LCA of waste treatment of diaper material

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Contents

Summary

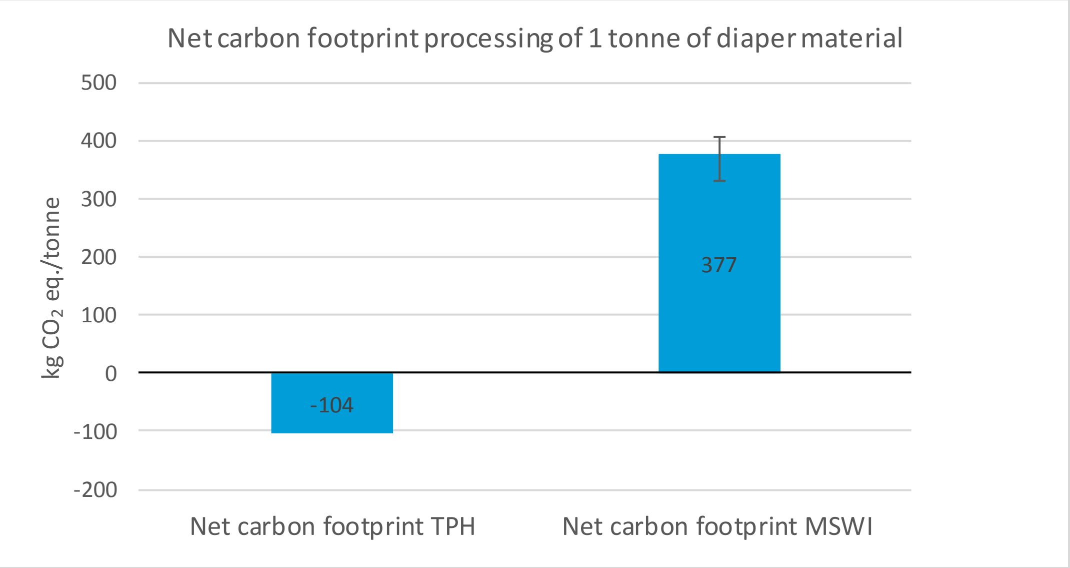
In this study for Elsinga, ARN and Milieusamenwerking en Afvalverwerking Regio Nijmegen (MARN), the following question is answered:
How does the environmental impact of the treatment of diapers by TPH compare with the incineration (with energy recovery) of this material in a municipal solid waste incinerator (MSWI)?

To accomplish this goal, an LCA is carried out to compare both waste treatment options. LCA's are often used to compare waste treatment options, and thereby gain insight into the environmental costs and benefits of recycling.

Life cycle impact results were assessed for:
- **The carbon footprint**: This shows a clear benefit of treatment in the TPH unit. Substitution of the TPH method for the conventional incineration yields a benefit of 480 kg CO_2-eq. per tonne diaper material treated.
- **The 16 other midpoints**: Treatment in a TPH unit is favourable for 12 out of 17 midpoints.
- **The 3 endpoints**: To assess the relevance of the scores on different midpoints, results on endpoint level were included. These show that treatment in the TPH is favourable for all three endpoints.

Global warming is the most important category; for the endpoints human health and ecosystems, global warming contributes most to the score of each treatment route. This means that, while locally other environmental impact categories may be important, the net carbon footprint, as shown in Figure 1, can serve as a proxy to compare both treatment options. The TDH option has a negative net carbon footprint, the MSWI option a net positive carbon footprint. The difference, the benefit of substituting treatment by TDH for MSWI, is ~480 kg CO_2-eq. per tonne diaper material

Figure 1 - Net carbon footprint of treating 1 tonne of diaper material



Note: "ARN" indicates the carbon footprint of processing 1 tonne of diaper material in the MSWI of ARN.

Review of the LCA by SGS Search indicates that there is 'no reason for doubt about the conclusions in the report' (see Annex C).

Glossary

Term or abbreviation	Meaning
Elsinga	Elsinga Beleidsplanning & Innovatie B.V.
ARN	ARN B.V.; municipal waste incinerator in Weurt
MARN	Milieusamenwerking en Afvalverwerking Regio Nijmegen
TPH	Thermal Pressure Hydrolysis at 250°C > 40 Bar
Diaper material	Refers to used baby diapers and incontinence products
MSWI	Municipal Solid Waste Incinerator
WWTP	Waste Water Treatment Plant
CHP	Combined Heat & Power plant
SAP	Superabsorbent polymer
GMB	Processor of waste water sewage sludge into granulated biosolids

1 Introduction

Elsinga Beleidsplanning & Innovatie B.V. ('Elsinga') and ARN B.V. developed an innovative technical solution for the recycling of used baby diapers and incontinence products. The processing method is based on 'thermal pressure hydrolysis at 250°C > 40 Bar' ('TPH') of the diapers and incontinence products, after which the plastics present in the diapers (LDPE/PP) are collected and biogas is produced.

In May 2017, Elsinga completed a CO_2 scan of their diaper recycling process. CE Delft reviewed this CO_2 scan, specifically addressing the methodological choices on which the analysis was based.
In October, Elsinga, ARN and Milieusamenwerking en Afvalverwerking Regio Nijmegen (MARN) asked CE Delft to conduct a detailed life cycle assessment (LCA) study, in which the processing of diapers with TPH is compared with a reference situation: incineration with energy recovery. The central question in this study is:

How does the environmental impact of the treatment of diapers by TPH compare with the incineration (with energy recovery) of this material in a municipal solid waste incinerator (MSWI)?

To answer this question, CE Delft modelled the environmental impact of both processing methods using LCA. LCA is an environmental impact assessment method that provides insight into the contribution of different process steps to different environmental impacts across all stages of a product's life. In addition to climate change impact (the CO_2-eq. footprint), a number of other environmental impact categories are taken into account, such as land use, acidification and particulate matter emissions. LCA is often used to compare different waste treatment options in order to determine the environmental benefits of e.g. recycling.

This report is written both for internal use by Elsinga, ARN and MARN as well as for external communication on the environmental performance of the TPH process.

In Chapter 2, the scope and methodology of this study are described. This entails, among other things, a description of the functional unit of the analysis and the designated system boundaries. In Chapter 3, we present the life cycle inventory, mainly based on input data supplied by Elsinga and ARN.
In Chapter 4, we show the result of the analysis. In Chapter 5 several sensitivity analyses are explored. An interpretation of results is given in Chapter 6. The review of the LCA by SGS Search is included in Annex C.

2 Goal and scope

2.1 Goal definition

The goal of this analysis is to assess the environmental performance of processing an input of 50% diapers and 50% incontinence material (together referred to as 'diaper material' in this study) according to the 'Elsinga' TPH process and to compare this to a reference situation of current waste management of such materials (i.e. incineration in a MSWI). To accomplish this goal, an LCA is carried out to compare both waste treatment options. This is an *ex-ante* analysis for the TPH route, as the process will be established at full-scale in 2018.
The assessed waste treatment routes are:

1. Reference route: Incineration of non-separately collected used diapers and incontinence material in an MSWI with energy recovery.
2. Processing of separately collected diapers and incontinence material by thermal pressure hydrolysis (TPH), through which recycled plastics and biogas are produced, as well as additional biogas from added (already digested) sewage sludge, and digestate which is processed into granulated biosolids used for energy recovery (with recovery of ammonium sulphate, a fertilizer, at the granulation plant).

2.2 Functional unit

The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs are to be related. In this assessment, the functional unit is defined as:

The processing of 1 tonne used diapers and incontinence products with a given composition, including the application of the products that are made in this process and any additional environmental costs or benefits from the integration of this technology into the existing waste treatment system.

The treatment methods assessed in this study are (or will be) both situated at the existing ARN site. In Chapter 3 (life cycle inventory) the composition of the input material mentioned in the functional unit is described in more detail.

2.3 Description of Elsinga's TPH process

Elsinga's TPH process is based on a pilot-scale configuration as tested by Elsinga and ARN. In the Netherlands, ARN and Elsinga have run over 150 tests with a pilot reactor of 300 litres.

The TPH process involves two or more reactors and one flash tank. The system is coupled with an existing sewage treatment plant with sludge digestion, from which dewatered digestate is obtained to act as an auxiliary material. This coupling offers additional advantages such as a higher amount of produced biogas, and the availability and close proximity of an existing digester. Additional biogas is produced from digested sewage sludge, which is added as an auxiliary input to the TPH process. Another advantageous connection is with a local MSWI, from which high pressure, high temperature steam is obtained.

First, one of the two reactors (potentially three) is filled with a combination of already digested digestate and used diapers. It is then heated to 250°C and pressurized to approximately ≥ 40 bar with steam. This continues for 10-40 minutes. Then, the temperature is lowered to around 100°C and the pressure to 1 bar. Steam is discharged to the second reactor, which also contains dewatered digestate and used diapers. Here, the heating procedure is similar to that of the first reactor. The steam is again discharged to the first reactor. Thus, alternatingly, one reactor is always heated with the steam from the other reactor, supplemented with fresh steam. Any excess steam is discharged to the flash tank.

During the TPH process, the organic material in the reactors undergoes hydrolysis: its cellular tissue and long polymer chains are broken down under the influence of water, heat and pressure to its original smaller molecular components. Simultaneously, the plastic fraction of the input material melts. This fraction becomes a floating layer on top of the other fractions, and can be separated from the organic slurry. The plastics are sent to a granulation facility and are reused in new products.

