Comparative mLCA on waste treatment of diaper and incontinence material

Revised

Commissioned by Rijkswaterstaat Water, Verkeer & Leefomgeving (WVL)

24 februari 2021

Colophon

Research data

Name research	Comparative mLCA on waste treatment of absorbing hygienic products – revised
Research type	Life cycle assessment (LCA)
Project number	26.19.00653
Date	24-02-2021

Commissioner

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1. INTRODUCTION

1.1. General

For the purpose of transition towards a Circular Economy the following developments are reason to perform this study:

- Within the framework of the project ‘High Quality Recycling’ a Multi-cycle LCA method is developed to distinguish between more and less high-quality recycling.
- In the Dutch National Waste Management Plan (Landelijk Afvalbeheerplan; LAP) the intention is included to steer on treatment methods by a Minimum Standard.
- There are various initiatives in the market for the treatment of used diapers.

The aim of this research is to compare the various initiatives by using the above-mentioned method (Multi-cycle LCA). The result of the study serves as an environmental basis for the future Minimum Standard for diapers in the LAP.

In the initial version environmental impact of recycling in life cycles beyond the first cycle was not taken into account. According to the mLCA method recycling in later life cycles should also be included, and type of recycling should depend on the application of the recycled material in a new life cycle. With this revision the initial error has been corrected.

1.2. Goal

The goal of this research is to compare the following treatment options for 1 ton of discarded diapers according to LAP Annex F9:

- Thermal pressure hydrolysis at 250 °C> 40 Bar ("TDH") of the waste, from which plastic (LDPE/PP), artificial fertilizer, biogas, and bio-granulate/compost are produced (ARN/Elsinga).
- Treatment in a rotating autoclave with high pressure steam from which plastic, cellulose material and super absorbent polymer are produced (FATER).

As reference is included:

- Incineration of diapers in an average Dutch waste incineration plant.

For both treatment options LCA studies have been executed: “LCA afvalverwerking luiermateriaal” (LCA waste treatment diaper material) [1] and “Report on scenarios of the collection and recycling of absorbent hygienic products” [2] on which this study will build.

This study considers that the treatment initiatives might not yet be full (industrial) scale or fully developed. Local circumstances, that might influence the outcome, have been taken into account as well. The quality of the recycled material (output) has been examined closely in order to determine what can be regarded as avoided material.

1.3. Scope

Functional unit

The functional unit is one (1) ton of used Adsorbent Hygienic Products (AHP), meaning a combination of diapers and incontinence material.

According to the two reports describing the above-mentioned treatment options, the composition of the AHP/diapers is about the same. It was confirmed by Elsinga and Fater that they are still representative for the average disposable diaper on the market. For this study we assume the composition given in Table 1, with a distinction between diapers and incontinence material based on “LCA afvalverwerking luiermateriaal” [1]. A slight change has been made to this composition, since the output of plastics from both the TPH and FaterSMART technologies did not match with the input. The input has been tweaked so that a plastic ratio of 45/55 PP/PE, which was adopted from ‘LCA afvalverwerking luiermateriaal’ [1], is now a ratio of 85/15 PP/PE, which better matches the output of both Elsinga and Fater’s process. The assumption is that 50 wt% of the input material exist of diaper and 50 wt% of incontinence material.

Table 1 shows the composition and the lower heating value (LHV) for both types of input. The LHVs have been adopted from “LCA afvalverwerking luiermateriaal”[1]. The assumption seemingly taken is that plastics burned are pure (i.e. without the addition of additives or filler material).

Table 1 Composition of the diaper (input material)

Material	LHV (MJ/kg)	Diapers (wt%)	Incontinence material (wt%)	Average composition (wt%)	LHV of one ton of diapers and incontinence material (50/50)
SAP	25	9,7%	3,9%	6,8%	1,70
Fluff-pulp	16,8	7,1%	17,9%	12,5%	2,10
Non-woven (PP)	41,6	6,2%	3,2%	4,7%	1,96
Elastic and self-adhesive tape	27,2	3,8%	0,2%	2,0%	0,54
PE film	41,2	1,5%	1,5%	1,5%	0,62
Glue	41	0,9%	0,8%	0,9%	0,35
Others	0	0,3%	0,0%	0,2%	0,00
Liquid biowaste	-2,6*	67,5%	67,5%	67,5%	-1,76
Plastic bags (PP)	41,6	3,0%	5,0%	4,0%	1,66
LHV AHP					7,175 MJ/kg

* This value concerns heating water from 15 ° C to 100 ° C and evaporation

System boundaries

Figure 1 shows a general (treatment method independent) flow chart.

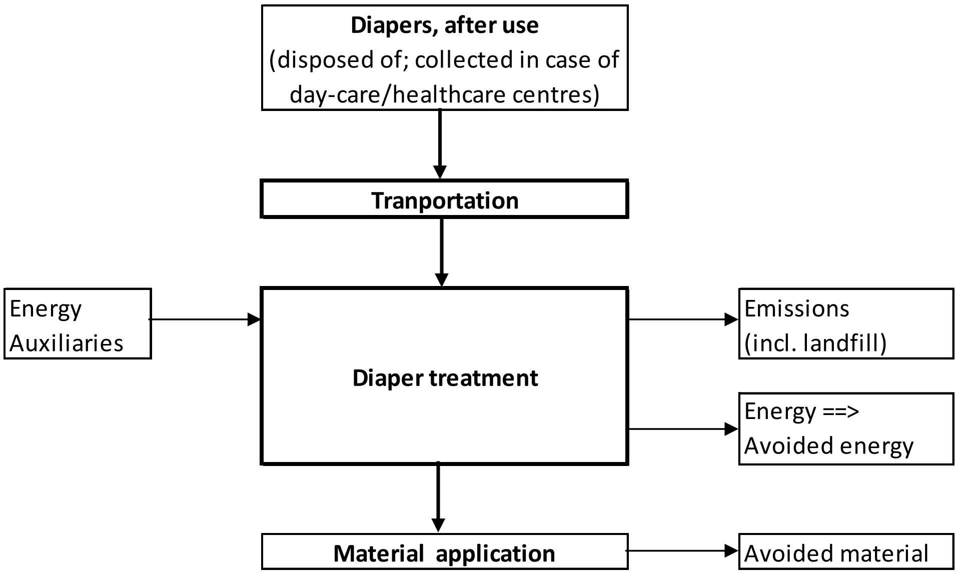

Figure 1: General follow chart for all treatment options

If recycled content can be applied and recycled multiple times, a generic recycling procedure of the recycled content and therewith avoided material has been taken into account up to three times, depending on amount and quality.

The system boundary at least encompasses all that is different when comparing alternative treatment options.

1.4. Basic principles of mLCA in this study

The multi-cycle LCA (mLCA) is discussed in LAP Annex F9 (F.9 bijlage 9; Uitvoeren van LCA's i.r.t. het LAP). The mLCA maps the life cycle of a material over a maximum of three consecutive usage cycles (Figure 1). The preservation of materials and raw materials is not only important in the first life cycle, but also in any life cycles thereafter.

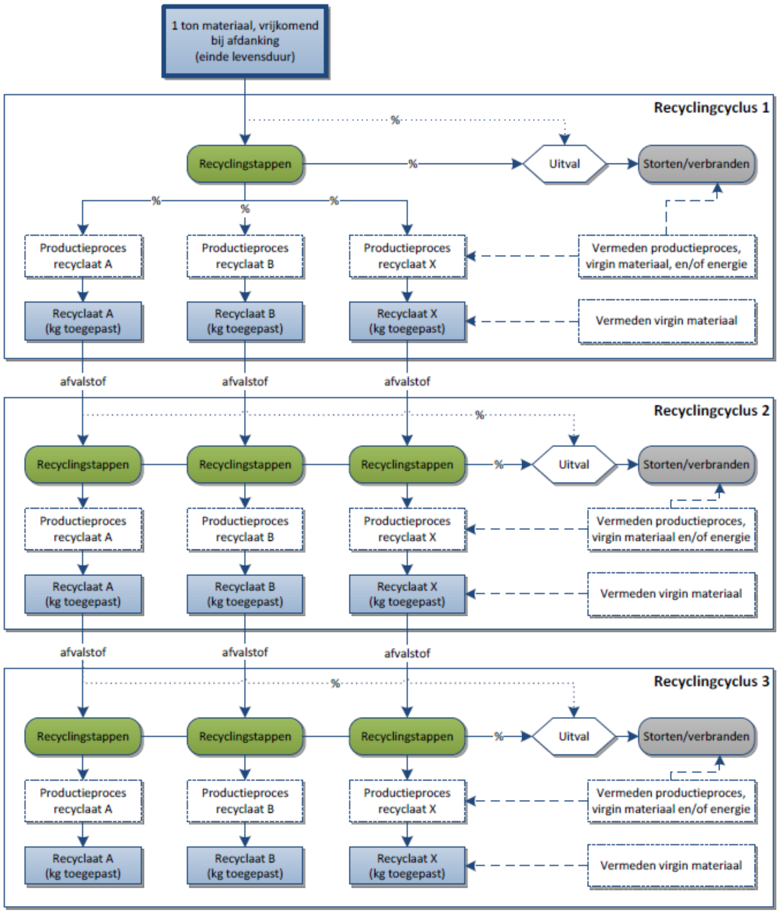

Figure 2 (=Figure 9 of LAP Annex F9) with general overview of process to be included

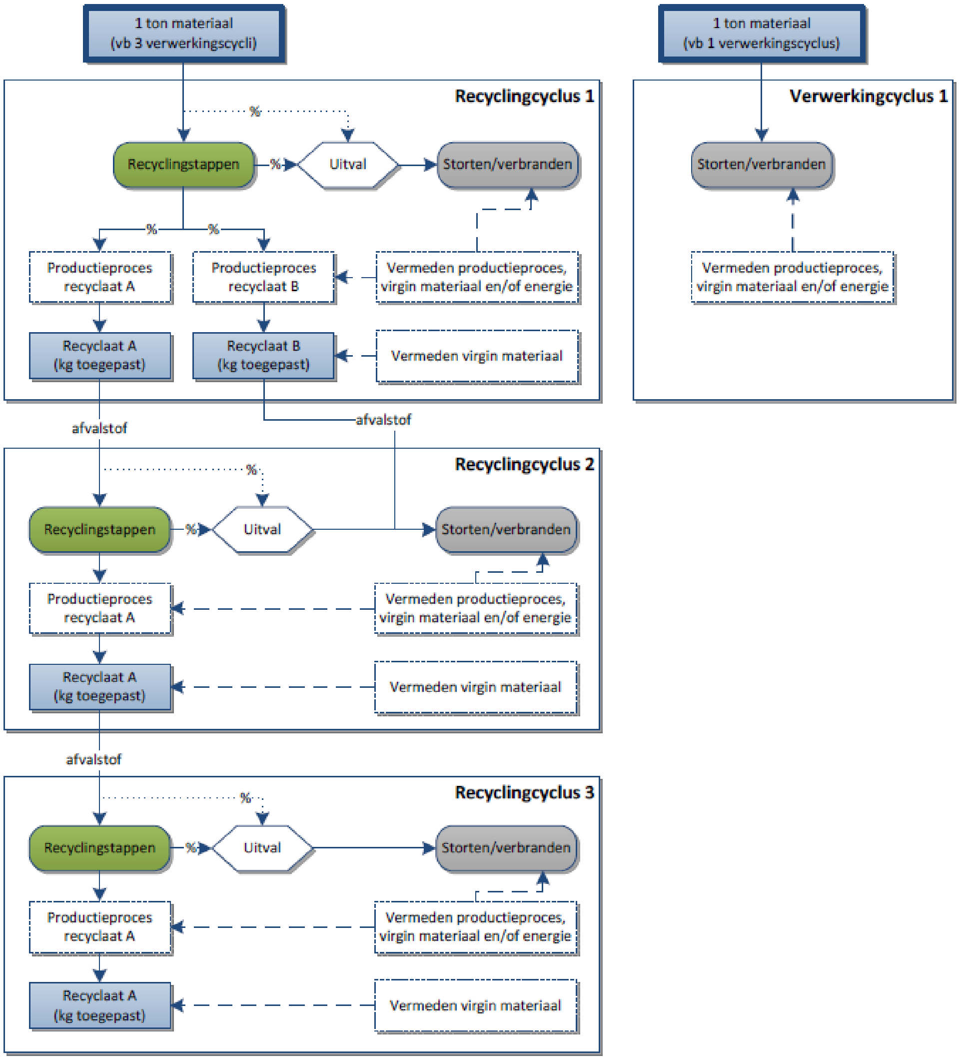

Figure 3 (=Figure 10 of LAP Annex F9) general overview of process to be included: 2 treatment options

In Figure 3 the right part represents incineration where the left part represents treatment options with material for recycling.

This mLCA method is prescribed in LAP3 to test deviating forms of processing against the minimum standard.

All relevant guidelines for executing LCA are included in this document.

The LCA has been performed in accordance with Appendix F.9 of LAP3 “Appendix 9; Performing LCAs i.r.t. the LAP "[3].

Ecoinvent 3.5, system model recycled content, is to be used for the inventory of this mLCA. The characterization and weighting are according to ReCiPe 2016. The mLCA results will always be expressed in ReCiPe 2016 points.

Appendix F9 states that the uptake and emission of biogenic CO_2 should not be included unless it is recorded for a long time (> 100 years). This corresponds to ReCiPe standards, because the uptake and emission of biogenic CO2 is not characterized in ReCiPe. Nonetheless, if it is relevant for a certain case, this subject will be discussed in more detail.

For the baseline scenarios, long-term emissions (>100 years) are excluded in the inventory.

All scenarios are calculated for 1 ton of material that is offered for processing at the individual consumer (or nearby collection point), day-care centre or healthcare centre.

Transportation distances and means will be based on averages, unless more specific information can be justified.

Avoided energy production as a result of generated energy in a waste incineration plant will be based on a lower heating value (LHV) of the material concerned and an efficiency of 18% electrical and 31% thermal (based on data over 2016) [5], using the following processes:
- For avoided electricity: the process "Electricity, high voltage {NL}| production mix | Cut-off, U" [Ecoinvent 3.5]; and
- For avoided heat: 'Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace >100kW | Cut-off, U' [Ecoinvent 3.5]

When the treatment of the diapers is combined with other fractions (for example during incineration), only emissions, use of energy and auxiliaries that are directly related to the diaper treatment will be included.

2. LIFE CYCLE INVENTORY

Waste collection

Both previous LCA studies have included waste collection as a part of the waste treatment process. In this study we assume a Dutch waste collection scenario for which "LCA afvalverwerking luiermateriaal" [1] is most representative, although the difference between both studies is marginal. Waste collection of one ton of AHP has been modeled according to the data given in Table 2.

Table 2 Decomposition of waste collection

Material or energy-use	Database process	Amount	Unit
Waste collection truck	Transport, freight, lorry 16-32 metric ton, euro5 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, U	80	tkm

2.1. Reference: waste incineration

As a reference to the TPH and FaterSMART technology of AHP waste treatment, a waste incineration plant is considered. The entire composition given in Table 2 is incinerated in an average Dutch waste incineration plant. The Lower Heating Value (LHV) of all components is also given in Table 2, as well as the total LHV of one ton of used AHP: 7,125 MJ/kg. Avoided energy production as a result of generated energy in a waste incineration plant will be based on an LHV of the material and an efficiency of 18% electrical and 31% thermal (based on data over 2016). Modelling details are found in Table 3. Note that proxies have been used for the incineration of glue, elastic and self-adhesive tape. These proxies are an approximation since no fitting Ecoinvent data is available. No material is recycled and therefor the mLCA only consists of a single cycle.

