40
Human non-carcinogenic toxicity	kg 1,4-DCB	486.54	478.33	444.86
Land use	m^2 a crop eq	73.06	61.69	44.73
Mineral resource scarcity	kg Cu eq	0.74	1.29	1.13
Fossil resource scarcity	kg oil eq	153.16	112.48	102.09
Water consumption (manufacturing)	m^3	7.80	7.11	3.88

Table 40: 100% of nappies reused by 2nd chid scenario results

[90] Based upon discussions with Nappy Alliance members.

The most significant changes were the Global warming potential which reduced from 344.57 $kgCO_2e$ to 308.52$kgCO_2e$ a 10.46% reduction. Water consumption reduced by 45.5% due to the high amount of mains water used in the nappy's manufacturing. Terrestrial acidification reduced by 13.49% and Fine particulate matter formation by 13%.

There is a high level of uncertainty as to how used liners are disposed of. However, the impact of these items including disposal is less than 3% of the total of the average reusable nappy system. Therefore, any changes to the disposable methods will not have any significant impact in the overall results.

Due to the 'wear and tear' of the nappies over its extended use (5 years) there is potential for the nappies to be too worn and therefore replaced. Therefore, the following (Table 41) shows the impact of reusing 70% of the nappies for a second child and buying 30% new replacement nappies. The highest impact in each category for second child use is highlighted in yellow (Table 40).

Impact category	Unit	Current disposable average	Current reusable average	2nd child 70% reuse scenario
Global warming potential	kg CO_2 eq	456.91	344.57	322.17
Stratospheric ozone depletion	kg CFC11 eq	2.33E-04	4.13E-04	3.77E-04
Ionizing radiation	kBq Co-60 eq	46.01	88.02	86.90
Ozone formation, Human health	kg NOx eq	0.85	0.95	0.88
Fine particulate matter formation	kg PM2.5 eq	0.45	0.55	0.51
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.89	0.97	0.90
Terrestrial acidification	kg SO_2 eq	1.04	1.30	1.19
Freshwater eutrophication	kg P eq	0.23	0.17	0.16
Marine eutrophication	kg N eq	0.06	0.26	0.25
Terrestrial ecotoxicity	kg 1,4-DCB	1903.33	1657.93	1594.99
Freshwater ecotoxicity	kg 1,4-DCB	26.16	28.18	27.25
Marine ecotoxicity	kg 1,4-DCB	35.61	46.10	39.88
Human carcinogenic toxicity	kg 1,4-DCB	18.82	19.09	17.56
Human non-carcinogenic toxicity	kg 1,4-DCB	486.54	478.33	458.09
Land use	m^2 a crop eq	73.06	61.69	52.24
Mineral resource scarcity	kg Cu eq	0.74	1.29	1.19
Fossil resource scarcity	kg oil eq	153.16	112.48	106.10
Water consumption (manufacturing)	m^3	7.80	7.11	4.91

Table 41: 70% of nappies reused by 2nd child scenario results

The most significant change in results is the Global warming potential which reduced from 344.57 $kgCO_2e$ to 322.17$kgCO_2e$ a 6.5% reduction. Water consumption reduced by 30.9% due to the high amount of mains waster used in the nappy's manufacturing. Terrestrial acidification reduced by 8.5% and Fine particulate matter formation by 8%.

12.8 Flushing faeces off disposable nappies

Due to lack of data, it was assumed that the faeces are typically left on the disposable nappy when it was disposed of. The impact of the treatment of faeces compared to flushing it down the toilet is given below (Table 42). A revised environmental impact is based upon 57% of faeces flushed down the toilet, which is the same as the reusable nappies. Therefore 43% would be landfilled or incinerated. The revised impact for faeces disposal would be 43% of current impact of faces disposal, plus the impact of 57% of flushing faeces down the toilet.

The results show the current and revised end of life impact and the revised total impact with the highest impact in each category highlighted in yellow.

Impact category	Unit	Current EOL impact	Revised EOL impact	Impact reduction	Revised total impact	Current reusable nappies
Global warming potential	kg CO_2 eq	149.24	136.69	12.55	444.35	344.57
Stratospheric ozone depletion	kg CFC11 eq	5.49E-05	5.90E-05	-4.10E-06	2.37E-04	4.13E-04
Ionizing radiation	kBq Co-60 eq	-0.58	-1.67	1.09	44.92	88.02
Ozone formation, Human health	kg NOx eq	0.13	0.13	-1.34E-03	0.86	0.95
Fine particulate matter formation	kg PM2.5 eq	0.03	0.03	-2.96E-03	0.46	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.14	0.14	-1.35E-03	0.89	0.97
Terrestrial acidification	kg SO_2 eq	0.07	0.07	-0.01	1.04	1.30
Freshwater eutrophication	kg P eq	0.05	0.03	0.02	0.21	0.17
Marine eutrophication	kg N eq	0.05	0.07	-0.02	0.09	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	292.34	293.84	-1.50	1904.83	1657.93
Freshwater ecotoxicity	kg 1,4-DCB	12.76	12.76	0.00	26.16	28.18
Marine ecotoxicity	kg 1,4-DCB	17.59	17.60	-0.01	35.62	46.10
Human carcinogenic toxicity	kg 1,4-DCB	2.19	2.48	-0.28	19.11	19.09
Human non-carcinogenic toxicity	kg 1,4-DCB	200.59	207.46	-6.87	493.42	478.33
Land use	m^2 a crop eq	0.27	0.10	0.17	72.89	61.69
Mineral resource scarcity	kg Cu eq	0.03	0.05	-0.02	0.76	1.29
Fossil resource scarcity	kg oil eq	4.70	4.29	0.41	152.74	112.48
Water consumption	m^3	0.14	-3.61	-3.61	4.05	7.11

Table 42: Flushing faeces off disposable nappies

Flushing of the faeces from the disposable nappy will reduce the Global warming potential by 2.7% and Ionizing radiation by 2%. However, some impacts will increase such as Marine eutrophication by 38% and Mineral resource scarcity by 3%. The former is due to increased water use.

12.9 Retail and consumer transport

The retail and consumer transport impacts are minimal and any changes to these will have little impact on the overall results.

12.10 Conclusions of the sensitivity analysis

The sensitivity analysis is a useful method to test key assumptions and variable used in this LCA study. It is acknowledged that atypical user behaviour could have an impact on these results and further consumer research could further insight.

Overall, across the various sensitivities applied to the data the changes to usage pattern (e.g., extended nappy use) does not significantly alter the environmental impact categories where each nappy type has a higher or lower impact although it does increase the Global warming potential (CO_2eq) by 9% for disposable nappies and 3% for reusable nappies.

Energy recovery and methane capture at end of life have a minimal impact on the overall results and this does not alter the main differences in the environmental impact categories between reusable and disposable nappies.

Increasing the number of nappies washed together with other items does not have a material impact the overall results. However, the prewashing of 12 nappies together will decrease the carbon footprint by between 2% and 3% of the of the reusable nappy systems.

The results of doubling the number of reusable nappies being tumble dried will increase the overall impact. However, reusable nappies will still have a lower GWP than disposable nappies.

Reuse of nappies for a second child has a more significant impact with the GWP reducing by ~6.5%, Terrestrial acidification reduced by ~ 8.5% and Fine particulate matter formation by 8%. All of the other environmental impact categories would reduce by at least 3.8%.

Flushing of the faeces from the disposable nappy will reduce the Global warming potential by 2.7% and Ionizing radiation by 2%. However, some impacts will increase such as Marine eutrophication by 38% and Mineral resource scarcity by 3%. The former is due to increased water use.

13 Conclusions

Nappies play a key role in a child's health and well-being, as well as ensuring convenient hygiene for the whole family. They are considered a necessity for a child in their early years particularly the first 2.5 years of life. This report provides the results from an environmental analysis across 18 environmental impact categories using Life Cycle Assessment (LCA) methodology and shows the cumulative environmental impact of the use of a disposable and a reusable nappy system for the first 2.5 years of a child's life.

The previous complete LCA study on disposable and reusable (cloth) nappies showed there is "*little or no difference between the environmental impact of reusable and disposable nappies*". This updated LCA study now shows there are differences in environmental impact between nappy formats. However, as the previous studies in 2005 and 2008 used different life cycle indicators, LCA system and modelling methodology direct comparisons with the previous reports should be done with caution.

As an example of the impacts, the Global warming potential (GWP) (carbon footprint) for disposable nappies for the first 2.5 years of a child's life is 456.91kgCO_2eq. This shows a ~27% reduction in the carbon footprint (CO_2eq) since the previous report. Since the previous LCA study there has been considerable reductions in the material impact of reusable nappies due to the design and configuration of nappy components. The reusable nappy carbon footprint shows a ~38.5% reduction compared to a 'flat cloth' (Terrys) modelled in the previous study. As an example of the impacts, the Global warming potential (GWP) (carbon footprint) for the reusable nappies for the 2.5 years of use is 344.57kgCO_2eq.

Although attention is often given to the Global warming potential (CO_2eq) the LCA methodology highlights variation in results across 18 environmental impact categories, all given equal significance in this study. The disposable nappies have a higher environmental impact across 7 of the impact categories: Global warming potential (GWP) (KgCO_2eq), Freshwater eutrophication (kg P eq), Terrestrial ecotoxicity (kg 1,4-DCB), Human non carcinogenic toxicity (kg 1,4-DCB), Land use (m^2 a crop eq), Fossil resource scarcity (kg oil eq), and water use in manufacturing (m^3). The production of the super absorbent polymer (SAP) and EoL treatment were key contributors to the difference, accounting for up to ~69% of these impacts. The weight of disposable nappies (128.36Kg) compared to reusable nappies (3.22Kg), end-of-life incineration and landfilling of the disposable nappies was also a major contributor to these impacts.

Reusable nappies have a higher environmental impact across 11 of the impact categories: Stratospheric ozone depletion (kg CFC11 eq), Ionizing Radiation (kBq Co-60 eq), Ozone formation-human health (kg NOx eq), Fine particulate matter formation (kg PM2.5 eq), Ozone Formation-terrestrial ecosystems (kg NOx eq), Terrestrial acidification (kg SO_2 eq), Marine eutrophication (kg N eq), Freshwater ecotoxicity (kg 1,4-DCB), Marine ecotoxicity (kg 1,4-DCB), human Carcinogenic toxicity (kg 1,4-DCB), Mineral resource scarcity (kg Cu eq) plus Water Consumption (flushing of toilet and washing machine use) (m^3). The main contributing factors (aside from materials) is electricity used in pre-washing, washing and drying operations (~438kWh), detergent use and the treatment of wastewater (toilet flushing and washing machine).