The other product, the liquid and warm slurry containing organic materials free of plastics, is sent to a digester in the nearby wastewater treatment facility. This input contributes to the heat requirement of the digester and is digested as additional feedstock in this digester. This digester is coupled with a combined heat and power unit (CHP), which uses the produced biogas for electricity generation.
The heat generated by the CHP is assumed to be used by the digester. Both the digester's heat demand as well as the production of heat from the CHP were not included in the calculation. The slurry produced by the digester is fed into a dewatering step. This produces solid digestate and reject water, the latter of which is sent to the waste water plant. The digestate is partly recirculated in the TPH or transported to GMB, which produces biosolids from the material, with recovery of ammonium sulphate, a fertilizer. The slurry which is fed to the digester (at 90°C) provides heat to the waste water sludge. This results in a lower heat demand by the digester from the CHP. The residual heat from the CHP can therefore be used in the waste water treatment process, increasing the treatment efficiency. This benefit is not included in the assessment because of lack of data on the influence on energy use at the WWTP, and to ensure a conservative assessment.

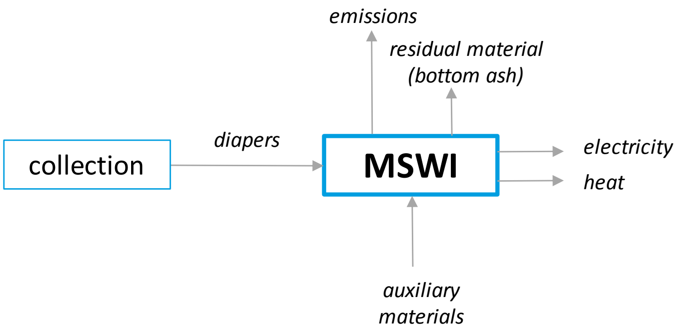
2.4 System boundaries

2.4.1 Reference case: incineration of diaper material

In the Netherlands, diapers material is currently incinerated (with energy recovery) as a means of waste management. No other waste treatment option is yet available, which is why this is the reference case in this LCA.

All MSWIs in the Netherlands have a so-called R1 status, meaning they have the status of 'useful application' and are sufficiently energy efficient. This means that MSWIs produce electricity and heat (see Figure 2). At the same time, the MSWIs emit CO_2 and other emissions through the incineration of municipal waste. In this LCA, the transport for collection of the input is also considered.

Figure 2 - Route 1: Incineration of incontinence materials with energy recovery (reference)

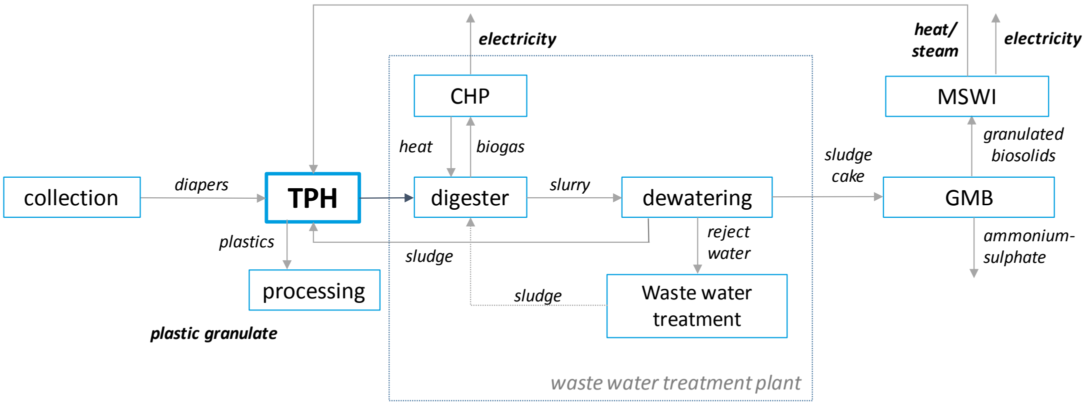


2.4.2 TPH of diaper material

The primary system under study is the processing of waste diaper material through TPH. Figure 3 shows the system boundaries of this LCA, based on the description in Section 2.3.

As described previously, Elsinga's TPH process is closely coupled with a nearby waste water treatment plant (WWTP), which delivers the sludge that is part of the input. It is also linked to a MSWI, which delivers steam to the process. This leads to allocation choices. In the analysis, environmental gains and burdens that are exclusively attributable to the TPH technique are taken into account and calculated. The argumentation is listed in the life cycle inventory chapter, for each process step where this is relevant.

Figure 3 - Route 2: Processing of diaper material with TPH, yielding granulated plastics, biogas and granulated biosolids



Some additional remarks regarding the LCA's system boundaries can be made:

- A small number of health care institutions collect incontinence materials using vacuum-sealed bags, both for materials that will be processed in an MSWI as well as by TPH. Since this is done for both routes (TPH as well as the reference situation), the energy use of this step is not included in this study.
- Plastic bags used for collection are taken into account in both routes, as they form an integral part of the input material.
- A sorting analysis by Elsinga of > 500 kg input material showed that some contaminations were present. Most materials are processed into plastic agglomerates and slurry, except for a few contaminations that will end up at an MSWI (these are removed from the slurry when the plastic is separated from the slurry). There are non-diaper materials in the input material, but most of this

can be processed in the TPH process. For diapers, only 0.3% of the input consists of residual material, which is eventually processed in an MSWI. Since the composition of this small stream is unknown, this is not included separately in the analysis. For incontinence material, 0.5% of the input consists of latex gloves and 0.4% consists of residual material. The incineration of latex gloves is added to the analysis, the residual material is not included separately. These data are based on sorting analyse, which are detailed in Annex A.

- The heat produced in the CHP is used at the WWTP, mainly in the digester. In the model, no additional heat is included; it is assumed that the heat from the CHP is sufficient. This also means that avoided production of heat is not taken into account. Because the slurry from the hot TPH provides additional heat to the digester, heat input from the CHP can be utilized elsewhere at the WWTP. This has the potential to decrease the electricity used for aeration and/or increase efficiency of the biological treatment. These potential effects were not taken into account in this assessment because of lack of data. We recommend assessing these impacts when the system has been running for a while, to see how the systems influence each other, and where optimization if possible.

2.5 Method and data collection

Primary data provided by Elsinga and ARN were used to model the foreground systems. Foreground systems include the composition of the incoming materials, the mass flows related to the TPH technology and the amounts of co-products (i.e. the recovered plastics, biogas and sludge which is processed into granulated biosolids). These input data were checked and validated by CE Delft. To complete the model, supplemental data from earlier CE Delft analyses (e.g. on biosolids production during sludge treatment, on waste water treatment, on waste incineration and on transport) and the Ecoinvent database (Ecoinvent, 2017) were used. Details on the life cycle inventory modelling are provided in Chapter 3.

The LCIA method used is ReCiPe 2016 (H), version 1.00. An adjustment to the method was made for the impact category Human non-carcinogenic toxicity, for the characterisation factor of emission of zinc to water. This adjustment will be incorporated in ReCiPe 2016, version 1.1 (RIVM, 2017). The SBK method used is version NMD 2.0, v.3.03, long-term emissions are excluded.

3 Life cycle inventory

This section provides details on the life cycle inventory modelling of both waste treatment routes (see Figures 1 and 2). The life cycle inventory is used to determine all flows to and from the environment associated with the functional unit, and forms the basis for the LCA’s impact assessment step, of which the results are presented in Chapter 4.

Section 3.1 discusses the input of this study, the composition of the waste stream. Section 3.2 describes the reference MSWI route, and Section 3.3 explains the TPH route. Each unit process (i.e. each box in Figures 1 and 2) is discussed separately.

3.1 Input: Diapers and incontinence products

The input material is assumed to consist of 50 wt% diapers and 50 wt% incontinence materials. Diapers and incontinence products consist of the same materials in different proportions. Table 1 presents the composition of both, including the lower heating value (LHV) of every material.

Table 1 - Composition of input material

Material	**LHV** (MJ/kg)	**Diapers** (wt%)	**Diapers** (LHV)	**Incontinence material** (wt%)	**Incontinence material** (LHV)
SAP	25.0	9.7%	2.4	3.9%	1.0
Fluff/pulp	16.8	7.1%	1.2	17.9%	3.0
Nonwoven (PP)	41.6	6.2%	2.6	3.0%	1.3
Elastics and adhesive tape	27.2	3.8%	1.0	0.3%	0.1
PE film (PE)	41.2	1.5%	0.6	1.7%	0.7
Adhesive	41.0	0.9%	0.4	0.8%	0.3
Other	0.0	0.3%	0.0	0.0%	0.0
Liquid biowaste	-2.6[1]	67.5%	-1.8	67.5%	-1.8
Plastic bags (PE)	41.2	3.0%	1.2	5.0%	2.1
LHV			7.7 MJ/kg		6.6 MJ/kg

The material ‘liquid biowaste’ refers to the wet content of used diapers and incontinence products (i.e. urine and faeces). As this consists almost solely of water, we assume that the lower heating value (LHV) is equal to that of water. As this water needs to be evaporated, it lowers the overall LHV of the input material. This has been taken into account based on the heat capacity and evaporation heat of water. The assumption that used diaper materials’ content makes up 67.5% of its composition is based on (Rijkswaterstaat, NVRD, 2015) and (CE Delft, 2014b).

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[1] This value includes heating water from 15 degrees centigrade to 100 degrees centigrade and vaporisation.

3.2 Route 1: Incineration in MSWI with energy recovery

In the reference route, the diaper materials are incinerated in an MSWI. The initial collection (at home) is considered out of scope (and is not significantly different between both routes) and is therefore not modelled (in neither route). The materials are collected at day-care centres and nursing facilities, of which the distance to the MSWI plant is on average 40 km. Transport by garbage collection vehicle is modelled based on STREAM datasets for transport by truck without a trailer, > 20 tonne (CE Delft, 2016b). Certain parameters were adjusted to represent garbage collection. The load factor was set to 40% (starts out empty, comes back ~80% full). Of the total route; 80% was assumed to take place in a urban environment, 15% in a semi-urban environment and 5% on highways. Total distance travelled in the collection route is assumed to be twice the average distance between the TPH and the collection point.

