LCA centralised washing of cloth diapers

CE Delft

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Content

Summary

The goal of this analysis is to determine the environmental impact of the use of washable diapers at Dutch daycare centres combined with a centralised washing process, over the whole lifecycle of the diapers (from cradle to grave). A life cycle assessment (LCA) is conducted in accordance with the ISO14040 and 14044 standards.

Three diaper systems are compared:

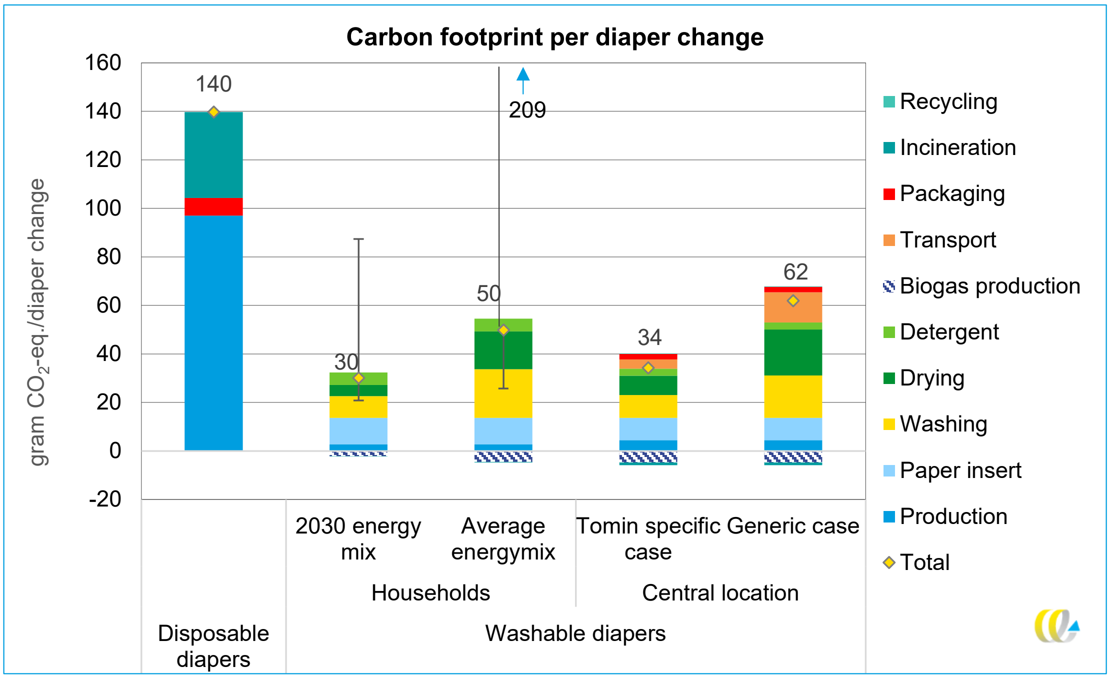
1. **Centralised diaper system**: The use of washable diapers at daycare centres, combined with a centralised washing process (referred to as the centralised diaper system). Two cases are included:
   - **Tomin-specific case**: This case represents the situation of a real-world pilot. It assumes 80% renewable electricity for washing and drying, and transport of diapers using electric vehicles (also charged with 80% renewable electricity).
   - **Generic case**: This case uses the same underlying process data from the pilot, but assumes the use of the average electricity mix for washing and drying and diesel-based transport.
2. **Household diaper system**: The use and washing of washable diapers in households[1].
3. **Disposable diapers**: Use of single-use diapers, with incineration at end-of-life. This system is representative of disposable diapers used in either households or daycare centres.

The LCA data for the centralised washable diaper system is considered relatively robust. It is based on primary data from the pilot programme, and the uncertainties are small. For the second and third diaper system, we use the results from the LCA conducted by CE Delft in 2023 (CE Delft, 2023b). As with the centralised diaper system, the results for the disposable diapers are considered robust. However, the household washable diaper system is less certain, because practices in households and their available equipment strongly determine the resulting carbon footprint. This uncertainty is studied in low-impact and high-impact scenarios for the household system.

Figure 1 compares the carbon footprints of the centralised washable diaper system, the disposable diaper system and the household washable diaper system. The error bars show variations in the low-impact and high-impact scenarios for the household system.

[1] This system is likely representative of local washing at daycare centres as well, but this was not within scope of this study. This is further discussed at the end of Section 3.1.2.

Figure 1 – Carbon footprint of one diaper change, in grams CO_2-eq./diaper change



Compared to disposable diapers (carbon footprint of 140 gram CO_2-eq./diaper change), the use of washable diapers at daycare centres combined with a centralised washing process results in a carbon footprint reduction between 56 and 75%.

The comparison of the centralised system and the household system is more complex. While the environmental benefits of the centralised system are comparatively certain, the benefits of the household system strongly depend on local washing and drying practices.

- The Tomin-specific case for centralised washing has a lower carbon footprint than the baseline scenario for households with the average electricity mix. When households use a more sustainable electricity mix, the baseline scenario results in a slightly lower carbon footprint than the Tomin-specific case for centralised washing. The generic case of the centralised system has a higher carbon footprint than the baseline scenario for households due to the (diesel-based) transport.
- If households run separate washing cycles for diapers and use inefficient equipment (the high-impact scenario), the centralised system has a far lower carbon footprint. Conversely, the carbon footprint of household washing is lower when using line drying and fully loaded washing machines (low-impact scenario).

While this study focuses on comparing the environmental impact of centralised and local washing, these systems are not at odds and can complement each other. Ultimately, the environmental impact of the diapering needs of young children is smallest when the amount of disposable diapers used is minimised, and when they are washed/dried efficiently (e.g. running full machines) with low-carbon energy sources.

1 Introduction

In 2023 CE Delft performed a life cycle assessment (LCA) studying and comparing the environmental impact of disposable and washable diapers, as commissioned by the Ministry of Infrastructure and Water management/Rijkswaterstaat (CE Delft, 2023b). This study focused on the use of diapers in Dutch households. The Ministry is also interested in the environmental impact of washable diapers in case of a centralised washing process for professional use in daycare centres and hospitals. In this context, a project is currently being carried out at the Tomingroep in Hilversum, where the washable diapers of 30 daycare centres of Partou are being washed and folded. These diapers are supplied by Billie Wonder and are being washed and dried with equipment from Lamme Textile Management. Lamme Textile Management also arranges the collection and delivery of the washable diapers.

This study determines the environmental impact of the washable diapers as used in this pilot. The environmental impact is compared to the environmental impact of disposable diapers that are incinerated after use and to washable diapers used in households.

This analysis is an addition to the report published in 2023 (CE Delft, 2023b). The focus of this report is on the new analysis of the centralised washing scenario. The comparisons made to the other diaper systems are based on the results from the 2023 analysis. We refer to the 2023 report for any detailed information on the data and assumptions used in that analysis.

This report describes the methodology used (Chapter 2), the results of the analysis (Chapter 3), followed by the discussion and conclusion of the analysis (Chapter 4). The data inventory is added in Annex A, as well as the detailed results of all impact categories (Annex B).

2 Method

2.1 Goal and scope

The goal of this analysis is to determine the environmental impact of the use of washable diapers at Dutch daycare centres combined with a centralised washing process, over the whole lifecycle of the diapers (from cradle-to-grave). The results are compared to the environmental impact of disposable diapers that are incinerated after use and to washable diapers used in households.

The environmental impact is determined with the indicators from the ReCiPe 2016 (H) method. We focus on the carbon footprint, which determines the contribution to global climate change through the emission of greenhouse gases. The carbon footprint is considered one of the most important environmental impact indicators from both a policy and societal perspective. Furthermore, the carbon footprint correlates strongly with the total environmental impact, for product systems consuming fossil energy (e.g. for the production of plastics or electricity)[2].

The analysis is carried out in accordance with the ISO 14040 and ISO 14044 standards for LCA.

The LCA is based on data from the pilot project carried out at the Tomin Groep in Hilversum. This project-specific data is combined with assumptions about operation at full scale (e.g. about transport distances, load factors).

Diaper systems

In this study, we compare three diaper systems (see Section 2.2 for more details):

1. The use of washable diapers at daycare centres is combined with a centralised washing process (referred to as the centralised diaper system).
2. The use and washing of washable diapers in households (referred to as the household diaper system)[3].
3. The use of disposable diapers (referred to as disposable diapers) which is representative of disposable diapers used at either households or daycare centres.

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[2] The results of all 18 environmental impact indicators included in the ReCiPe method are provided in Annex B.
[3] This system is likely representative of local washing at daycare centres as well, but this was not within the scope of this study. This representativeness for daycare centres is discussed in more detail in Section 3.1.2.

The main focus of this analysis is on the first diaper system. The washable diapers consist of a resistant layer on the outside, which is combined with an absorbing layer on the inside. Both parts can be washed and reused. In use, a disposable paper liner is added on the inside. Within the first diaper system, we distinguish between two cases:

- **Tomin-specific case**: This case represents the situation of the pilot described in Chapter 1 and Section 2.2.1 and assumes 80% renewable electricity for washing and drying, and transport of diapers using electric vehicles (also charged with 80% renewable electricity).
- **Generic case**: This case uses the quantitative data from the pilot, but assumes the use of the average electricity mix for washing and drying and diesel transport. The reason for including this case is that if centralised washing systems were implemented at alternative locations (e.g. not at Tomin Groep), it is uncertain whether it would still take place with mostly renewable energy.

For the second and third diaper system, we use the results from the LCA conducted by CE Delft in 2023. These results have not been updated with the newest version of the ecoinvent database[4]. Table 1 provides an overview of the differences between the Tomin-specific case and the generic case.

Table 1 – Differences between the Tomin-specific case and the generic case

	Tomin-specific case	**Generic case**
Electricity	80% solar electricity, 20% Dutch average electricity mix	Dutch average electricity mix
Transport	Electric vehicles powered by Tomin electricity mix	Diesel transport

Scope

The study considers the entire life cycle of the diapers (‘cradle-to-grave’). This means that all stages are included, from raw material extraction and production, to use and waste treatment at end-of-life (EOL). The study further assumes use in the Netherlands under current conditions (2025).

The details of the system boundaries are discussed in Section 2.2.

[4] An indicative carbon footprint calculation of the 2023 models using the newest database versions and impact assessment methods shows that the results for the washable diapers in the household system would not change considerably. The results for the disposable diapers would be slightly (<10%) higher with the newer databases and methods. This means that the results for the disposable diapers presented in this report can be slight underestimations. Note that it was beyond the scope of the present study to update the entire model (i.e. all scenarios, all midpoint and endpoint environmental impact indicators, verifying whether new relevant datasets were added, etc.).