A number of factors influence the overall environmental impact of nappies on the environment. The reduction in the GWP of the UK's grid energy mix, the efficiency of washing machines and tumble dryers has improved. This is largely driven by EU legislation on eco design energy label requirements for washing machines and tumble dryers and the introduction of heat pump tumble dryers which are much more energy efficient.

Despite the production of energy from incineration (energy from waste – EfW) the carbon footprint of the end-of-life stage for disposable nappies has increased the total disposable nappy life cycle impact. This is due to an increase in the amount of waste being incinerated in the UK. The environmental impact of disposable nappies could be reduced by disposing of them on sites with energy recovery. There is also potential for the nappies to be recycled but data was not made available for this study to determine any potential environmental savings. This merits further investigation into the potential benefits of nascent technologies and infrastructure for disposable nappy recycling which could have a positive impact.

User behaviour plays an important role in understanding and mitigating the environmental impact of nappies. Consumer research shows that children are being potty trained at a later stage in their development. The results also showed that at 2.5 years 37% of babies using disposables and 35% of babies using reusable nappies were still in nappies. This is an increase of 19.4% and 17.4% respectively over the previous LCA studies.

Whilst the disposable nappies still have a higher Global warming potential (CO_2e), reusable nappies have a higher impact in 11 environmental categories. This are mainly due to the electricity used in prewashing, washing and tumble drying the reusable nappies, water used by the washing machine and toilet flushing and the treatment of the wastewater and detergent. Future interventions to advance potty training at an earlier stage of the child's life could present future environmental benefits.

The impact of reusable nappies could be reduced by the consumer using more energy efficient washing machines and tumble dryers or by air drying the nappies. Reusing nappies for a second child could reduce the Global warming potential by ~6.5% (344.57kgCO_2e to 322.17kgCO_2e) and water consumption by 30.9% due to the high amount of mains waster used in the nappy's manufacturing. Terrestrial acidification would reduce by 8.5% and Fine particulate matter formation by 8%.

14 Selected References

Listed below are a selection of references used during the research for this LCA study.

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- Environment Agency. Life Cycle Assessment of disposable and Reusable Nappies in the UK. 2005
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- Environment Agency. Time to Change? A study of how parents and carers use disposable and reusable nappies. Project Record P1-481/PR. 2005
- Bambino Mio/You survey April 2021. Nappy usage behaviour study
- The Great Cloth Nappy Census 2020, hosted by www.thenappygurus.com

Washing machine information

- https://newlifeappliances.co.uk/blog/are-you-putting-too-much-or-too-little-into-your-washing-machine/
- https://www.ukwhitegoods.co.uk/help/buying-advice/washing-machine/2789-washing-machine-load-sizes
- http https://www.currys.co.uk/gbuk/household-appliances/laundry/washing-machines/332_3119_30206_xx_xx/xx-criteria.html
- Fortunebusinessinsights.com/washing-machine-market-102645 and the product fiche associated with each product

Tumble dryer information

- https://www.currys.co.uk/gbuk/household-appliances/laundry/tumble-dryers/332_3121_30208_xx_xx/xx-criteria.htm l and the product fiche associated with each product

Methane from Landfill

- J. Krause, Giles W. Chickering & Timothy G. Townsend (2016) Translating landfill methane generation parameters among first-order decay models, Journal of the Air & Waste Management Association, 66:11, 1084-1097

Appendix A: Disposable Nappy Material Composition and Processes Inventories

Input per nappy	Unit	Amount	Ecoinvent data set
		Product materials and processing	
Fluff pulp	g	8.34	Sulfate pulp, bleached {RER}| sulfate pulp production, from softwood, bleached | Cut-off, S
SAP	g	13.22	SAP
PP	g	7.49	textile, non-woven polypropylene {EU}| textile production, non-woven polypropylene, spun bond | Cut-off, U
PE	g	1.16	Polyethylene, high density, granulate {RER| market for | Cut-off, S
LDPE	g	0.39	Polyethylene, low density, granulate {RER}| market for | Cut-off, S
PET	g	0.07	Polyethylene terephthalate, granulate, bottle grade {RER}| market for | Cut-off, S
Polyester	g	0.26	Polyethylene, high density, granulate {RER}| market for | Cut-off, S
Elastic	g	1.13	Polyurethane, rigid production | Cut-off, U
Glue/Adhesives	g	1.18	Polypropylene, granulate {RER}| market for | Cut-off, S
Calcium carbonate	g	0.19	Calcium carbonate, precipitated {RER}| calcium carbonate production, precipitated | Cut-off, S
Tape	g	0.37	Polypropylene, granulate {RER}| market for | Cut-off, S
Lotion	g	0.01	Not modelled
Other	g	0.02	Not modelled
Corrugated board packaging	g	0.52	Corrugated board box {RER}| market for corrugated board box | Cut-off, S
PE film packaging	g	0.47	Polyethylene, low density, granulate {RER}| market for | Cut-off, S
Extrusion, plastic film	g	2.65	Extrusion, plastic film {GLO}| market for | Cut-off, S
		Production energy and water use	
Electricity (87% from renewables)	kWh	1.75E-02	Various broken down - Electricity, medium voltage {Europe without Switzerland}| market group for | Cut-off, S, Electricity, high voltage {NO}| electricity production, hydro, reservoir, alpine region | Cut-off, S Electricity, high voltage {RoW}| electricity production, wind, >3MW turbine, onshore | Cut-off, S, Electricity, low voltage {RoW}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, S
Natural Gas	kWh	9.54E-04	Heat, central or small-scale, natural gas {Europe without Switzerland}| market for heat, central or small-scale, natural gas | Cut-off, S

Input per nappy	Unit	Amount	Ecoinvent data set
Product materials and processing			
Water	g	18.90	Tap water {Europe without Switzerland}| market for | Cut-off, S
Production waste			
Waste to incineration	g	0.46	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration | Cut-off, S, Waste graphical paper {RoW}| treatment of, municipal incineration | Cut-off, S and
Waste to recycling	g	0.81	Waste plastic recycling 0.6kwh EU grid average used, and fluff recycled as Waste paper, sorted {RoW}| cellulose fibre production | APOS, S
Waste to landfill	g	0.07	Waste plastic, mixture {R Waste graphical paper {RoW}| treatment of, sanitary landfill | Cut-off, S and {RoW}| treatment of waste plastic, mixture, sanitary landfill | Cut-off, S
Wastewater	m3	1.20E-05	Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, S
Material distribution			
Transport, freight, lorry >32 metric ton, euro5	tkm	0.02	Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, S
Transport, freight, sea, container ship	tkm	0.03	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, S
Product distribution			
Transport, freight, lorry >32 metric ton, euro5	tkm	0.03	Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, S
Car to collect nappies	km	22.88	Transport, passenger car, EURO 5 {RER}| market for | Cut-off, S
End of life collection			
Municipal waste collection service by 21 metric ton lorry	tkm	6.96E-04	Municipal waste collection service by 21 metric ton lorry {GLO}| market for | Cut-off, S

Table 43: Life cycle inventory of disposable nappy

Note: Other and lotion were below the cut off level and have not been included

Input per 1kg SAP	Weight	Unit
Acrylic acid {RER}| market for acrylic acid | Cut-off, S	0.32	kg
Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, S	0.71	kg
Sodium sulfate, anhydrite {RER}| market for | Cut-off, S	1.70	g
Zinc oxide {GLO}| market for | Cut-off, S	140.00	g
Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, S	209.00	g
Water, deionised {Europe without Switzerland}| market for water, deionised | Cut-off, S	5.01	kg
Electricity, medium voltage {Europe without Switzerland}| market group for | Cut-off, S	7.80	MJ

Table 44: Life cycle inventory of SAP

Appendix B: Disposable nappy system life cycle impacts

Life cycle impacts of disposable nappy system. These tables include the materials, distribution, collection from retailer, use and disposal via household waste

Impact category	Unit	Materials& production	Production waste	Distribution	Collection from retailer	EOL	Total
Global warming	kg CO_2 eq	283.70	4.84	5.98	7.33	149.24	451.08
Stratospheric ozone depletion	kg CFC11 eq	1.55E-04	1.84E-06	8.96E-06	3.66E-06	5.49E-05	2.24E-04
Ionizing radiation	kBq Co-60 eq	41.72	6.15E-02	2.71E-01	1.75E-01	-5.83E-01	41.64
Ozone formation, Human health	kg NOx eq	0.61	1.92E-03	4.10E-02	1.84E-02	1.31E-01	0.80
Fine particulate matter formation	kg PM2.5 eq	0.37	7.61E-04	1.43E-02	8.37E-03	2.87E-02	0.42
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.64	1.94E-03	4.23E-02	1.92E-02	1.35E-01	0.84
Terrestrial acidification	kg SO_2 eq	0.85	1.82E-03	3.02E-02	1.98E-02	6.58E-02	0.97
Freshwater eutrophication	kg P eq	0.16	1.54E-04	2.33E-03	2.63E-03	4.57E-02	0.21
Marine eutrophication	kg N eq	0.02	1.39E-03	6.73E-05	1.32E-04	4.58E-02	0.06
Terrestrial ecotoxicity	kg 1,4-DCB	1211.38	2.23	292.34	42.29	292.34	1840.58
Freshwater ecotoxicity	kg 1,4-DCB	9.54	0.46	0.19	0.66	12.76	23.61
Marine ecotoxicity	kg 1,4-DCB	12.96	0.63	0.40	0.84	17.59	32.43
Human carcinogenic toxicity	kg 1,4-DCB	13.15	0.13	0.41	0.68	2.19	16.56
Human non-carcinogenic toxicity	kg 1,4-DCB	238.21	7.94	7.60	7.16	200.59	461.50
Land use	m^2 a crop eq	48.30	0.02	1.02	0.24	0.27	49.86
Mineral resource scarcity	kg Cu eq	0.55	4.06E-03	1.99E-02	4.37E-02	3.47E-02	0.66
Fossil resource scarcity	kg oil eq	137.27	0.10	4.26	2.27	4.70	148.60
Water consumption	m^3	5.76	-0.03	0.02	0.02	0.14	5.91
Weight of nappies inc. packaging	Kg	132.12					