Incineration of the diaper materials is modelled according to the performance of average Dutch MSWIs, with energy and heat recovery.

The average LHV of the diaper material is determined based on each component's weight and LHV (see Table 1). The amounts of generated heat and electricity are derived based on the LHV of the diapers materials' components and the thermal and electrical efficiency of an average Dutch MSWI plant. These average efficiencies, as well as average high/low efficiencies in the Netherlands and those of ARN, are shown in Table 2. They are derived from (RWS, 2014). The high and low categories are determined by their overall efficiency, respectively 63 and 22%. The values for these are based on the average of the installations with a higher or lower overall efficiency. Even though the electrical efficiency of the 'low' category is higher than the electrical efficiency in the 'high' category, the overall efficiency is much lower because of the low thermal efficiency.

Table 2 - MSWI (net) energy efficiencies

Category	Efficiency (total) (%)	Electrical efficiency (%)	Thermal efficiency (%)
Average efficiency installation	36	16	19
Average of **high** efficiency installations	63	11	52
Average of **low** efficiency installations	22	16	6
ARN	36	17	23

Based on (RWS, 2014).

The generated heat and electricity from the MSWI are assumed to replace other production sources, yielding an environmental credit from system expansion. The credit is determined based on average Dutch electricity production for electricity and average European industrial heat production from natural gas combustion for heat.

Table 3 - Relevant processes in MSWI modelling, amounts are based on efficiencies as listed in Table 2

Process	Modelled process	Background
Avoided production of electricity	Average Dutch electricity	Dutch electricity mix, based on production data ('stroometiket') of the Dutch electricity generation. For more details see (CE Delft, 2014a). Grid and transformation losses are not included (and therefore not avoided).
Avoided production of heat	Heat, district or industrial, natural gas	Ecoinvent
Transport	80 tkm by garbage collection vehicle, > 20 t, EURO 5	Standard assumed transport vehicle and distance for municipal waste transport in the Netherlands. Based on distribution of MSWIs and resulting average vicinity of an MSWI.

To include the required auxiliaries and emissions from the incineration, Ecoinvent waste incineration processes were selected. The heat input included in the Ecoinvent processes (by default) were removed, since the heat requirements for the MSWI process are already accounted for in the (net) thermal/electrical efficiencies of the average Dutch MSWI facility. The selected processes are listed in Table 4. In this table it is indicated which Ecoinvent process was selected for which material. Also, if applicable, underlying assumptions for the use of proxies and additional changes (to heat) are described.

Table 4 - Selected incineration processes

Material	Incineration process or proxy	Background
SAP	Waste plastic, mixture {CH}| treatment of, municipal incineration	For this material, no Ecoinvent incineration process is available. Therefore, the municipal incineration of mixed waste plastic is selected as a proxy. CO_2 emissions from this material were adjusted to match the carbon content in SAP.
Fluff pulp	Waste paperboard {CH}| treatment of, municipal incineration	Fluff pulp in diaper materials is assumed to consist of cellulosic fibres. For cellulose, no Ecoinvent incineration process is available. Therefore, the municipal incineration of waste paperboard is selected as a proxy.
Nonwoven (PP)	Waste polypropylene {CH}| treatment of, municipal incineration	-
Elastics and adhesive tape	Waste rubber, unspecified {CH}| treatment of, municipal incineration	Elastics are often made from rubber. Therefore, the municipal incineration of waste rubber is selected.
PE film	Waste polyethylene {CH}| treatment of, municipal incineration	-
Adhesive	Waste plastic, mixture {CH}| treatment of, municipal incineration	We assume that this is synthetic material (e.g. glue). For glue, no Ecoinvent incineration process is available. Therefore, the municipal incineration of mixed waste plastic is selected as a proxy.
Liquid biowaste	Raw sewage sludge {CH}| treatment of, municipal incineration	'Liquid biowaste' refers to the wet organic components of the content of diaper material. Since the composition of this material will be similar to the composition of sewage sludge, the municipal incineration of sewage sludge was selected as a proxy.
Plastic bags (PE)	Waste polyethylene {CH}| treatment of, municipal incineration	-
Other	-	Insignificant amount. Not expected to affect the LCA's impact assessment results. Therefore, it is not included in MSWI modelling.

3.3 Route 2: TPH producing recycled plastics, biogas and sludge

3.3.1 Collection

Table 5 shows how the collection process is modelled. The distance travelled from collection to TPH processing ranges from a few km to 75 km. The average distance is assumed to be 40 km, which is travelled using a garbage collection vehicle. This is assumed to take place in a collection route. Transport by garbage collection vehicle is modelled based on STREAM (CE Delft, 2016b) datasets for transport by truck without a trailer, > 20 tonne. Parameters were adjusted to approximate garbage collection, as described in Section 3.2.

Table 5 - Transport collection

Process	Amount per tonne treated diaper material	Modelled process
Transport incontinence materials to TPH	80 tkm	Garbage collection vehicle, > 20 t, EURO 5.

3.3.2 Energy use of TPH process

At the PTH installation the input is broken down under high temperature and pressure in a batch process. ARN and Elsinga provided data on steam (pressure/heat) use and electricity consumption for stirring. Table 6 provides details on the modelling.

Table 6 - Energy inputs in TPH process

Process	Amount per tonne treated diaper material	Modelled process
Electricity consumption	18 kWh	Dutch electricity mix, based on production data ('stroometiket') of the Dutch electricity generation. For more details see (CE Delft, 2014a).
Steam consumption	981 MJ	Steam from adjoined MSWI. Emission factor steam: 59.5 kg CO_2-eq. per GJ steam.

Steam is used from the adjoining MSWI is at high pressure (> 40 bar) and temperature (250°C). Based on an emission factor of 105.7 kg CO_2 per GJ waste (RVO.nl, 2016), with a biogenic content of 55%, one GJ of waste accounts for 47.6 kg CO_2. Because the weighted average efficiency of the boilers is ~81.9%, this translates to an emission factor of 58.1 kg CO_2 per GJ of steam.

3.3.3 Plastic processing

After cooling, the TPH process yields two outputs:

1. Liquid slurry containing organic materials, which is sent to a digester in the nearby wastewater treatment facility[2].
2. Solid mixed plastics. containing 95% of the plastics present in the input materials, which are sent to a granulation facility.

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[2] Elsinga has researched the risks associated to the release of microplastics to the environment (confidential report).

The plastic stream amounts to 96.6 kg per tonne treated diaper material, excluding some (7%wt.) contaminations in this stream. The 96.6 kg consists of 55% (51 kg) polyethylene and 45% (42 kg) polypropylene.

The plastics are transported and granulated. The contaminations are removed and incinerated.
A small amount of unknown compatibiliser is used in the granulation. The granulated plastics can be used in new products. A producer of horticultural products has shown interest in purchasing the granulated plastics. Table 7 summarises the modelling of processing the plastics.

Table 7 - Plastic processing

Component	Amount	Process/proxy for process
Transport plastics from TPH to processor (147 km)	14 tkm per tonne diaper material	Diesel truck without trailer, > 20 t max. capacity, EURO 5.
Granulation of plastics	93 kg per tonne diaper material	Extrusion, plastic pipes {RER}| production.
Compatibiliser	0.01 kg per kg of produced granulate	Chemical, organic {GLO}| market for (proxy for compatibiliser).
Electricity consumption associated with removing contaminations	0.175 kWh per kg of produced granulate	Average Dutch electricity (CE Delft).
Incineration of contaminations	7% of plastic input	Incineration with energy recovery in average MSWI. Exact composition unknown. Assumption: mixed plastics.
Avoided production of virgin PE	28 kg per tonne diaper material	Polyethylene, high density, granulate, production.
Avoided production of virgin PP	65 kg per tonne diaper material	Polypropylene, granulate, production.

3.3.4 Digester and CHP

The liquid slurry containing organic materials is sent to a digester in the nearby wastewater treatment facility. In the digester, ~40% of the organic material is degraded. No (road) transport is necessary, as the TPH is physically coupled with the treatment plant. The digester is coupled with a combined heat and power unit (CHP), which uses the produced biogas for electricity and heat generation.

The 88 Nm^3 of produced biogas is specifically attributable to the TPH process, and contains biogas from the processing of diaper material (72 Nm^3) as well as biogas from the processing of the previously digested sewage sludge (16 Nm^3).

The use of electricity, heat and additives, as well as emissions of the digester are modelled with Ecoinvent data, as shown in Table 8. This includes energy required for pumping.

Table 8 - Digester

Component	Amount per tonne treated diaper material	Process
Produced biogas from digester (input to CHP)	88 Nm^3	-
Treatment of sludge in digester	1 ton	Sewage sludge {CH}| treatment of by anaerobic digestion.

For the CHP plant, efficiencies from Ecoinvent are used. The produced biogas has a CH_4 content of 62%, which has a LHV of 50 MJ/kg. The produced heat is used internally (in the digester); no environmental benefit is assigned. The electricity that is produced and delivered back to the grid is modelled as avoided average Dutch electricity. Emissions (other than fossil CO_2) from burning biogas in the CHP were modelled separately, using Ecoinvent processes. Modelling details are provided in Table 9.