Functional unit
The functional unit defines the function of the system under study and ensures that all different processes or products can be compared with one another. In this study, the functional unit is one diaper change for a child.

For the washable diaper used in the daycare centres, we account for reuse by dividing the impacts of production and end-of-life over the total number of uses during the technical lifetime of the diaper. In this way, one diaper change in a disposable system can be compared with one in a reusable system.

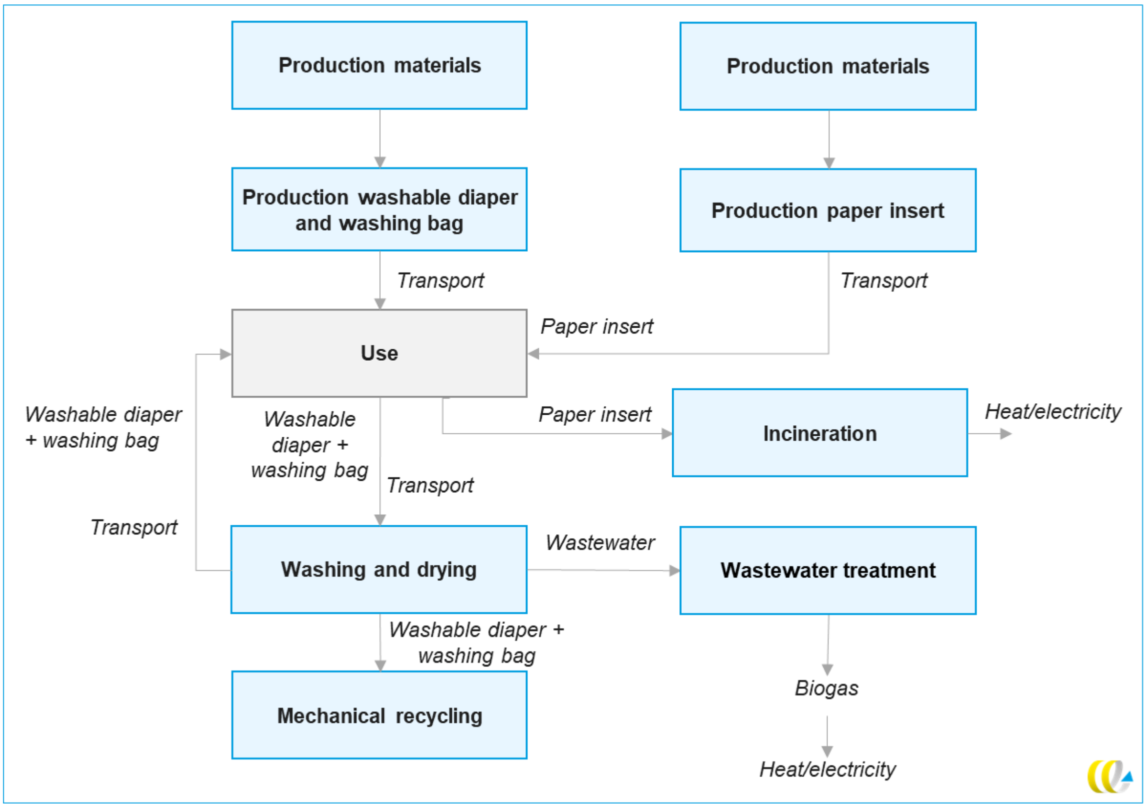
Co-products and allocation
In the three diaper systems, various co-products are generated. In Dutch incineration plants, electricity and heat are produced, and biogas is produced during wastewater treatment (see details in Section 2.2).

To account for this in the LCA, we assume that the co-products displace the regular production of an equivalent amount of product. For example, since electricity is produced through the incineration of the liner used in washable diapers, conventional power plants need to generate less electricity. The environmental impacts of this conventional production are therefore subtracted from the environmental impact of the diapers.
This approach is also referred to as substitution.

2.2 System boundaries

2.2.1 Centralised diaper system
Figure 2 illustrates the simplified system boundaries of the analysis of using washable diapers at daycare centres combined with centralised washing. Please note that minor inputs and outputs of the processes are not shown. The system is described below in Figure 2; detailed information on how the system is modelled is provided in Annex A.

Figure 2 – System boundaries of the use of washable diapers at daycare centres combined with centralised washing



The analysis starts at the production of raw materials, which are used to produce the washable diapers, washing bags and paper inserts. The washable diapers consist of a resistant layer on the outside (polyester/TPU blend), which is combined with an absorbing layer on the inside (hemp/cotton blend). There are five diaper sizes; in this analysis we used the average weight and composition. The washing bag is made of polyester and TPU. The (disposable) paper liner consists of cellulose with a thin PET lining.

For the production of the washable diaper components and washing bag, we modelled the production of the fabric (knitting and finishing). Final construction of the products is not included in the model. The production of the paper inserts is assumed to be similar to the production of tissue paper, as modelled in the dataset used[5].

All products are assumed to be produced in China and transported to the Netherlands by boat over a distance of 20,000 km.

5 The production process of the PET lining on the insert is not included in the model as the PET lining contributes less than 5% to its total mass. Note that the material for the PET lining is included in the model.

Clean, washable diapers are delivered to the daycare centres. At each diaper change, a resistant layer, an absorbing layer and a paper insert are used. After each use, the paper insert is disposed of and sent to incineration. The resistant and absorbing layers are collected in separate washing bags, which hold, on average, either 25 resistant layers or 17 absorbing layers.

The full washing bags are collected at daycare centres and transported to the washing location in Hilversum. The total distance covered during the collection of the washing bags is 100 km. The clean, washable diapers are returned to the daycare centres during the same transport ride. During one transport, a total of 3,420 resistant and absorbing layers are assumed to be collected and distributed.

The washable diapers are washed and dried with separate programs for the resistant and absorbing layers, which differ in electricity and water consumption and amount and type of detergents used. All equipment runs on electricity. The staff uses protective equipment (gloves, masks, gowns and safety glasses) when handling the dirty diapers. The washed and dried resistant and absorbing layers are manually folded together and packaged in plastic bags and crates, which are returned to the daycare centres.

The wastewater from the washing process is treated at a wastewater treatment facility, resulting in the production of biogas[6], which can be combusted in a Combined Heat and Power (CHP) installation for the production of electricity and heat. The avoided conventional production of electricity and heat has been included in the model.

The washable products are assumed to have a lifetime of 300 (resistant layers and washing bags) or 450 (absorbing layers) washing cycles (based on communication by Billie Wonder). At the end-of-life the products will be mechanically recycled. As it is uncertain what the quality of the recycled textile will be and what conventional product will be replaced, substitution of primary products is not included in the model.

2.2.2 Washable diapers in households

Figure 3 shows the simplified system boundaries of the analysis of the use of washable diapers in households. Hereafter, we provide a summary of the main assumptions. This analysis is described in full detail in the report from 2023 CE Delft (2023b). The representativeness of this system of local washing at daycare centres is discussed in the text box in Section 3.1.2.

The analysis assumes an all-in-one washable diaper of 130 gram, consisting of a mixture of polyester (50%), bamboo viscose (25%) and cotton (25%). The production of the raw materials is included in the model; the assembly of the diaper itself is not. It is assumed that paper inserts are used, which are reused 2.6 times on average before being disposed

6 This does not take place at every wastewater treatment plant, but for comparison with the washable diaper used at households, it is included in the model. The amount of biogas produced is based on the average Dutch digester (see Annex A.6).

of (Billenboetiek, 2022). The diapers are assumed to have a lifetime of 450 diaper changes (Kliphuis, 2022). Transport from the production location to the consumer is not included in the model.

After use, the diapers are washed. As the environmental impact of the washing process depends on several variables, which are to a large extent user dependent, three scenarios for the washing process are studied: a baseline scenario, a low impact scenario and a high impact scenario. Table 2 provides an overview of the differences between the main parameters for these three scenarios.

Table 2 – Overview of the differences between the baseline, high-impact and low-impact scenarios for washable diapers used at households

Parameter	Baseline	High impact	Low impact
Loading factor washing machine/dryer	50%	18%	100%
Fraction of laundry mechanically dried (vs. line drying)	50%	50%	0%
Electricity consumption prewash (kWh/wash)	0.13	0.33	0.13
Electricity consumption main wash (kWh/wash)	0.72	1.67	0.72
Electricity consumption dryer (kWh/wash)	2.20	4.63	2.20
Water consumption washing machine (L/wash)	107	154	107

The wastewater from the washing process is treated at a wastewater treatment facility, resulting in the production of biogas[7], which can be combusted in a CHP installation for the production of electricity and heat. The avoided conventional production of electricity and heat has been included in the model.

At the end-of-life the diapers are incinerated, resulting in emissions and the production of heat and electricity[8].

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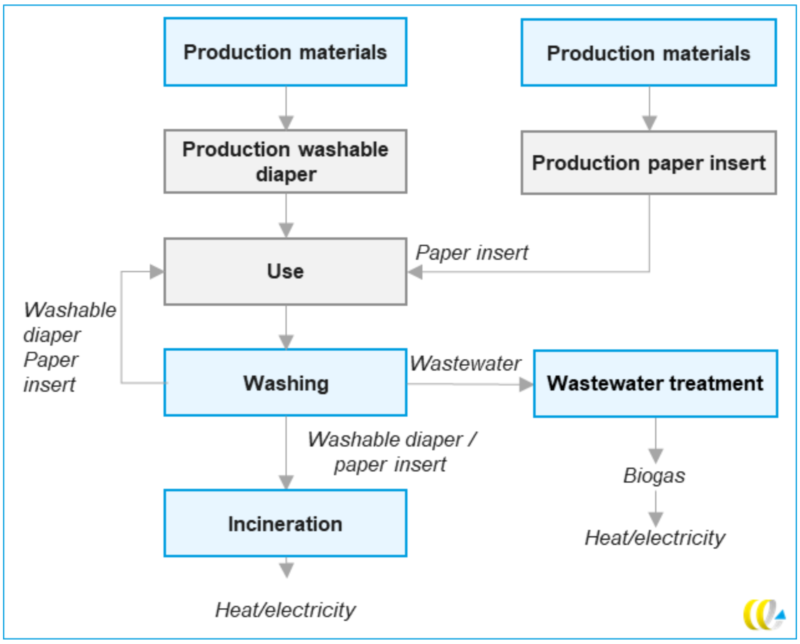
[7] This does not take place at every wastewater treatment plant, but for comparison with the washable diaper used at households, it is included in the model. The amount of biogas produced is based on the average Dutch digester (see Annex A.6).