Table 3 Material and energy inputs and outputs of the reference waste incineration

Material or energy	Database process	Amount	Unit
Incineration of excreta	Raw sewage sludge {CH}| treatment of, municipal incineration | Cut-off, U	675	kg
Incineration of cellulose	Waste paperboard {Europe without Switzerland}| treatment of waste paperboard, municipal incineration | Cut-off, U	125	kg
Incineration of polypropylene	Waste polypropylene {CH}| treatment of, municipal incineration | Cut-off, U	87	kg
Incineration of polyethylene	Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, municipal incineration | Cut-off, U	15	kg
Incineration of SAP and glue	Waste plastic, mixture {Europe without Switzerland}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U	68+8,5	kg
Incineration of elastic and self-adhesive tape	Waste rubber, unspecified {Europe without Switzerland}| treatment of waste rubber, unspecified, municipal incineration | Cut-off, U	20	kg
Electrical energy gained	Electricity, high voltage {NL}| production mix | Cut-off, U	0,18 * 7175 = 1292	MJ
Thermal energy gained	Heat, district or industrial, natural gas {NL}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U	0,31 * 7175 = 2224	MJ

2.2. Thermal Pressure Hydrolysis (TPH)

Elsinga's TPH process is closely tied to the nearby sewage treatment plant and the waste incineration plant. The sewage treatment plant delivers sewage sludge, which acts as a medium in which chemical separation and sterilization can take place. After the separation of plastics, the added excreta can be further digested to produce biogas, from which electricity and heat are produced in a Combined Heat and Power (CHP) installation. The remaining sludge is then dewatered after which a sludge cake remains. The sludge cake can be composted to win ammonium sulfate and bio-granulate (compost). In Figure 4 a schematic overview of the entire process is shown. All process steps will be further explored in this chapter, and assumptions and modelling in SimaPro are listed. All recovered materials are covered in the final paragraph even if they are recovered in an earlier step of the process.

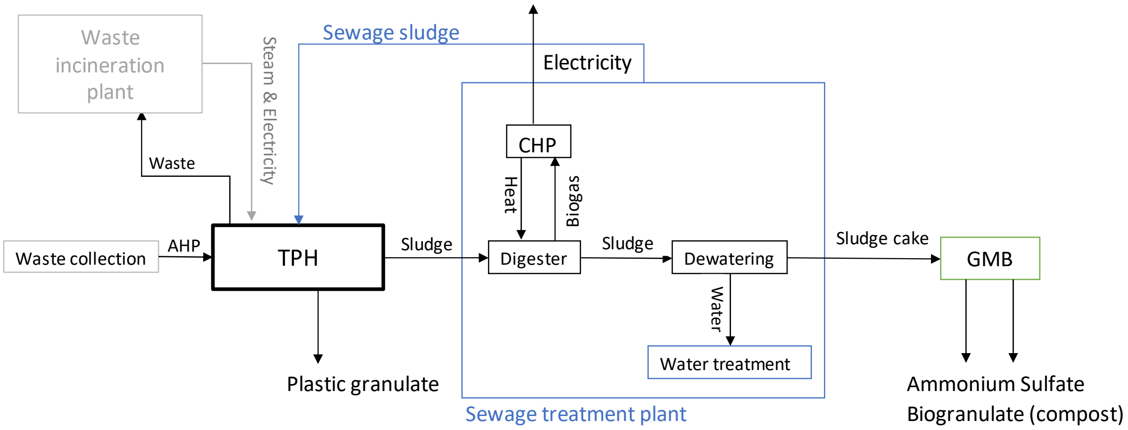

Figure 4 Schematic overview of the thermal pressure hydrolysis process

TPH-process

Firstly, the reactor vessel is filled with AHP material, and sewage sludge. The mixture is heated with steam till about 250 °C and pressurized to ≥ 40 bar. This process takes roughly 40 minutes during which the sludge is mixed. In this time the organic material is hydrolyzed; i.e. organic material and super absorbent polymers (SAP) decompose into smaller molecules under the effects of high temperature and pressure. Polypropylene and polyethylene melt and float to the top of the mixture in the form granules of 1 – 2 cm. The mixture is then cooled and depressurized after which the plastic granules can be separated. Within the separation step, granules are sieved at 20 mm, cleaned, and dried with residual heat. Any contamination is also separated in this step and ends up in an incineration plant. After separation the granules can be directly used in an extruder to make new plastic products. The sludge is transported back to the sewage treatment plant for further processing.

Table 4 shows the background processes, relevant amounts, and assumptions we have applied for this process step. 981 MJ of heat is used in the TPH process. Sewage sludge does not attribute to the environmental impact since it is a secondary stream.

Table 4 Material and energy inputs of the TPH process

Process step	Material or energy-use	Database process	Amount	Unit
TPH	Sewage sludge	Digester sludge {GLO}| digester sludge, Recycled Content cut-off | Cut-off, U	428,6	kg
TPH	Electrical energy use	Electricity, low voltage {NL}| market for | Cut-off, U	18	kWh
TPH	Heating with steam	Heat, district or industrial, other than natural gas {NL}| heat, from municipal waste incineration to generic market for heat district or industrial, other than natural gas | Cut-off, U	981	MJ
Waste treatment / TPH	Incineration of contamination	Waste plastic, mixture {Europe without Switzerland}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U	20	kg

Digester and CHP

The remaining sludge is pumped to the digester where biogas is produced from the organic material (excreta, and hydrolyzed cellulose & SAP). 88 m^3 of biogas is produced of which 72 m^3 can be linked to digestion of AHP, and 16 m^3 to the sewage sludge. However, all the 88 m^3 biogas is attributed to the TPH process, because the sewage sludge would otherwise have a lower yield. The sewage sludge is treated in the same manner it would have otherwise been in the sewage treatment plant. There is one exception however; in this case the sewage sludge has taken part in the TPH-process. This process (heat/pressure) 'loosens' carbon-containing substances in the sludge, which are then released more easily in the process of digesting. Hence the extra 16 m^3 can only be obtained precisely because the sludge is part of the AHP recycling pathway. Note that extra heat is required in the previous step because the sludge is heated together with the AHP; i.e. less than the 981 MJ would have been required if no sludge took part in the process. Thereby both loads and benefits of sludge in the TDH-process are included. Other benefits, such as in the last step, are not attributed to the TPH process, because the sludge would have undergone the same treatment either way. The extra heat necessary for heating the sludge in the TDH-process does not play a role in other steps.

The obtained biogas is burned in a combined heat and power (CHP) installation. Part of the produced heat and electricity is used in the digester, while the rest is calculated as avoided energy. To determine which part of the produced heat and electricity is used in the digester, data from ecoinvent was taken. According to this data, 4,18 kWh/m^3, and 66,8 MJ/m^3 is used by the digester. We further assumed 1,315 m^3 sludge is digested. This was approximated by calculating the leftover mass after TPH process (sludge + AHP – plastics), assuming an average density of 1 ton/m^3.

Table 5 shows the used ecoinvent processes and relevant inputs for the digester and CHP process. The ecoinvent digestion of sewage sludge process has been adapted to not include the input of heat and electricity, since the energy is already obtained from the CHP powered by the biogas. The energy used by the digester is later subtracted from the produced energy (see Table 8), to avoid double counting.

Emissions from the burning of biogas has been included with the ecoinvent processes shown below. These have been changed to not include the production of biogas, as this has already been produced by the digestion of sludge and remaining AHP. The amount of energy produced is calculated with the CHP efficiency (37% electrical energy, 53% thermal energy), and the energy content of biogas determined from:

- CH_4 content of biogas of 62%
- the LHV of CH_4 of 50 MJ/kg
- and a density of CH_4 of 0,66 kg/m^3.

Multiplying those three values gives an energy content of 20,46 MJ/m^3.

Table 5 Material and energy inputs of the digester and CHP

Process step	Material or energy-use	Database process	Amount	Unit
Digester	Digestion of sludge	Sewage sludge {CH}| treatment of by anaerobic digestion | Cut-off, U| Adjusted; no electricity and heat input	1,315	m3
CHP	Emissions of burning of biogas	Electricity, high voltage {NL}| heat and power co-generation, biogas, gas engine | Cut-off, U | Adjusted, no biogas input	0,37 * (88*20,46) / 3,6	kWh
CHP	Emissions of burning of biogas	Heat, central or small-scale, other than natural gas {NL}| heat and power co-generation, biogas, gas engine | Cut-off, U | Adjusted, no biogas input	0,53 * (88*20,46)	MJ

The assumptions made for the digester are considered conservative because the sludge from the TPH process is delivered to the digester at high temperature (approx. 90 °C). This will reduce the required heat for the digester.

Dewatering & wastewater treatment

After the digesting process, the remaining digested slurry is transported to a dewatering process in which remaining water is separated from the solid material. The digestate or sludge cake, the remaining mix of originally excreta, cellulose, and SAPs, is first separated and transported to a different facility for the last processing step. Silt from the original sewage sludge is separated from the wastewater with a centrifuge. The wastewater is further treated in the sewage treatment plant.

In Table 6 the used ecoinvent processes and relevant inputs for the dewatering and wastewater treatment are shown. The centrifuge which separates silt from wastewater uses 0,120 kWh/kg dry matter; 60,2 kg dry matter (silt) is present in the remaining water.

Table 6 Energy inputs of the for dewatering and wastewater treatment

Process step	Material or energy-use	Database process	Amount	Unit
Dewatering	Centrifuge	Electricity, low voltage {NL}| market for | Cut-off, U	7,2	kWh
Wastewater treatment	Wastewater treatment	Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | Cut-off, U	332	liter
Wastewater treatment	Treated water	Water (as emission to water)	332	kg

Sludge treatment and production of bio-granulate

In the final step, the sludge cake is transported to GMB in Tiel, where it is further processed to a bio-granulate, or compost. The sludge that remains has different sources. Part of the sludge originates directly from the sewage treatment plant, another part is also originally from the sewage treatment plant but 'made an extra round' via the TPH process, and another part originates form the excreta from the diapers. The sludge originating from the sewage treatment plant would have undergone the same treatment, so we cannot attribute its treatment (and possible benefits) to the TPH process. Only the treatment of the sludge originating from the excreta from diapers and its benefits are included in the calculation here. 40% or 114 kg of the sludge cake originates from excreta from diapers (see calculations on the next page for the deduction of 40%).

The transport of the entire sludge cake (285 kg) to GMB is attributed to the TPH process, since normally the sludge cake would be treated at the sewage treatment plant next door. However, due to contractual agreements and certification, the sludge cake originating from the TPH process has to be processed at GMB. Table 7 shows SimaPro modelling details.

By composting the sludge cake at GMB, ammonium sulphate and a bio-granulate can be obtained. The bio-granulate can be used as a fertilizer, however, it is not allowed to be used in the Netherlands due to disallowance of presence of AHP in the compost among other reasons. The bio-granulate is therefore transported to northern France, where its use is allowed. Transport to France is included, with Paris as destination by proxy. 86,1 kg of the produced 215,5 can be attributed to the AHP recycling process, for this calculation see page 12.

Table 7 Transport and processes for the sludge treatment

Process step	Material or energy-use	Database process	Amount	Unit
GMB	Transport to facility	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, U	35,1 * 285/1000	tkm
GMB	Composting	Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U	114	kg
GMB	Transport bio-granulate Tiel (GMB) to Paris	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, U	476 km * 86,1 kg = 40,98	tkm

Avoided primary raw materials and energy

This final paragraph covers all recovered materials over the course of 3 cycles in accordance with the mLCA method. The application of the recycled materials determines whether the same material can be retrieved in subsequent cycles. As long as the recycled material is recoverable again, for instance in a new diaper, subsequent cycles in the mLCA will calculate an additional recycling step (based on the new application) and also extra benefits due to avoided primary material production material. The energy recovery of burned materials can likewise only take place once, however materials lost to incineration in subsequent cycles will be allocated in their corresponding cycle. Table 8 shows SimaPro input for initially recovered materials.

In the TPH process, plastics are separated from the waste stream. Out of 102 kg of plastic input, 93 kg is recovered. The plastics are recovered in the same fraction of the input, 85/15 PP/PE. These plastics can be used in production of new diapers. While it is not entirely clear in what stream the lost plastics are lost, it is likely they end up in the contamination stream. We assume the recovered plastics replace virgin PP and PE. The retrieved granulate is a mix of PP and PE and could therefore be perceived as less valuable than pure polymers. Nevertheless, a mix of plastics (and mix of characteristics), can be desirable in certain products. In practice it is shown this is the case. Therefore, we can assume the mix of plastics is just as valuable as pure granulate would be.

The contamination output cannot be used to replace primary raw materials and is therefore burned in a waste incineration plant. The energy is recovered, but of course that is a one-time occurrence and will not take place in subsequent cycles. We assume the contamination stream has a lower heating value (LHV) similar to a mix of plastics: 28,67 MJ/kg. We further assume lost plastics are contained in this stream.

The biogas produced in the digester is burned in a CHP installation which produces heat and electricity. The CHP feeds the digester with energy: 4,18 kWh/m^3 and 66,8 MJ/m^3; these amounts have been subtracted from the produced energy. Most of the heat can be used inside the sewage treatment plant to increase its efficiency, and electricity can be fed to the grid. The energy can only be recovered one time.

In the final step, ammonium sulphate and bio-granulate is recovered from composting of the sludge cake. Normally this recovery process also takes place for regular sludge cakes, it is not known whether the TPH process has different yields. We therefore we assume the recovery process is the same for the TPH-sludge cake as it is for regular sludge cakes, and that the same yields can be achieved.

- 0,302 ton of bio-granulate can be produced per ton of sewage sludge.
- The sludge cake from the TPH process (input: 1 ton of AHP, and 428,6 kg of sewage sludge) yields 215,5 kg bio-granulate.
- 129,4 kg bio-granulate can be allocated to sewage sludge (428,6 * 0,302)
- The rest, 86,1 kg, can be attributed to the AHP (86,1 / 215,5 = 40%).

Furthermore, GMB produces approximately 220,75 kg ammonium sulphate per ton recovered bio-granulate from the sludge cake as well.

- 220,75 * 215,5/1000 = 47,6 kg ammonium sulphate
- Of which 220,75 * 86,1/1000 = 19,01 kg can be allocated to the 1 ton of AHP.

Both the bio-granulate and ammonium sulphate can only be recovered in the first cycle, since they both cannot be used as input for new diapers in this form.

The nutritional value of bio-granulate produced by GMB has been shared and is as follows:

- N: 45,7 gr/kg dry matter
- P_2O_5: 96,2 gr/kg dry matter
- K_2O: 3,9 gr/kg dry matter

The avoided material for the produced compost is a market mix of fertilizers. The Ecoinvent process has been altered to not include the transport from a ‘market for’ process.

Finally, we have also included the carbon sequestration caused by the use of bio-granulate as a compost. An earlier study by IVAM (‘Herziening levenscyclusanalyse voor GFT-afval’) [6] determined that 10% of introduced carbon will be sequestrated after 100 years. This is based on a literature study in which a range of 0% to 22% carbon sequestration was identified. The carbon (C) content of the bio-granulate is 273 gr/kg dry matter. 0,0273 kg carbon (10%) or 0,10 kg CO_2 will be sequestrated per kilogram bio-granulate. IVAM studied the carbon sequestration effects of organic waste, which is something very different than AHP or the excreta contained in them. The assumption of 10% could therefore feel insufficiently substantiated. However, the effect of carbon sequestration is very small (<0,5%) in the final result, hence we determined no further research into carbon sequestration is required.