Table 9 - CHP

Component	Amount per tonne treated diaper material	Process
Amount of CH_4 in biogas	62%vol.	-
Electrical efficiency of CHP	37%	Ecoinvent information
Thermal efficiency of CHP	53%	Ecoinvent information
Avoided electricity production from biogas in CHP	251 kWh [3] (2.09 kWh per Nm^3)	Average Dutch electricity (see Table 3).
Heat production from biogas in CHP	1293 MJ [4] (10.8 MJ per Nm^3)	Not modelled as avoided heat.
Emissions from burning biogas for electricity generation	Total: 184 kWh (2.09 kWh/Nm^3 | 88 Nm^3)	Based on: Electricity, high voltage {NL}| heat and power co-generation, biogas, gas engine.
Emissions from burning biogas for heat generation	Total: 950 MJ (10.8 MJ/Nm^3 | 88 Nm^3)	Based on: Heat, central or small-scale, other than natural gas {NL}| heat and power co-generation, biogas, gas engine.

The data presented here represent conservative quantifications, for a number of reasons:

- Data are based on two linked TPH reactors, which share waste heat (residual steam). In practice, three reactors will be combined.
- The slurry which is fed to the digester (at 90°C) provides heat to the waste water sludge. This results in a lower heat demand by the digester from the CHP. The residual heat from the CHP can therefore be used in the waste water treatment process, increasing the treatment efficiency.
- The heat generated by the CHP is not given a benefit in this assessment; it is assumed the heat is used by the digester. Again; excess residual heat from the CHP can be used to increase treatment efficiency at the WWTP.

3.3.5 Dewatering

The slurry produced by the digester is fed into a dewatering step. No transportation is required, as the dewatering step takes place at the same location (pump energy is included in the model used for the digester). Through centrifugation of the input slurry, water is separated from the slurry's solid materials. The electricity use associated with the dewatering step is based on a value of 0.120 kWh/kg dry matter (STOWA, 2012) and a dry matter content of the input of 60.2 kg.

The remaining solid materials are referred to as digestate. This output, amounting to 285 kg/tonne treated diaper material, is treated at GMB. The reject water that is separated from the solids amounts to 332 litres/tonne. This water is processed by the wastewater treatment plant. Energy use and emissions associated with this process are obtained from Ecoinvent.

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[3] Based on density CH_4 of 0.66 kg/m^3, LHV of CH_4 of 50 MJ/kg, electrical efficiency of 37%.

[4] Based on density CH_4 of 0.66 kg/m^3, LHV of CH_4 of 50 MJ/kg, thermal efficiency of 53%.

Modelling details for dewatering and waste water treatment are shown in Table 10 and Table 11.

Table 10 - Dewatering

Component	Amount per tonne treated diaper material	Process
Electricity use for dewatering	7.2 kWh	Average Dutch electricity

Table 11 – Waste water treatment

Component	Amount per tonne treated diaper material	Process
Waste water treatment	332 litres	Wastewater, average {CH}| treatment of, capacity 1.1E10l/year, electricity use was set to the Dutch electricity mix

3.3.6 Sludge treatment/biosolid granulate production

The treatment of the remaining 285 kg of sludge cake occurs at GMB, which is located in Tiel. The modelling is based on earlier work by CE Delft: an LCA of the treatment of the composting of sludge by GMB (confidential) (CE Delft, 2017). It was assumed the processing of the 'TPH sludge cake' is identical to the processing of waste water sludge, including the recovery of ammonium sulphate. At the moment there is no reason to assume otherwise, this could be assess further when the installation is running full-scale. As the impact of the sludge treatment on the overall results is negligible, a potential change in sludge processing will not likely affect the results significantly.

Sludge cake leaving the WWTP to be treated at GMB has several sources: partially WWTP sludge, partially WWTP sludge which has been treated in the TDH, and partially sludge from the organic material in the diaper material. In this study we include additional inputs and outputs when several systems overlap. This means that the treatment of the WWTP sludge which passes through the TDH reactor is not included in the model for the TDH route, because this WWTP sludge would have been treated otherwise anyways. The additional biogas produced from the previously digested sludge is included in the model.

The following data is available:
- one tonne diaper material plus 428.6 kg of (digested) WWTP sludge yields 215.5 kg granulated biosolids;
- one tonne WWTP sludge normally yields 302 kg granulated biosolids.

This leads to the conclusion that 1 tonne diaper material results in 86 kg granulated biosolids. This is summarized in Table 12. It was assumed the composition of the sludge from the diaper material is equal to the composition of sewage sludge.

Table 12 - Sludge treatment

Component	Amount	Notes
Biosolids yield, from sludge	0.302 t/t sewage sludge	(CE Delft, 2017)
Biosolids production from 1 t treated diaper material and 428.6 kg sludge	215.5 kg	Biosolids yield from 285 kg sludge cake.
…of which from sludge	129.4 kg	Biosolids production attributable to sludge is (428.6 * 0.302 =) 129 kg. This part is not included in the model.
…of which from treated diaper material	86.1 kg	Subtracting the biosolid production attributable to sewage sludge from the total biosolid production (from 285 kg sludge cake) yields the biosolids production attributable to the treated diaper material.

3.3.7 Incineration of biosolids

It is assumed the biosolids from sludge treatment are transported to an MSWI and incinerated with energy recovery. The transport distance is 40 km. The LHV of the biosolids is derived from (CE Delft, 2017). Electricity and heat outputs are again determined using the average Dutch MSWI energy efficiency (see Table 13), yielding an environmental credit.

Table 13 - Incineration of biosolids (86.1 kg per tonne diaper material)

Component	Amount per tonne treated diaper material	Process
Transport (biosolids to MSWI), 40 km	3.4 tkm	Large truck, Diesel, EURO 5.
Avoided electricity production	23 kWh	Average Dutch electricity (see Table 3).
Avoided heat production	96 MJ	Heat, district or industrial, natural gas.

4 Results

In this section, we describe the most important results of the analysis of Elsinga's TPH process and the reference case (incineration of the input material in an MSWI). First, the carbon footprint results are presented, zooming in on the contributions of different processes and their respective share in the overall carbon footprint. Large process contributors are selected for sensitivity analyses, presented in Chapter 5. We also express the results of the LCA at midpoint- and endpoint level using the ReCiPe 2016 method.

4.1 Carbon Footprint

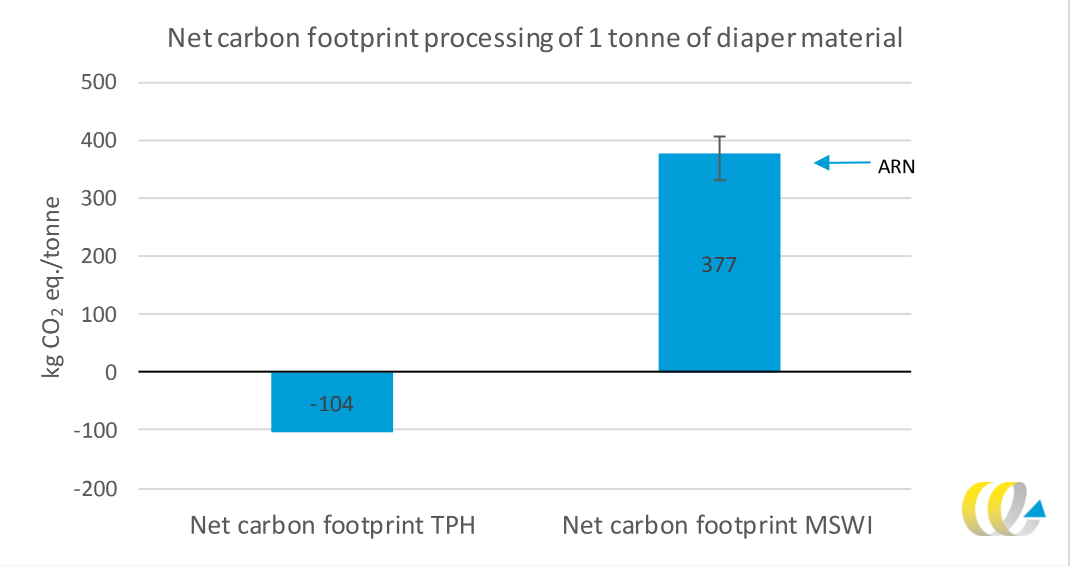
Because the carbon footprint is the most important midpoint category, these results are presented separately and on a detailed level. The reasons for the overall importance of the carbon footprint are:

- the most important inputs of the TPH process are energy; both electricity and heat;
- biogas, one of the outputs, is an energy carrier, which when used substitutes biogenic CO_2 for fossil CO_2; the other output, granulate, substitutes a virgin fossil source.

4.1.1 Net carbon footprint

Figure 4 presents the net carbon footprint results for processing 1 tonne of diaper materials by both the TPH process as well as by the current conventional processing method: incineration in a MSWI. The difference between both processes is ~480 kg CO_2/tonne input. This means the substitution of the TPH method for the MSWI method (in this situation) provides a climate benefit of ~480 kg CO_2 per tonne of processed diaper material.