[8] There is no specific collection system in place for washable diapers used in households. Therefore, it is likely that at least a considerable part of the washable diapers ends up in the residual waste stream, as is also the case for other types of textile waste. Even if the washable diapers are disposed of in the textile waste collection containers, it is uncertain whether they can be mechanically recycled. In daycare centres, on the other hand, a specific collection system for the washable diapers can be set up. Furthermore, all diapers used in the daycare centres have the same composition, making mechanical recycling easier.

Figure 3 – System boundaries of the use of washable diapers in households

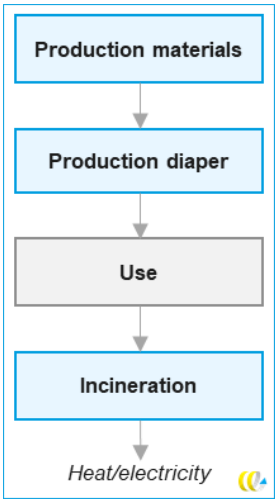


2.2.3 Disposable diapers

Figure 4 shows the simplified system boundaries of the analysis of the use of disposable diapers that are incinerated after use. This analysis is described in full detail in the report from 2023 (CE Delft, 2023b). Hereafter, we provide a summary of the main assumptions.

The analysis assumes a diaper of 33.3 grams consisting of pulp (27%), super absorbent polymer (38%), PE/PP (29%) and some other materials such as glue and elastic (7%). Transport to the retailer and consumer is not included in the model. At the end-of-life the disposable diapers are incinerated, resulting in emissions and the production of heat and electricity.

Figure 4 – System boundaries of disposable diapers that are incinerated after use



2.3 Data collection and modelling

In this study, only the centralised diaper system is modelled; the results of the other two systems are based on the model made in the study from 2023. Primary data on the foreground system of the centralised system(e.g. diaper composition, transport distances, energy consumption, washing and drying) was provided by the parties involved in the pilot. For the waste treatment processes, secondary data was collected. Table 3 provides an overview of the data sources for each process. The full data inventory is included in Annex A. This annex provides information on, e.g. product compositions and weights, inputs to the washing process and modelling details (datasets selected and assumptions made).

Environmental background data was taken from the ecoinvent database (v3.11) (Wernet et al., 2016) and CE Delft studies (CE Delft, 2023a, 2023c).

Table 3 – Overview of data sources per unit process

Process	Primary/secondary data	Source
Diaper composition	Primary data	Billie Wonder
Diaper lifetime	Primary data	Billie Wonder
Transport to washing	Primary data	Tomingroep
Washing and drying	Primary data	Tominegroep/Lamme textile management
Packaging	Primary data	Billie Wonder/Partou
Waste treatment	Secondary data	Literature/Ecoinvent

The LCA model is built in the SimaPro LCA software (version 10.2). The results are calculated using the ReCiPe 2016 (H/A) impact assessment method (version 1.11). Long-term emissions are excluded from the analysis. The hierarchic (H/A) weighting set from the ReCiPe method was used to calculate the endpoint results.

Comparability to the 2023 analysis

Please note that the results for disposable diapers and washable diapers used in households were generated using the 1.07 version of the ReCiPe 2016 method. Furthermore, a previous version of the ecoinvent database was used to model the diaper systems. Updating the old models and generating new results was out of scope for this new analysis. This results in a small uncertainty in the comparison of the different diaper systems.

2.4 Sensitivity analyses

To study the influence of uncertainties in the model on the conclusions of the study, we perform three sensitivity analyses. These analyses cover parameters with a large uncertainty and/or a large influence on the results.

- **Diaper lifetime**: The lifetime of the washable diapers and washing bags is based on the technical lifetime expressed as the maximum number of wash cycles. The washable diapers also have a maximum lifetime in years (unrelated to the number of wash cycles) due to degradation of the material. It is possible that during this period, the diapers are not washed (and used) as often as technically possible. In a sensitivity analysis, we study the break-even point to find out how often the washable diapers should be used to have a lower carbon footprint than washable diapers used in households and disposable diapers.
- **Transport distance**: The dirty washable diapers are collected during the same transport ride as the clean diapers are distributed. The total transport distance collecting and distributing diapers at several daycare centres is assumed to be 100 km, as estimated by Lamme Textile Management. In a sensitivity analysis, we study how the carbon footprint of the centralised washing of washable diapers changes when a total transport distance of 200 km or 50 km is assumed.
- **Detergent composition**: The composition of the detergent used in the centralised washing process is based on the safety data sheets. These sheets only provide a range of the percentage of active substances present in the detergent. In the main analysis, we assume the average value of these ranges. In a sensitivity analysis, we assume either the lower end or the higher end of the range in the detergent models. We analyse how this affects the carbon footprint of the centralised washing of washable diapers.

3 Results

This chapter presents the results of the analysis. The focus of this chapter is on the carbon footprint results (Section 3.1). First, the results of the centralised washable diaper system are described in Section 3.1.1, followed by a comparison to disposable diapers and the household washable diaper system in Section 3.1.2. In Section 3.2, the uncertainties in the model are analysed in several sensitivity analyses.

The carbon footprint is, from both a policy and societal perspective, seen as one of the most important environmental impact indicators. Furthermore, for product systems consuming fossil energy (e.g. for the production of plastics or electricity), the carbon footprint correlates strongly with the total environmental impact. The results for all environmental impact categories on a midpoint and endpoint level are presented in Annex B.

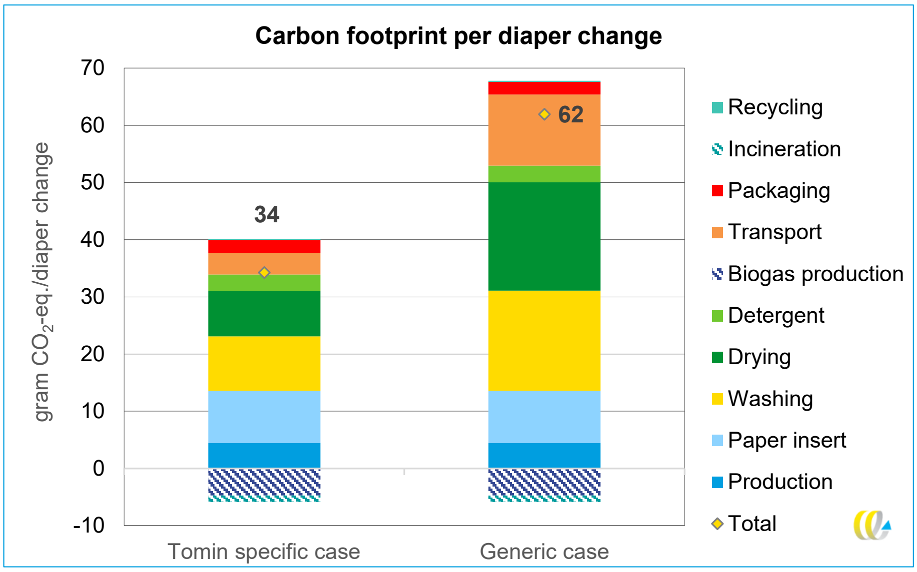
3.1 Results carbon footprint

3.1.1 Centralised washable diaper system

Figure 5 shows the carbon footprint of one diaper change for both the Tomin-specific case and the generic case. Note that environmental burdens (i.e. contributions to climate change) are shown as positive values above the x-axis. Environmental credits, i.e. avoided climate change impacts, are shown as negative values.

Content

Figure 5 – The carbon footprint of one diaper change for the Tomin-specific case and the generic case, in gram CO_2-eq./diaper change



In the Tomin-specific case, the carbon footprint of one diaper change is estimated at 34 gram CO_2-eq. Almost all processes included in the model have a contribution of 7% or larger to the total carbon footprint. Only the impact of end-of-life treatment (recycling and incineration) is relatively small.

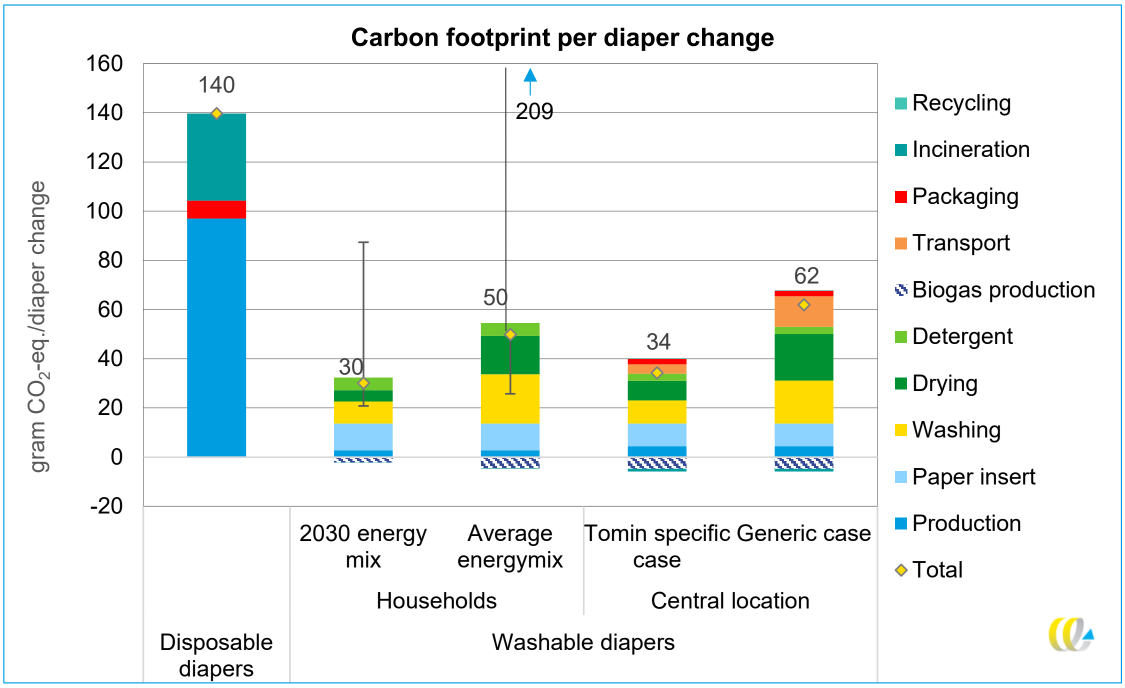
The carbon footprint of one diaper change in the generic case is estimated at 62 gram CO_2-eq. The main differences in carbon footprint between this generic case and the Tomin case are:

- the higher contribution of washing and drying in the generic case. In the Tomin-specific case, the electricity mix has a lower carbon footprint, due to the higher share of renewable electricity from solar panels, compared to the generic case, where we assume the use of the average electricity mix.
- the higher contribution of transport in the generic case. In the Tomin-specific case, we assume transport with electric vehicles running on 80% renewable electricity, whereas in the generic case, we assume transport with vehicles fuelled with diesel.