Table 8 Cycle 1 - Avoided primary raw materials and energy

Process step	Material or energy-use	Database process	Amount	Unit
TPH	Polypropylene	Polypropylene, granulate {RER}| production | Cut-off, U	93 * 0,85	kg
TPH	Polyethylene	Polyethylene, high density, granulate {RER}| production | Cut-off, U	93 * 0,15	kg

Process step	Material or energy-use	Database process	Amount	Unit
Waste treatment	Electricity	Electricity, high voltage {NL}| production mix | Cut-off, U	11 * 28,67 * 0,18 / 3,6	kWh
Waste treatment	Heat	Heat, district or industrial, natural gas {NL}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U	11 * 28,67 * 0,31	MJ
Plastics lost in waste fraction	Electricity	Electricity, high voltage {NL}| production mix | Cut-off, U	9 * 28,67 * 0,18 / 3,6	kWh
Plastics lost in waste fraction	Heat	Heat, district or industrial, natural gas {NL}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U	9 * 28,67 * 0,31	MJ
Digester and CHP	Electricity	Electricity, high voltage {NL}| production mix | Cut-off, U	(0,37 * (88 * 20,46) / 3,6) - (4,18 * 1,315) = 179,6	kWh
Digester and CHP	Heat	Heat, district or industrial, natural gas {NL}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U	(0,53 * (88 * 20,46)) - (66,8 * 1,315) = 866,4	MJ
GMB	Compost	Nitrogen fertiliser, as N {GLO}| market for | Cut-off, U | Without transport	0,0457 * 86,1	kg
GMB	Compost	Phosphate fertiliser, as P2O5 {GLO}| market for | Cut-off, U | Without transport	0,0962 * 86,1	kg
GMB	Compost	Potassium fertiliser, as K2O {GLO}| market for | Cut-off, U | Without transport	0,0039 * 86,1	kg
GMB	Carbon sequestration by use compost	Emission to air: Carbon dioxide, fossil	- 0,1 * 86,1	kg
GMB	Ammonium sulphate	Ammonium sulfate, as N {RER}| ammonium sulfate production | Cut-off, U	19,01	kg

The recovered plastic granules can be used in production of new diapers. However in practice the plastic is offered to the market and thus not necessarily used in new diapers. For this study, it is assumed the recycled plastic granules are used in new common plastic products, after which they are recycled.

Collection, recycling and benefits are attributed for two additional cycles. For collection a flat 50 km of transport is assumed. Plastics will be recycled with a generic plastic recycling process in subsequent cycles. In the generic recycling process, a generic 5% loss of material is taken into account. Finally it is assumed the subsequently recycled plastic retains its quality. Table 9 shows SimaPro input for a second cycle.

Table 9 Cycle 2 – Collection, generic recycling and avoided primary raw materials and energy

Process step	Material or energy-use	Database process	Amount	Unit
Collection	PP + PE	Transport, freight, lorry, unspecified {RER}| market for transport, freight, lorry, unspecified | Cut-off, U	93 kg * 50 km = 4,65	tkm
Recycling	PP + PE	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	93	kg
Recovered material	Polypropylene	Polypropylene, granulate {RER}| production | Cut-off, U	93 * 0,95 * 0,85 = 75,10	kg
Recovered material	Polyethylene	Polyethylene, high density, granulate {RER}| production | Cut-off, U	93 * 0,95 * 0,15 = 13,25	kg

In similar fashion to cycle 2, the now remaining 88,35 kg of plastics are once again reused in common plastic products and recycled by means of generic recycling of plastic. In the end 83,93 kg plastics are recovered. Table 10 shows SimaPro input for a third cycle.

Table 10 Cycle 3 - Avoided primary raw materials and energy

Process step	Material or energy-use	Database process	Amount	Unit
Collection	PP + PE	Transport, freight, lorry, unspecified {RER}| market for transport, freight, lorry, unspecified | Cut-off, U	88,35 kg * 50 km = 4,42	tkm
Recycling	PP + PE	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	88,35	kg
Recovered material	Polypropylene	Polypropylene, granulate {RER}| production | Cut-off, U	88,35 * 0,95 * 0,85 = 71,34	kg
Recovered material	Polyethylene	Polyethylene, high density, granulate {RER}| production | Cut-off, U	88,35 * 0,95 * 0,15 = 12,59	kg

2.3. FaterSMART technology

The core treatment process by Fater is a rotating autoclave. High-pressure steam used in the autoclave sterilizes the material after which the material is passed through a shredder, dryer and separator to recover three fractions of materials: plastics, cellulose, and super absorbent polymers (SAP). A schematic overview can be found in Figure 5. The details of the process are confidential; therefore, the method of modeling and amounts are not listed in this rapport. All recovered materials are covered in the final paragraph, including method of modelling.

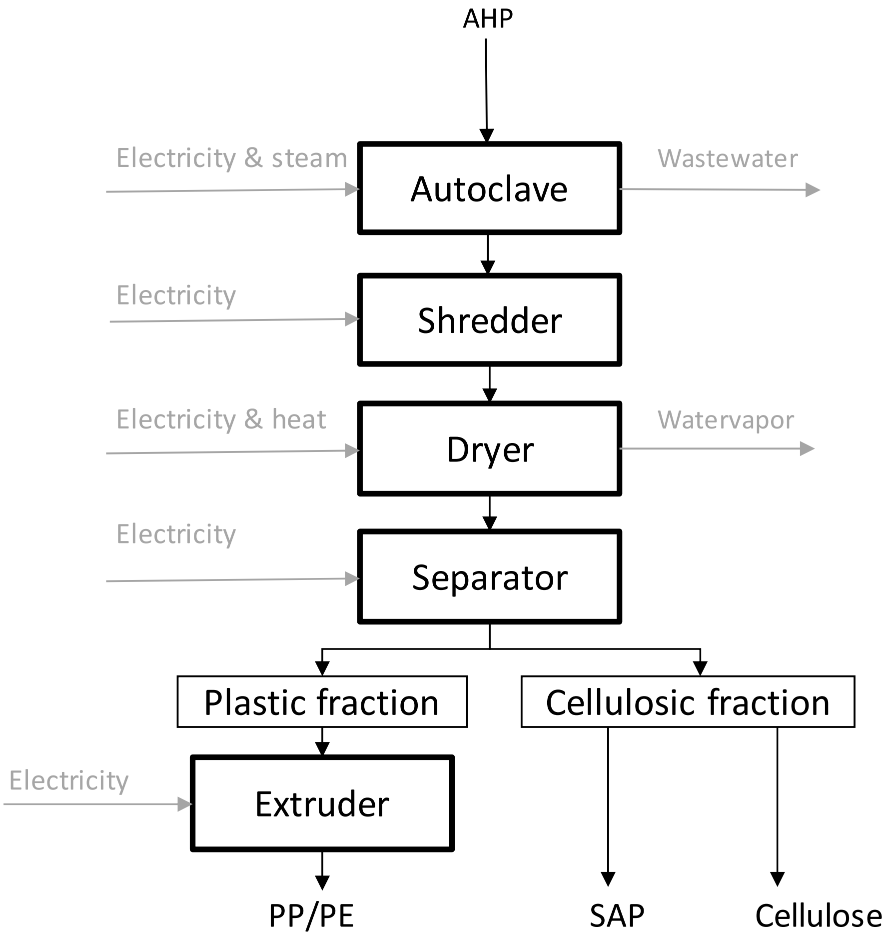

Figure 5 Schematic overview of the FaterSMART technology

Within the rotating autoclave, excreta are eliminated from the used AHPs with a combination of movement and high-pressured steam. This process also sterilizes the AHP, after which the products are transported by conveyor belt to a shredder and a drying. Moisture, bad odors, and potentially present pathogens are eliminated in the process. Finally, the shredded and mixed materials are transported, again by conveyor belt, to a battery of separators in series where the three fractions are separated through a system of rotating cylinders. The cellulosic fraction is thereafter recovered, whereas the plastic fraction passes through an extruder that cuts the material is pieces (granules). In total, the FaterSMART process uses 230 kWh of electricity and 100 Nm^3 of natural gas. Other amounts are confidential. The non-confidential part of the used Ecoinvent profiles is given in Table 11.

Table 11 Ecoinvent database processes used in the modelling of the FaterSMART technology

Material or energy	Database process
Electricity	Electricity, low voltage {NL}| market for | Cut-off, U
High-pressure steam / heat	Heat, district or industrial, other than natural gas {NL}| heat, from municipal waste incineration to generic market for heat district or industrial, other than natural gas | Cut-off, U
High-pressure steam	Water, well, in ground, NL
Wastewater treatment	Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | Cut-off, U
Treated water	Water (as emission to water)
Electricity	Electricity, low voltage {NL}| market for | Cut-off, U
Water-emission	Water (to air)

Avoided primary raw materials and energy

This final paragraph covers all recovered materials over the course of 3 cycles in accordance with the mLCA method. The application of the recycled materials determines whether the same material can be retrieved in subsequent cycles. As long as the recycled material is recoverable again, in for instance a new diaper, subsequent cycles in the mLCA will calculate an additional recycling step (based on the new application) and also extra benefits due to avoided primary material production material. However, single time applications, such as incineration are only counted the first cycle. Table 12shows SimaPro input for initially recycled materials.

Whether any loss of material occurs in the FaterSMART technology is unknown, however from supplied product information we can deduce the separation process is not perfect. For example, the composition of the cellulose has a minimum standard of consisting of ≥ 90% kraft cellulose, ≤ 5% SAP, and ≤ 5% plastics. The target quality is ≥ 95% kraft cellulose, and ≤ 5% SAP, with only traces of plastics. While this information is not stated for the plastics, the product information for SAP has a similar minimum and target standard (minimum standard: ≥ 80% SAP, ≤ 20% cellulose; target: ≥ 95% SAP, ≤ 5% cellulose). For the sake of the mLCA calculation we will assume a worst-case scenario for the kraft cellulose composition while still meeting the minimum standard. This means 10% of cellulose is lost in SAP stream or elsewhere. Losses of SAP and plastics are deduced with a mass-balance check; 6,13% of plastics are lost each cycle and 9,19% of SAP is lost each cycle. All assumed values meet the minimum standard or higher.

We assume plastics are produced in the same ratio as the input (85/15; PP/PE). These plastics are suitable for injection moulding processes and can be used in production of objects for different contexts (e.g. detergent caps). Although the retrieved plastics are a mix of PE and PP, since the mix can be used to create various products, we assume this mix to be just as valuable as pure polymers. Cellulose can also be used in multiple cycles. However, quality of cellulose fibers will decrease each cycle. We assume the cellulose can be recycled up to 3 times. This is represented with an additional “loss”-fraction in each cycle. Finally, SAP can be used as SAP in bed pads, which can be again retrieved as AHP. To model avoidance of new SAPs produced we had to resort to components of SAPs as we do not have access in background databases to any SAP. The most common type of SAP produced in the world is sodium polyacrylate. It is produced with two main components: acrylic acid, and sodium hydroxide with a ratio of 1:1. Unfortunately, other components and production process is unknown. Extra additives could have either a lower or higher environmental impact than the main components, with higher being the more likely. For this reason, the approach could be considered a worst-case approximation.

Table 12 Cycle 1 - Avoided primary raw materials and energy

Material or energy-use	Database process	Amount	Unit
Polypropylene	Polypropylene, granulate {RER}| production | Cut-off, U	102 * 0,85 * 0,9387 = 81,39	kg
Polyethylene	Polyethylene, high density, granulate {RER}| production | Cut-off, U	102 * 0,15 * 0,9387 = 14,36	kg
Cellulose	Sulfate pulp, unbleached {RER}| sulfate pulp production, from softwood, unbleached | Cut-off, U	125 * 0,9 * (2/3) = 75	kg
SAP	Acrylic acid {RER}| production | Cut-off, U	68 * 0,9081 * 0,5	kg
SAP	Sodium hydroxide, without water, in 50% solution state {RER}| chlor-alkali electrolysis, membrane cell | Cut-off, U	68 * 0,9081 * 0,5	kg

The recovered materials can be used in production of new diapers. However, in practice materials are offered to the market and thus not necessarily used in new diapers. For this study, it is assumed the recycled materials are separately used in new common recyclable products, depending on the material, after which they are recycled again.

Collection, recycling and benefits are attributed for two additional cycles. For collection a flat 50 km of transport is assumed. Plastics will be recycled with a generic plastic recycling process in subsequent cycles. A similar approach is taken for cellulose and SAPs, though, since no generic recycling process is available, the generic recycling process of plastics used by proxy. Since SAPs are polymers too, this process can be attributed as representable. In the case of cellulose this is a bit of a stretch, and perhaps a slightly larger impact that the reality. Nevertheless, we assume environmental impact of cellulose recycling and plastic recycling won't be very different, despite being quite a different process. The bottom line is that recycling of cellulose will lead to extra benefits to the total score.

In the generic recycling process, a generic 5% loss of material is taken into account for plastics (PP/PE), and 10% loss of material is assumed for cellulose and SAP. Due to recycling limits of cellulose, a quality factor is also included. It is assumed the subsequently recycled plastic and SAP retain their quality. Table 13 shows SimaPro input for a second cycle.

Table 13 Cycle 2 - Avoided primary raw materials and energy

Material or energy-use	Database process	Amount	Unit
Collection PP/PE, cellulose, SAP	Transport, freight, lorry, unspecified {RER}| market for transport, freight, lorry, unspecified | Cut-off, U	(95,75 + 112,5 + 61,75 kg) * 50 km	tkm
Recycling PP/PE	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	95,75	kg
Recycling cellulose	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	(125 * 0,9 =) 112,5	kg
Recycling SAP	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	61,75	kg
Polypropylene	Polypropylene, granulate {RER}| production | Cut-off, U	95,75 * 0,85 * 0,95 = 77,3	kg
Polyethylene	Polyethylene, high density, granulate {RER}| production | Cut-off, U	95,75 * 0,15 * 0,95 = 13,6	kg
Cellulose	Sulfate pulp, unbleached {RER}| sulfate pulp production, from softwood, unbleached | Cut-off, U	75 * 0,9 * (2/3) = 45	kg
SAP	Acrylic acid {RER}| production | Cut-off, U	61,75 * 0,90 * 0,5 = 27,79	kg
SAP	Sodium hydroxide, without water, in 50% solution state {RER}| chlor-alkali electrolysis, membrane cell | Cut-off, U	61,75 * 0,90 * 0,5 = 27,79	kg

In similar fashion to cycle 2, the now remaining three materials are once again reused in common products and recycled. SimaPro input for the third cycle is shown in Table 14.