Figure 4 - Net carbon footprints of TPH and MWSI, based on 1 tonne input of diaper material



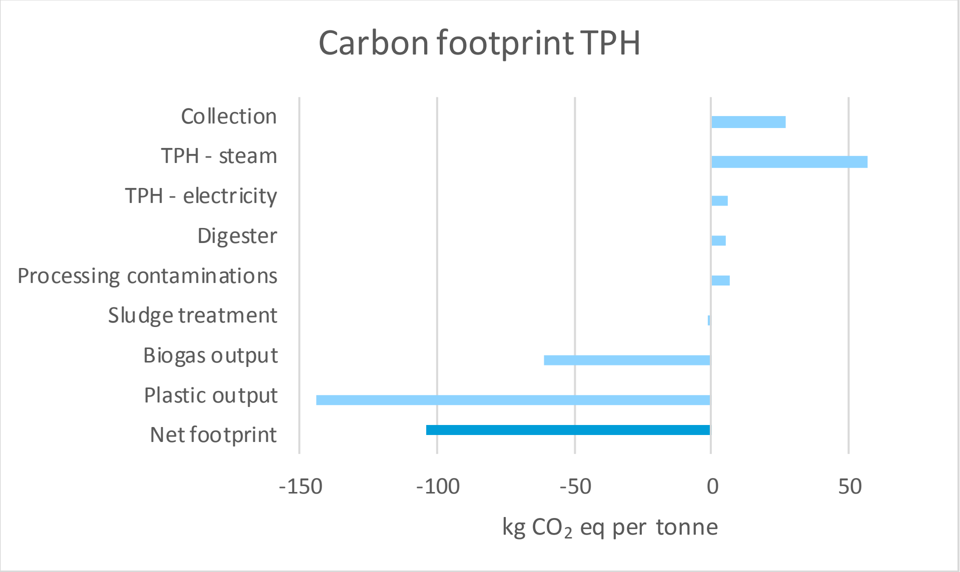
4.1.2 Detailed carbon footprint TPH

Figure 5 and Table 14 present the contribution of different process components to the carbon footprint of the TPH process. Two aspects provide the main environmental benefit:
- the production of plastics;
- the production of biogas.

These products represent an environmental benefit because production of virgin materials, or use of fossil materials, is avoided.

The remaining processes impose a climate burden, of which the most important aspect is the steam (~50% of the climate burden). When summing all process components, the resulting carbon footprint associated with the TPH process is -104 kg CO_2-eq./tonne input material.

Figure 5 - Detailed overview of carbon footprint TPH.



From the visualisation above, three main process contributors can be identified. Most striking is the avoided production of plastics, responsible for -144 kg CO_2-eq. per tonne input. The plastics consist of PP and PE, as present in the input material in the form of nonwoven material, film, and plastic bags for collection. They are sieved off, granulated and subsequently reused in new products. A buyer has been found for the granulate, who will use it in an existing product manufacturing line. The plastics are therefore assumed to replace fossil-based virgin plastics. Associated plastic manufacturing processes such as extrusion, the use of a compatibilizer, and the removal of contaminations are taken into account.

Secondly, the production of biogas results in a carbon footprint of -61 kg CO_2-eq./tonne input. This benefit results from the production of 88 Nm^3 of biogas that is specifically attributable to the TPH process, and which is used in a combined heat and power unit (CHP) which produces electricity and heat.

Thirdly, the use of high-temperature, high-pressure steam as energy carrier in the TPH process results in a carbon impact of 57 kg CO_2-eq./tonne input. The applied emission factor of 58.1 kg CO_2-eq. per GJ of steam is an important factor in this result. We present an optimization case for steam use in Chapter 5.

The remaining process components that are necessary for the operation of the TPH process add up to a carbon impact of around 45 kg CO_2-eq./tonne input. Most relevant is the collection of the input material (27 kg CO_2-eq./tonne), which is transported by a garbage truck. All process contributions are summarized in Table 14.

Table 14 - Carbon footprint per process component of TPH.

Process component	**Carbon footprint (kg CO_2-eq./tonne input)**
TPH - steam	57
TPH - electricity	6
Processing sludge and energy recovery from biosolids	-1
Biogas output	-61
Plastic output	-144
Digester	5
Collection	27
Processing contaminations	7
Net footprint	**-104**

4.1.3 Detailed carbon footprint MSWI

Dutch MSWIs produce electricity and heat, the quantity of both depending on their efficiency. For the reference case, an average MSWI was modelled with an overall net efficiency of 36%. The net carbon footprint of this MSWI is 377 kg CO_2-eq./tonne input. The incineration processes, as shown in Figure 6 and listed in Table 4, are responsible for an impact of 509 kg CO_2-eq., mainly through their emissions. The avoided production of electricity and heat lowers the overall carbon footprint by 159 kg CO_2-eq.

Figure 6 - Detailed overview of carbon footprint of incineration of 1 tonne input in an average MSWI

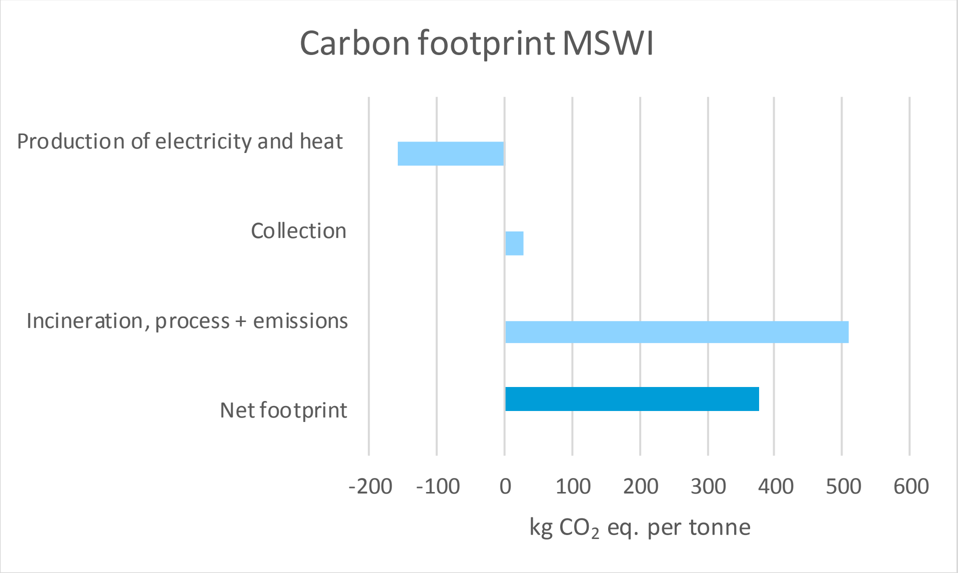


Table 15 - Detailed overview carbon footprint MSWI

Process component	Carbon footprint (kg CO_2-eq./tonne input)
Production of electricity and heat	-159
Collection	27
Incineration, process + emissions	509
Net footprint	**377**

4.2 Results on midpoint and endpoint level

Midpoint indicators focus on single environmental problems; the ReCiPe method presents 17 midpoints, for which the results for both diaper material processing routes are shown in Table 16. The green bullets indicate the route with the lowest score for that impact category.

Table 16 - Midpoint results – comparing both routes at midpoint level

Midpoint	Unit	MSWI route	TPH route	Influences endpoint category
Global warming	kg CO_2-eq.	376.6	-104.0●	Human health Ecosystems
Stratospheric ozone depletion	kg CFC11-eq.	0.0●	0.0	Human health
Ionizing radiation	kBq Co-60-eq.	-15.5●	2.2	Human health
Ozone formation. Human health	kg NO_x-eq.	0.3	-0.1●	Human health
Fine particulate matter formation	kg $PM_{2.5}$-eq.	0.0	-0.1●	Human health
Ozone formation. Terrestrial ecosystems	kg NO_x-eq.	0.3	-0.2●	Ecosystems
Terrestrial acidification	kg SO_2-eq.	0.1	-0.2●	Ecosystems
Freshwater eutrophication	kg P-eq.	0.0	0.0●	Ecosystems
Terrestrial ecotoxicity	kg 1,4-DCB e	0.0●	0.1	Ecosystems
Freshwater ecotoxicity	kg 1,4-DCB e	15.4	1.3●	Ecosystems
Marine ecotoxicity	kg 1,4-DBC e	20.3	1.8●	Ecosystems
Human carcinogenic toxicity	kg 1,4-DBC e	8.8	-1.7●	Human health
Human non-carcinogenic toxicity	kg 1,4-DBC e	1,250.0	158.0●	Human health
Land use	m^2a crop-eq.	-4.3●	6.9	Ecosystems
Mineral resource scarcity	kg Cu-eq.	0.0●	0.1	Resources
Fossil resource scarcity	kg oil-eq.	-45.9	-153.6●	Resources
Water consumption	m^3	-0.3	-1.0●	Human health Ecosystems

Note: The ReCiPe 2016 (H) method, version 1.00 was adjusted to include the update related to emission of zinc to water in the category 'human non-carcinogenic toxicity', which is scheduled to be incorporated in version 1.1.

The TPH route has a lower score for all except five categories at midpoint level. These are stratospheric ozone depletion, ionizing radiation, terrestrial ecotoxicity, land use, and mineral resource scarcity. Insight into the importance of these differences can be given by looking at endpoint results. Endpoints represent the grouping of all midpoints into three categories: the effect on human health, on ecosystem health and on resource scarcity. The endpoint on which the midpoints score are listed in the last column in Table 16.

The endpoint results are listed in Table 17. The benefits of processing used diaper materials with the TPH process now become more apparent. For each endpoint, the TPH route has a better performance.

Table 17 - Endpoint results – green bullets indicate the route with the lowest score for that category

Endpoint	Unit	MSWI route	TPH route
Human health	DALY	0.00039	-0.00014●
Ecosystems	species.yr	1.09E-06	-3.00E-07●
Resources	USD2013	-11	-61●

Figure 7 and Figure 8 provide detailed insight into the contribution of the midpoints to the endpoint scores. The endpoints ‘human health’ and ‘ecosystems’ are selected because of the large number of midpoint categories that impact both these endpoints. As these two figures show, global warming is the most important category; for both endpoints global warming contributes most to the score of each treatment route. . The result on the category ‘global warming’ is highly correlated to the result on the endpoint ‘resources’ (therefore this endpoint is not presented separately).