Table 45: Disposable nappy environmental impacts by lifecycle stage

Impact category	Unit	Total	Acrylic acid {RER}| market for acrylic acid | Cut-off, S	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, S	Sodium sulfate, anhydrite {RER}| market for | Cut-off, S	Zinc oxide {GLO}| market for | Cut-off, S	Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, S	Water, deionised {Europe without Switzerland} | market for water, deionised | Cut-off, S	Electricity, medium voltage {Europe without Switzerland} | market group for | Cut-off, S
Global warming	kg CO_2 eq	0.04	8.48E-03	1.21E-02	1.55E-05	1.43E-03	4.57E-03	2.96E-05	1.13E-02
Stratospheric ozone depletion	kg CFC11 eq	2.19E-08	5.76E-10	1.30E-08	6.02E-12	5.44E-10	2.27E-09	2.88E-11	5.43E-09
Ionizing radiation	kBq Co-60 eq	8.17E-03	4.19E-04	1.34E-03	2.53E-06	9.49E-05	3.30E-04	2.72E-06	5.98E-03
Ozone formation, Human health	kg NOx eq	7.66E-05	9.81E-06	3.17E-05	3.76E-08	3.37E-06	1.15E-05	6.13E-08	2.02E-05
Fine particulate matter formation	kg PM2.5 eq	5.86E-05	5.00E-06	2.68E-05	4.95E-08	2.07E-06	7.93E-06	7.86E-08	1.67E-05
Ozone formation, Terrestrial ecosystems	kg NOx eq	7.86E-05	1.05E-05	3.20E-05	3.83E-08	3.43E-06	1.22E-05	6.24E-08	2.04E-05
Terrestrial acidification	kg SO_2 eq	1.24E-04	1.40E-05	4.66E-05	1.46E-07	4.23E-06	1.67E-05	1.99E-07	4.19E-05
Freshwater eutrophication	kg P eq	2.16E-05	1.28E-06	6.31E-06	8.66E-09	4.84E-07	2.15E-06	1.44E-08	1.14E-05
Marine eutrophication	kg N eq	1.59E-06	6.97E-08	5.98E-07	8.85E-10	2.76E-08	9.42E-08	1.25E-09	7.99E-07
Terrestrial ecotoxicity	kg 1,4-DCB	0.22	1.49E-02	5.39E-02	1.65E-04	1.15E-01	1.77E-02	1.79E-04	1.36E-02
Freshwater ecotoxicity	kg 1,4-DCB	1.62E-03	1.82E-04	6.64E-04	1.48E-06	9.48E-05	1.98E-04	1.83E-06	4.81E-04
Marine ecotoxicity	kg 1,4-DCB	2.23E-03	2.39E-04	8.76E-04	1.97E-06	2.09E-04	2.62E-04	2.45E-06	6.42E-04
Human carcinogenic toxicity	kg 1,4-DCB	2.08E-03	2.12E-04	7.98E-04	1.46E-06	8.77E-05	2.33E-04	3.47E-06	7.42E-04
Human non-carcinogenic toxicity	kg 1,4-DCB	0.05	3.39E-03	1.50E-02	2.99E-05	8.10E-03	4.12E-03	4.00E-05	1.45E-02
Land use	m^2 a crop eq	8.57E-04	5.52E-05	3.16E-04	6.42E-07	3.89E-05	1.41E-04	7.45E-07	3.04E-04
Mineral resource scarcity	kg Cu eq	8.94E-05	1.30E-05	4.12E-05	1.08E-07	6.62E-06	1.41E-05	2.10E-07	1.42E-05
Fossil resource scarcity	kg oil eq	0.01	4.24E-03	3.02E-03	4.92E-06	4.53E-04	2.75E-03	7.73E-06	3.02E-03
Water consumption	m^3	7.73E-04	5.52E-05	3.21E-04	5.42E-07	6.43E-06	1.21E-04	6.93E-05	1.99E-04

Table 46: Environmental impact of 13.2g of SAP

Impact category	Units	Materials& production	Production waste	Distribution	Collection from retailer	EOL
Global warming	kg CO_2 eq	69%	1%	4%	2%	25%
Stratospheric ozone depletion	kg CFC11 eq	100%	0%	1%	<1%	-1%
Ionizing radiation	kBq Co-60 eq	76%	0%	5%	2%	16%
Ozone formation, Human health	kg NOx eq	88%	<1%	3%	2%	7%
Fine particulate matter formation	kg PM2.5 eq	76%	<1%	5%	2%	16%
Ozone formation, Terrestrial ecosystems	kg NOx eq	88%	<1%	3%	2%	7%
Terrestrial acidification	kg SO_2 eq	75%	<1%	1%	1%	22%
Freshwater eutrophication	kg P eq	25%	2%	<1%	<1%	73%
Marine eutrophication	kg N eq	66%	0%	16%	2%	16%
Terrestrial ecotoxicity	kg 1,4-DCB	40%	2%	1%	3%	54%
Freshwater ecotoxicity	kg 1,4-DCB	40%	2%	1%	3%	54%
Marine ecotoxicity	kg 1,4-DCB	79%	1%	3%	4%	13%
Human carcinogenic toxicity	kg 1,4-DCB	52%	2%	2%	2%	44%
Human non-carcinogenic toxicity	kg 1,4-DCB	97%	<1%	2%	1%	1%
Land use	m^2 a crop eq	84%	1%	3%	7%	5%
Mineral resource scarcity	kg Cu eq	92%	0%	3%	2%	3%
Fossil resource scarcity	kg oil eq	97%	-1%	<1%	<1%	2%
Water consumption	m^3	69%	1%	4%	2%	25%

Table 47: Disposable nappy environmental impact per lifecycle stage: % of total impact

Appendix C: Reusable Nappies Evaluated – 13 Formats

Nappy	Child weight range (kg)	Months (Age)	Format
RA1	2-8	0-6	All-in-one newborn nappy
RA2	2-16	2-30	Pocket nappy
RB1	4+	0-30	All-in-one nappy
RB2	<9	0-12	Wrap small size
RB3	>9	12-30	Wrap large size
RB4	0-16	0-30	Insert
RC1	2-5.5	0-3	Two-part newborn nappy with additional inserts
RC2	3-16	0-30	Two-part nappy
RC3	3-16	0-30	Two-part nappy
RD1	2-16	0-30	All-in-one nappy
RD2	3.5-16	0-30	Insert - night use
RD3	3.5-16	0-30	Outer wrap
RD4	3.5-16	0-30	Insert

Table 48: Reusable nappies evaluated

Appendix D: Reusable Nappies Systems – 8 Combinations

Nappy system	Nappy combinations	Number of items
1	RA1, RA2	20 of each
2	RB1	20
3	RB2, RB3, RB4	RB2 10, RB3 10, RB4 20
4	RC1, RC2	RC1 12 & 20 inserts, RC2 20
5	RC1, RC3	RC1 12 & 20 inserts, RC3 20
6	RD1	20
7	RD3, RD4	RD3 8, RD4 12
8	RD2, RD3, RD4	RD2 4, RD3 8, RD4 8

Table 49: Reusable nappies systems

Appendix E: Reusable Nappy Material Composition and Processes Inventories

Inputs	Ecoinvent data set
Water for washing machine	Tap water {Europe without Switzerland}| market for | Cut-off, S
Electricity for washing machine	Electricity, low voltage {GB}| market for | Cut-off, S
Wastewater for washing machine	Wastewater, from residence {RoW}| market for wastewater, from residence | Cut-off, S
Detergent for washing machine	Model developed by Giraffe Innovation
Viscose fibres	Fibre, viscose {GLO}| market for fibre, viscose | Cut-off, S
Cotton	Textile, knit cotton {GLO}| market for | Cut-off, S
Flax	Fibre, flax {GLO}| market for fibre, flax | Cut-off, S
Non-woven polyester	Textile, non-woven polyester {GLO}| market for textile, non-woven polyester | Cut-off, S
Manmade rubber	Polybutadiene {RER}| production | Cut-off, S
Polyurethane	Polyurethane, rigid production | Cut-off, U
Nylon	Nylon 6-6 {RoW}| market for nylon 6-6 | Cut-off, S
POM	Polyoxymethylene (POM)/EU-27 Polybutadiene {RER}| production | Cut-off, S
HDPE	Polyethylene, high density, granulate {GLO}| market for | Cut-off, S
LLDPE	Polyethylene, linear low density, granulate {GLO}| market for | Cut-off, S
LDPE	Polyethylene, low density, granulate {GLO}| market for | Cut-off, S

Inputs	Ecoinvent data set
Paper instructions	Printed paper {GLO}| market for | Cut-off, S
Corrugated box board	Corrugated board box {RER}| market for corrugated board box | Cut-off, S
Euro pallet	EUR-flat pallet {GLO}| market for | Cut-off, S
Processes	
Extrusion	Extrusion, plastic film {GLO}| market for | Cut-off, S
Weaving synthetic fibres	Weaving, synthetic fibre {GLO}| market for weaving, synthetic fibre | Cut-off, S
Electricity in China	Electricity, medium voltage {CN}| market group for | Cut-off, S
Electricity UK	Electricity, medium voltage {GB}| market for | Cut-off, S
Gas heating	Heat, central or small-scale, natural gas {CH}| market for heat, central or small-scale, natural gas | Cut-off, S
Injection moulding	Injection moulding {GLO}| market for | Cut-off, S
Woven PP	PP knit Cut-off, U
Distribution	
Transport, freight, lorry >32 metric ton, euro5	Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, S
Municipal waste collection service by 21 metric ton lorry	Municipal waste collection service by 21 metric ton lorry {GLO}| market for | Cut-off, S
Transport, freight, sea, container ship	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, S
Faeces and urine in non-recyclables bin sent for incineration	Raw sewage sludge {RoW}| treatment of municipal incineration | Cut-off, S
Faeces and urine in non-recyclables bin sent to landfill	Municipal solid waste {RoW}| treatment of sanitary landfill | Cut-off, S
Treatment of faeces and urine flushed down toilet	Wastewater, from residence {RoW}| market for wastewater, from residence | Cut-off, S
7.5-16 metric ton lorry from retailer to user	500km as part of the nappy system not as individual nappy component