3.1.2 Comparison of different diaper systems

Figure 6 shows how the carbon footprints of the centralised washable diaper system compare to the carbon footprints of disposable diapers and the household washable diaper system (studied in 2023).

Figure 6 – The carbon footprint of one diaper change for different diaper systems (disposable diapers, household washable diaper system with the 2030 electricity mix and the average electricity mix, centralised washable diaper system for the Tomin-specific case and the generic case), results shown in gram CO_2-eq./diaper change



This figure contains the following information:

- The bar on the left shows the carbon footprint of one diaper change with disposable diapers. Disposable diapers have an estimated carbon footprint of 140 gram CO_2-eq. per diaper change.
- The second and third bars from the left show the carbon footprint of the household washable diaper system. The bar on the left shows the carbon footprint when using the predicted 2030 Dutch electricity mix, the bar on the right when using the current average Dutch electricity mix.
  - The carbon footprint of the household system is estimated at 30 gram CO_2-eq. per diaper change when using the 2030 Dutch electricity mix in the baseline analysis. In the low impact scenario (100% load factor, only line drying) this can be reduced to 21 gram CO_2-eq. per diaper changer (indicated with range). However, with a high impact washing scenario (washing diapers separately, inefficient equipment), the carbon footprint can increase up to 87 gram CO_2-eq. per diaper change.
  - The carbon footprint of the household system is estimated at 50 gram CO_2-eq. per diaper change when using the average electricity mix in the baseline analysis. In the low impact scenario (100% load factor, only line drying), this can be reduced to 26 gram CO_2-eq. per diaper changer (indicated with range). However, with a high impact washing scenario (washing diapers

separately, inefficient equipment), the carbon footprint can increase up to 209 gram CO_2-eq. per diaper change.

- The fourth and fifth bars from the left show the carbon footprint of the centralised washable diaper system. These results are the same as the results shown in Figure 5.

Figure 5 results in several findings, which are discussed below.

The carbon footprint of the centralised washable diaper system is about 56-75% lower than disposable diapers

Disposable diapers have an estimated carbon footprint of 140 gram CO_2-eq. per diaper change. This is considerably higher than the carbon footprint of the washable diapers in the centralised system (34 and 62 gram CO_2-eq./diaper change). The main reason for this difference is the fact that in the disposable diaper system, a new diaper is used for each diaper change. The entire carbon footprint of the production and end-of-life treatment of the diaper is therefore attributed to one diaper change. In the washable diaper system, the carbon footprint of production and end-of-life treatment of the diaper is divided over the 300-450 diaper changes, resulting in a smaller carbon footprint per diaper change.

In the Tomin-specific case, the centralised system is likely to have a lower carbon footprint than the household system with the average electricity mix

The carbon footprint of the household system is estimated at 50 gram CO_2-eq. per diaper change when using the average electricity mix (ranging from 26 gram CO_2-eq. in the low impact scenario to 209 gram CO_2-eq. in the high impact scenario). Therefore, the carbon footprint of the centralised system in the Tomin case (34 g CO_2-eq./diaper change) is likely to be lower than the carbon footprint of washing diapers in households. Only with sustainable washing practices, the household system with the average electricity mix has a lower carbon footprint.

With the 2030 electricity mix, the carbon footprint of the household system is reduced to 30 gram CO_2-eq. per diaper change (ranging from 21 gram CO_2-eq. to 87 gram CO_2-eq. per diaper change). In that case, the carbon footprint of the Tomin-specific case of the centralised system is comparable to the carbon footprint of the household system.

In the generic case, the centralised system can have a comparable carbon footprint to the household system

In the generic case, the centralised system has a carbon footprint of 62 g CO_2-eq. per diaper change. This is higher than the baseline results for washing in households with both the average electricity mix (50 g CO_2-eq./diaper change) and the 2030 electricity mix (30 g CO_2-eq./diaper change). However, when the washing process in households is not optimal (e.g. washing diapers separately from other laundry, using inefficient washing machines/dryers), the carbon footprint of the household system can increase to 209 g CO_2-eq./diaper change with the average electricity mix and 87 g CO_2-eq./diaper change with the 2030 electricity mix. In this case, the carbon footprint of the centralised system is lower than the carbon footprint of the household system.

The carbon footprint difference between the centralised system and the household system is caused by the transport to the central washing location and the packaging

For the household system with the average electricity mix and the generic case of the centralised system, the same electricity mix was assumed. When we compare the results of these two scenarios, we see that the sum of the carbon footprint of the production processes, washing and drying processes and end-of-life processes is nearly the same. The higher carbon footprint of the centralised system is caused by the transport to and from the washing location and the packaging of the dirty washable diapers before washing and clean diapers after washing. These are processes which are not relevant in the household system.

Comparison to local washing at daycare centres

In Figure 6, the carbon footprint of centralised washing is compared to local washing at households. The question may arise how these results compare to the carbon footprint of local washing at daycare centres.

In the household system, the carbon footprint depends to a large extent on the washing and drying process. Local washing practices at daycare centres have not been officially studied. Nevertheless, we can describe which conditions must be met for the results of the household system to be representative of local washing at daycare centres. We note the following:

- The high-impact scenario of the household system assumes a comparatively low loading factor of washing machines/dryers and inefficient equipment (see also Table 2). As the washing process at daycare centres can be controlled quite well (e.g. ensuring high loading factors), it is very likely that the carbon footprint will be lower than the maximum carbon footprint of the household system.
- In the baseline scenario of the household system, a 50% load factor and 50% mechanical drying is assumed. These factors have a considerable effect on the carbon footprint. If these conditions are met, the carbon footprint of local washing could be comparable to the carbon footprint of the household system. However, this will also depend on the energy efficiency of the washing machines and dryers used.
- In the household system, the use and washing of washing bags is not included. If these were used with local washing at daycare centres, this would slightly increase the carbon footprint per diaper change.

To conclude, local washing at daycare centres likely falls within the result ranges shown for the household system. The exact carbon footprint of local washing at daycare centres will differ per location and mostly depend on washing practices and the efficiency of the machines. With high load factors, mostly line drying, efficient machines and the use of renewable electricity, local washing at daycare centres can result in a lower

> carbon footprint than centralised washing, as transport of the diapers is avoided. Future research, based on real-world data on energy efficiency, loading factors, etc., can determine the carbon footprint of local washing at daycare centres with greater precision.

3.2 Sensitivity analyses

3.2.1 Break-even analysis lifetime diapers

The carbon footprint of the washable diapers partly depends on the lifetime of the diapers, as the impact of production and end-of-life is distributed over all diaper changes during the lifetime. In the baseline analysis, we assume a lifetime of 300 uses for the resistant layer and washing bags and 450 uses for the absorbing layer. In this sensitivity analysis, we analyse the effect of the lifetime of the washable diapers on the conclusions by studying at which amount of uses the carbon footprint of the centralised system in the Tomin-specific case becomes higher than the baseline result of the household system with the average electricity mix and the carbon footprint of disposable diapers.

The analysis shows that the carbon footprint of the Tomin-specific case is higher than the baseline results of the household system when the washable diapers are used 76% less than what is assumed in the main analysis. This 76% shorter lifetime corresponds with a lifetime of 72 diaper changes for the resistant layers and washing bags, and 108 diaper changes for the absorbing layers.

The carbon footprint of the centralised system in the Tomin-specific case is higher than the carbon footprint of disposable diapers when the amount of uses is about 96.5% less than assumed in the main analysis. This corresponds to a lifetime of approximately 14 diaper changes for the resistant layers and washing bags and 21 diaper changes for the absorbing layers.

This sensitivity analysis shows that the effect of the lifetime of the washable diapers on the total carbon footprint is limited. This is due to the fact that only 10% of the carbon footprint of the Tomin-specific case is determined by processes of which the carbon footprint is affected by the lifetime (production, incineration and recycling).

Please note that these results do not indicate that the washable diapers in the centralised system only have to be used ~20 times. The longer the lifetime, the more sustainable the diapers are.

The results of the break-even analysis are summarised in Table 4.

Table 4 – Number of uses below which the carbon footprint of the centralised system is higher than the carbon footprint of the household system or disposable diapers

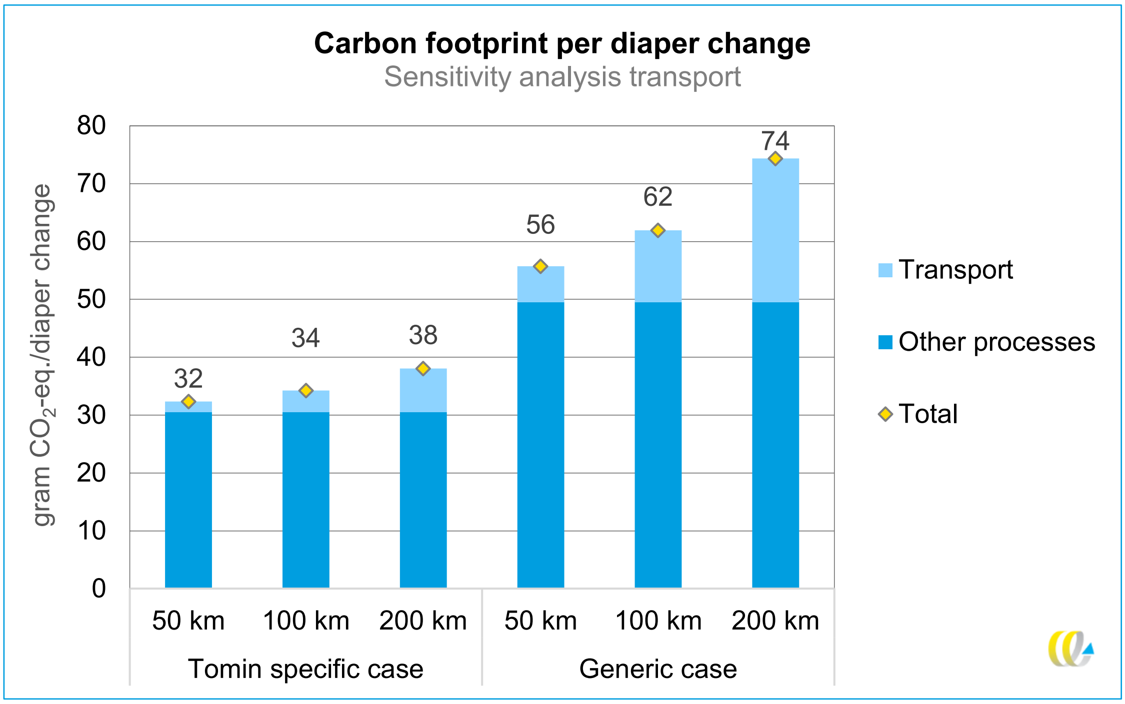
	Baseline analysis (technical lifetime)	Break-even point (comparison to household system)	Break-even point (comparison to disposable diapers)
Resistant layer and washing bag	300	72	14
Absorbing layer	450	108	21

3.2.2 Transport distance

In the main analysis, we assume a total transport distance of 100 km to collect washable diapers at multiple locations. This distance may vary in other circumstances, for example, with smaller or larger distances between individual day care centres and to the washing facility or with separate transport for the collection of dirty washable diapers and distribution of clean washable diapers.