Figure 7 - Contribution of the different midpoint categories to the endpoint Human Health

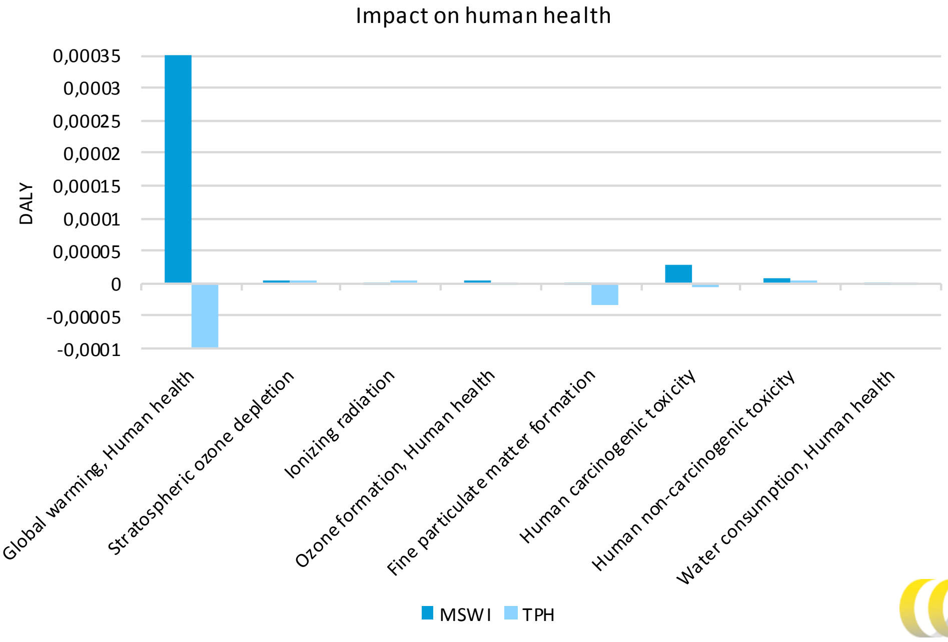
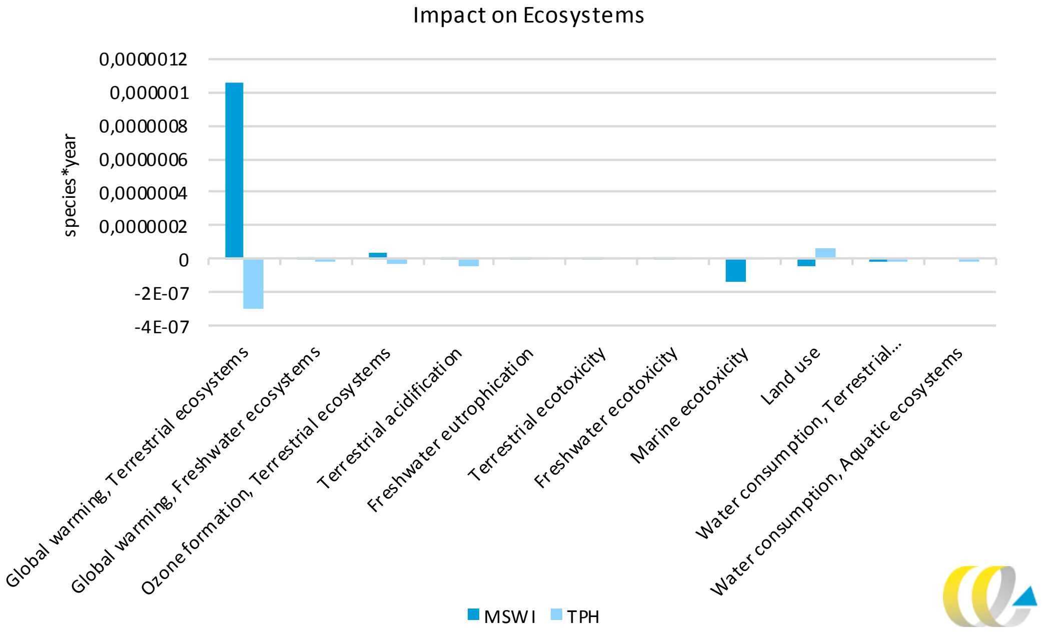


Figure 8 - Contribution of the different midpoint categories to the endpoint Ecosystems



4.3 Environmental impact of plastic granulate from the TPH process

This section elaborates on the environmental impact of the granulate material from the TPH process. In the construction sector the SBK method is used regularly to quantify the environmental impact. For materials used in building applications, SBK's Environmental Indicator (MKI, or MilieuKostenIndicator in Dutch) is used to quantify environmental impact in a single value. This can be used to compare products easily. This method is based on the CML-2 method, which is a different impact assessment method than ReCiPe. Therefore, some midpoint categories differ (as can be seen when comparing Table 18 and Table 16).The SBK method used is NMD 2.0.

4.3.1 Functional unit: 1 tonne plastic granulate

The functional unit in this study is treatment of 1 tonne of diaper material. To convert this to the environmental impact of one of the output materials (i.e. the plastic granulate), the impacts are allocated to three different aspects:

- treatment of diaper material; since this is a waste material, treatment is necessary and has a price;
- production of biogas;
- production of plastic granulate.

Economic allocation was used to determine the allocation factor for the granulate. Allocation means the division of impact over different products and/or functions which have an economic value. Waste treatment has an economic value, and therefore part of the environmental impact of treatment of the diaper material is allocated to the treatment process. Based on the prices of diaper treatment, of electricity from use of biogas in a CHP and of granulate, 35.9% of the process emissions are allocated to the granulate (Elsinga, 2017). The granulate price estimate is based on a test in which the characteristics of the material were determined, and on estimates of the buyer. These data are confidential.

This means 35.9% of the impact of treating 1 tonne of diaper material is allocated to the 96.6 kg granulate which is produced per tonne diaper material treated. This information is used to determine the environmental profile of TPH granulate, see Section 4.3.2.

4.3.2 Results

The Environmental Indicator results are summarized in Table 18, for 1 tonne of plastic granulate from the TDH process. Because the functional unit is different (from the functional unit used in the base case comparing TPH to MSWI treatment), the results need to be interpreted differently.
The functional unit which matches the results in Table 18 is ‘1 tonne granulate’ (not ‘treatment of 1 tonne diaper material’). These values can be used to compare different granulates, and can help buyers to weight environmental impact quantitatively in their decision for different materials.

Table 18 - Environmental Indicator results for 1 tonne plastic granulate from TDH process for treatment of diaper material

Category	Unit for category	Value category	Environmental price (€)	Share of category in total environmental price (%)
1 Abiotic depletion, non-fuel (AD)	kg Sb-eq.	9.07E-04	0.0	0.0%
2 Abiotic depletion, fuel (AD)	kg Sb-eq.	1.66E+00	0.0	0.0%
4 Global warming (GWP)	kg CO_2-eq.	5.89E+02	29.5	54.9%
5 Ozone layer depletion (ODP)	kg CFC-11-eq.	3.09E-05	0.0	0.0%
6 Photochemical oxidation (POCP)	kg C_2H_4	1.16E-01	0.2	0.4%
7 Acidification (AP)	kg SO_2-eq.	1.63E+00	6.5	12.1%
8 Eutrophication (EP)	kg PO_4--- eq.	2.76E-01	2.5	4.6%
9 Human toxicity (HT)	kg 1,4-DB eq.	7.34E+01	6.6	12.3%
10 Ecotoxicity, fresh water (FAETP)	kg 1,4-DB eq.	1.99E+00	0.1	0.1%
12 Ecotoxcity, marine water (MAETP)	kg 1,4-DB eq.	8.16E+04	8.2	15.2%
14 Ecotoxicity, terrestric (TETP)	kg 1,4-DB eq.	1.65E+00	0.1	0.2%
101 Energy, primary, renewable (MJ)	MJ	9.09E+02	0.0	0.0%
102 Energy, primary, non-renewable (MJ)	MJ	4.03E+03	0.0	0.0%
103 Energy, primary (MJ)	MJ	4.93E+03	0.0	0.0%
104 Water, fresh water use (m^3)	m^3	3.48E-01	0.0	0.0%
105 Waste, non hazardous (kg)	kg	6.51E+01	0.0	0.0%
106 Waste, hazardous (kg)	kg	1.99E-02	0.0	0.0%
Total	-	-	**53.6**	**100%**

Note: The result for ecotoxicity in marine water is relatively high. Recently, a new version of the SBK method has become available (version NMD 2.1). This method is, however, not prescribed yet. To ensure comparability of the results for granulate with other products, version NMD 2.0, v.3.03 was used. With version NMD 2.1 the value for marine water ecotoxicity would have a negative environmental price.

5 Sensitivity analyses

Four sensitivity analyses are elaborated on in this chapter:

1. Additional collection of diapers: What happens when diapers are collected at home and brought to the day care centre, and parents decide to switch from bike to car to be able to do that?
2. Optimisation of steam use: What is the benefit of using excess steam?
3. Value of granulated plastic: How are the TDH results influenced by choosing a minimal value for the granulate (worst case)?
4. MSWI efficiency: How are the MSWI results and TDH results influenced by different (high or low) MSWI efficiencies?

5.1 Additional collection of diapers

Diapers are used both at day care centres and at home, however, so many different collection systems can be envisioned. In the default case (discussed in Chapter 3), it is assumed that only diapers collected at day care centres will be treated with TPH (and that parents will not change their transport behaviour to bring 'home diapers' to the day care centre). In this sensitivity analysis, we focus on the possibility of also treating diapers used at home, assuming that parents/guardians will transport these to day care centres (or other centralised locations) for collection.