Table 50: Materials, energy, processing and transport inputs for reusable nappies (ecoinvent)

Materials/assemblies	Amount	Unit
Fibre, viscose market for fibre, viscose	0.05	kg
Textile, non-woven polyester	0.05	kg
Nylon 6-6	3.00E-03	kg
Polyurethane, rigid production	0.03	kg
Polyoxymethylene (POM)	0.001	kg
Polybutadiene production	0.002	kg
Corrugated board box	10.63	g
Tap water	7.00E-03	tonne
Polyethylene, high density, granulate	1.00E-03	kg
Polyethylene, linear low density, granulate	4.15E-04	kg
Polyethylene, low density, granulate	0.0415	g
Printed paper	1.00E-03	kg
EUR-flat pallet	8.35E-04	p
Processes		
Weaving, synthetic fibre	2.50E-03	kg
Weaving, synthetic fibre	3.00E-03	kg
Extrusion, plastic film	0.03	kg
Injection moulding	1.00E-03	kg
Electricity, medium voltage {CN}	0.5	kWh
Heat, central or small-scale, natural gas	0.4	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.06	tkm
Transport, freight, sea, container ship	2.79	tkm
Extrusion, plastic film	1.00E-03	kg
Extrusion, plastic film	4.15E-04	kg

Extrusion, plastic film	0.04	g
Transport, freight, lorry >32 metric ton, euro 5	0.15	tkm
Transport, freight, sea, container ship	0.15	tkm

Table 51: Reusable Nappy RA1 material composition and processes

Materials/assemblies	**Amount**	**Unit**
Fibre, viscose market for fibre, viscose	0.06	kg
Textile, non-woven polyester	0.07	kg
Polyurethane, rigid production	0.04	kg
Polyoxymethylene (POM)	0.01	kg
Polybutadiene production	2E-3	kg
Corrugated board box	10.609	g
Tap water	0.01	ton
Polyethylene, high density, granulate	0.01	kg
Polyethylene, linear low density, granulate	0.46	g
Polyethylene, low density, granulate	0.046	g
Printed paper	1	g
EUR-flat pallet	9.25E-05	p
Processes		
Weaving, synthetic fibre	0.06	kg
Extrusion, plastic film	0.04	kg
Electricity, medium voltage {CN}	0.5	kWh
Heat, central or small-scale, natural gas	0.40	kWh
Transport, freight, lorry >32 metric ton, euro5	0.07	tkm
Transport, freight, sea, container ship	3.61	tkm
Extrusion, plastic film	0.01	kg
Extrusion, plastic film	0.046	g
Transport, freight, lorry >32 metric ton, euro 5	0.18	tkm
Transport, freight, sea, container ship	0.18	tkm

Table 52: Reusable Nappy RA2 material composition and processes

Materials/assemblies	**Amount**	**Unit**
Textile, non-woven polyester	0.12	kg
Nylon 6-6	4.44E-03	kg
Polyurethane, rigid production	1.23E-02	kg
Polyoxymethylene (POM)	2.72E-03	kg
Polybutadiene production	1.97E-03	kg
Nylon 6	4.90E-03	g
Corrugated board box	0.049	g
Tap water	0.15	ton
Processes		
Weaving, synthetic fibre	4.44E-03	kg
Extrusion, plastic film	1.23E-02	kg
Extrusion, plastic pipes	4.90E-03	kg
Injection moulding	2.72E-03	kg
Electricity, medium voltage {CN}	0.8	kWh
Heat, central or small-scale, natural gas	0.06	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.04	tkm
Transport, freight, sea, container ship	3.596	tkm
Transport, freight, lorry >32 metric ton, euro 5	0.196	tkm
Transport, freight, sea, container ship	0.19	tkm

Table 53: Reusable Nappy RB1 material composition and processes

Materials/assemblies	Amount	Unit
Polyurethane, rigid production	9.21	g
Polybutadiene production	2.15	g
Nylon 6-6	7.37	g
Corrugated board box	21.80	g
Tap water	0.04	ton
Processes		
Extrusion, plastic film	9.21	g
Electricity, medium voltage {CN}	0.53	kWh
Heat, central or small-scale, natural gas	0.02	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.02	tkm
Transport, freight, sea, container ship	0.78	tkm
Weaving, synthetic fibre	7.37	g
Transport, freight, lorry >32 metric ton, euro 5	0.04	tkm
Transport, freight, sea, container ship	0.04	tkm

Table 54: Reusable Nappy RB2 material composition and processes

Materials/assemblies	Amount	Unit
Polyurethane, rigid production	9.95	g
Polybutadiene production	2.43	g
Nylon 6-6	8.38	g
Corrugated board box	21.80	g
Tap water	0.04	ton
Processes		
Extrusion, plastic film	9.95	g
Electricity, medium voltage {CN}	0.54	kWh
Heat, central or small-scale, natural gas	0.02	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.01	tkm
Transport, freight, sea, container ship	0.82	tkm
Weaving, synthetic fibre	8.38	g
Transport, freight, lorry >32 metric ton, euro 5	0.04	tkm
Transport, freight, sea, container ship	0.04	tkm

Table 55: Reusable Nappy RB3 material composition and processes

Materials/assemblies	Amount	Unit
Textile, knit cotton	112.00	g
Fibre, flax market for fibre, flax	7.44	g
Processes		
Electricity, medium voltage {CN}	0.56	kWh
Heat, central or small-scale, natural gas	0.02	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.02	tkm
Transport, freight, sea, container ship	2.313	tkm
Transport, freight, lorry >32 metric ton, euro 5	0.11	tkm
Transport, freight, sea, container ship	0.11	tkm

Table 56: Reusable Nappy RB4 material composition and processes

Materials/assemblies	Amount	Unit
Fibre, viscose market for fibre, viscose	0.06	kg
Textile, non-woven polyester	0.01	g
Nylon 6-6	3E-03	kg
Polyester knit	0.04	kg
Polyurethane, rigid production	0.01	kg
Polyoxymethylene (POM)	0.60	g
Polybutadiene production	2E-03	kg
Corrugated board box	3.96	g
Polyethylene, low density, granulate	0.05	g
Processes		
Weaving, synthetic fibre	0.06	kg
Weaving, synthetic fibre	3E-03	kg
Extrusion, plastic film	6E-03	kg
Electricity, medium voltage {CN}	0.15	kWh
Injection moulding	0.6	g
Transport, freight, lorry >32 metric ton, euro 5	0.01	tkm
Transport, freight, sea, container ship	1.33	tkm
Extrusion, plastic film	0.05	g
Transport, freight, lorry >32 metric ton, euro 5	0.12	tkm
Transport, freight, sea, container ship	0.12	tkm

Table 57: Reusable Nappy RC1 material composition and processes

Materials/assemblies	Amount	Unit
Textile, woven cotton	27	g
Fibre, viscose market for fibre, viscose	0.06	kg
Textile, non-woven polyester	3.5	g
Polyester knit	0.08	kg
Polyurethane, rigid production	0.01	kg
Polyoxymethylene (POM)	0.01	kg
Polybutadiene production	3E-03	kg
Corrugated board box	0.01	g
Polyethylene, low density, granulate	1.18	g
Polyethylene, high density, granulate, recycled	0.021	g
Processes		
Weaving, synthetic fibre	0.06	kg
Extrusion, plastic film	3E-03	kg
Injection moulding	0.01	kg
Electricity, medium voltage {CN}	0.15	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.02	tkm
Transport, freight, sea, container ship	3.49	tkm
Extrusion, plastic film	1.19	g
Injection moulding	0.02	g
Transport, freight, lorry >32 metric ton, euro 5	0.18	tkm
Transport, freight, sea, container ship	0.18	tkm

Table 58: Reusable Nappy RC2 material composition and processes

Materials/assemblies	Amount	Unit
Textile, woven cotton	27.00	g
Fibre, viscose market for fibre, viscose	0.06	kg
Textile, non-woven polyester	8.50	g
Nylon 6-6	0.01	kg
Polyester knit	0.08	kg
Polyurethane, rigid production	0.01	kg
Polyoxymethylene (POM)	0.01	kg
Polybutadiene production	3E-03	kg
Corrugated board box	5.00	g
Polyethylene, low density, granulate	1.18	g
Polyethylene, high density, granulate, recycled	0.41	g
Processes		
Weaving, synthetic fibre	5E-03	kg
Extrusion, plastic film	0.01	kg
Injection moulding	5E-03	kg
Electricity, medium voltage {CN}	0.01	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.02	tkm
Transport, freight, sea, container ship	3.34	tkm
Extrusion, plastic film	1.18	g
Injection moulding market for	0.42	g
Transport, freight, lorry >32 metric ton, euro 5	0.17	tkm
Transport, freight, sea, container ship	0.17	tkm

Table 59: Reusable Nappy RC3 material composition and processes

Materials/assemblies	Amount	Unit
Fibre, viscose market for fibre, viscose	0.05	kg
Textile, non-woven polyester	0.02	kg
PP knit Cut-off, U	0.01	kg
Polyester knit Cut-off	0.04	kg
Nylon 6-6	0.01	kg
Polyurethane, rigid production	5E-03	kg
Polyoxymethylene (POM)	0.02	kg
Polybutadiene production	3E-03	kg
Processes		
Weaving, synthetic fibre	0.05	kg
Extrusion, plastic film	0.01	kg
Weaving, synthetic fibre	0.01	kg
Injection moulding	2E-03	kg
Electricity, medium voltage {GB}	0.21	kWh
Heat, central or small-scale, natural gas	0.03	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.20	tkm
Transport, freight, lorry >32 metric ton, euro 5	0.05	tkm
Transport, freight, lorry >32 metric ton, euro 5	9.5E-04	tkm
Transport, freight, sea, container ship	0.64	tkm
Transport, freight, sea, container ship	0.06	tkm
Transport, freight, sea, container ship	0.35	tkm
Transport, freight, lorry >32 metric ton, euro 5	3E-03	tkm
Transport, freight, lorry >32 metric ton, euro 5	0.14	tkm
Transport, freight, sea, container ship	0.14	tkm