Figure 7 shows the result of the sensitivity analysis where we assumed transport distances of 50 km, 100 km (main analysis) and 200 km. The carbon footprint of transport is shown in light blue. All other processes are combined in the dark blue bar to simplify the graph.

Figure 7 – Carbon footprint per diaper change in the centralised diaper system. Sensitivity analysis of the transport distance



In the Tomin-specific case, the effect of different transport distances is small, as we assume transport with an electric vehicle powered with 80% renewable electricity. With a transport distance of 50 km, the total carbon footprint of the washable diapers decreases by 2 g CO_2-eq./diaper change compared to a transport distance of 100 km. The carbon footprint increases by 4 g CO_2-eq./diaper change with a transport distance of 200 km.

In the generic case with diesel transport, the transport distance has a stronger influence on the results, as the carbon footprint per km is higher. With a transport distance of 50 km, the total carbon footprint of the washable diapers decreases by 6 g CO_2-eq./diaper change compared to a transport distance of 100 km. The carbon footprint increases by 12 g CO_2-eq./diaper change with a transport distance of 200 km.

For both the Tomin-specific case and the generic case, these changes in the transport distance do not change the conclusions of the comparison to disposable diapers and the household system.

3.2.3 Detergent composition

The composition of the detergent used in the centralised washing process is based on the safety data sheets of detergents used by Tomin. These sheets only provide a range of the percentage of active substances present in the detergent. In the main analysis, we assume the average value of these ranges. In this sensitivity analysis, we assume either the lower end or the higher end of the range in the detergent models.

Table 5 shows the carbon footprint of the detergent used per diaper change. With the average composition, the detergent has a carbon footprint of 2.9 g CO_2-eq./diaper change. This decreases by 1.2 g CO_2-eq./diaper change when we assume the lower end of the range in the composition. On the other hand, the carbon footprint of the detergent increases by 0.9 g CO_2-eq./diaper change when we assume the higher end of the range in the detergent composition.

The amount of detergent used in the Tomin-specific case and the generic case is assumed to be the same. Therefore, a change in the carbon footprint of the detergent will have the same effect on both cases. In both cases, the conclusions of the analysis are not affected when a higher or lower concentration of active substances is assumed.

Table 5 – Carbon footprint of detergent used in the washing process, for different compositions of the detergents, in g CO_2-eq./diaper change

	Carbon footprint detergent (g CO_2-eq./diaper change)
Detergent – lower concentration of active substances	1.7
Detergent – average composition	2.9
Detergent – higher concentration of active substances	3.8

3.3 Other environmental impacts

The three diaper systems are also compared on all 18 environmental impact categories, both at midpoint and at endpoint level. The analysis of the midpoint results is presented in Annex B. Here, the endpoints are discussed.

On the endpoint level, the midpoint results are aggregated into three indicators: human health, ecosystems and resources.

Figure 8 shows the endpoint results of the diaper systems studied. The highest impact of each damage category is set to 100%; the other impacts are scaled to that value.
The absolute values for each endpoint category for the centralised system are shown in Table 6. The absolute values for the other two diaper systems can be found in the 2023 report.

On all endpoints, the disposable diapers have a higher impact than both the centralised and household systems. The Tomin case of the centralised system has a lower impact than the household system for all endpoint categories. When comparing the generic case of the centralised system to the household system, we see that the centralised system has a higher impact on resources, a lower impact on ecosystems and a comparable impact on human health.

Figure 8 – Environmental impact of disposable and washable diapers on endpoint-level (The highest impact for each damage category is set to 100%.)

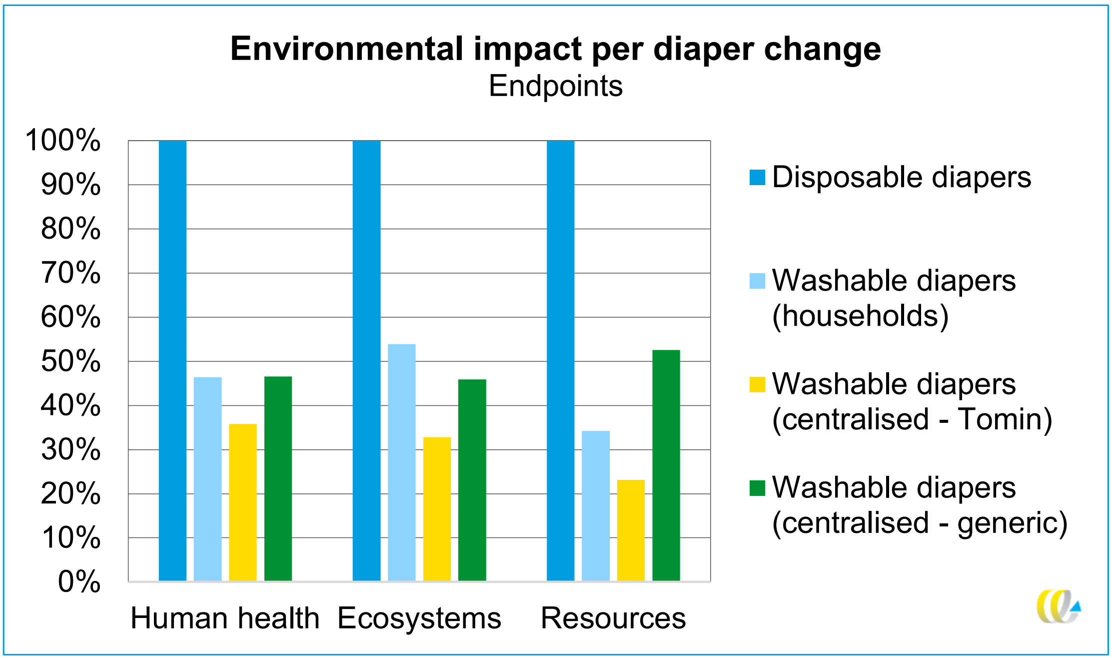


Table 6 – Environmental impact of the centralised system for both the Tomin-specific case and the generic case, on endpoint-level, per diaper change

Endpoint	Unit (per diaper change)	Tomin-specific case	Generic case
Human health	DALY	8.06E-08	1.05E-07
Ecosystems	species.yr	2.18E-10	3.05E-10
Resources	USD2013	2.73E-03	6.22E-03

4 Discussion and conclusion

4.1 Uncertainties

The LCA modelling of the centralised washable diaper system is considered relatively robust. It is based on primary data from the pilot programme, and the uncertainties are small. In particular, the processes that contribute most to the carbon footprint (i.e. production of the paper insert, washing and drying) have low uncertainties. Similarly, the results for the disposable diapers (taken from the 2023 CE Delft analysis) are considered relatively certain.

In contrast, however, the household washable diaper system (also modelled in the 2023 study) is subject to larger uncertainties. Here, practices in households and their available equipment strongly determine the resulting carbon footprint. This uncertainty is captured in the large range of results seen in the low-impact and high-impact scenarios for the household system. This wide spread in impact should be kept in mind when interpreting the results.

A number of specific uncertainties in the modelling of the centralised washable diaper system and the comparison to the prior results can be pointed out:

- The diaper composition is based on an average washable diaper (which has been defined by Billie Wonder). In practice, five different diaper sizes are used. These diaper sizes only vary in weight, not in composition. If more diapers of a larger size are used than assumed by Billie Wonder, the average weight will increase. This will result in a small increase in the carbon footprint of production and recycling. As the contribution of these processes to the total carbon footprint is relatively low, this is not expected to result in a change in the conclusions.
- For the lifetime of the washable diapers, we assumed the technical lifetime expressed as the maximum number of wash cycles. The diapers also have a maximum lifetime in years (unrelated to the number of wash cycles). It is possible that during this period, the diapers are not washed (and used) as often as technically possible. The sensitivity analysis described in Section 3.2.1 shows that only when the washable diapers are used 76% less than the technical lifetime, the carbon footprint of centralised washing of diapers used in daycare centres is

higher than the baseline carbon footprint of washable diapers used in households with the average electricity mix.

- We assume that the collection of dirty washable diapers and distribution of clean washable diapers takes place during the same transport ride, over a transport distance of 100 km. Separate transport for collection and distribution, or larger distances between the daycare centres, could result in larger transport distances. On the other hand, if more daycare centres participate in the centralised washing, transport distances could be reduced. The sensitivity analysis described in Section 3.2.2 shows that neither a lower transport distance of 50 km nor a higher transport distance of 200 km changes the conclusions of the analysis.
- The composition of the detergents is uncertain, as this is based on the information provided by safety data sheets, which only show ranges of the active substances present. The sensitivity analysis described in Section 3.2.3 shows that the effect of this uncertainty on the total carbon footprint of centralised washing is small.

The results of the analysis of the centralised washing system are compared to the results for the use of washable diapers in households and the use of disposable diapers, which were studied by CE Delft in 2023. The results of the 2023 study were not updated in this analysis. As a consequence, different versions of the background datasets were used in the model of the centralised washing of diapers and the models of the washable diapers used in households and the disposable diapers. This results in a small uncertainty in the comparison of the different diaper systems.

4.2 Conclusions

This LCA studies the environmental impact of washable diapers used in daycare centres, combined with a centralised washing process (the centralised system), over the whole lifecycle of the diapers. The environmental impact of this system is compared to the environmental impact of washable diapers used in households (the household system) and disposable diapers.