Table 14 Cycle 3 - Avoided primary raw materials and energy

Material or energy-use	Database process	Amount	Unit
Collection PP/PE, cellulose, SAP	Transport, freight, lorry, unspecified {RER}| market for transport, freight, lorry, unspecified | Cut-off, U	(90,96 + 101,25 + 55,58 kg) * 50 km	tkm
Recycling PP/PE	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	90,96	kg
Recycling cellulose	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	(112,5 * 0,9 =) 101,25	kg
Recycling SAP	Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U	55,58	kg
Polypropylene	Polypropylene, granulate {RER}| production | Cut-off, U	90,96 * 0,85 * 0,95 = 73,45	kg
Polyethylene	Polyethylene, high density, granulate {RER}| production | Cut-off, U	90,96 * 0,15 * 0,95 = 12,96	kg
Cellulose	Sulfate pulp, unbleached {RER}| sulfate pulp production, from softwood, unbleached | Cut-off, U	45 * 0,9 * (2/3) = 27	kg
SAP	Acrylic acid {RER}| production | Cut-off, U	55,58 * 0,90 * 0,5 = 25	kg
SAP	Sodium hydroxide, without water, in 50% solution state {RER}| chlor-alkali electrolysis, membrane cell | Cut-off, U	55,58 * 0,90 * 0,5 = 25	kg

3. LIFECYCLE IMPACT ASSESSMENT

The characterization and weighting applied are according to ReCiPe 2016. Results of the two processes along with the reference process is shown in this chapter. The results include endpoint of the ReCiPe method and the global warming potential. The endpoint ReCiPe method weighs various environmental impact to a single score. Among the environmental impacts are Global Warming, Acidification, water use, land use, and many more. A full list can be deduced from the midpoint results given in appendix A.

Table 15 and Figure 6 show these totaled results. Detailed results can be seen in the next chapters contribution analysis. Please also note that the results are a product of the assumptions made in this study. A couple of assumptions are further explored in the sensitivity analysis, which better indicates that the result of this study should be interpreted as a range of environmental impact. See the sensitivity analysis for this range of results.

Table 15 Results ReCiPe Endpoint (H) and global warming potential

Category		Waste incineration	TPH	FaterSMART
Total	Pt	**3,36**	**-18,61**	**-14,97**
Human health	Pt	3,20	-15,96	-11,71
Ecosystems	Pt	0,32	-1,36	-1,93
Resources	Pt	-0,15	-1,29	-1,32
Global warming	kg CO_2-eq	241,66	-657,45	-451,53

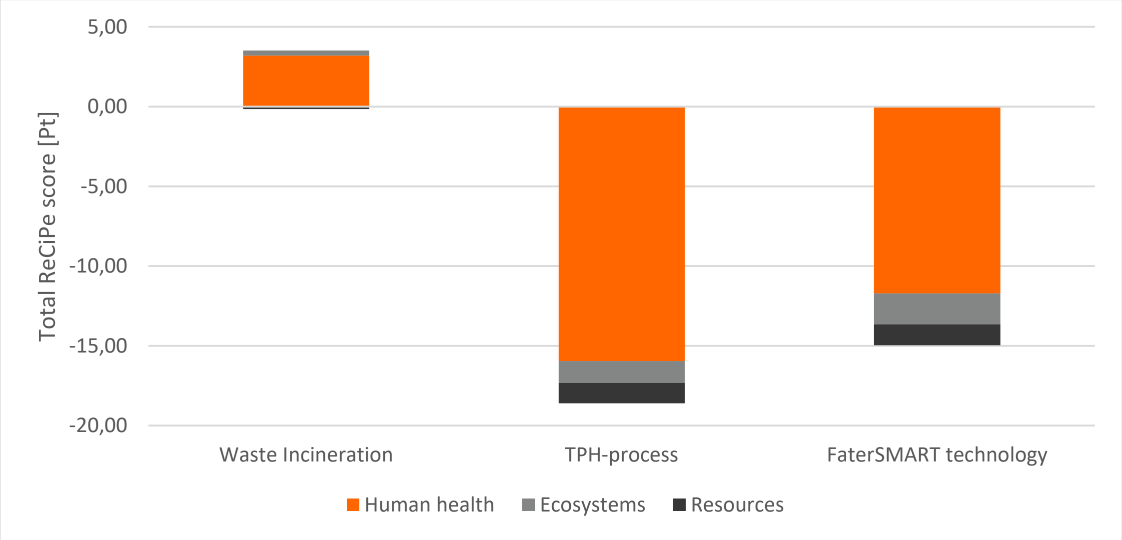

Figure 6 Results ReCiPe Endpoint scores

4. LIFECYCLE INTERPRETATION

4.1. Contribution analysis

Figure 7 and Figure 8 depict the contribution analysis by ReCiPe score and global warming potential respectively. Figure 7 is a more refined version of Figure 6. Here, the positive values (above the x-axis) are environmental impacts, and negative values (below the x-axis) are avoided environmental impact. The sum of these values gives the same result as shown in Figure 6. Unsurprisingly, both the TPH-process and FaterSMART technology have their largest avoided impact in the first cycle of the mLCA, though the differences are somewhat remarkable. With FaterSmart technology all three recovered materials, can be recovered in subsequent cycles, which is not the case for the TPH process, where only plastics are recovered in multiple cycles. This explains the difference in cycles 2 and 3 between the two. The avoided impact is further explored in Figure 9 and Figure 10.

Impacts of the processes themselves also show significant differences. The FaterSMART technology has double the impact of the TPH-process, excluding generic recycling of cycles 2 and 3, mostly due to the fact that the TPH process requires less energy overall. The energy source in the TPH process is steam that originates from a waste incineration plant, and no emissions have been allocated to its use. The steam used in the FaterSMART technology has the same origin. The difference however is that a larger portion of the energy use in the FaterSMART technology is electricity. To investigate this difference in energy source, the sensitivity analysis will further explore the allocation of steam and electricity.

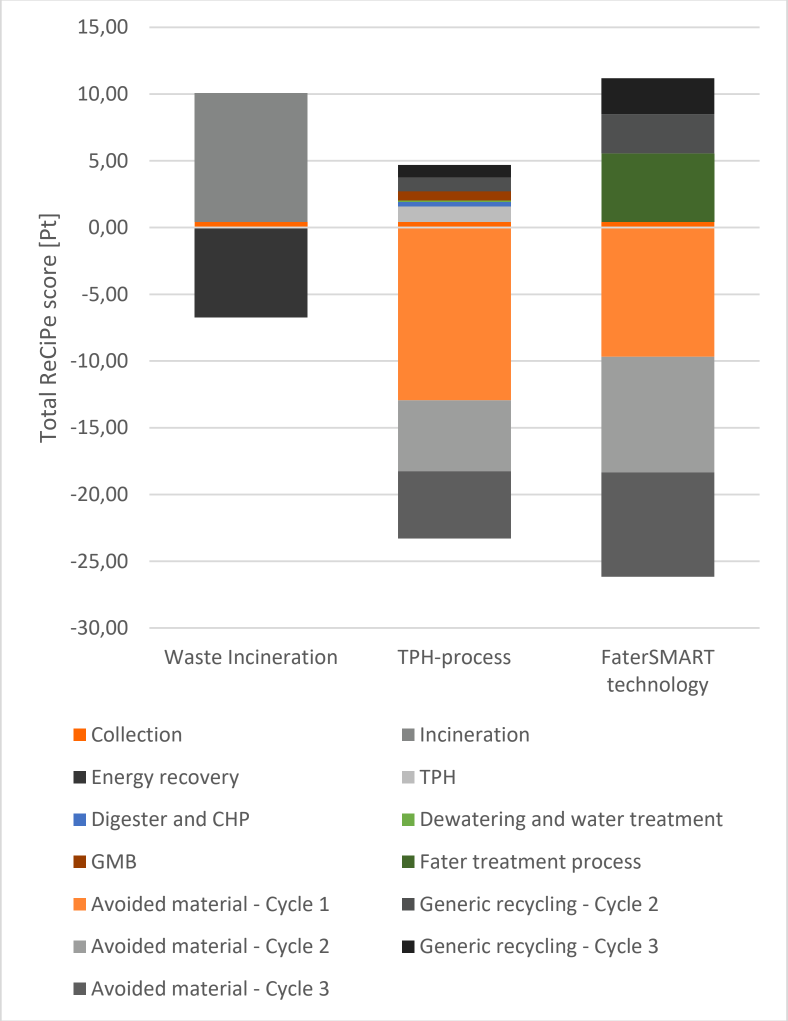

Figure 7 Contribution analysis by process steps in ReCiPe score

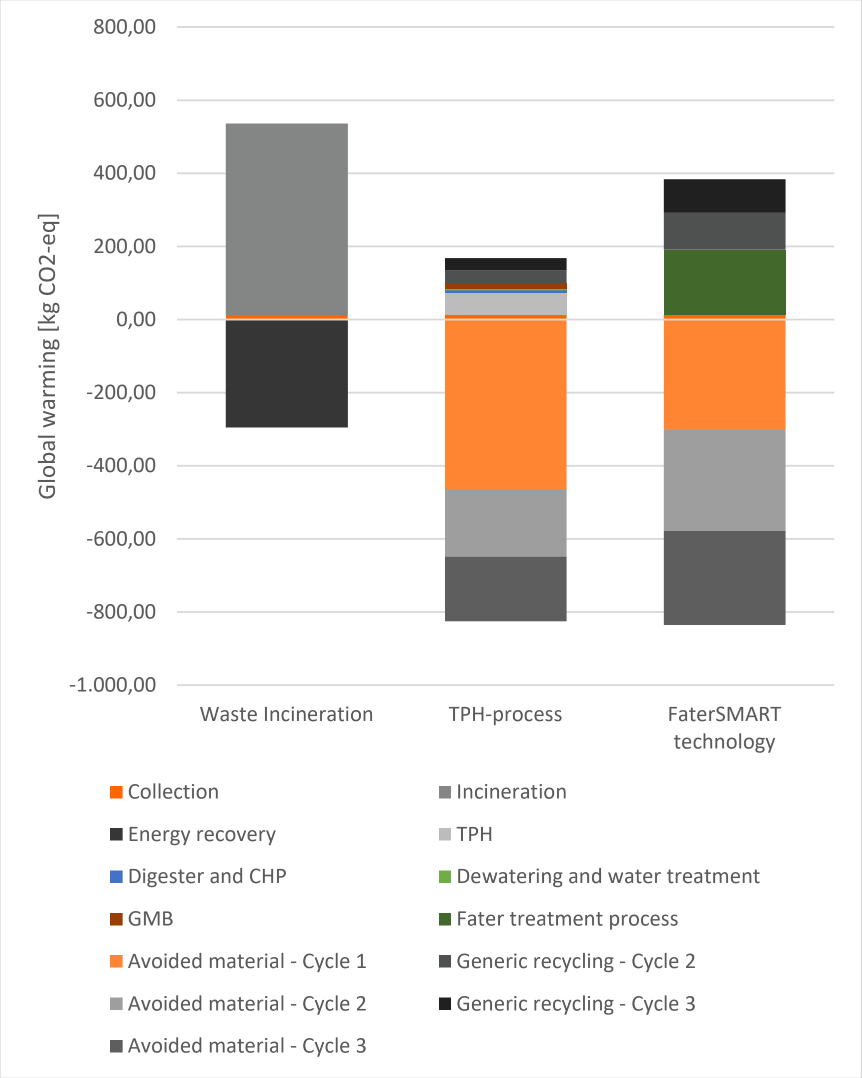

Figure 8 Contribution analysis by process steps in Global warming potential

From Figure 9 and Figure 10 one can deduce that the amount of recycled plastics in both processes are nearly identical, even in subsequent cycles. Part of the difference is seen in the recycling of cellulose and SAPs. The FaterSMART technology retrieves the cellulose and SAPs so that they are useable in subsequent cycles. The TPH-process converts both these materials to biogas, but also makes use of the excreta, from which valuable agricultural nutrients are retrieved.

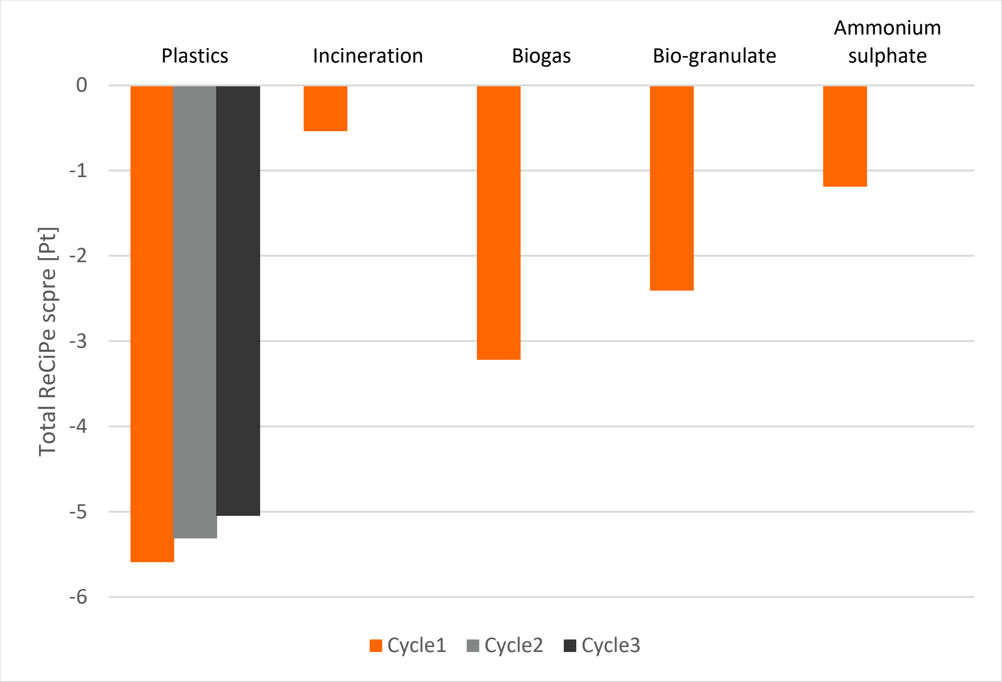

Figure 9 TPH-process avoided impact per product and cycle

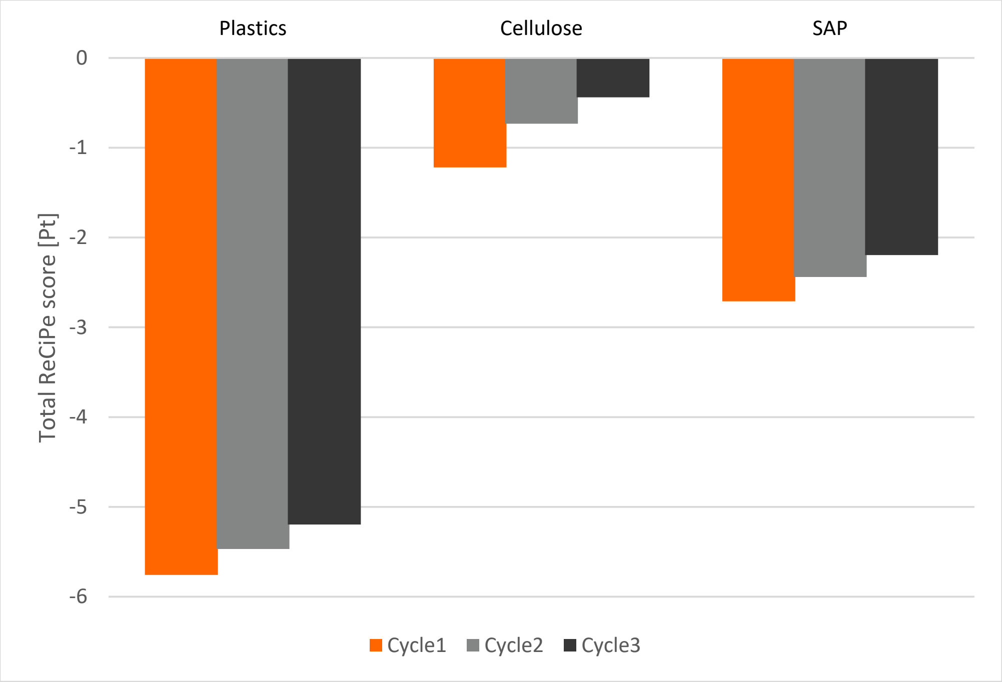

Figure 10 FaterSMART technology avoided impact per product and cycle

4.2. Sensitivity analysis

In the sensitivity analysis multiple assumptions and recycling options are further investigated for each treatment option. As indicated earlier, energy (steam and electricity) allocation has been investigated. As well as a difference in application of recycled material for each treatment option.