Table 60: Reusable Nappy RD1 material composition and processes

Materials/assemblies	**Amount**	**Unit**
Fibre, viscose market for fibre, viscose	0.16	kg
Textile, non-woven polyester	0.02	kg
Nylon 6-6	5.90E-03	kg
Polyoxymethylene (POM)	3.40E-03	kg
Corrugated board box	9.00E-03	kg
Processes		
Weaving, synthetic fibre	0.16	kg
Weaving, synthetic fibre	5.9E-03	kg
Injection moulding	3.4E-03	kg
Electricity, medium voltage {GB}	0.16	kWh
Heat, central or small-scale, natural gas	0.02	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.67	tkm
Transport, freight, lorry >32 metric ton, euro 5	0.03	tkm
Transport, freight, sea, container ship	0.06	tkm
Transport, freight, sea, container ship	0.098	tkm
Transport, freight, lorry >32 metric ton, euro 5	1.7E-03	tkm
Transport, freight, sea, container ship	2.21	tkm

Table 61: Reusable Nappy RD2 material composition and processes

Materials/assemblies	**Amount**	**Unit**
Polyester knit Cut-off, U	0.05	kg
Nylon 6-6	5.90E-03	kg
Polyurethane, rigid production	8.00E-03	kg
Polyoxymethylene (POM)	2.60E-03	kg
Polybutadiene production	1.65E-03	kg
Processes		
Weaving, synthetic fibre	5.90E-03	kg
Extrusion, plastic film	8.00E-03	kg
Injection moulding	2.60E-03	kg
Electricity, medium voltage {GB}|	0.18	kWh
Heat, central or small-scale, natural gas	0.03	kWh
Transport, freight, lorry >32 metric ton, euro5	8.3E-04	tkm
Transport, freight, sea, container ship	0.06	tkm
Transport, freight, sea, container ship	0.05	tkm

Table 62: Reusable Nappy RD3 material composition and processes

Materials/assemblies	Amount	Unit
Fibre, viscose market for fibre, viscose	0.06	kg
Textile, non-woven polyester	0.03	kg
Polyoxymethylene (POM)	2.1E-03	kg
Processes		
Weaving, synthetic fibre	0.06	kg
Injection moulding	2.1E--03	kg
Electricity, medium voltage {GB}	0.06	kWh
Heat, central or small-scale, natural gas	9E-03	kWh
Transport, freight, lorry >32 metric ton, euro 5	0.27	tkm
Transport, freight, lorry >32 metric ton, euro 5	6.1E-03	tkm
Transport, freight, lorry >32 metric ton, euro 5	3.3E-03	tkm
Transport, freight, sea, container ship	0.02	tkm
Transport, freight, sea, container ship	0.15	tkm
Transport, freight, lorry >32 metric ton, euro 5	0.11	tkm
Transport, freight, sea, container ship	0.11	tkm

Table 63: Reusable Nappy RD4 material composition and processes

Materials/assemblies -disposable liner	Amount	Unit
Fibre, viscose market for fibre, viscose	1.16	g
Weaving, synthetic fibre	1.16	g
Materials/assemblies -reusable liner	**Amount**	**Unit**
Textile, non-woven polyester	10	g
Weaving, synthetic fibre	10	g

Table 64: Nappy liners material composition and processes

Appendix F: Reusable nappy systems

Life cycle impacts of reusable nappy systems

These tables include the materials, distribution use and disposal via household waste of a complete nappy system. These all assume the nappy or nappy pad is washed together with 5 others of the same type in a mixed washing load after prewashing. It also assumes the same for the tumble drying.

Material	Amount (g)
Bamboo (viscose)	1089.50
Microfibre (polyester)	1301.31
Polyurethane	166.825
Velcro strip	168.00
Elastic	52.00
Poppers	51.55
Nylon	0.12
Cotton	395.00
Polyester	12.25
Polypropylene	25.00
Processing	
Weaving, synthetic fibre	2390.81
Injection moulding	51.67
Extrusion, plastic film	191.83
Carton box for packaging	496.92
Jute for packaging	18.50
Transport	tKm
Transport, freight, lorry >32 metric ton, euro 5	1.27
Transport, freight, sea, container ship	62.68

Table 65: Average reusable nappy system composition

System 1		Materials & production	Materials & production	Waste	Waste	Delivery	Delivery	Use	Use	EoL	EoL	Total
Impact category	Unit	RA1	RA2	RA1	RA2	RA1	RA2	RA1	RA2	RA1	RA2	
Global warming	kg CO_2 eq	26.32	33.76	2.29	2.78	0.13	0.13	54.43	153.77	5.02	13.77	292.41
Stratospheric ozone depletion	kg CFC11 eq	2.71E-05	3.48E-05	2.43E-06	2.76E-06	1.01E-07	9.45E-08	5.09E-05	1.44E-04	2.31E-05	7.16E-05	3.56E-04
Ionizing radiation	kBq Co-60 eq	1.11	1.66	0.10	0.14	3.04E-03	2.84E-03	15.30	45.87	0.07	0.16	64.40
Ozone formation, Human health	kg NOx eq	0.07	0.10	0.01	0.01	4.61E-04	4.30E-04	0.15	0.42	0.01	0.03	0.80
Fine particulate matter formation	kg PM2.5 eq	0.05	0.06	4.02E-03	0.01	1.62E-04	1.52E-04	0.09	0.25	4.25E-03	0.01	0.47
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.08	0.10	0.01	0.01	4.76E-04	4.45E-04	0.15	0.43	0.01	0.03	0.82
Terrestrial acidification	kg SO_2 eq	0.11	0.14	0.01	0.01	3.42E-04	3.19E-04	0.20	0.58	0.01	0.03	1.09
Freshwater eutrophication	kg P eq	0.01	0.01	5.70E-04	7.62E-04	9.53E-06	8.90E-06	0.03	0.08	1.17E-02	0.01	0.14
Marine eutrophication	kg N eq	1.74E-03	2.13E-03	1.59E-04	1.68E-04	7.82E-07	7.30E-07	0.04	0.11	0.01	0.04	0.19
Terrestrial ecotoxicity	kg 1,4-DCB	61.10	94.99	5.39	7.38	3.27	3.06	285.73	803.00	5.62	16.48	1286.02
Freshwater ecotoxicity	kg 1,4-DCB	0.86	1.18	0.08	0.10	2.48E-03	2.31E-03	3.80	11.14	1.29	4.61	23.06
Marine ecotoxicity	kg 1,4-DCB	1.13	10.39	0.10	0.13	4.96E-03	4.63E-03	4.80	14.07	1.70	6.44	38.77
Human carcinogenic toxicity	kg 1,4-DCB	1.02	2.53	0.09	0.11	2.45E-03	2.28E-03	2.81	8.00	0.20	1.07	15.84
Human non-carcinogenic toxicity	kg 1,4-DCB	19.44	27.35	1.75	2.27	0.09	0.08	58.42	167.55	28.15	104.07	409.18
Land use	m^2a crop eq	1.98	13.89	0.17	0.26	0.01	0.01	8.26	23.42	0.21	0.15	48.37
Mineral resource scarcity	kg Cu eq	0.12	0.17	0.01	0.01	3.76E-04	3.52E-04	0.20	0.57	0.01	0.04	1.13
Fossil resource scarcity	kg oil eq	7.64	10.33	0.67	0.82	0.05	0.04	18.58	53.29	0.35	0.94	92.72
Water consumption	m^3	0.42	0.61	0.04	0.05	2.38E-04	2.22E-04	1.34	3.76	0.03	-3.62	2.63
Nappy weight	kg	2.92	3.40	2.29	2.78	0.13	0.13					6.32
Water use	m^3							6.54	28.68		5.65	40.87

Table 66: Reusable nappy system 1

Impact category	Unit	Materials & production RB1	Waste RB1	Delivery RB1	Use RB1	EoL RB1	Total
Global warming	kg CO_2 eq	41.45	0.23	0.09	254.08	13.98	309.83
Stratospheric ozone depletion	kg CFC11 eq	2.38E-05	1.22E-07	6.84E-08	2.37E-04	8.05E-05	3.41E-04
Ionizing radiation	kBq Co-60 eq	1.90	0.01	2.05E-03	75.26	0.16	77.34
Ozone formation, Human health	kg NOx eq	0.12	6.59E-04	3.11E-04	0.70	0.04	0.86
Fine particulate matter formation	kg PM2.5 eq	0.07	4.11E-04	1.10E-04	0.41	0.01	0.49
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.12	6.80E-04	3.22E-04	0.71	0.04	0.87
Terrestrial acidification	kg SO_2 eq	0.16	9.19E-04	2.31E-04	0.95	0.03	1.15
Freshwater eutrophication	kg P eq	0.01	6.11E-05	6.44E-06	0.13	0.01	0.15
Marine eutrophication	kg N eq	2.15E-03	1.11E-05	5.28E-07	0.18	0.04	0.22
Terrestrial ecotoxicity	kg 1,4-DCB	99.78	0.52	2.21	1324.01	16.65	1443.16
Freshwater ecotoxicity	kg 1,4-DCB	1.34	0.01	1.67E-03	18.32	5.44	25.11
Marine ecotoxicity	kg 1,4-DCB	12.32	0.01	3.35E-03	23.14	7.54	43.00
Human carcinogenic toxicity	kg 1,4-DCB	3.43	0.01	1.65E-03	13.20	1.18	17.82
Human non-carcinogenic toxicity	kg 1,4-DCB	31.65	0.18	0.06	276.07	122.66	430.61
Land use	m^2a crop eq	13.55	0.01	0.01	38.57	0.16	52.30
Mineral resource scarcity	kg Cu eq	0.24	1.32E-03	2.54E-04	0.94	0.04	1.22
Fossil resource scarcity	kg oil eq	12.27	0.06	0.03	87.73	0.98	101.08
Water consumption	m^3	3.38	0.02	1.61E-04	6.21	-3.62	6.00
Nappy weight	kg	2.87					2.87
Water use	m^3				21.19	5.65	26.84