The LCA is based on data from the pilot project carried out at the Tomingroep in Hilversum. This project-specific data is combined with assumptions about operation at full scale (e.g. about transport distances, load factors). The uncertainty in the data is small. The sensitivity analyses show that the existing uncertainties only have a small influence on the results (as discussed in Section 4.1).

The LCA shows that washable diapers can offer a substantial carbon footprint reduction compared to disposable diapers (up to 80%). This is the case both for a centralised washable diaper system and for a household system (unless we assume a fairly conservative high-impact scenario).

The comparison of the centralised system and the household system is more complex. While the environmental benefits of the centralised system are comparatively certain, the benefits of the household system strongly depend on local washing and drying practices.

- The Tomin-specific case for centralised washing has a lower carbon footprint than the baseline scenario for households with the average electricity mix. When households use a more sustainable electricity mix, the baseline scenario results in a slightly lower carbon footprint than the Tomin-specific case for centralised washing. The generic case of the centralised system has a higher carbon footprint than the baseline scenario for households due to the (diesel-based) transport.
- If households run separate washing cycles for diapers and use inefficient equipment (the high-impact scenario), the centralised system has a far lower carbon footprint. Conversely, the carbon footprint of household washing is lower when using line drying and fully loaded washing machines (low-impact scenario).

Comparing the two variants of the centralised diaper system highlights the importance of the energy mix, as well as of how diapers are transported. The use of renewable energy results in a substantial reduction of the carbon footprint of washing and drying. Similarly, the use of electric vehicles reduces the carbon footprint of transporting the used and clean washable diapers. In this scenario (the Tomin-specific case), the carbon footprint of the centralised system is lower than the baseline scenario for households (with the current energy mix[9]).

For other environmental impacts (beyond the carbon footprint), the conclusions are roughly the same. If we consider the environmental endpoint indicators (discussed in more detail in Annex B), the washable diaper systems have a lower impact in all cases than disposable diapers. The Tomin-specific centralised system results in the lowest environmental impact on the aggregated human health, ecosystems and resource indicators.

In this comparison, it should be kept in mind that the carbon footprint estimates for the household system are subject to a larger number of uncertainties than the centralised system. The latter is based on primary data determined in a real-world project context (e.g. for the energy use and loading rates of the washing and drying machines). For the former, a large range of possible scenarios can be envisioned. These can include a low-impact scenario in which energy-efficient washing machines and dryers only run when fully loaded, as well as a high-impact scenario in which the opposite is true. This means that

[9] Also for households, the amount of energy used for washing and drying determines the carbon footprint of washable diaper use. As the average Dutch electricity mix becomes increasingly renewable over time, the carbon footprint of the washable diapers used by households decreases as well. When modelled with the expected 2030 Dutch mix, the baseline household system overtakes the Tomin-specific centralised system again with a slightly lower carbon footprint.

the environmental benefits of the centralised system are more certain, as they are not subject to variations between households.

While this study focuses on comparing the environmental impact of washable diapers when used at home or when washed at a central location, these systems are not at odds and can complement each other. In the current programme, children go to their daycares wearing disposable diapers, and leave the same way. Expanding the system so that more washable diapers are used would offer the largest carbon footprint benefits. For example, parents could loan washable diapers owned by daycares for use at home, and hand them in for centralised washing. Alternatively, parents could own the washable diapers, give them to daycares for use during the day, and wash them at home afterwards. Ultimately, the environmental impact of the diapering needs of young children is smallest when the amount of disposable diapers used is minimised, and when they are washed/dried efficiently (e.g. running full machines) with low-carbon energy sources.

5 Literature

Billenboetiek. (2022). *Billenboetiek*. https://www.billenboetiek.nl/popolini/poplini-inlegvellen/

CE Delft. (2018). *Milieu-informatie textiel : Update 2018*.

CE Delft. (2021). *Klimaatimpact van afvalverwerkroutes in nederland: Co2-kentallen voor recyclen en verbranden voor 13 afvalstromen*.

CE Delft. (2023a). *Ketenemissies elektriciteit, actualisatie elektriciteitsmix 2021*.

CE Delft. (2023b). *Levenscyclusanalyse van wasbare en eenmalige luiers*.

CE Delft. (2023c). *Stream personenvervoer. Emissiekentallen modaliteiten 2022*.

Ecoinvent. (2021). *Ecoinvent v3.8*. Ecoinvent.

Kliphuis, M. (2022, 22-9-2022). *Toetsen wasscenario's wasbare luiers* [Interview]. CE Delft.

Nationale Milieudatabase. (2022). *Bepalingsmethode milieuprestatie bouwwerken versie 1.1 (maart 2022)*. Stichting Nationale Milieudatabase. https://milieudatabase.nl/wp-content/uploads/2022/04/Bepalingsmethode_Milieuprestatie_Bouwwerken_maart_2022.pdf

STOWA. (2016). *Handboek slibgisting*.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). *The ecoinvent database version 3 (part i): Overview and methodology*.

A Data inventory

A.1 Production diapers

Table 7 shows the inventory data for the production of one diaper (consisting of a resistant layer, an absorbing layer and a paper insert).

Table 7 – Data inventory for the production of one diaper

Process/material	Unit	Amount	Environmental impact modelling *Ecoinvent processes in italics*
Resistant layer			
Polyester	g	50.7	*Fibre, polyester {GLO}| market for*
Thermoplastic polyurethane	g	12.6	*Polyurethane, rigid foam {RoW}| market for*
Rubber	g	3.2	*Synthetic rubber {GLO}| market for*
POM	g	3.0	*Polyurethane, rigid foam {RoW}| market for*[1]
Production process	g	69.6	*Textile, knit cotton {RoW}| textile production, cotton, circular knitting* (input of cotton set to zero) *Finishing, textile, knit cotton {GLO}| finishing, textile, knit cotton*
Absorbing layer			
Hemp	g	37.9	*Yarn, cotton {GLO}| yarn production, cotton, ring spinning, for knitting*; cotton input replaced by hemp input. Hemp model based on (CE Delft, 2018).
Cotton	g	88.3	*Yarn, cotton {GLO}| market for*
Polyester	g	0.5	*Fibre, polyester {GLO}| market for*
Rubber	g	0.3	*Synthetic rubber {GLO}| market for*
POM	g	0.8	*Polyurethane, rigid foam {RoW}| market for*[1]
Production process	g	127.7	*Textile, knit cotton {RoW}| textile production, cotton, circular knitting* (input of cotton set to zero) *Finishing, textile, knit cotton {GLO}| finishing, textile, knit cotton*

Process/material	Unit	Amount	Environmental impact modelling *Ecoinvent processes in italics*
Insert			
Cellulose	g	2.9	*Tissue paper {GLO}| market for*
Polyester	g	0.1	*Fibre, polyester {GLO}| market for*
Production process	g	3.0	The impact of production is assumed to already be included in the dataset for the production of tissue paper.

1: The ecoinvent database does not contain a dataset for POM. The EF database does contain such a dataset, but that database may only be used in PEF studies (which this analysis is not). The environmental impact of polyurethane was comparable to the environmental impact of POM (based on the PEF database value); therefore, this dataset is used as a proxy.

All components are produced in China and transported to the Netherlands by containership over a distance of 20,000 km. The dataset for transport by containership is based on the STREAM study performed by CE Delft (2023c).

A.2 Use phase

Table 8 shows the technical lifetime of the resistant layers, absorbing layers and washing bags. The lifetime is expressed in the maximum number of washing cycles the products can endure.

Table 8 – Technical lifetime of the diapers and washing bags (in washing cycles per product)

Product	Lifetime (washing cycles)
Resistant layers	300
Absorbing layers	450
Washing bags	300

A.3 Transport to washing location

Table 9 shows the inventory data of the transport to and from the washing location. The transport distance is the total distance covered, starting and ending at the washing location. It is assumed that within one transport, both clean washable diapers are delivered to the daycare centres and dirty washable diapers are collected. The amount of absorbing and resistant layers per transport refers to either the amount of clean products at the start of the transport or the amount of dirty products at the end of the transport.

Table 9 – Inventory data of transport to and from the washing location

	Unit	Amount
Number of absorbing layers per transport	p	3,420
Number of resistant layers per transport	p	3,420
Transport distance	km	100

Mode of transport Tomin-specific case

In the Tomin-specific case, all transport to and from the washing location is taking place with an electric vehicle powered by the electricity mix of the Tomin Groep (80% solar energy, 20% average mix (see Section 2.1)). The environmental impact of electric transport is based on the model of an electric passenger car (CE Delft, 2023c) with either a renewable electricity mix or the average electricity mix as input. The dataset is corrected for the average occupancy of 1.31 passengers to find the environmental impact per km.

Mode of transport generic case

In the generic case, we assume transport with vehicles running on diesel.
The environmental impact of diesel transport is based on the model of a diesel passenger van CE Delft (2023c). The dataset is corrected for the average occupancy of 2.4 passengers to find the environmental impact per km.

A.4 Washing and drying

Table 10 shows the inventory data for the washing and drying process. Each day, 20 washing cycles are 10 drying cycles are run at the centralised location.

Table 10 – Inventory data of the washing and drying process, per washing or drying cycle

Process/material	**Unit**	**Amount**	**Amount**	**Environmental impact modelling** ***Ecoinvent processes in italics***
Washing		**Resistant layers**	**Absorbing layers**	
Load factor	p	513	257	Estimation based on the amount of resistant and absorbing layers used per week and the number of washing and drying cycles.
Electricity	kWh	6.7	6.7	Tomin-specific case: 80% *Electricity, low voltage {NL}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted* + 20% average Dutch electricity mix (CE Delft, 2023a) Generic case: 100% average Dutch electricity mix (CE Delft, 2023a)
Water	litre	600	700	*Tap water {Europe without Switzerland}| market for*

Process/material	Unit	Amount	Amount	Environmental impact modelling ***Ecoinvent processes in italics***
Washing		**Resistant layers**	**Absorbing layers**	
Detergents	ml	160 40 80 240	160 40 - 200	Coolcare Solvan 564 Mulan Mineral Free Peracid Asepsis Modelling details in Table 11
Wastewater treatment	litre	600	700	*Wastewater, average {Europe without Switzerland}| market for*
Drying				
Load factor	p	1,026	513	Estimation based on the amount of resistant and absorbing layers used per week and the number of washing and drying cycles.
Electricity	kWh	7	24	Tomin-specific case: 80% *Electricity, low voltage {NL}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted* + 20% average Dutch electricity mix (CE Delft, 2023a) Generic case: 100% average Dutch electricity mix (CE Delft, 2023a)

Table 11 shows the inventory data for the production of detergents. The data is based on the information in the safety data sheets. These sheets only show the ranges of the active substances present. In the model, we assumed the average of this range. The remainder of the detergent is assumed to be composed of deionised water.