Energy allocation

In the main scenario both treatment processes' heat and electricity consumption are modeled with the same database processes, shown in Table 16. Heat originates from a waste incineration plant, from which all emissions are allocated to the incineration of waste (i.e. no environmental impact is attributed to the use of this heat). The electricity is modelled so that it originates directly from the grid, with all environmental impact included.

Table 16 Energy modeling processes

Energy	Database process
Heat/Steam	Heat, district or industrial, other than natural gas {NL}| heat, from municipal waste incineration to generic market for heat district or industrial, other than natural gas | Cut-off, U
Electricity	Electricity, low voltage {NL}| market for | Cut-off, U

The heat is modeled so that it is obtained from a waste incineration plant, allocating all emissions to the incineration of waste; therefor in this LCA it comes with no environmental impact. For this to actually happen, the treatment needs to take place in close proximity to a waste incineration plant. In other words, it is highly dependent on the location of treatment. Elsinga's plant is located close to an incineration plant, and FATER's planned plant will be too. On the other hand, electricity is modelled so that it comes directly from the Dutch electricity grid. Electricity does not have the same location dependency. An electricity plant can supply electricity to the other side of the country with minimal losses. So, while in truth the electricity consumed might be originating from a waste incineration plant, use of the electricity does reduce available ('no-emission allocated') electricity on the grid, albeit with fewer losses. Therefore, we think the current modeling is the best representation of environmental impact.

Nevertheless, to explore the effect of these choices, we have changed the allocation of both heat and electricity separately in this sensitivity analysis, as shown in Table 17. The heat process in Table 17 is heat produced by an industrial furnace. Contrary to the original process, all emissions are attributed to the production of heat. The electricity process on the other hand is electricity produced by a waste incineration plant, from which all emissions are allocated to the incineration of waste (i.e. the electricity comes without environmental impact). These two allocation changes will be investigated separately show a worst-case and best-case result for the energy allocation.

Table 17 Energy modeling sensitivity analysis

Energy	Database process
Heat/Steam	Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace >100kW | Cut-off, U
Electricity	Electricity, for reuse in municipal waste incineration only {NL}| treatment of municipal solid waste, incineration | Cut-off, U

The results of this sensitivity analysis on energy allocation are shown in Table 18, Table 19, and Figure 11. The difference of energy allocation makes for a fairly small deviation from the original value for the TPH process. Addition of emissions from use of the steam causes just a 1,4 point (+7,5%) higher ReCiPe score, and 69 kg (+10,5%) higher CO_2-emissions. The difference from change of allocation for electricity is even smaller: a 0,4 point (-2%) lower ReCiPe score and 16 kg (-2%) fewer CO_2-emissions. If recovery of materials is left out of this equation, changes would obviously be relatively larger, as can be seen in Figure 11.

Allocation of energy sources is far more significant in case of the FaterSMART technology. Using heat from an industrial furnace would increase ReCiPe score by 5 whole points (+33%), and CO_2 emissions by 248 kg (+55%). Using electricity directly from a waste incineration plant would reduce ReCiPe score by almost 4 points (-25%) and reduce CO_2 emissions by 150 kg (-33%).

The difference of significance between the two can only be explained by the relative amount of energy used in the processes. To recover cellulose and SAPs with the FaterSMART technology, the material has to be dried. Drying, or removal of water by evaporation, is a very energy intensive process. Another difference is that FaterSMART technology is mainly mechanically driven (high electricity use), whereas the TPH-process is more chemically driven; as an example, the material is composted, and the composting process supplies its own heat with the production of biogas.

Table 18 Results sensitivity analysis steam allocation

Category		TPH-process - original	TPH-process – steam allocation	FaterSMART - original	FaterSMART – steam allocation
Total	Pt	-18,61	-17,21	-14,97	-9,95
Global warming	kg CO_2-eq	-657,45	-588,41	-451,53	-203,57

Table 19 Results sensitivity analysis electricity allocation

Category		Elsinga - original	Elsinga – electricity allocation	FATER - original	FATER – electricity allocation
Total	Pt	-18,61	-19,02	-14,97	-18,72
Global warming	kg CO_2-eq	-657,45	-673,81	-451,53	-600,84

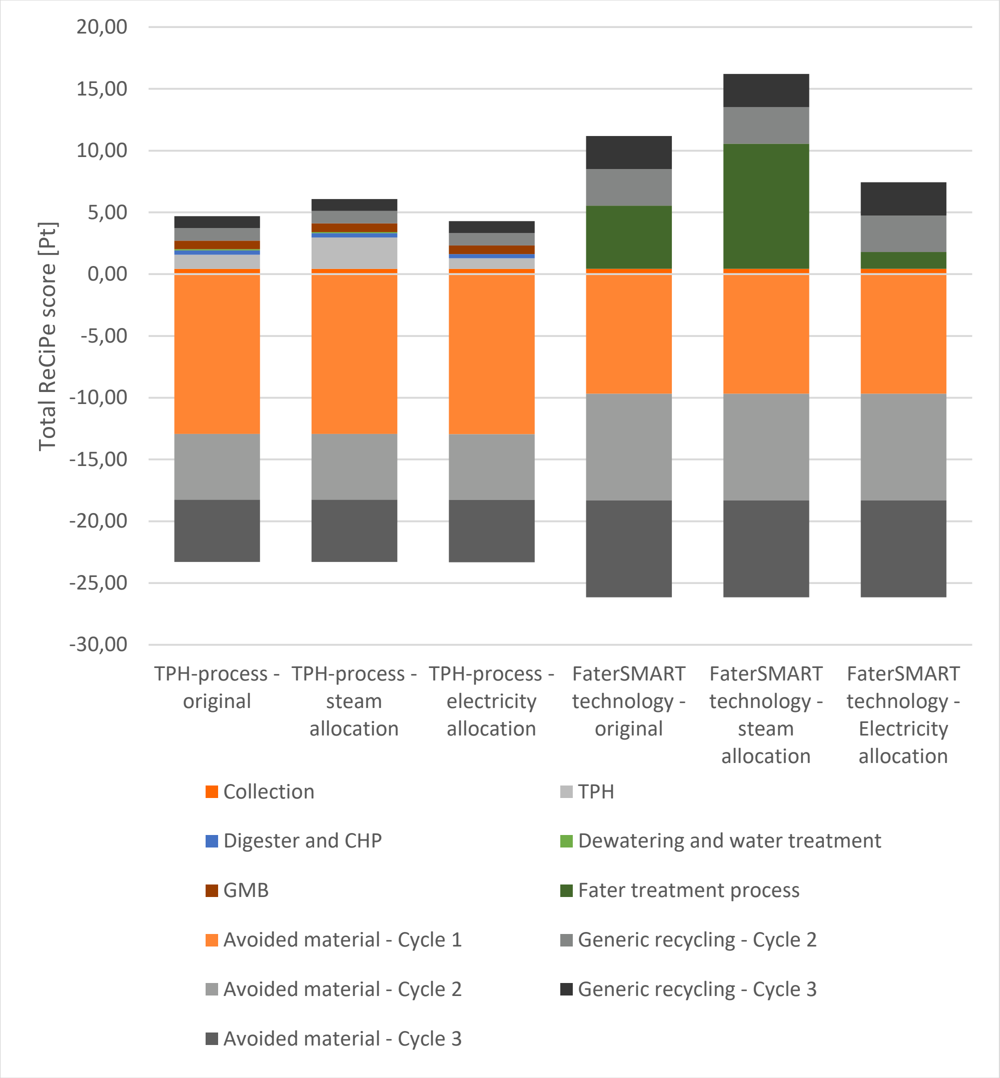

Figure 11 Sensitivity analysis steam and electricity allocation

Bio-granulate incineration

Besides a sensitivity analysis on the allocation of energy we have also investigated alternatives of recycling for both treatment options. The bio-granulate produced in the final step of the TPH-process can either be used as fertilizer or it can be burned in a waste incineration plant to recover energy. Since bio-granulate is not allowed to be used as a fertilizer in the Netherlands, incineration in a waste incineration plant is a very likely alternative. The energy recovery, like use as fertilizer, can only take place once, so the change will be seen in the first cycle of the mLCA. We have used the same data as the previous LCA study “LCA afvalverwerking luiermateriaal” [1], where the bio-granulate is first transported 40 km to a waste incineration plant. Exact modelling of this change can be found in Table 20.

Table 20 Material and energy inputs - energy recovery from incineration of bio-granulate

Process step	Material or energy-use	Database process	Amount	Unit
GMB + incineration	Transport to facility	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, U	40 * 86,1/1000	tkm
GMB + incineration	Incineration	Biowaste {CH}| treatment of, municipal incineration with fly ash extraction | Cut-off, U	86,1	kg
Cycle 1	Heat recovery from incineration	Heat, district or industrial, natural gas {NL}| heat and power co-generation, natural gas,	96	MJ

Process step	Material or energy-use	Database process	Amount	Unit
		conventional power plant, 100MW electrical | Cut-off, U		
Cycle 1	Electricity recovery from incineration	Electricity, high voltage {NL}| production mix | Cut-off, U	23	kWh

The results of the sensitivity analysis of bio-granulate recycling options is shown in Table 21 and Figure 12, including original FaterSmart results for comparison. Notably, the results show a larger difference than the sensitivity analysis on energy allocation did. The added benefit of using bio-granulate as a fertilizer is larger than the energy recovered from incinerating bio-granulate, during which process additional emissions are released. The difference amounts to 1,92 points (+10%) ReCiPe score and 44 kg (+7%) more CO_2 emissions.

Table 21 Results sensitivity analysis - waste incineration bio-granulate

Category		TPH-process - original	TPH-process – waste incineration bio-granulate	FaterSMART - original
Total	Pt	-18,61	-16,69	-14,97
Global warming	kg CO_2-eq	-657,45	-613,10	-451,53

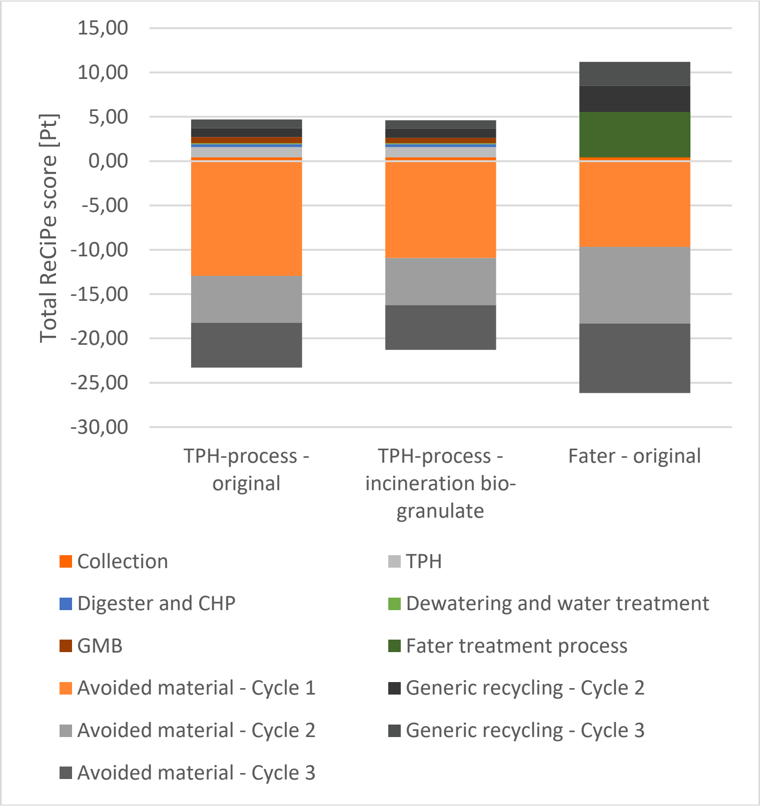

Figure 12 Results sensitivity analysis – waste incineration bio-granulate

SAP application

The recycling alternative investigated for the FaterSMART technology is the application of SAPs. SAPs can replace SAPs in bed pads or other Adsorbent Hygienic Products. Alternatively, the SAPs can be used as thickening agent in detergents. This is a one-time application, since we assume SAPs cannot be retrieved from sewage, where detergents usually end up. In detergents SAPs usually replace xanthan gum. Since xanthan gum is not available in background databases, a different thickening agent is avoided as a proxy. Maize starch was selected due to its comparability with xanthan gum. It was found that maize starch can substitute xanthan gum 1 on 1 in cooking recipes, meaning their thickening qualities should be equivalent. We assume the same holds true in detergents. We also assume that SAP has comparable thickening qualities. Amounts and database process is given in Table 22.

Table 22 Sensitivity analysis - Cycle 1, 2, and 3 - Avoided primary raw materials production of SAPs

Material	Database process	Amount	Unit
SAP	Maize starch {RoW}| production | Cut-off, U	68 * 0,9081 = 61,75	kg

The results of this sensitivity analysis are shown in Table 23, Figure 13, and Figure 14, the first two figures include TPH-process original results for comparison. Recycling SAPs as bed pads is clearly more advantageous than replacement of thickening agent. While the first cycle shows only a small difference in advantage of the thickening agent. Later cycles are a deciding factor in favor of recycling SAPs as bed pads, despite requiring more recycle processing for SAPs in later cycles. It is due to the mLCA method of valuation in the multiple cycles that bed pads are the favored recycling option. Unlike the bed pads, a thickening agent can only be valued once. The difference totals to 3 points (+20%) higher ReCiPe score and an increase of 141 kg (+31%) CO_2 emissions.