Table 67: Reusable nappy system 2

		Materials & Production	Materials & Production	Materials & Production	Waste	Waste	Delivery	Delivery	Delivery
Impact category	Unit	RB2	RB3	RB4	RB2	RB3	RB2	RB3	RB4
Global warming	kg CO_2 eq	7.52	7.83	37.07	0.06	0.06	0.02	0.02	0.10
Stratospheric ozone depletion	kg CFC11 eq	5.49E-06	5.89E-06	1.61E-04	4.13E-08	4.49E-08	1.38E-08	1.45E-08	7.66E-08
Ionizing radiation	kBq Co-60 eq	0.21	0.22	1.36	1.57E-03	1.70E-03	4.14E-04	4.37E-04	2.30E-03
Ozone formation, Human health	kg NOx eq	0.02	0.02	0.12	1.58E-04	1.66E-04	6.29E-05	6.62E-05	3.49E-04
Fine particulate matter formation	kg PM2.5 eq	0.01	0.01	0.08	8.75E-05	9.23E-05	2.22E-05	2.34E-05	1.23E-04
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.02	0.02	0.12	1.60E-04	1.68E-04	6.50E-05	6.85E-05	3.60E-04
Terrestrial acidification	kg SO_2 eq	0.03	0.03	0.26	2.02E-04	2.13E-04	4.67E-05	4.92E-05	2.59E-04
Freshwater eutrophication	kg P eq	1.55E-03	1.62E-03	0.02	1.17E-05	1.24E-05	1.30E-06	1.37E-06	7.21E-06
Marine eutrophication	kg N eq	4.63E-04	5.04E-04	0.12	3.50E-06	3.86E-06	1.07E-07	1.12E-07	5.92E-07
Terrestrial ecotoxicity	kg 1,4-DCB	8.65	8.89	85.40	0.06	0.06	0.45	0.47	2.48
Freshwater ecotoxicity	kg 1,4-DCB	0.15	0.15	2.15	1.10E-03	1.16E-03	3.38E-04	3.56E-04	1.87E-03
Marine ecotoxicity	kg 1,4-DCB	0.19	0.20	12.72	1.44E-03	1.53E-03	6.77E-04	7.14E-04	3.76E-03
Human carcinogenic toxicity	kg 1,4-DCB	0.29	0.31	2.49	2.20E-03	2.38E-03	3.34E-04	3.52E-04	1.85E-03
Human non-carcinogenic toxicity	kg 1,4-DCB	3.92	4.09	40.35	0.03	0.03	0.01	0.01	0.07
Land use	m^2a crop eq	0.18	0.18	28.68	1.32E-03	1.37E-03	1.39E-03	1.46E-03	0.01
Mineral resource scarcity	kg Cu eq	0.01	0.01	0.10	6.30E-05	6.93E-05	5.14E-05	5.41E-05	2.85E-04
Fossil resource scarcity	kg oil eq	1.74	1.82	8.03	0.01	0.01	0.01	0.01	0.04
Water consumption	m^3	0.41	0.47	12.22	3.07E-03	3.59E-03	3.25E-05	3.43E-05	1.80E-04
Nappy weight	kg	0.19	0.21	2.36					
Water use	m^3								

Table 68: Reusable nappy system 3

		Use	Use	Use	EoL	EoL	EoL	Total
Impact category	Unit	RB2	RB3	RB4	RB2	RB3	RB4	
Global warming	kg CO_2 eq	19.50	34.91	246.33	0.50	0.62	12.95	367.48
Stratospheric ozone depletion	kg CFC11 eq	1.83E-05	3.27E-05	2.30E-04	8.26E-07	9.46E-07	7.60E-05	5.31E-04
Ionizing radiation	kBq Co-60 eq	5.30	9.38	71.74	5.81E-04	1.44E-03	0.16	88.37
Ozone formation, Human health	kg NOx eq	0.05	0.10	0.68	3.86E-04	1.01E-03	0.03	1.03
Fine particulate matter formation	kg PM2.5 eq	0.03	0.06	0.39	6.90E-05	2.08E-04	0.01	0.60
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.05	0.10	0.69	3.91E-04	1.04E-03	0.03	1.05
Terrestrial acidification	kg SO_2 eq	0.07	0.13	0.92	1.85E-04	4.91E-04	0.03	1.47
Freshwater eutrophication	kg P eq	9.71E-03	0.02	0.12	3.15E-06	5.13E-06	0.01	0.19
Marine eutrophication	kg N eq	0.01	0.02	0.17	4.44E-04	4.80E-04	0.03	0.37
Terrestrial ecotoxicity	kg 1,4-DCB	102.85	184.34	1286.75	0.18	0.32	16.30	1697.17
Freshwater ecotoxicity	kg 1,4-DCB	1.34	2.38	17.58	0.04	0.04	5.31	29.14
Marine ecotoxicity	kg 1,4-DCB	1.68	3.00	22.20	0.05	0.06	7.36	47.47
Human carcinogenic toxicity	kg 1,4-DCB	1.00	1.79	12.77	0.01	0.01	1.17	19.84
Human non-carcinogenic toxicity	kg 1,4-DCB	20.77	37.09	266.59	1.11	1.25	119.33	494.66
Land use	m^2a crop eq	2.96	5.30	37.40	5.28E-04	9.81E-04	0.16	74.87
Mineral resource scarcity	kg Cu eq	0.07	0.13	0.91	1.30E-04	2.22E-04	0.04	1.27
Fossil resource scarcity	kg oil eq	6.61	11.80	84.74	0.01	0.03	0.97	115.83
Water consumption	m^3	0.48	0.86	6.03	7.46E-04	8.35E-04	-3.62	16.87
Nappy weight	kg							2.63
Water use	m^3	3.99	7.11	24.66			5.651	41.41

Table 69: Reusable nappy system 3

		Materials & Production	Materials & production	Waste	Waste	Delivery	Delivery	Use	Use	EoL	EoL	Total
Impact category	Unit	RC1	RC2	RC1	RC2	RC1	RC2	RC1	RC2	RC1	RC2	
Global warming	kg CO_2 eq	7.90	25.47	1.43	4.20	0.16	0.16	22.90	263.10	3.98	12.31	341.60
Stratospheric ozone depletion	kg CFC11 eq	7.48E-06	4.68E-05	1.01E-06	8.54E-06	1.18E-07	1.18E-07	2.14E-05	2.44E-04	2.28E-05	6.87E-05	4.21E-04
Ionizing radiation	kBq Co-60 eq	0.42	1.43	7.09E-02	2.26E-01	3.54E-03	3.54E-03	6.63	76.76	0.01	0.16	85.71
Ozone formation, Human health	kg NOx eq	0.02	0.08	4.05E-03	1.27E-02	5.37E-04	5.37E-04	0.06	0.72	0.01	0.03	0.94
Fine particulate matter formation	kg PM2.5 eq	0.02	0.06	2.99E-03	8.77E-03	1.89E-04	1.89E-04	0.04	0.42	1.92E-03	0.01	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.02	0.08	4.13E-03	1.30E-02	5.55E-04	5.55E-04	0.06	0.73	0.01	0.03	0.96
Terrestrial acidification	kg SO_2 eq	0.04	0.14	6.69E-03	2.30E-02	3.99E-04	3.99E-04	0.09	0.98	0.01	0.03	1.30
Freshwater eutrophication	kg P eq	4.84E-03	9.52E-03	4.08E-04	1.58E-03	1.11E-05	1.11E-05	0.01	0.13	1.68E-03	0.01	0.17
Marine eutrophication	kg N eq	5.96E-04	2.50E-02	7.35E-05	5.03E-03	9.12E-07	9.12E-07	0.02	0.19	3.87E-03	0.03	0.27
Terrestrial ecotoxicity	kg 1,4-DCB	26.43	83.74	4.16	12.13	3.82	3.82	119.74	1360.32	1.53	15.96	1631.64
Freshwater ecotoxicity	kg 1,4-DCB	0.30	1.28	5.24E-02	1.98E-01	2.89E-03	2.89E-03	1.63	18.73	1.36	4.59	28.13
Marine ecotoxicity	kg 1,4-DCB	10.93	1.55	6.93E-02	2.33E-01	0.01	0.01	2.06	23.67	2.18	6.02	46.73
Human carcinogenic toxicity	kg 1,4-DCB	1.71	0.89	5.09E-02	1.42E-01	2.85E-03	2.85E-03	1.19	13.62	0.20	1.02	18.82
Human non-carcinogenic toxicity	kg 1,4-DCB	7.00	26.74	1.19	3.96	0.11	0.11	24.76	283.82	29.72	104.20	481.60
Land use	m^2a crop eq	12.51	5.56	1.42E-01	9.20E-01	0.01	0.01	3.48	39.56	0.06	0.11	62.36
Mineral resource scarcity	kg Cu eq	0.03	0.11	5.48E-03	1.57E-02	4.39E-04	4.39E-04	0.08	0.97	2.87E-03	0.04	1.26
Fossil resource scarcity	kg oil eq	2.75	7.31	0.43	1.25	0.06	0.06	7.87	89.92	0.17	0.88	110.69
Water consumption	m^3	0.12	2.88	2.18E-02	5.68E-01	2.78E-04	2.78E-04	0.56	6.43		-3.71	6.97
Nappy weight	kg	1.02	3.48									4.50
water use	m^3							6.39	21.23		5.65	33.27