Table 11 – Inventory data of the detergents, per litre of detergent

Process/material	Unit	Amount	Environmental impact modelling ***Ecoinvent processes in italics***
Coolcare			
Alcoholethoxylate	g	280	Ranges between 15% and 40% *25% Ethoxylated alcohol (AE3) {RER}| market for* *25% Ethoxylated alcohol (AE11) {GLO}| market for* *25% Ethoxylated alcohol (AE7) {RER}| market for* *25% Ethoxylated alcohol (AE>20) {GLO}| market for*
Glycerine	g	80	Ranges between 5% and 10% *Glycerine {RER}| market for glycerine*
Sodium cumenesulfonate	g	80	Ranges between 5% and 10% *Sodium cumenesulfonate {GLO}| market for*
2,2-dimethyl-1,3-dioxolan-4-ylmethanol	g	40	Ranges between 3% and 5% *Chemical, organic {GLO}| market for*
Sodiumdodecylbenzene-sulfonate	g	40	Ranges between 3% and 5% *Chemical, organic {GLO}| market for*

Process/material	Unit	Amount	Environmental impact modelling ***Ecoinvent processes in italics***
Coolcare			
Deionised water	g	50	*Water, deionised {Europe without Switzerland}| market for*
Solvan 564			
Sodium hydroxide	g	450	Ranges between 30% and 60% *Sodium hydroxide, without water, in 50% solution state {RER}| market for*
Deionised water	g	550	*Water, deionised {Europe without Switzerland}| market for*
Mulan Mineral Free			
Ethoxylated alcohol	g	450	Ranges between 30% and 60% *25% Ethoxylated alcohol (AE3) {RER}| market for* *25% Ethoxylated alcohol (AE11) {GLO}| market for* *25% Ethoxylated alcohol (AE7) {RER}| market for* *25% Ethoxylated alcohol (AE>20) {GLO}| market for*
Alcoholethoxylate	g	450	Ranges between 30% and 60% *25% Ethoxylated alcohol (AE3) {RER}| market for* *25% Ethoxylated alcohol (AE11) {GLO}| market for* *25% Ethoxylated alcohol (AE7) {RER}| market for* *25% Ethoxylated alcohol (AE>20) {GLO}| market for*
Ethanol	g	20	Ranges between 1% and 3% *Ethanol, without water, in 99.7% solution state, from ethylene {RER}| market for*
Deionised water	g	80	*Water, deionised {Europe without Switzerland}| market for*
Peracid Asepsis			
Hydrogen peroxide	g	200	Ranges between 10% and 30% *Hydrogen peroxide, without water, in 50% solution state {RER}| market for*
Acetic acid	g	80	Ranges between 5% and 10% *Acetic acid {GLO}| market for*
Peracetic acid	g	40	Ranges between 3% and 5% *Peracetic acid {RER}| market for*
Deionised water	g	680	*Water, deionised {Europe without Switzerland}| market for*

In the washing process protective equipment is used. Table 12 shows the inventory data of all protective equipment used in the washing process.

Table 12 – Inventory data for the production of all protective equipment used in the washing process and of the waste treatment of the disposable equipment

Process/material	**Unit**	**Amount**	**Environmental impact modelling** *Ecoinvent processes in italics*
Disposable gown			
Amount per day	p	20	
Polyethylene	g/p	16	*Polyethylene, low density, granulate {RER}| polyethylene production*
Production process	g/p	16	*Extrusion, plastic film {RER}| extrusion*
Waste treatment	g/p	16	Incineration emissions: Waste polyethylene {CH}| treatment of waste polyethylene, municipal incineration FAE Electricity recovered: 0.122 MJ (*Average Dutch electricity mix (CE Delft, 2023a)*) Heat recovered: 0.211 MJ (*Heat, district or industrial, natural gas {Europe without Switzerland}| market for*)
Safety glasses			
Amount per day	p	0.01	Assumption: safety glasses have a lifetime of 100 days
Polycarbonate	g/p	52	*Polycarbonate {RER}| polycarbonate production*
Latex gloves			
Amount per day	p	40	
Latex	g/p	6	*Latex {RER}| market for*
Production process	kWh/p	0,01	*Electricity, high voltage {CN}| market group for*
Waste treatment	g/p	6	Incineration emissions: *Waste rubber, unspecified {CH}| treatment of waste rubber, unspecified, municipal incineration FAE* (direct CO2-emissions set to 0) Direct CO2-emissions: 0.019 kg Electricity recovered: 0.029 MJ (*Average Dutch electricity mix (CE Delft, 2023a)*) Heat recovered: 0.049 MJ (*Heat, district or industrial, natural gas {Europe without Switzerland}| market for*)
Mask			
Amount per day	p	2	
Nonwoven PP	g/p	5	*Textile, nonwoven polypropylene {RoW}| textile production, nonwoven polypropylene, spunbond*
Aluminium	g/p	0.95	*Aluminium, primary, ingot {RoW}| market for*
Rubber	g/p	3	*Synthetic rubber {RoW}| synthetic rubber production*
Waste treatment	g/p	8	Waste treatment model based on 100% PP Incineration emissions: *Waste polypropylene {CH}| treatment of waste polypropylene, municipal incineration FAE*

Process/material	Unit	Amount	Environmental impact modelling *Ecoinvent processes in italics*
			Electricity recovered: 0.056 MJ (*Average Dutch electricity mix (CE Delft, 2023a)*) Heat recovered: 0.097 MJ (*Heat, district or industrial, natural gas {Europe without Switzerland}| market for*)

A.5 Packaging

The resistant and absorbing layers are collected in separate washing bags at the daycare centres. One washing bag contains, on average, either 25 resistant layers or 17 absorbing layers. Table 13 provides the inventory data for the production of one washing bag.

Table 13 – Inventory data for the production of one washing bag

Process/material	Unit	Amount	Environmental impact modelling *Ecoinvent processes in italics*
Washing bag			
Polyester	g	180.2	*Fibre, polyester {GLO}| market for*
Thermoplastic polyurethane	g	49.8	*Polyurethane, rigid foam {RoW}| market for*
Rubber	g	4.7	*Synthetic rubber {GLO}| market for*
Production process	g	234.6	*Textile, knit cotton {RoW}| textile production, cotton, circular knitting* (input of cotton set to zero) *Finishing, textile, knit cotton {GLO}| finishing, textile, knit cotton*

After washing and drying, the resistant and absorbing layers are packaged in a plastic bag and a plastic crate. It is estimated that one bag and one crate contain 25 resistant and absorbing layers. Table 14 provides the inventory data for the production of one plastic crate and one plastic bag.

Table 14 – Inventory data for the production of the plastic crate and bag

Process/material	Unit	Amount	Environmental impact modelling *Ecoinvent processes in italics*
Plastic crate			
Polypropylene	kg	1.43	*Polypropylene, granulate {RoW}| polypropylene production*
Production process	kg	1.43	*Injection moulding {RoW}| injection moulding*

Process/material	Unit	Amount	Environmental impact modelling *Ecoinvent processes in italics*
Plastic bag			
Polyethylene	g	10	*Polyethylene, low density, pellets, recycled {RER}| market for*
Production process	g	10	*Extrusion, plastic film {RER}| extrusion*

A.6 Production of biogas at wastewater treatment

The washing of diapers leads to an increase in organic material in wastewater, originating from urine and faeces, from which biogas can be recovered. A used diaper contains an average of 7.6 g of organic dry matter (ODM).

In practice, biogas production from sludge digestion usually ranges between 200-500 L of biogas per kg ODM (STOWA, 2016). Here, we assume an average value of 350 L/kg ODM. This corresponds to 2.66 L of biogas per diaper change (350 L/kg × 7.6 g = 2.66 L). The electricity and heat that can be produced from the recovered biogas in a CHP, and the associated emissions, are shown in Table 15. The average calorific value of biogas varies between 20-23 MJ/Nm³ (STOWA, 2016). In this ase, we assume an average value of 21.5 MJ/Nm³. The electrical and thermal efficiency of an average CHP unit are 37% and 53%, respectively (Ecoinvent, 2021).

Table 15 – Data inventory for the production of biogas from the organic dry matter in used diapers, per diaper change

Process	Unit	Amount	Direct emissions modelling *Ecoinvent processes in italics*
Input			
Organic dry matter	g	7.6	
Biogas production	liter	2.66	
Avoided the production of electricity by combusting biogas in a CHP	Wh	5.88	Average Dutch electricity mix (CE Delft, 2023a)
Avoided the production of heat by combusting biogas in a CHP	kJ	30.3	*Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas*

Process	Unit	Amount	Direct emissions modelling *Ecoinvent processes in italics*
Output			
Emissions of combusting biogas for electricity production	Wh	5.88	Direct emissions of the dataset: *Electricity, high voltage {NL}| heat and power co-generation, biogas, gas engine.*
Emissions of combusting biogas for heat production	kJ	30.3	Direct emissions of the dataset: *Heat, central or small-scale, other than natural gas {NL}| heat and power co-generation, biogas, gas engine.*

A.7 Waste treatment

At end-of-life, the resistant and absorbing layers of the washable diapers and washing bags are mechanically recycled. The paper inserts are incinerated. Table 16 shows the modelling details for the mechanical recycling of textile (CE Delft, 2021). Avoided conventional production of textile is not included in the model, as it is uncertain what the quality of the recycled textile is. Table 17 and Table 18 show the modelling details for incineration.