Table 23 Results sensitivity analysis - recycling SAPs

Category		FaterSMART - original	FaterSMART – recycling SAPs	TPH-process - original
Total	Pt	-14,97	-11,91	-18,61
Global warming	kg CO_2-eq	-451,53	-310,18	-657,45

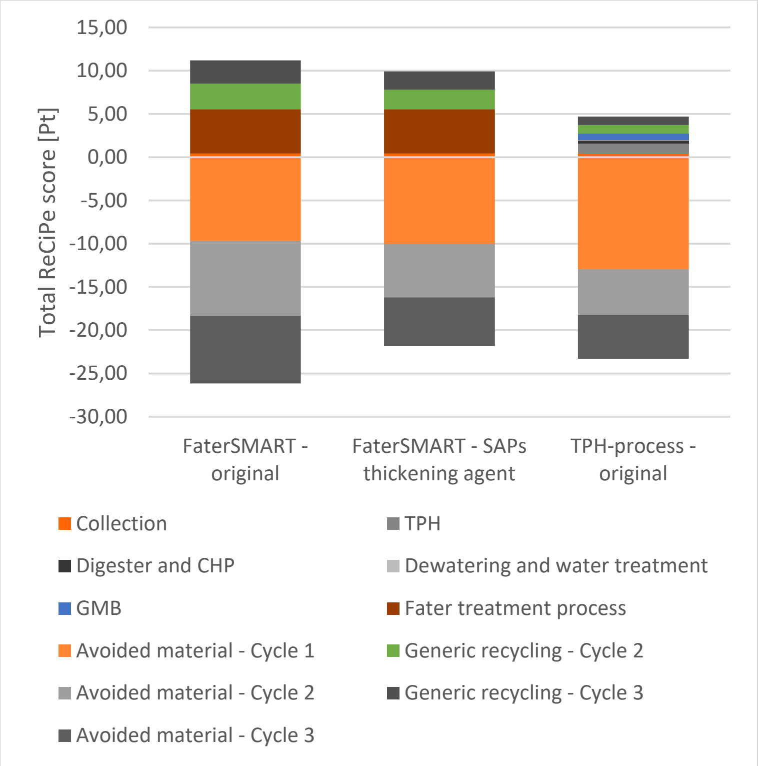

Figure 13 Results sensitivity analysis - application SAPs as thickening agent

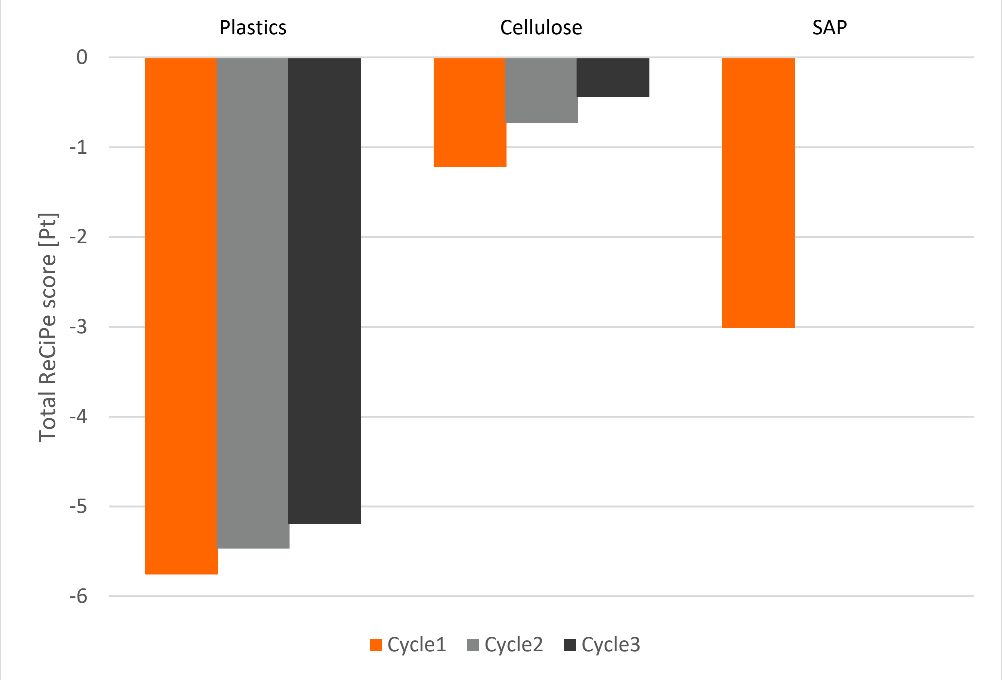

Figure 14 Results sensitivity analysis - application of SAPs as thickening agent – avoided impact per product and per cycle

Figure 15 shows the range of results the sensitivity analysis has led to. In chapter 3 it was noted that the results are a product of the assumptions made in this study. In the sensitivity analysis we have shown and tested the effect of these assumptions, giving a range of outcomes. The range is depicted in the figure below.

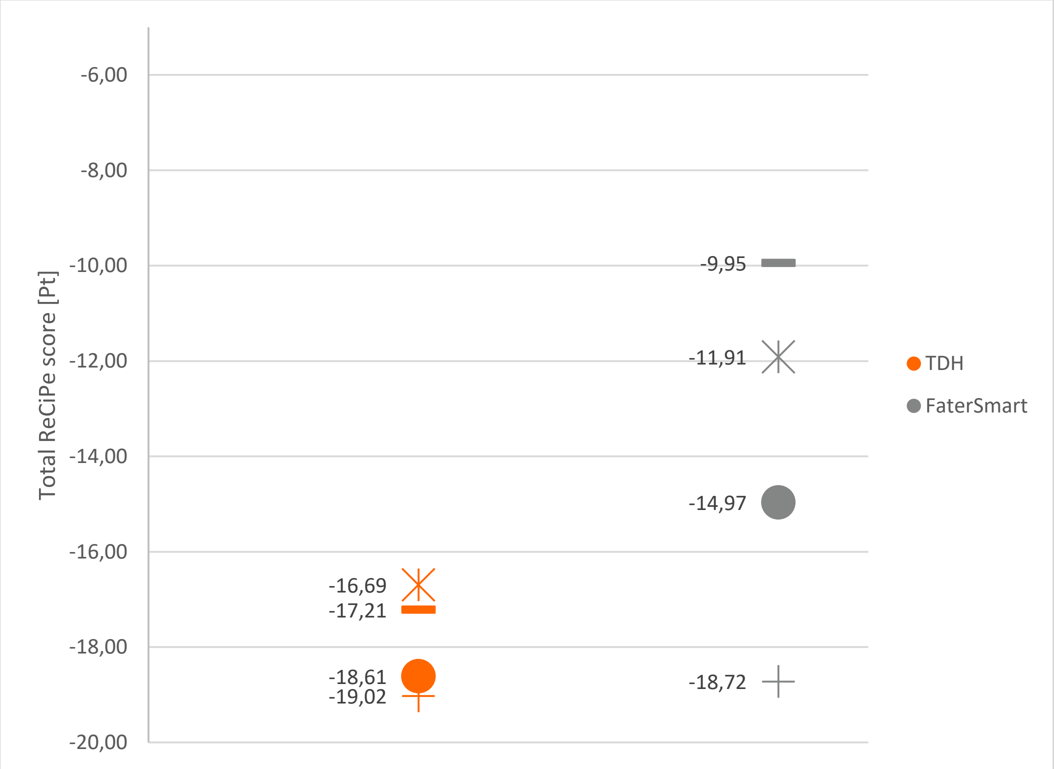

Figure 15 Range of results. Main results (circle), steam allocation (minus), electricity allocation (plus), recycling alternative (cross) results are given for both recycling options

5. CONCLUSION

The main results of this study show that both technologies are clearly a better alternative than the point of reference, incineration of AHP. Looking at the main results, Elsinga’s treatment process has an advantage over Fater’s treatment process. Elsinga’s better score can be attributed to a lower energy requirement overall. Besides comparison of the main results, an analysis was made of alternative calculation choices in the sensitivity analysis. By making different allocation choices, the difference in results of both treatment options either shrink or increase. When analyzing the treatment options beyond their mLCA results, both processes show their advantages and disadvantages, which have been analyzed in the contribution analysis.

Of the recovered materials, plastics have the biggest benefit. Both the FaterSMART and TDH process manage the retrieve most of the plastic. In addition, the FaterSMART technology retrieves SAPs and cellulose, both of which can be retrieved in subsequent lifecycles, through a generic application and recycling process. This translates in a decent additional benefit. The extra benefits however come with a larger electrical energy requirement of Fater’s treatment process. Elsinga’s thermal pressure hydrolysis on the other hand does not retrieve SAPs and cellulose as a material; these are instead mainly converted to biogas, and thereafter energy. But in addition, nutrients for the agricultural sector are retrieved from excreta, eventually leading to total benefits comparable to Fater’s result. In short, these two completely different treatment processes lead to different materials and energy being recovered, but the benefits of both processes are comparable. In the end the energy consumption, and its environmental impact, is the deciding factor.

Energy consumption allocation choices have been analyzed in the sensitivity analysis. We believe the baseline choices are the best representation of environmental impact, however these choices are the product of (planned) location. Additional plants might not have the luxury of having a waste incineration plant or another residual heat source next door. By changing allocation choices of energy consumption, we have shown that, depending on the choice, the results of both treatment options become near identical, or instead larger in terms of overall environmental impact, with the latter option being in the TDH process’ favor.

The results are a product of the assumptions made in this study and ultimately should be interpreted as a range, but the end results, whether a range or not, clearly show that either method of recycling of AHP lead to overall reduced environmental impact and is therefore a significantly better alternative than incineration.

6. REFERENCES

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[3] Bijlage F.9 LAP3: Uitvoeren van LCA's i.r.t. het LAP, July 2019 (https://lap3.nl/publish/pages/121785/lap3_f9_lca_19_07_2019.pdf).
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[5] Written communication based on the annual review of the R1 status for 2016 [RWS-WVL 2018]
[6] Herziening levenscyclusanalyse voor GFT-afval – Herberekening LCA bij het MER-LAP, Grontmij Nederland en IVAM UVA – 10 november 2004

APPENDIX A RECIPE MIDPOINT RESULTS

TPH: Main results

Calculation:	Analyse											
Results:	Effectbeoordeling											
Product:	1 ton _Volledig Elsinga proces - HERZIEN (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)											
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H											
Indicator:	Karakterisatie											
Skip categories:	Met resultaat = 0											
Sluit infrastructuurprocessen uit:	Nee											
Sluit lange termijnemissies uit:	Ja											
Sorted on item:	Effectcategorie											
Sort order:	Oplopend											
Effectcategorie	**Eenheid**	**Totaal**	**Inzameling luiers en incontinentie materiaal**	**TDH - Recycling Luiers**	**Vergister en WKK**	**Ontwatering + Waterzuivering**	**GMB**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 1**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 2**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 2**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 3**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 3**
Global warming	kg CO2 eq	-6,57E+02	1,32E+01	5,93E+01	6,60E+00	4,84E+00	1,61E+01	-4,63E+02	3,46E+01	-1,86E+02	3,29E+01	-1,76E+02
Stratospheric ozone depletion	kg CFC11 eq	-8,17E-04	9,68E-06	2,70E-05	5,00E-05	3,07E-06	3,90E-05	-9,68E-04	1,20E-05	-4,44E-07	1,14E-05	-4,22E-07
Ionizing radiation	kBq Co-60 eq	-3,43E-01	1,05E-01	8,61E-02	1,10E-02	3,48E-02	9,45E-02	-9,50E-01	1,44E-01	-2,91E-03	1,37E-01	-2,77E-03
Ozone formation, Human health	kg NOx eq	-1,15E+00	4,20E-02	2,71E-02	3,12E-02	6,56E-03	3,63E-02	-7,53E-01	7,26E-02	-3,51E-01	6,89E-02	-3,33E-01
Fine particulate matter formation	kg PM2.5 eq	-5,06E-01	1,47E-02	9,08E-03	2,02E-02	3,27E-03	3,39E-02	-3,65E-01	3,01E-02	-1,44E-01	2,86E-02	-1,37E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-1,26E+00	4,32E-02	2,73E-02	3,18E-02	6,65E-03	3,72E-02	-7,99E-01	7,51E-02	-3,88E-01	7,13E-02	-3,68E-01
Terrestrial acidification	kg SO2 eq	-1,48E+00	3,32E-02	3,22E-02	6,63E-02	1,18E-02	1,88E-01	-1,07E+00	6,49E-02	-4,45E-01	6,17E-02	-4,23E-01
Freshwater eutrophication	kg P eq	-2,69E-02	1,97E-04	8,89E-04	2,40E-04	6,63E-04	2,91E-04	-2,48E-02	9,99E-04	-3,27E-03	9,49E-04	-3,10E-03
Marine eutrophication	kg N eq	-2,71E-04	2,52E-05	1,36E-04	5,45E-06	1,93E-03	1,71E-04	-1,57E-03	2,18E-04	-7,15E-04	2,07E-04	-6,79E-04
Terrestrial ecotoxicity	kg 1,4-DCB	2,76E+02	1,74E+02	3,69E+01	9,79E+00	5,24E+00	1,18E+02	-4,65E+02	2,05E+02	-1,43E+00	1,95E+02	-1,36E+00
Freshwater ecotoxicity	kg 1,4-DCB	-5,34E-02	3,00E-02	7,12E-03	6,88E-03	3,98E-03	2,16E-02	-1,70E-01	3,98E-02	-1,58E-02	3,79E-02	-1,50E-02
Marine ecotoxicity	kg 1,4-DCB	-1,64E-01	1,23E-01	4,10E-02	1,43E-02	1,05E-02	8,64E-02	-7,00E-01	1,57E-01	-2,33E-02	1,49E-01	-2,21E-02
Human carcinogenic toxicity	kg 1,4-DCB	-1,37E+00	6,14E-02	2,39E-01	4,88E-02	4,91E-02	1,19E-01	-1,63E+00	6,59E-01	-7,87E-01	6,26E-01	-7,48E-01
Human non-carcinogenic toxicity	kg 1,4-DCB	-6,03E+00	2,41E+00	6,07E-01	4,85E-01	9,31E-01	1,80E+00	-1,82E+01	3,29E+00	-2,38E-01	3,12E+00	-2,26E-01
Land use	m2a crop eq	-2,97E+00	5,50E-01	3,25E-01	9,33E-02	1,34E-01	7,16E-01	-7,19E+00	1,25E+00	-1,42E-02	1,18E+00	-1,35E-02
Mineral resource scarcity	kg Cu eq	-7,74E-01	2,54E-02	1,50E-02	4,17E-02	7,57E-03	2,89E-02	-1,20E+00	1,79E-01	-2,02E-02	1,70E-01	-1,91E-02
Fossil resource scarcity	kg oil eq	-4,55E+02	4,63E+00	3,37E+00	3,71E-01	1,29E+00	3,93E+00	-2,17E+02	7,39E+00	-1,36E+02	7,02E+00	-1,30E+02
Water consumption	m3	-6,37E+00	3,68E-02	1,96E-01	1,10E-02	-5,78E-01	2,58E-02	-3,77E+00	1,72E-01	-1,35E+00	1,63E-01	-1,28E+00