Table 70: Reusable nappy system 4

		Materials & Production	Materials & Production	Waste	Waste	Delivery	Delivery	Use	Use	EoL	EoL	Total
Impact category	Unit	RC1	RC3	RC1	RC3	RC1	RC3	RC1	RC3	RC1	RC3	
Global warming	kg CO_2 eq	7.90	23.24	1.43	3.78	0.16	0.04	22.90	264.30	3.83	12.34	340.07
Stratospheric ozone depletion	kg CFC11 eq	7.48E-06	4.68E-05	1.01E-06	8.67E-06	1.18E-07	2.82E-08	2.14E-05	2.46E-04	2.28E-05	6.89E-05	4.23E-04
Ionizing radiation	kBq Co-60 eq	0.42	1.33	0.07	0.21	3.54E-03	8.47E-04	6.63	79.91	0.01	0.16	88.74
Ozone formation, Human health	kg NOx eq	0.02	0.07	4.05E-03	0.01	5.37E-04	1.29E-04	0.06	0.72	0.01	0.03	0.94
Fine particulate matter formation	kg PM2.5 eq	0.02	0.05	2.99E-03	0.01	1.89E-04	4.53E-05	0.04	0.42	1.92E-03	0.01	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.02	0.07	4.13E-03	0.01	5.55E-04	1.33E-04	0.06	0.74	0.01	0.03	0.96
Terrestrial acidification	kg SO_2 eq	0.04	0.13	0.01	0.02	3.99E-04	9.54E-05	0.09	0.99	1.64E-3	0.03	1.31
Freshwater eutrophication	kg P eq	4.84E-03	0.01	4.08E-04	1.48E-03	1.11E-05	2.66E-06	0.01	0.13	0.01	0.01	0.17
Marine eutrophication	kg N eq	5.96E-04	0.03	7.35E-05	0.01	9.12E-07	2.18E-07	0.02	0.19	3.86E-3	0.03	0.27
Terrestrial ecotoxicity	kg 1,4-DCB	26.43	85.59	4.16	12.17	3.82	0.91	119.74	1373.18	1.53	15.96	1643.48
Freshwater ecotoxicity	kg 1,4-DCB	0.30	1.25	0.05	0.19	2.89E-03	6.91E-04	1.63	19.29	1.36	4.59	28.66
Marine ecotoxicity	kg 1,4-DCB	10.93	1.51	0.07	0.23	5.79E-03	1.38E-03	2.06	24.37	1.78	6.03	47.39
Human carcinogenic toxicity	kg 1,4-DCB	1.71	0.83	0.05	0.13	2.85E-03	6.83E-04	1.19	13.77	0.17	1.02	18.91
Human non-carcinogenic toxicity	kg 1,4-DCB	7.00	25.56	1.19	3.77	0.11	2.52E-02	24.76	288.59	29.72	104.34	485.05
Land use	m^2a crop eq	12.51	5.57	0.14	0.94	1.18E-02	2.83E-03	3.48	40.13	0.01	0.11	62.94
Mineral resource scarcity	kg Cu eq	0.03	0.11	0.01	0.02	4.39E-04	1.05E-04	0.08	0.98	2.87E-03	0.04	1.27
Fossil resource scarcity	kg oil eq	2.75	7.05	0.43	1.21	0.06	1.33E-02	7.87	91.69	0.12	0.88	112.12
Water consumption	m^3	0.12	2.83	0.02	0.57	2.78E-04	6.65E-05	0.56	4.41	0.01	-3.71	6.93
Nappy weight	kg	1.02	3.42									4.32
water use	m^3							6.39	21.23		5.65	33.27

Table 71: Reusable nappy system 5

Impact category	Unit	Materials & Production RD1	Waste RD1	Delivery RD1	Use RD1	EoL RD1	Total
Global warming	kg CO_2 eq	18.77	2.21	0.12	250.44	14.25	285.80
Stratospheric ozone depletion	kg CFC11 eq	1.58E-05	1.48E-06	9.19E-08	2.34E-04	7.78E-05	3.29E-04
Ionizing radiation	kBq Co-60 eq	1.79	0.24	2.76E-03	73.61	0.16	75.80
Ozone formation, Human health	kg NOx eq	0.05	0.01	4.19E-04	0.69	0.04	0.78
Fine particulate matter formation	kg PM2.5 eq	0.04	3.84E-03	1.48E-04	0.40	0.01	0.45
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.05	0.01	4.33E-04	0.70	0.04	0.79
Terrestrial acidification	kg SO_2 eq	0.08	0.01	3.11E-04	0.94	0.03	1.06
Freshwater eutrophication	kg P eq	0.01	5.92E-04	8.66E-06	0.12	0.01	0.15
Marine eutrophication	kg N eq	0.00	1.61E-04	7.10E-07	0.18	0.03	0.21
Terrestrial ecotoxicity	kg 1,4-DCB	69.89	7.42	2.97	1306.52	16.55	1403.35
Freshwater ecotoxicity	kg 1,4-DCB	0.87	0.09	2.25E-03	17.97	5.39	24.33
Marine ecotoxicity	kg 1,4-DCB	11.70	0.12	4.51E-03	22.69	7.46	41.99
Human carcinogenic toxicity	kg 1,4-DCB	2.09	0.08	2.22E-03	13.00	1.19	16.36
Human non-carcinogenic toxicity	kg 1,4-DCB	20.00	2.07	0.08	271.62	121.31	415.08
Land use	m^2a crop eq	13.92	0.20	0.01	38.02	0.16	52.31
Mineral resource scarcity	kg Cu eq	0.10	0.01	3.42E-04	0.93	0.04	1.08
Fossil resource scarcity	kg oil eq	5.87	0.68	0.04	86.33	0.99	93.90
Water consumption	m^3	0.47	0.06	2.17E-4	6.13	-3.62	3.04
Nappy weight	kg	2.63					2.51
water use	m^3	18.77			25.00	5.65	30.65

Table 72: Reusable nappy system 6

		Materials & Production	Materials & Production	Waste	Waste	Delivery	Delivery	Use	Use	EoI	EoI	Total
Impact category	Unit	RD3	RD4	RD3	RD4	RD3	RD4	RD3	RD4	RD3	RD4	
Global warming	kg CO_2 eq	1.98	12.67	0.75	0.30	0.02	0.07	114.46	11.51	0.41	11.36	383.00
Stratospheric ozone depletion	kg CFC11 eq	2.44E-06	1.03E-05	9.28E-07	1.39E-07	1.20E-08	5.13E-08	1.07E-04	7.11E-05	1.60E-06	7.11E-05	4.19E-04
Ionizing radiation	kBq Co-60 eq	0.31	0.99	0.12	0.03	3.60E-04	1.54E-03	31.91	0.10	9.00E-04	0.10	102.70
Ozone formation, Human health	kg NOx eq	4.30E-03	0.04	1.56E-03	7.74E-04	5.46E-05	2.33E-04	0.31	0.03	1.05E-03	0.03	1.05
Fine particulate matter formation	kg PM2.5 eq	2.63E-03	0.03	9.85E-04	6.61E-04	1.93E-05	8.23E-05	0.18	0.01	1.52E-04	0.01	0.61
Ozone formation, Terrestrial ecosystems	kg NOx eq	4.44E-03	0.03	1.61E-03	8.04E-04	5.65E-05	2.41E-04	0.32	0.03	1.06E-03	0.03	1.07
Terrestrial acidification	kg SO_2 eq	0.01	0.06	2.26E-03	1.42E-03	4.05E-05	1.73E-04	0.43	0.02	4.84E-04	0.02	1.42
Freshwater eutrophication	kg P eq	4.76E-04	0.01	1.83E-04	9.81E-05	1.13E-06	4.83E-06	0.06	0.01	6.34E-06	0.01	0.20
Marine eutrophication	kg N eq	2.64E-04	0.00	1.02E-04	1.26E-05	9.27E-08	3.96E-07	0.08	0.02	6.34E-6	0.02	0.27
Terrestrial ecotoxicity	kg 1,4-DCB	5.01	57.34	1.51	1.44	0.39	1.66	601.51	10.35	0.14	10.35	1939.72
Freshwater ecotoxicity	kg 1,4-DCB	0.10	0.64	0.04	0.01	2.94E-04	1.26E-03	7.96	5.07	0.07	5.07	30.94
Marine ecotoxicity	kg 1,4-DCB	0.13	11.39	0.05	0.02	5.88E-04	2.51E-03	10.04	7.05	0.09	6.65	50.30
Human carcinogenic toxicity	kg 1,4-DCB	0.08	1.91	0.03	0.01	2.90E-04	1.24E-03	5.90	0.95	0.01	0.91	21.33
Human non-carcinogenic toxicity	kg 1,4-DCB	2.03	15.16	0.78	0.31	0.01	0.05	122.64	112.27	1.54	112.27	514.67
Land use	m^2a crop eq	0.09	13.80	0.03	0.04	1.20E-3	0.01	17.38	0.13	6.70E-04	0.09	68.03
Mineral resource scarcity	kg Cu eq	4.02E-03	0.09	1.52E-03	2.45E-03	4.46E-05	1.91E-04	0.42	0.02	1.54E-04	0.02	1.44
Fossil resource scarcity	kg oil eq	0.60	4.04	0.22	0.09	0.01	0.02	39.00	0.70	0.01	0.64	127.31
Water consumption	m^3	0.03	0.24	0.01	0.01	2.83E-05	1.21E-04	2.82	-1.76	7.09E-04	-1.85	7.27
Nappy weight	kg	0.44	1.23									1.54
water use	m^3							11.27	5.65		5.65	41.14