Table 16 – Modelling details for mechanical incineration of textile

Process	Unit	Amount	Direct emissions modelling *Ecoinvent processes in italics*
Transport to recycling	km	200	*Transport, freight, lorry, 16-32 metric ton, diesel, EURO 5 {RER}*
Electricity	kWh	0.5	Average Dutch electricity mix (CE Delft, 2023a)
Incineration of losses	kg	0.2	*Waste textile, soiled {CH}| treatment of waste textile, soiled, municipal incineration FAE*

Table 17 – Modelling details for waste incineration

Processes	Environmental impact modelling *Ecoinvent processes in italics*
Electric efficiency	18% (Nationale Milieudatabase, 2022)
Thermal efficiency	31% (Nationale Milieudatabase, 2022)
Avoided electricity production	Average Dutch electricity mix (CE Delft, 2023a)
Avoided heat production	*Heat, district or industrial, natural gas {Europe without Switzerland}| market for*
Transport to incineration	80 km *Transport, freight, lorry, 16-32 metric ton, diesel, EURO 5 {RER}| market for*

Table 18 – Material specific data inventory for incineration

	LHV (MJ/kg)	**Direct emissions modelling** *Ecoinvent processes in italics*
Cellulose	15.9	*Waste paperboard {CH}| treatment of waste paperboard, municipal incineration FAE*
Hemp	17	*Biowaste {CH}| treatment of biowaste, municipal incineration FAE*
Cotton	17	*Biowaste {CH}| treatment of biowaste, municipal incineration FAE*
Polyester	22.9	*Waste polyethylene terephthalate {CH}| treatment of waste polyethylene terephthalate, municipal incineration FAE*
POM	20	*Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration FAE*
Rubber	27.2	*Waste rubber, unspecified {CH}| treatment of waste rubber, unspecified, municipal incineration FAE*
TPU	30.7	*Waste polyurethane {CH}| treatment of waste polyurethane, municipal incineration FAE*

B Detailed results

B.1 Midpoint results

In the main analysis we focused on the comparison of the carbon footprints of the different diaper systems. With the ReCiPe method, the impact on a total of 18 environmental impact categories can be determined. Figure 9 shows the results of this comparison. In this graph, for each impact category, the diaper system with the highest impact is set to 100%. The impacts of the other diaper systems are shown relative to this maximum impact.

For the household system, we take the baseline result of the case where the use of the average electricity mix is assumed.

Table 19 shows the absolute results for each environmental impact category for the centralised system. The absolute values for the other two diaper systems can be found in the 2023 report.

Please note that from the amount of impact categories on which a system scores higher or lower, it can not necessarily be concluded which system is more sustainable. To be able to draw conclusions about this, the midpoint results must be normalised, weighted and combined in endpoint categories, which are discussed in Section 1.1.

Content

Figure 9 – Environmental impact of disposable and washable diapers on midpoint-level (The highest impact for each impact category is set to 100%.)

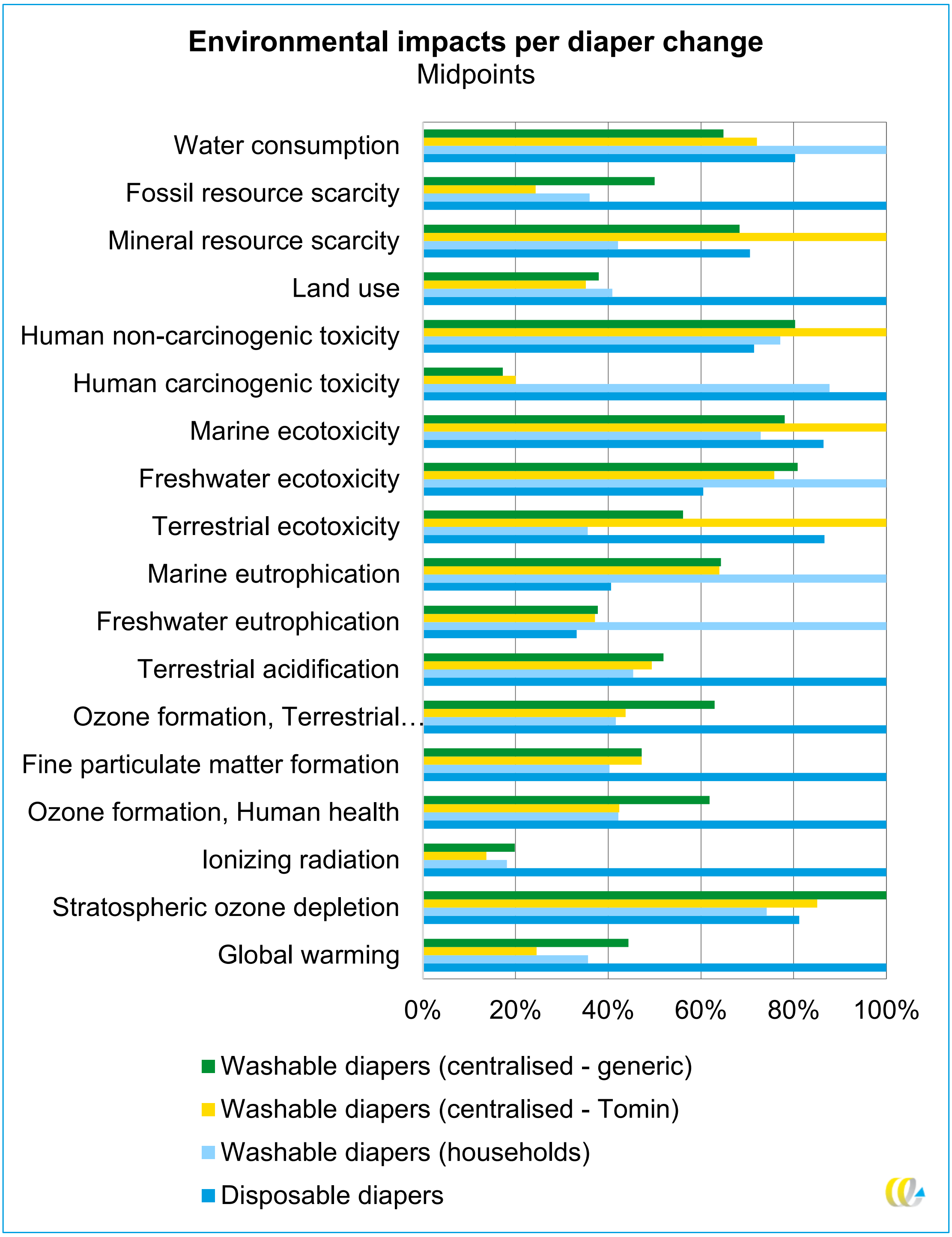


Table 19 – Environmental impact of washable diapers used in daycare centres for both the Tomin-specific case and the generic case, at midpoint-level, per diaper change

Impact category	Unit (per diaper change)	Tomin-specific case	Generic case
Global warming	kg CO_2-eq.	3.43E-02	6.19E-02
Stratospheric ozone depletion	kg CFC11-eq.	5.26E-08	6.18E-08
Ionizing radiation	kBq Co-60-eq.	2.11E-04	3.06E-04
Ozone formation, Human health	kg No_x-eq.	9.24E-05	1.35E-04
Fine particulate matter formation	kg $PM_{2.5}$-eq.	6.36E-05	6.35E-05
Ozone formation, Terrestrial ecosystems	kg NO_x-eq.	9.88E-05	1.42E-04
Terrestrial acidification	kg SO_2-eq.	1.55E-04	1.62E-04
Freshwater eutrophication	kg P-eq.	1.20E-05	1.21E-05
Marine eutrophication	kg N-eq.	3.19E-05	3.21E-05
Terrestrial ecotoxicity	kg 1,4-DCB	2.48E-01	1.39E-01
Freshwater ecotoxicity	kg 1,4-DCB	1.47E-04	1.57E-04
Marine ecotoxicity	kg 1,4-DCB	3.11E-04	2.43E-04
Human carcinogenic toxicity	kg 1,4-DCB	2.55E-04	2.19E-04
Human non-carcinogenic toxicity	kg 1,4-DCB	3.08E-02	2.48E-02
Land use	m_2a crop-eq.	6.24E-03	6.73E-03
Mineral resource scarcity	kg Cu-eq.	2.77E-04	1.89E-04
Fossil resource scarcity	kg oil-eq.	9.67E-03	1.99E-02
Water consumption	m^3	1.47E-03	1.32E-03

B.1.1 Comparison of the Tomin-specific and generic case

The Tomin-specific case has a lower environmental impact than the generic case on nine environmental impact categories. On 6 impact categories, the impact of the Tomin case is higher than the impact of the generic case. On 3 impact categories, the impact is comparable for both cases. In the Tomin case, more renewable electricity is consumed than in the generic case. On the 6 impact categories where the Tomin case has a higher impact than the generic case, the Tomin electricity mix also has a higher impact than the average electricity mix, which is used in the generic case.

B.1.2 Comparison to disposable diapers

Table 20 shows how the midpoint results of the centralised system compare to the midpoint results of the disposable diapers:

- On 10 impact categories, the centralised system has a lower impact than disposable diapers.
- On 3 impact categories, the impact of the centralised system in the Tomin case is lower than the impact of the disposable diapers, but the impact of the generic case is higher.
- On 5 impact categories, the impact of the centralised system is higher than the impact of disposable diapers.

Table 20 – Overview of the comparison of the centralised system and disposable diapers

Washable diapers have a lower impact than disposable diapers	In the Tomin case, washable diapers have a lower impact, in the generic case, a higher impact than disposable diapers	Washable diapers have a higher impact than disposable diapers
Global warming	Terrestrial ecotoxicity	Stratospheric ozone depletion
Ionizing radiation	Marine ecotoxicity	Freshwater eutrophication
Ozone formation, human health	Mineral resource scarcity	Marine eutrophication
Fine particulate matter formation		Freshwater ecotoxicity
Ozone formation, terrestrial ecosystems		Human non-carcinogenic toxicity
Terrestrial acidification		
Human carcinogenic toxicity		
Land use		
Fossil resource scarcity		
Water consumption		

B.1.3 Comparison to the household system

Table 21 shows how the midpoint results of the centralised system compare to the midpoint results of the household system:

- On 6 impact categories, the centralised system has a lower impact than the household system.
- On 3 impact categories, the impact of the Tomin case of the centralised system is lower than the impact of the household system, but the impact of the generic case is higher.
- On 9 impact categories, the impact of the centralised system is higher than the impact of the household system.

Table 21 – Overview of the comparison of the centralised system and the household system

The centralised system has a lower impact than the household system	In the Tomin case, the centralised system has a lower impact, in the generic case, a higher impact than the household system	The centralised system has a higher impact than the household system
Freshwater eutrophication	Global warming	Stratospheric ozone depletion
Marine eutrophication	Ionizing radiation	Ozone formation, human health
Freshwater ecotoxicity	Fossil resource scarcity	Terrestrial acidification
Human carcinogenic toxicity		Terrestrial ecotoxicity
Land use		Marine ecotoxicity
Water consumption		Human non-carcinogenic toxicity
		Mineral resource scarcity
		Fine particulate matter formation
		Ozone formation, terrestrial