TPH: Sensitivity analysis – steam/heat allocation

Calculation:	Analyse											
Results:	Effectbeoordeling											
Product:	1 ton _Volledig Elsinga proces - Gevoeligheid stoom - Herzien (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)											
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H											
Indicator:	Karakterisatie											
Skip categories:	Met resultaat = 0											
Sluit infrastructuurprocessen uit:	Nee											
Sluit lange termijnemissies uit:	Ja											
Sorted on item:	Effectcategorie											
Sort order:	Oplopend											
Effectcategorie	**Eenheid**	**Totaal**	**Inzameling luiers en incontinentie materiaal**	**TDH - Recycling Luiers - gevoeligheid stoom**	**Vergister en WKK**	**Ontwatering + Waterzuivering**	**GMB**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 1**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 2**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 2**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 3**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 3**
Global warming	kg CO2 eq	-588,41	1,32E+01	1,28E+02	6,60E+00	4,84E+00	1,61E+01	-4,63E+02	3,46E+01	-1,86E+02	3,29E+01	-1,76E+02
Stratospheric ozone depletion	kg CFC11 eq	-8,02E-04	9,68E-06	4,19E-05	5,00E-05	3,07E-06	3,90E-05	-9,68E-04	1,20E-05	-4,44E-07	1,14E-05	-4,22E-07
Ionizing radiation	kBq Co-60 eq	-2,77E-01	1,05E-01	1,52E-01	1,10E-02	3,48E-02	9,45E-02	-9,50E-01	1,44E-01	-2,91E-03	1,37E-01	-2,77E-03
Ozone formation, Human health	kg NOx eq	-1,11E+00	4,20E-02	7,01E-02	3,12E-02	6,56E-03	3,63E-02	-7,53E-01	7,26E-02	-3,51E-01	6,89E-02	-3,33E-01
Fine particulate matter formation	kg PM2.5 eq	-4,94E-01	1,47E-02	2,13E-02	2,02E-02	3,27E-03	3,39E-02	-3,65E-01	3,01E-02	-1,44E-01	2,86E-02	-1,37E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-1,22E+00	4,32E-02	7,21E-02	3,18E-02	6,65E-03	3,72E-02	-7,99E-01	7,51E-02	-3,88E-01	7,13E-02	-3,68E-01
Terrestrial acidification	kg SO2 eq	-1,44E+00	3,32E-02	6,83E-02	6,63E-02	1,18E-02	1,88E-01	-1,07E+00	6,49E-02	-4,45E-01	6,17E-02	-4,23E-01
Freshwater eutrophication	kg P eq	-2,68E-02	1,97E-04	1,03E-03	2,40E-04	6,63E-04	2,91E-04	-2,48E-02	9,99E-04	-3,27E-03	9,49E-04	-3,10E-03
Marine eutrophication	kg N eq	-2,63E-04	2,52E-05	1,44E-04	5,45E-06	1,93E-03	1,71E-04	-1,57E-03	2,18E-04	-7,15E-04	2,07E-04	-6,79E-04
Terrestrial ecotoxicity	kg 1,4-DCB	2,80E+02	1,74E+02	4,06E+01	9,79E+00	5,24E+00	1,18E+02	-4,65E+02	2,05E+02	-1,43E+00	1,95E+02	-1,36E+00
Freshwater ecotoxicity	kg 1,4-DCB	-5,14E-02	3,00E-02	9,12E-03	6,88E-03	3,98E-03	2,16E-02	-1,70E-01	3,98E-02	-1,58E-02	3,79E-02	-1,50E-02
Marine ecotoxicity	kg 1,4-DCB	-3,61E-02	1,23E-01	1,69E-01	1,43E-02	1,05E-02	8,64E-02	-7,00E-01	1,57E-01	-2,33E-02	1,49E-01	-2,21E-02
Human carcinogenic toxicity	kg 1,4-DCB	-1,31E+00	6,14E-02	2,97E-01	4,88E-02	4,91E-02	1,19E-01	-1,63E+00	6,59E-01	-7,87E-01	6,26E-01	-7,48E-01
Human non-carcinogenic toxicity	kg 1,4-DCB	-5,76E+00	2,41E+00	8,76E-01	4,85E-01	9,31E-01	1,80E+00	-1,82E+01	3,29E+00	-2,38E-01	3,12E+00	-2,26E-01
Land use	m2a crop eq	-2,93E+00	5,50E-01	3,66E-01	9,33E-02	1,34E-01	7,16E-01	-7,19E+00	1,25E+00	-1,42E-02	1,18E+00	-1,35E-02
Mineral resource scarcity	kg Cu eq	-7,56E-01	2,54E-02	3,26E-02	4,17E-02	7,57E-03	2,89E-02	-1,20E+00	1,79E-01	-2,02E-02	1,70E-01	-1,91E-02
Fossil resource scarcity	kg oil eq	-4,28E+02	4,63E+00	3,02E+01	3,71E-01	1,29E+00	3,93E+00	-2,17E+02	7,39E+00	-1,36E+02	7,02E+00	-1,30E+02
Water consumption	m3	-6,35E+00	3,68E-02	2,11E-01	1,10E-02	-5,78E-01	2,58E-02	-3,77E+00	1,72E-01	-1,35E+00	1,63E-01	-1,28E+00

TPH: Sensitivity analysis – electricity allocation

Calculation:	Analyse											
Results:	Effectbeoordeling											
Product:	1 ton _Volledig Elsinga proces - Gevoeligheid elektriciteit - Herzien (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)											
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H											
Indicator:	Karakterisatie											
Skip categories:	Met resultaat = 0											
Sluit infrastructuurprocessen uit:	Nee											
Sluit lange termijnemissies uit:	Ja											
Sorted on item:	Effectcategorie											
Sort order:	Oplopend											
Effectcategorie	**Eenheid**	**Totaal**	**Inzameling luiers en incontinentie materiaal**	**TDH - Recycling Luiers - gevoeligheid elektriciteit**	**Vergister en WKK**	**Ontwatering + Waterzuivering - gevoeligheid elektriciteit**	**GMB**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 1**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 2**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 2 - HERZIEN**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 3**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 3 - HERZIEN**
Global warming	kg CO2 eq	-673,81	1,32E+01	4,76E+01	6,60E+00	1,67E-01	1,61E+01	-4,63E+02	3,46E+01	-1,86E+02	3,29E+01	-1,76E+02
Stratospheric ozone depletion	kg CFC11 eq	-8,26E-04	9,68E-06	2,05E-05	5,00E-05	4,72E-07	3,90E-05	-9,68E-04	1,20E-05	-4,44E-07	1,14E-05	-4,22E-07
Ionizing radiation	kBq Co-60 eq	-4,60E-01	1,05E-01	3,06E-03	1,10E-02	1,54E-03	9,45E-02	-9,50E-01	1,44E-01	-2,91E-03	1,37E-01	-2,77E-03
Ozone formation, Human health	kg NOx eq	-1,17E+00	4,20E-02	1,22E-02	3,12E-02	6,05E-04	3,63E-02	-7,53E-01	7,26E-02	-3,51E-01	6,89E-02	-3,33E-01
Fine particulate matter formation	kg PM2.5 eq	-5,16E-01	1,47E-02	2,04E-03	2,02E-02	4,51E-04	3,39E-02	-3,65E-01	3,01E-02	-1,44E-01	2,86E-02	-1,37E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-1,28E+00	4,32E-02	1,22E-02	3,18E-02	6,17E-04	3,72E-02	-7,99E-01	7,51E-02	-3,88E-01	7,13E-02	-3,68E-01
Terrestrial acidification	kg SO2 eq	-1,52E+00	3,32E-02	5,92E-03	6,63E-02	1,28E-03	1,88E-01	-1,07E+00	6,49E-02	-4,45E-01	6,17E-02	-4,23E-01
Freshwater eutrophication	kg P eq	-2,81E-02	1,97E-04	1,90E-05	2,40E-04	3,15E-04	2,91E-04	-2,48E-02	9,99E-04	-3,27E-03	9,49E-04	-3,10E-03
Marine eutrophication	kg N eq	-3,11E-04	2,52E-05	1,07E-04	5,45E-06	1,92E-03	1,71E-04	-1,57E-03	2,18E-04	-7,15E-04	2,07E-04	-6,79E-04
Terrestrial ecotoxicity	kg 1,4-DCB	2,60E+02	1,74E+02	2,55E+01	9,79E+00	6,72E-01	1,18E+02	-4,65E+02	2,05E+02	-1,43E+00	1,95E+02	-1,36E+00
Freshwater ecotoxicity	kg 1,4-DCB	-5,56E-02	3,00E-02	5,48E-03	6,88E-03	3,33E-03	2,16E-02	-1,70E-01	3,98E-02	-1,58E-02	3,79E-02	-1,50E-02
Marine ecotoxicity	kg 1,4-DCB	-1,84E-01	1,23E-01	2,69E-02	1,43E-02	4,89E-03	8,64E-02	-7,00E-01	1,57E-01	-2,33E-02	1,49E-01	-2,21E-02
Human carcinogenic toxicity	kg 1,4-DCB	-1,46E+00	6,14E-02	1,70E-01	4,88E-02	2,13E-02	1,19E-01	-1,63E+00	6,59E-01	-7,87E-01	6,26E-01	-7,48E-01
Human non-carcinogenic toxicity	kg 1,4-DCB	-6,52E+00	2,41E+00	2,60E-01	4,85E-01	7,92E-01	1,80E+00	-1,82E+01	3,29E+00	-2,38E-01	3,12E+00	-2,26E-01
Land use	m2a crop eq	-3,41E+00	5,50E-01	1,23E-02	9,33E-02	8,47E-03	7,16E-01	-7,19E+00	1,25E+00	-1,42E-02	1,18E+00	-1,35E-02
Mineral resource scarcity	kg Cu eq	-7,89E-01	2,54E-02	4,25E-03	4,17E-02	3,28E-03	2,89E-02	-1,20E+00	1,79E-01	-2,02E-02	1,70E-01	-1,91E-02
Fossil resource scarcity	kg oil eq	-4,59E+02	4,63E+00	2,39E-01	3,71E-01	3,49E-02	3,93E+00	-2,17E+02	7,39E+00	-1,36E+02	7,02E+00	-1,30E+02
Water consumption	m3	-6,55E+00	3,68E-02	6,88E-02	1,10E-02	-6,29E-01	2,58E-02	-3,77E+00	1,72E-01	-1,35E+00	1,63E-01	-1,28E+00

TPH: Sensitivity analysis – incineration bio-granulate

Calculation:	Analyse										
Results:	Effectbeoordeling										
Product:	1 ton _Volledig Elsinga proces - Gevoeligheid verbranden bio-granulaat - Herzien (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)										
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H										
Indicator:	Karakterisatie										
Skip categories:	Met resultaat = 0										
Sluit infrastructuurprocessen uit:	Nee										
Sluit lange termijnemissies uit:	Ja										
Sorted on item:	Effectcategorie										
Sort order:	Oplopend										
Effectcategorie	**Eenheid**	**Totaal**	**Inzameling luiers en incontinentie materiaal**	**TDH - Recycling Luiers**	**Vergister en WKK**	**Ontwatering + Waterzuivering**	**GMB (+AVI) - gevoeligheid verbranden bio-granulaat**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 1 - gevoeligheid verbranden bio-granulaat**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 2**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 2 - HERZIEN**	**HERZIEN - Inzameling & verwerking plastics - Elsinga - ronde 3**	**Elsinga - Vermeden primaire grondstoffen en energie - recyclingstap 3 - HERZIEN**
Global warming	kg CO2 eq	-6,13E+02	1,32E+01	5,93E+01	6,60E+00	4,84E+00	1,28E+01	-4,16E+02	3,46E+01	-1,86E+02	3,29E+01	-1,76E+02
Stratospheric ozone depletion	kg CFC11 eq	1,15E-04	9,68E-06	2,70E-05	5,00E-05	3,07E-06	8,46E-05	-8,14E-05	1,20E-05	-4,44E-07	1,14E-05	-4,22E-07
Ionizing radiation	kBq Co-60 eq	-2,13E-01	1,05E-01	8,61E-02	1,10E-02	3,48E-02	5,46E-02	-7,79E-01	1,44E-01	-2,91E-03	1,37E-01	-2,77E-03
Ozone formation, Human health	kg NOx eq	-1,05E+00	4,20E-02	2,71E-02	3,12E-02	6,56E-03	3,74E-02	-6,54E-01	7,26E-02	-3,51E-01	6,89E-02	-3,33E-01
Fine particulate matter formation	kg PM2.5 eq	-4,13E-01	1,47E-02	9,08E-03	2,02E-02	3,27E-03	3,15E-02	-2,70E-01	3,01E-02	-1,44E-01	2,86E-02	-1,37E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-1,16E+00	4,32E-02	2,73E-02	3,18E-02	6,65E-03	3,79E-02	-6,98E-01	7,51E-02	-3,88E-01	7,13E-02	-3,68E-01
Terrestrial acidification	kg SO2 eq	-1,22E+00	3,32E-02	3,22E-02	6,63E-02	1,18E-02	1,84E-01	-8,06E-01	6,49E-02	-4,45E-01	6,17E-02	-4,23E-01
Freshwater eutrophication	kg P eq	-1,50E-02	1,97E-04	8,89E-04	2,40E-04	6,63E-04	2,96E-04	-1,28E-02	9,99E-04	-3,27E-03	9,49E-04	-3,10E-03
Marine eutrophication	kg N eq	4,36E-04	2,52E-05	1,36E-04	5,45E-06	1,93E-03	4,25E-04	-1,12E-03	2,18E-04	-7,15E-04	2,07E-04	-6,79E-04
Terrestrial ecotoxicity	kg 1,4-DCB	4,44E+02	1,74E+02	3,69E+01	9,79E+00	5,24E+00	4,22E+01	-2,21E+02	2,05E+02	-1,43E+00	1,95E+02	-1,36E+00
Freshwater ecotoxicity	kg 1,4-DCB	6,15E-02	3,00E-02	7,12E-03	6,88E-03	3,98E-03	1,01E-02	-4,34E-02	3,98E-02	-1,58E-02	3,79E-02	-1,50E-02
Marine ecotoxicity	kg 1,4-DCB	9,13E-02	1,23E-01	4,10E-02	1,43E-02	1,05E-02	3,60E-02	-3,94E-01	1,57E-01	-2,33E-02	1,49E-01	-2,21E-02
Human carcinogenic toxicity	kg 1,4-DCB	-9,58E-01	6,14E-02	2,39E-01	4,88E-02	4,91E-02	2,03E-01	-1,31E+00	6,59E-01	-7,87E-01	6,26E-01	-7,48E-01
Human non-carcinogenic toxicity	kg 1,4-DCB	3,90E+00	2,41E+00	6,07E-01	4,85E-01	9,31E-01	8,09E-01	-7,29E+00	3,29E+00	-2,38E-01	3,12E+00	-2,26E-01
Land use	m2a crop eq	-1,72E+00	5,50E-01	3,25E-01	9,33E-02	1,34E-01	5,15E-01	-5,74E+00	1,25E+00	-1,42E-02	1,18E+00	-1,35E-02
Mineral resource scarcity	kg Cu eq	1,24E-01	2,54E-02	1,50E-02	4,17E-02	7,57E-03	2,93E-02	-3,05E-01	1,79E-01	-2,02E-02	1,70E-01	-1,91E-02
Fossil resource scarcity	kg oil eq	-4,51E+02	4,63E+00	3,37E+00	3,71E-01	1,29E+00	2,17E+00	-2,12E+02	7,39E+00	-1,36E+02	7,02E+00	-1,30E+02
Water consumption	m3	-5,59E+00	3,68E-02	1,96E-01	1,10E-02	-5,78E-01	7,83E-02	-3,04E+00	1,72E-01	-1,35E+00	1,63E-01	-1,28E+00

FaterSmart Technology: Main results

Calculation:	Analyse
Results:	Effectbeoordeling
Product:	1 ton _Volledig Fater proces - Herzien (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H
Indicator:	Karakterisatie
Skip categories:	Met resultaat = 0
Sluit infrastructuurprocessen uit:	Nee
Sluit lange termijnemissies uit:	Ja
Sorted on item:	Effectcategorie
Sort order:	Oplopend