Table 73: Reusable nappy system 7

		Materials & Production	Materials & Production	Materials & Production	Waste	Waste	Waste	Delivery	Delivery	Delivery	Use	Use	Use	EoL	EoL	EoL	Total
Impact category	Unit	RD3	RD2 (night)	RD4 (day)	RD3	RD2 (night)	RD4 (day)	RD3	RD2 (night)	RD4 (day)	RD3	RD2 (night)	RD4 (day)	RD3	RD2 (night)	RD4 (day)	
Global warming	kg CO_2 eq	1.98	5.64	8.36	0.75	0.79	0.19	0.02	0.03	0.04	114.46	131.27	158.96	0.41	6.58	7.60	436.34
Stratospheric ozone depletion	kg CFC11 eq	2.44E-06	4.60E-06	6.83E-06	9.28E-07	4.49E-07	9.18E-08	1.20E-08	2.21E-08	3.38E-08	1.07E-04	1.23E-04	1.48E-04	1.60E-06	3.87E-05	4.69E-05	4.81E-04
Ionizing radiation	kBq Co-60 eq	0.31	0.43	0.65	0.12	0.07	0.02	3.60E-04	6.65E-04	1.02E-03	31.91	41.84	45.70	9.00E-04	0.08	0.06	121.09
Ozone formation, Human health	kg NOx eq	4.30E-03	0.02	0.02	1.56E-03	2.34E-03	5.11E-04	5.46E-05	1.01E-04	1.54E-04	0.31	0.36	0.44	1.05E-03	0.02	0.02	1.20
Fine particulate matter formation	kg PM2.5 eq	2.63E-03	0.01	0.02	9.85E-04	1.96E-03	4.36E-04	1.93E-05	3.56E-05	5.43E-05	0.18	0.21	0.26	1.52E-04	0.01	0.00	0.70
Ozone formation, Terrestrial ecosystems	kg NOx eq	4.44E-03	0.02	0.02	1.61E-03	2.39E-03	5.31E-04	5.65E-05	1.04E-04	1.59E-04	0.32	0.37	0.45	1.06E-03	0.02	0.02	1.22
Terrestrial acidification	kg SO_2 eq	0.01	0.03	0.04	2.26E-03	4.31E-03	9.38E-04	4.05E-05	7.48E-05	1.14E-04	0.43	0.50	0.59	4.84E-04	0.01	0.01	1.63
Freshwater eutrophication	kg P eq	4.76E-04	1.87E-03	4.58E-03	1.83E-04	2.57E-04	6.47E-05	1.13E-06	2.09E-06	3.19E-06	0.06	0.07	0.08	6.34E-06	0.01	0.01	0.22
Marine eutrophication	kg N eq	2.64E-04	4.18E-04	6.39E-04	1.02E-04	3.81E-05	8.32E-06	9.27E-08	1.71E-07	2.61E-07	0.08	0.09	0.11	4.44E-04	0.02	0.01	0.32
Terrestrial ecotoxicity	kg 1,4-DCB	5.01	31.86	37.84	1.51	3.98	0.95	0.39	0.72	1.09	601.51	688.58	831.85	0.14	8.15	6.83	2218.91
Freshwater ecotoxicity	kg 1,4-DCB	0.10	0.29	0.42	0.04	0.03	0.01	2.94E-04	5.42E-04	8.28E-04	7.96	9.95	11.26	0.07	2.67	3.35	36.10
Marine ecotoxicity	kg 1,4-DCB	0.13	0.39	7.52	0.05	0.04	0.01	5.88E-04	1.09E-03	1.66E-03	10.04	12.57	14.21	0.09	3.50	4.65	53.16
Human carcinogenic toxicity	kg 1,4-DCB	0.08	0.21	1.26	0.03	0.03	0.01	2.90E-04	5.36E-04	8.18E-04	5.90	6.91	8.22	0.01	0.57	0.62	23.82
Human non-carcinogenic toxicity	kg 1,4-DCB	2.03	6.91	10.01	0.78	0.79	0.20	0.01	0.02	0.03	122.64	146.11	171.52	1.54	59.91	74.10	595.83
Land use	m^2a crop eq	0.09	1.05	9.11	0.03	0.14	0.03	1.20E-03	2.22E-03	3.40E-03	17.38	20.27	24.13	6.70E-04	0.06	0.08	72.34
Mineral resource scarcity	kg Cu eq	4.02E-03	0.03	0.06	4.96E-03	1.62E-03	6.58E-03	4.46E-05	8.24E-05	1.26E-04	0.42	0.49	0.59	1.54E-04	0.02	0.02	1.64
Fossil resource scarcity	kg oil eq	0.60	1.51	2.67	0.22	0.22	0.06	0.01	0.01	0.02	39.00	46.65	54.53	0.01	0.46	0.46	146.20
Water consumption	m^3	0.03	0.11	0.16	0.01	0.02	3.69E-03	2.83E-05	5.22E-05	7.97E-05	2.82	3.18	3.90	7.09E-04	-1.86	-1.16	7.21
Nappy weight	kg	0.44	0.61	0.86													1.05
water use	m^3										11.27	12.84	15.98			5.65	45.75

Table 74: Reusable nappy system 8

Nappy system		
Impact category	Unit	Average reusable nappy system
Global warming	kg CO_2 eq	344.57
Stratospheric ozone depletion	kg CFC11 eq	4.13E-04
Ionizing radiation	kBq Co-60 eq	88.02
Ozone formation, Human health	kg NOx eq	0.95
Fine particulate matter formation	kg PM2.5 eq	0.55
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.97
Terrestrial acidification	kg SO_2 eq	1.30
Freshwater eutrophication	kg P eq	0.17
Marine eutrophication	kg N eq	0.26
Terrestrial ecotoxicity	kg 1,4-DCB	1657.93
Freshwater ecotoxicity	kg 1,4-DCB	28.18
Marine ecotoxicity	kg 1,4-DCB	46.10
Human carcinogenic toxicity	kg 1,4-DCB	19.09
Human non-carcinogenic toxicity	kg 1,4-DCB	478.33
Land use	m^2a crop eq	61.69
Mineral resource scarcity	kg Cu eq	1.29
Fossil resource scarcity	kg oil eq	112.48
Water consumption	m^3	7.11
Nappy weight	kg	3.22
Water use	m^3	36.65

Table 75: Average reusable nappy environmental impact

		Materials and production	Waste	Delivery	Use	EoL
Global warming	kg CO_2 eq	10%	1%	0.05%	85%	4%
Stratospheric ozone depletion	kg CFC11 eq	12%	1%	0.03%	67%	21%
Ionizing radiation	kBq Co-60 eq	2%	0.2%	<0.01%	98%	0%
Ozone formation, Human health	kg NOx eq	10%	1%	0.06%	85%	4%
Fine particulate matter formation	kg PM2.5 eq	12%	1%	0.04%	85%	2%
Ozone formation, Terrestrial ecosystems	kg NOx eq	10%	1%	0.06%	85%	4%
Terrestrial acidification	kg SO_2 eq	13%	1%	0.03%	84%	2%
Freshwater eutrophication	kg P eq	6%	0.5%	0.01%	86%	8%
Marine eutrophication	kg N eq	8%	1%	<0.01%	78%	13%
Terrestrial ecotoxicity	kg 1,4-DCB	6%	0.5%	0.24%	92%	1%
Freshwater ecotoxicity	kg 1,4-DCB	5%	0.4%	0.01%	75%	20%
Marine ecotoxicity	kg 1,4-DCB	5%	0.4%	0.02%	74%	21%
Human carcinogenic toxicity	kg 1,4-DCB	7%	1%	0.02%	86%	6%
Human non-carcinogenic toxicity	kg 1,4-DCB	6%	0.5%	0.02%	66%	27%
Land use	m^2 a crop eq	11%	1%	0.02%	88%	0.3%
Mineral resource scarcity	kg Cu eq	12%	1%	0.04%	84%	3%
Fossil resource scarcity	kg oil eq	8%	1%	0.05%	90%	1%
Water consumption	m^3	44%	2%	<0.01%	102%	-48%

Table 76 Reusable nappy environmental impact per lifecycle stage: % of total impact

- Water released back into system due to flushing.

Appendix G: Environmental Factors

Abiotic depletion
This is the depletion due to extraction of minerals and fossil fuels based on the remaining reserves and rate of extraction. It is based on using the equation, Production/ (Ultimate Reserve) and comparing this to the result for Antimony (Sb), which is used as the reference case. The reference unit for abiotic depletion is therefore kg Sb equivalent.

Abiotic depletion, fossil fuels
The characterization factor of fossil depletion is the amount of extracted fossil fuel extracted, based on the lower heating value. The unit is MJ (1 kg of oil equivalent has a lower heating value of 42 MJ).

Acidification
Describes the acidifying effect of substances, their acid formation potential (ability to form H+ ions) is calculated and set against a reference substance, kg SO_2.

Eutrophication
Nitrates and phosphates are essential for life but increased concentrations in water can encourage excessive growth of algae, reducing the oxygen within the water and damaging ecosystems. Eutrophication potential is expressed using the reference unit, kg PO4 equivalents for freshwater and kg N equivalents for marine water.

Fossil fuel scarcity
Fossil resource use determined as the Fossil Fuel Potential in kg oil equivalents. It is defined as the ratio between the higher heating value of a fossil resource and the energy content of crude oil.

Global warming Potential
A measure of the release of greenhouse gas (GHG) emissions into the atmosphere. When released into the atmosphere these gases absorb and emit thermal infrared radiation, trapping heat within the atmosphere, and contributing to climate change. This is also known as the carbon footprint. Global warming potential (GWP) is expressed as CO_2 equivalents/ kg emissions.

Land use
A measure in m2·yr annual crop equivalents of the relative species loss caused by a specific land use type for example annual crops, forestry, urban land, pasture etc.

Mineral resource scarcity
The primary extraction of a mineral resource will lead to an overall decrease in ore grade, meaning the concentration of that resource in ores worldwide, which in turn will increase the number of ore produced per kilogramme of mineral resource extracted.

Ozone depletion
The characterization factor for ozone layer depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). The unit is yr./kg CFC-11 equivalents.

Photochemical oxidant formation
The characterization factor of photochemical oxidant formation is defined as the marginal change in the 24h-average European concentration of ozone. Photochemical Ozone Creation Potential (POCP, also known as summer smog) for emission of substances to air is calculated with the United Nations Economic Commission for Europe (UNECE) trajectory model

(including fate), and expressed using the reference unit, kg ethene (C_2H_4) equivalents/kg emission.

Toxicity
The fate and effects of chemical emissions expressed in kg 1,4-dichlorobenzene-equivalents (1,4DCB-eq) was used as characterisation factor for human, freshwater, marine and terrestrial ecotoxicity

Water use
The characterisation factor at midpoint level is m^3 of water consumed per m^3 of water extracted per functional unit.

Appendix H: Data quality indicators

The data quality matrix was applied to the following data points:

Score	1 (Best)	2	3	4	5 (Worst)
Reliability of the source	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g., by industrial expert)	Non-qualified estimate
Representative	Representative data from sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal correlation	Less than three years of difference to year of study	Less than six years of difference	Less than 10 years of difference	Less than 15 years of difference	Age of data unknown or more than 15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Table 77: Data quality indicator matrix

Data	Reliability	Representative	Temporal correlation	Geographical correlation	Technological correlation
Transportation of raw materials	2	2	1	1	1
Masses of raw materials	1	1	1	1	1
Energy use at site	2	2	2	1	1
Waste production	3	1	1	1	1
End of life disposal and recycling	2	2	2	2	2

Table 78: Data quality indicators reusable nappies

Data	Reliability	Representative	Temporal correlation	Geographical correlation	Technological correlation
Transportation of raw materials	2	2	1	1	2
Masses of raw materials	1	1	1	1	1
Energy use at site	1	1	1	1	1
Waste production	1	1	1	1	1
End of life disposal and recycling	2	2	2	2	2

Table 79: Data quality indicators disposable nappies