Two effects are considered here: (additional) plastic bags required to gather diapers, and (additional) transport of bagged diapers to a collection point. The latter may result from parents opting to drive to the collection point, to avoid cycling or using public transit while carrying used diapers. Table 19 details the assumptions made in this analysis. The purpose of this sensitivity analysis is to gain insight into the sensitivity of the results to potential changes in collection methods, and whether this is of significance and should be further researched or incorporated in communication.

Table 19 - Sensitivity analysis parameters of additional diaper collection

Parameter	Value	Reasoning
Share of diapers gathered after use at home	20%	Assumption
Plastic bag weight	10 g	Estimate
Average weight used diapers per bag	500 g	Assumption
Additional plastic bags required	2 kg	200 additional bags required per tonne of used diaper materials (functional unit)
Transport distance by car	1.5 km 33 trips	Round trip distance per trip to collection points; ca. 3 kg diapers per trip. Assumption.

Table 20 provides details on the modelling changes for this sensitivity analysis. The additional plastic bags are made from LDPE, which can be treated in the TPH process. In this analysis, these bags are viewed as additional materials entering TPH on top of the default input material (1 tonne used diapers and incontinence materials of given composition; Section 3.1). The steam and electricity use of the TPH process increases since more material is processed; they are assumed to remain unchanged per kg of input. As in the default system, after TPH the additional plastic is filtered out (95% recovery rate), transported, granulated and sold. Other steps (e.g. biogas yield) are unaffected.

Table 20 - Sensitivity analysis modelling changes for additional diaper collection. All processes included here are additional to the modelling described as in Section 3.3

Component	Amount per tonne treated diapers	Process
Virgin LDPE production	2 kg	Polyethylene, low density, granulate {GLO}.
Plastic bag production	2 kg	Extrusion, plastic film {RER}. Proxy for film blowing.
Transport to collection point	49.5 km	Transport, car (CE Delft, 2015).
Plastic granulation	2 kg	Includes transport, extrusion energy, system expansion credits, etc. as described in Section 3.3.3.
TPH process	2 kg	Energy inputs for running TPH reactor, as described in Section 3.3.2.

Results

The additional collection steps result in a carbon footprint of 13.2 kg CO_2-eq./tonne input. The overall result hereby changes from about -104 to -90.8 kg CO_2-eq./tonne input. This indicates that potential changes in the collection process will have a limited influence on the overall footprint.

5.2 Optimisation of steam use

The TPH process produces 250 kg of excess low-pressure (approximately 4 bar) residual steam in a flash tank per tonne of treated diaper materials. This steam is currently not used, but represents about 0.5 GJ of (latent) heat. Given the proximity of several processes that require or export heat (e.g. the TPH itself, the digester, the WWTP, the CHP unit), it might be possible to optimise the TPH process further by utilising the residual steam in a different process. In this sensitivity analysis, we investigate the case where an additional 0.5 GJ of heat (per functional unit) displaces conventional heat production from natural gas.

Results

As expected, the use of the residual steam as a replacement of heat production from natural gas results in an improved environmental performance of the overall TPH process. The benefit is large: the utilization of residual steam results in -37 kg CO_2-eq./tonne input, lowering the overall carbon footprint from -103 to -140 kg CO_2-eq./tonne input.

5.3 Value of granulated plastic

In the default analysis, it is assumed that the plastics recovered from the TPH reactor replace virgin PE and PP after being granulated. A buyer has been found for this product, and the produced granulate can be used in several different applications in horticulture: in flowerpots, trays, support sticks for plants and plastic pallets. Because it consists of a mix of PE and PP polymer, it may, however, be considered less valuable than (virgin) pure polymers.

To give insight into the influence of the value of the plastic product, we lower the environmental credits assigned to the production of granulated plastics based on their economic value in this sensitivity analysis. We assume that the value of granulated plastic is 50% lower than virgin plastic, and therefore lower the credits given by 50%. This can be seen as the minimum value to be expected. Other modelled processes (e.g. energy for granulation, transport) remain unchanged.

Results

The quality of the plastic produced by the TPH process is an important parameter in determining the overall carbon footprint of the treatment method. When modelling the recovered plastics as plastics with a 50% lower value than virgin plastics, the carbon footprint changes from -104 to -3 kg CO_2-eq./tonne input. All other processes remain unchanged, but the environmental benefit from replacing plastics changes from -144 to -43 kg CO_2-eq./tonne input. The environmental benefit is cut by more than half, because transport and processing of the plastics is incorporated in this phase. Because the amount does not change, the impact of these factors does not change either.

This sensitivity assessment highlights two aspects:

- The importance of obtaining high-quality plastics from the process. Lowering the quality of the plastics that will be replaced lowers the environmental benefit of the total process.
- Even with a value which can be seen as the minimal value to be expected (as assessed in this analysis), the TPH process realizes a negative net carbon footprint (emissions are avoided), and outperforms the processing of diaper materials in an MSWI by far.

5.4 MSWI-efficiencies

The electrical- and thermal efficiencies of MSWIs play a role in determining the climate impact of the reference-processing route for diaper materials. In the Netherlands, MSWI electrical- and thermal efficiencies vary quite widely, between around 22 and 66% (RWS, 2014).

In this sensitivity assessment, we add two different MSWI electrical and thermal efficiencies to the previous analysis of the MSWI route: a worst case and a best case. In addition, we use the same efficiencies to reflect on the changes in overall performance of the TPH process.

Table 21 - Input for sensitivity assessment MSWI-efficiencies

Category	Efficiency (total) (%)	Electrical efficiency (%)	Thermal efficiency (%)
Average	36	16	19
High (best case)	63	11	52
Low (worst case)	22	16	6

Results

Table 22 summarizes the results of this sensitivity analysis for the MSWI. The CO_2 footprints of transport and incineration processes remain the same, since they are not influenced by an MSWI’s efficiency. The avoided production of electricity and heat is higher in the best case, resulting in an overall carbon footprint which is 45 kg CO_2-eq./tonne input lower than that of an average MSWI. For the worst case MSWI, the carbon footprint is 31.6 kg CO_2-eq./tonne input higher. These results are already incorporated in Figure 4 in Chapter 4.

Table 22 - Results sensitivity assessment MSWI's

Category	Average (kg CO_2-eq./tonne input)	High efficiency (kg CO_2-eq./tonne input)	Low efficiency (kg CO_2-eq./tonne input)
Production of electricity and heat	-159	-204	-128
Collection	27	27	27
Incineration, process + emissions	509	509	509
Net footprint	**377**	**332**	**408**

For the TPH process, the efficiency of the MSWI influences the impact of the treatment of sludge, and the treatment of residual materials. This results in a carbon footprint which is 3 kg CO_2-eq. per tonne lower in case of a high efficiency MSWI, and of 3 kg CO_2-eq. higher in case of a low efficiency MSWI.

6 Interpretation

In this study, two treatment methods for treatment of diaper material were studied: incineration with energy recovery in an MSWI and treatment in a TPH unit linked to a MWSI and a WWTP. Life cycle impact results were assessed for:

- **The carbon footprint**: This shows a clear benefit of treatment in the TPH unit.
- **The 16 other midpoints**: Treatment in a TPH unit is favourable for 12 out of 17 midpoints.
- **The 3 endpoints**: To assess the relevance of the scores on different midpoints, results on endpoint level were included. These show that treatment in the TPH is favourable for all three endpoints.

The assessment of the midpoints and endpoints shows that the impact on global warming is most influential for the endpoints Human Health and Ecosystems. While other impact categories can be influential on a very local scale, the overall comparison of both treatment options can therefore be done by looking at the carbon footprint.

Overall, the environmental impact of treatment in the TPH is more favourable than treatment in a MSWI. Treatment in the TPH unit results in useful products, plastics and biogas. While treatment in a MSWI does generate electricity and useful heat, the emissions of the process tip the balance to a net positive carbon footprint (net emission of CO_2-eq.).
The TPH unit still need to be built on full scale. Modelled data were verified and checked for consistency, and estimate were made conservatively. It is possible that further optimization, especially around heat production and heat use at the TPH unit but also at the WWTP, is possible. The sensitivity analyses show that potentially, some variation in impact is possible, however, the sensitivity tests show that the TPH will still result in a net negative carbon footprint (CO_2 emissions are avoided).

Circular economy & fit of TPH treatment in existing systems

As shown in the results, treatment of diaper material in a TPH unit can have environmental benefits. Recovery and recycling of plastics and digestion of biogenic material to produce biogas are environmentally preferable over incineration with energy recovery (the MSWI route). The advantages of this method of diaper treatment are specific to the modelled process, were the TPH unit is linked to both the MSWI for heat (steam) and the WWTP for digestion of the biogenic material (with biogas recovery and use in a CHP). These linkages provide the benefit of sharing services. While all inputs and outputs particular to the diaper treatment method were modelled, the environmental footprint of such inputs and outputs would be larger for a stand-alone installation using fossil energy. An example is heat; while heat (steam) from an MSWI has an environmental footprint, which was included in the model, the footprint of heat ‘from scratch’ is much larger. It is therefore, important to remember that these results are specific to this situation.

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A ReCiPe method

This annex gives an introduction to the ReCiPe-methodology which is used as the method for the LCA conducted in this study.

The ReCiPe-methodology is developed for the Dutch government and is used for many LCA-studies in the Netherlands. The ReCiPe-methodology translates a long list of primary results in easier to interpret indicators. With this method the environmental effects can be shown on two different levels:

Midpoints: problem-oriented environmental effects, such as climate change and acidification. In the ReCiPe-methodology there are 17 midpoints. The midpoint-level is a direct translation from substance/emission to environmental effect. The midpoint-level gives an insight into the different environmental effects and is characterized by a high level of transparency. The damage caused is not shown in this category, for this end the three endpoints (Level 2) are more useful.

Endpoints: impact-oriented environmental effects, the effects on nature, effect on humans and effect on resources. In the ReCiPe-methodology the 17 midpoints are categorized into 3 endpoints. At the endpoint-level the environmental effects are normalized and recalculated towards damage into three endpoint categories:

1. Damage to human health.
2. Damage to ecosystems.
3. Damage to resource availability

Table 23 - Environmental effect categories, units and weighting according to ReCiPe 2016

Midpoints	Unit	Endpoints
Global warming	kg CO_2-eq.	Human Health (DALY)
Stratospheric ozone depletion	kg CFC11-eq.	
Ionizing radiation	kBq Co-60-eq.	
Ozone formation. Human health	kg NO_x-eq.	
Fine particulate matter formation	kg $PM_{2.5}$-eq.	
Human carcinogenic toxicity	kg 1,4-DCB e	
Human non-carcinogenic toxicity	kg 1,4-DCB e	
Water consumption	m^3	
Global warming	kg CO_2-eq.	Ecosystems (species.year)
Ozone formation. Terrestrial ecosystems	kg NO_x-eq.	
Terrestrial acidification	kg SO_2-eq.	
Freshwater eutrophication	kg P eq.	
Terrestrial ecotoxicity	kg 1,4-DCB e	
Freshwater ecotoxicity	kg 1,4-DCB e	
Marine ecotoxicity	kg 1,4-DCB e	
Land use	m^{2}a crop eq.	
Water consumption	m^3	
Mineral resource scarcity	kg Cu eq.	Resources ($)
Fossil resource scarcity	kg oil eq.	

Source: (RIVM, 2016).

B Sorting Analyses

This annex summarizes the result of sorting analyses. Over 500 kg of material, both diaper material and incontinence material was sorted.

Table 24 - Result of sorting analyses

Material	Diapers (%)	Incontinence material (%)
Diapers	88.1	1.4
Incontinence material	6.2	92.7
Paper	3.4	0.2
Plastic foil	1.6	4.8
Latex gloves	-	0.5
Food waste	0.4	-
Residual fraction	0.3	0.4

C Review SGS Search

A review of the LCA was done by SGS Search. Relevant comments were integrated in the report.

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MEMO

Aan : **Geert Cuperus (RWS WVL)**
Van : Harry van Ewijk (SGS Search)
Onze ref. : 26.17.00450
Datum : 9-2-2018 (eerste opmerkingen bij CE report / Elsinga)
Betreft : Review LCA-studies recycling luiers

Achtergrond

Recycling van luiers is in opkomst. Er zijn enkele technieken ontwikkeld die op het punt van doorbreken staan. Gemeenten zijn zeer geïnteresseerd en willen graag luiers inzamelen. Toch is er nog twijfel, men vraagt regelmatig of recycling duurzamer is dan verbranden. Met dit project moet duidelijk worden of recycling al of niet beter is dan verbranden.

Aanpak

Door twee bedrijven zijn LCA-studies uitgevoerd naar de door hun ontwikkelde technieken. Dit betreft Fater en Elsinga. Fater heeft een operationele installatie in Italië, deze zal dienen als blauwdruk voor een installatie van AEB in Amsterdam. Elsinga heeft in samenwerking met ARN een eerste installatie ontwikkeld in Nijmegen. Van beide processen is een LCA-rapport beschikbaar.

Voor de onderhavige studie dient een review te worden uitgevoerd van de beide LCA's. Op basis van de review moet inzicht ontstaan hoe recycling van luiers scoort ten opzichte van verbranding. Volgens de genoemde bedrijven zou blijken dat recycling beter scoort, onder anderen op zaken zoals klimaatopwarming. Als hiervan inderdaad sprake is, dan moet tevens een beeld ontstaan hoe groot de "winst" is (range) en in welke omstandigheden daarvan sprake is. Wat dit laatste betreft moet uit de review blijken of een betere score vooral te wijten is aan specifieke lokale omstandigheden, danwel of (en in welke mate) de uitkomsten van de LCA's veralgemeniseerd kunnen worden.

De review moet daarnaast uiteraard ook ingaan op de juiste uitvoering van de LCA's en op uitgangspunten. Ten aanzien van de uitgangspunten is het gewenst inzicht te krijgen in de waarde van de uitgangspunten: zijn deze juist, is er sprake van variatie etc.

Op de Fater LCA is al eerder een eerste reactie beschreven (memo 15-12-2017). Dit memo bevat de eerste reactie op de Elsinga LCA (CE Delft).

Resultaten

Het (uiteindelijke) resultaat van de review is:

- Een beoordeling van de juiste uitvoering van de LCA's en bevestiging van de uitkomsten
- Een aanbeveling op welke wijze de bevindingen veralgemeniseerd kunnen worden voor recycling van luiers

LCA AFVALVERWERKING LUIERMATERIAAL, IN OPDRACHT VAN ELSINGA BELEIDSPLANNING EN INNOVATIE, ARN, MARN; CE DELFT, 18 DECEMBER 2017

Algemeen

Het LCA-rapport is goed opgebouwd volgens de gangbare normen en conventies. Definities, waaronder beschrijving van de functionele eenheid, zijn helder. Als er bij het lezen al vragen opkomen dan worden deze veelal direct daarna beantwoord. Aannamen en onzekerheden zijn goed beschreven en voor zover mogelijk ook uitgewerkt in gevoeligheidsanalyses.

Het resultaat valt of staat met de proces- en systeemdata van beide systemen. Voor de traditionele route, verbranden in een AVI met energieterugwinning, zijn deze op basis van praktijkcijfers beschikbaar en is dat duidelijk. Voor het nieuwe proces, de TDH-route, moet *ex ante* worden teruggevallen op de pilots en expert judgement. Dat geeft meer onzekerheid, maar alles overziend is er vanuit LCA-methodisch oogpunt geen reden aan te nemen dat het gepresenteerde resultaat een te rooskleurig beeld geeft, al ontbeert de LCA-reviewer specifieke proceskennis.

De opmerkingen en vragen hieronder moeten in het licht gezien worden van de algemene indruk. Het zijn dus detailvragen, waarbij er vooraf niet de indruk is dat ze zullen leiden tot substantiële aanpassing en andere conclusies.

Opmerkingen en vragen

- Paragraaf 2.2
  De “bepaalde samenstelling” uit de functionele eenheid wordt in deze paragraaf niet benoemd. Maar wel verderop, onder meer in paragraaf 2.3, 2^e regel op bladzijde 7 “gebruikt luiermateriaal’.
- Paragraaf 2.3
  “Het andere product, de vloeibare en warme slurry die bestaat uit waterig organisch materiaal zonder kunststof, wordt naar een vergister in de nabijgelegen RWZI verpompt.” roept de vraag op of de scheiding van stromen zo goed werkt. Met andere woorden: welk deel blijft gemengd? Paragraaf 3.3.3 stelt dat 95% uiteindelijk wordt teruggewonnen. Geldt dat percentage hier al, of ligt het hier nog hoger?
- Paragraaf 2.4.1
  Voor het eerst bij figuur 2, maar ook verderop in het rapport komt de vraag op hoe met emissies van biogene oorsprong (CO_2 en CH_4) is omgegaan.
  Het rapport noemt driemaal biogene inhoud/materialen (is dat alleen cellulose / fluff pulp?) en eenmaal biogene CO_2 maar gaat bijvoorbeeld niet in op de karakterisatie. Hoe is het meegenomen?
- Paragraaf 3.2
  In tabel 3 (en ook tabellen 9 en 13) zou het opnemen van het exacte proces beter zijn, om zo te kunnen beoordelen of niet ook (onterecht) net- en transformatieverliezen zijn vermeden.
- Paragraaf 3.3.2
  Onderaan bladzijde 13 is helder dat 55% van 105,7 kg 58,1 kg is, maar wat voegt “resulteert 1 GJ afval in een uitstoot van 7,6 kg CO_2” toe?
- Paragraaf 3.3.3, tabel 7
  - Als extrusie is bedoeld als aanname voor granuleren, dan dat vermelden.
  - De hoeveelheid op de laatste 2 regels klopt niet (28 kg in plaats van 0,28 kg).

- Paragraaf 4.1
  “- granulaat is een substituut voor een virgin fossiele bron.” Dat kan als je kolen vervangt, maar niet in geval van biomassa.
- Paragraaf 4.1.2
  “Op basis van Figuur 5 kunnen de drie belangrijkste impacts” ➔ “Op basis van Figuur 5 kunnen de drie belangrijkste bijdragen aan het versterkt broeikaseffect”
- Paragraaf 4.3
  Het plotseling gebruik van de MKI om single-score te kunnen vergelijken lijkt raar. ReCiPe 2008 staat ook in de literatuurlijst en lijkt dan logischer.
  Het roept ook de vraag op hoe de vergelijking in 4.2 uitvalt op basis van MKI.
  Er mag nadrukkelijker worden vermeld dat CML-2 (in combinatie met MKI) iets anders is dan ReCiPe.
- Paragraaf 4.3.2, tabel 18
  Een nadere beschouwing, bijvoorbeeld een opmerking over de >50% bijdrage aan de MKI door toxiciteit, ontbreekt.
  (De “Noot” onder de tabel lijkt hier niet passend.)

Voorlopige conclusie

Er is geen reden voor twijfel over de conclusies in het rapport, waaronder:
“CO_2-voetafdruk: het vervangen van de huidige conventionele methode door de TDH-methode levert in de huidige situatie een klimaatwinst van 480 kg CO2-eq. per ton verwerkt luiermateriaal.”