Effectcategorie	**Eenheid**	**Totaal**	**AHP Collection**	**Fater treatment process**	**Avoided material - Cycle 1**	**General collection & treatment - Cycle 2**	**Avoided material - Cycle 2**	**General collection & treatment - Cycle 3**	**Avoided material - Cycle 3**
Global warming	kg CO2 eq	-4,52E+02	1,32E+01	1,78E+02	-3,01E+02	1,01E+02	-2,77E+02	9,23E+01	-2,57E+02
Stratospheric ozone depletion	kg CFC11 eq	3,56E-05	9,68E-06	9,86E-05	-5,33E-05	3,49E-05	-4,60E-05	3,20E-05	-4,03E-05
Ionizing radiation	kBq Co-60 eq	-6,16E-01	1,05E-01	1,28E+00	-1,07E+00	4,18E-01	-9,24E-01	3,84E-01	-8,10E-01
Ozone formation, Human health	kg NOx eq	-9,14E-01	4,20E-02	2,66E-01	-6,07E-01	2,11E-01	-5,36E-01	1,93E-01	-4,83E-01
Fine particulate matter formation	kg PM2.5 eq	-4,19E-01	1,47E-02	1,63E-01	-2,85E-01	8,75E-02	-2,52E-01	8,03E-02	-2,27E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-1,03E+00	4,32E-02	2,71E-01	-6,54E-01	2,18E-01	-5,80E-01	2,00E-01	-5,24E-01
Terrestrial acidification	kg SO2 eq	-1,28E+00	3,32E-02	5,05E-01	-8,00E-01	1,89E-01	-7,23E-01	1,73E-01	-6,61E-01
Freshwater eutrophication	kg P eq	-7,56E-03	1,97E-04	1,43E-02	-1,03E-02	2,90E-03	-9,13E-03	2,66E-03	-8,19E-03
Marine eutrophication	kg N eq	-1,00E-03	2,52E-05	2,39E-03	-1,72E-03	6,34E-04	-1,53E-03	5,82E-04	-1,38E-03
Terrestrial ecotoxicity	kg 1,4-DCB	1,04E+03	1,74E+02	2,81E+02	-2,23E+02	5,96E+02	-1,84E+02	5,47E+02	-1,55E+02
Freshwater ecotoxicity	kg 1,4-DCB	1,76E-01	3,00E-02	5,32E-02	-4,97E-02	1,16E-01	-4,24E-02	1,06E-01	-3,71E-02
Marine ecotoxicity	kg 1,4-DCB	8,24E-01	1,23E-01	3,03E-01	-1,86E-01	4,54E-01	-1,55E-01	4,17E-01	-1,33E-01
Human carcinogenic toxicity	kg 1,4-DCB	9,78E-01	6,14E-02	1,27E+00	-1,48E+00	1,91E+00	-1,33E+00	1,75E+00	-1,21E+00
Human non-carcinogenic toxicity	kg 1,4-DCB	1,17E+01	2,41E+00	9,99E+00	-7,87E+00	9,54E+00	-6,14E+00	8,75E+00	-4,97E+00
Land use	m2a crop eq	-1,91E+02	5,50E-01	4,57E+00	-1,03E+02	3,62E+00	-6,22E+01	3,32E+00	-3,77E+01
Mineral resource scarcity	kg Cu eq	6,27E-01	2,54E-02	2,73E-01	-2,56E-01	5,20E-01	-2,21E-01	4,78E-01	-1,93E-01
Fossil resource scarcity	kg oil eq	-4,33E+02	4,63E+00	5,10E+01	-1,88E+02	2,15E+01	-1,76E+02	1,97E+01	-1,65E+02
Water consumption	m3	-7,68E+00	3,68E-02	2,00E+00	-4,26E+00	4,99E-01	-3,48E+00	4,58E-01	-2,94E+00

FaterSmart Technology: Sensitivity analysis – steam/heat allocation

Calculation:	Analyse								
Results:	Effectbeoordeling								
Product:	1 ton _Volledig Fater proces - gevoeligheid stoom/warmte (worse-case) - Herzien (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)								
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H								
Indicator:	Karakterisatie								
Skip categories:	Met resultaat = 0								
Sluit infrastructuurprocessen uit:	Nee								
Sluit lange termijnemissies uit:	Ja								
Sorted on item:	Effectcategorie								
Sort order:	Oplopend								
Effectcategorie	**Eenheid**	**Totaal**	**AHP Collection**	**Fater treatment process**	**Avoided material - Cycle 1**	**General collection & treatment - Cycle 2**	**Avoided material - Cycle 2**	**General collection & treatment - Cycle 3**	**Avoided material - Cycle 3**
Global warming	kg CO2 eq	-203,57	1,32E+01	4,26E+02	-3,01E+02	1,01E+02	-2,77E+02	9,23E+01	-2,57E+02
Stratospheric ozone depletion	kg CFC11 eq	8,92E-05	9,68E-06	1,52E-04	-5,33E-05	3,49E-05	-4,60E-05	3,20E-05	-4,03E-05
Ionizing radiation	kBq Co-60 eq	-3,80E-01	1,05E-01	1,51E+00	-1,07E+00	4,18E-01	-9,24E-01	3,84E-01	-8,10E-01
Ozone formation, Human health	kg NOx eq	-7,59E-01	4,20E-02	4,20E-01	-6,07E-01	2,11E-01	-5,36E-01	1,93E-01	-4,83E-01
Fine particulate matter formation	kg PM2.5 eq	-3,76E-01	1,47E-02	2,06E-01	-2,85E-01	8,75E-02	-2,52E-01	8,03E-02	-2,27E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-8,65E-01	4,32E-02	4,32E-01	-6,54E-01	2,18E-01	-5,80E-01	2,00E-01	-5,24E-01
Terrestrial acidification	kg SO2 eq	-1,15E+00	3,32E-02	6,35E-01	-8,00E-01	1,89E-01	-7,23E-01	1,73E-01	-6,61E-01
Freshwater eutrophication	kg P eq	-7,06E-03	1,97E-04	1,48E-02	-1,03E-02	2,90E-03	-9,13E-03	2,66E-03	-8,19E-03
Marine eutrophication	kg N eq	-9,72E-04	2,52E-05	2,42E-03	-1,72E-03	6,34E-04	-1,53E-03	5,82E-04	-1,38E-03
Terrestrial ecotoxicity	kg 1,4-DCB	1,05E+03	1,74E+02	2,94E+02	-2,23E+02	5,96E+02	-1,84E+02	5,47E+02	-1,55E+02
Freshwater ecotoxicity	kg 1,4-DCB	1,83E-01	3,00E-02	6,04E-02	-4,97E-02	1,16E-01	-4,24E-02	1,06E-01	-3,71E-02
Marine ecotoxicity	kg 1,4-DCB	1,29E+00	1,23E-01	7,64E-01	-1,86E-01	4,54E-01	-1,55E-01	4,17E-01	-1,33E-01
Human carcinogenic toxicity	kg 1,4-DCB	1,19E+00	6,14E-02	1,48E+00	-1,48E+00	1,91E+00	-1,33E+00	1,75E+00	-1,21E+00
Human non-carcinogenic toxicity	kg 1,4-DCB	1,27E+01	2,41E+00	1,10E+01	-7,87E+00	9,54E+00	-6,14E+00	8,75E+00	-4,97E+00
Land use	m2a crop eq	-1,91E+02	5,50E-01	4,71E+00	-1,03E+02	3,62E+00	-6,22E+01	3,32E+00	-3,77E+01
Mineral resource scarcity	kg Cu eq	6,90E-01	2,54E-02	3,37E-01	-2,56E-01	5,20E-01	-2,21E-01	4,78E-01	-1,93E-01
Fossil resource scarcity	kg oil eq	-3,36E+02	4,63E+00	1,47E+02	-1,88E+02	2,15E+01	-1,76E+02	1,97E+01	-1,65E+02
Water consumption	m3	-7,63E+00	3,68E-02	2,06E+00	-4,26E+00	4,99E-01	-3,48E+00	4,58E-01	-2,94E+00

FaterSmart Technology: Sensitivity analysis – electricity allocation

Calculation:	Analyse								
Results:	Effectbeoordeling								
Product:	1 ton _Volledig Fater proces - Gevoeligheid elektriciteit (Best-case) - Herzien (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)								
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H								
Indicator:	Karakterisatie								
Skip categories:	Met resultaat = 0								
Sluit infrastructuurprocessen uit:	Nee								
Sluit lange termijnemissies uit:	Ja								
Sorted on item:	Effectcategorie								
Sort order:	Oplopend								
Effectcategorie	**Eenheid**	**Totaal**	**AHP Collection**	**Fater treatment process**	**Avoided material - Cycle 1**	**General collection & treatment - Cycle 2**	**Avoided material - Cycle 2**	**General collection & treatment - Cycle 3**	**Avoided material - Cycle 3**
Global warming	kg CO2 eq	-600,84	1,32E+01	2,86E+01	-3,01E+02	1,01E+02	-2,77E+02	9,23E+01	-2,57E+02
Stratospheric ozone depletion	kg CFC11 eq	-4,72E-05	9,68E-06	1,58E-05	-5,33E-05	3,49E-05	-4,60E-05	3,20E-05	-4,03E-05
Ionizing radiation	kBq Co-60 eq	-1,68E+00	1,05E-01	2,15E-01	-1,07E+00	4,18E-01	-9,24E-01	3,84E-01	-8,10E-01
Ozone formation, Human health	kg NOx eq	-1,10E+00	4,20E-02	7,55E-02	-6,07E-01	2,11E-01	-5,36E-01	1,93E-01	-4,83E-01
Fine particulate matter formation	kg PM2.5 eq	-5,09E-01	1,47E-02	7,25E-02	-2,85E-01	8,75E-02	-2,52E-01	8,03E-02	-2,27E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-1,22E+00	4,32E-02	7,81E-02	-6,54E-01	2,18E-01	-5,80E-01	2,00E-01	-5,24E-01
Terrestrial acidification	kg SO2 eq	-1,62E+00	3,32E-02	1,70E-01	-8,00E-01	1,89E-01	-7,23E-01	1,73E-01	-6,61E-01
Freshwater eutrophication	kg P eq	-1,87E-02	1,97E-04	3,19E-03	-1,03E-02	2,90E-03	-9,13E-03	2,66E-03	-8,19E-03
Marine eutrophication	kg N eq	-1,36E-03	2,52E-05	2,03E-03	-1,72E-03	6,34E-04	-1,53E-03	5,82E-04	-1,38E-03
Terrestrial ecotoxicity	kg 1,4-DCB	8,89E+02	1,74E+02	1,35E+02	-2,23E+02	5,96E+02	-1,84E+02	5,47E+02	-1,55E+02
Freshwater ecotoxicity	kg 1,4-DCB	1,55E-01	3,00E-02	3,22E-02	-4,97E-02	1,16E-01	-4,24E-02	1,06E-01	-3,71E-02
Marine ecotoxicity	kg 1,4-DCB	6,44E-01	1,23E-01	1,23E-01	-1,86E-01	4,54E-01	-1,55E-01	4,17E-01	-1,33E-01
Human carcinogenic toxicity	kg 1,4-DCB	8,97E-02	6,14E-02	3,78E-01	-1,48E+00	1,91E+00	-1,33E+00	1,75E+00	-1,21E+00
Human non-carcinogenic toxicity	kg 1,4-DCB	7,26E+00	2,41E+00	5,54E+00	-7,87E+00	9,54E+00	-6,14E+00	8,75E+00	-4,97E+00
Land use	m2a crop eq	-1,95E+02	5,50E-01	5,65E-01	-1,03E+02	3,62E+00	-6,22E+01	3,32E+00	-3,77E+01
Mineral resource scarcity	kg Cu eq	4,90E-01	2,54E-02	1,36E-01	-2,56E-01	5,20E-01	-2,21E-01	4,78E-01	-1,93E-01
Fossil resource scarcity	kg oil eq	-4,73E+02	4,63E+00	1,10E+01	-1,88E+02	2,15E+01	-1,76E+02	1,97E+01	-1,65E+02
Water consumption	m3	-9,30E+00	3,68E-02	3,81E-01	-4,26E+00	4,99E-01	-3,48E+00	4,58E-01	-2,94E+00

FaterSmart Technology: Sensitivity analysis – SAPs application

Calculation:	Analyse								
Results:	Effectbeoordeling								
Product:	1 ton _Volledig Fater proces - gevoeligheid SAPs recycling (worse-case) - Herzien (van project 26.19.00653 LCA Recycling van luiers RWS-WVL)								
Methode:	ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H								
Indicator:	Karakterisatie								
Skip categories:	Met resultaat = 0								
Sluit infrastructuurprocessen uit:	Nee								
Sluit lange termijnemissies uit:	Ja								
Sorted on item:	Effectcategorie								
Sort order:	Oplopend								
Effectcategorie	**Eenheid**	**Totaal**	**AHP Collection**	**Fater treatment process**	**Avoided material - Cycle 1**	**General collection & treatment - Cycle 2**	**Avoided material - Cycle 2**	**General collection & treatment - Cycle 3**	**Avoided material - Cycle 3**
Global warming	kg CO2 eq	-3,10E+02	1,32E+01	1,78E+02	-2,67E+02	7,76E+01	-1,98E+02	7,16E+01	-1,86E+02
Stratospheric ozone depletion	kg CFC11 eq	-5,18E-04	9,68E-06	9,86E-05	-6,71E-04	2,69E-05	-4,27E-06	2,48E-05	-2,72E-06
Ionizing radiation	kBq Co-60 eq	1,41E+00	1,05E-01	1,28E+00	-4,69E-01	3,23E-01	-7,36E-02	2,98E-01	-4,52E-02
Ozone formation, Human health	kg NOx eq	-7,94E-01	4,20E-02	2,66E-01	-6,16E-01	1,63E-01	-4,20E-01	1,50E-01	-3,78E-01
Fine particulate matter formation	kg PM2.5 eq	-3,25E-01	1,47E-02	1,63E-01	-3,05E-01	6,75E-02	-1,72E-01	6,23E-02	-1,55E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	-8,97E-01	4,32E-02	2,71E-01	-6,60E-01	1,68E-01	-4,59E-01	1,55E-01	-4,15E-01
Terrestrial acidification	kg SO2 eq	-1,14E+00	3,32E-02	5,05E-01	-9,99E-01	1,45E-01	-5,00E-01	1,34E-01	-4,60E-01
Freshwater eutrophication	kg P eq	-3,93E-03	1,97E-04	1,43E-02	-1,51E-02	2,24E-03	-4,01E-03	2,07E-03	-3,59E-03
Marine eutrophication	kg N eq	-2,11E-01	2,52E-05	2,39E-03	-2,13E-01	4,89E-04	-8,45E-04	4,51E-04	-7,65E-04
Terrestrial ecotoxicity	kg 1,4-DCB	1,04E+03	1,74E+02	2,81E+02	-2,44E+02	4,60E+02	-3,61E+01	4,24E+02	-2,22E+01
Freshwater ecotoxicity	kg 1,4-DCB	-5,51E-02	3,00E-02	5,32E-02	-2,68E-01	8,92E-02	-2,27E-02	8,23E-02	-1,93E-02
Marine ecotoxicity	kg 1,4-DCB	6,96E-01	1,23E-01	3,03E-01	-3,14E-01	3,50E-01	-5,13E-02	3,23E-01	-3,92E-02
Human carcinogenic toxicity	kg 1,4-DCB	1,01E+00	6,14E-02	1,27E+00	-1,42E+00	1,47E+00	-9,05E-01	1,36E+00	-8,27E-01
Human non-carcinogenic toxicity	kg 1,4-DCB	-4,64E+01	2,41E+00	9,99E+00	-6,94E+01	7,36E+00	-2,14E+00	6,79E+00	-1,37E+00
Land use	m2a crop eq	-2,94E+02	5,50E-01	4,57E+00	-2,07E+02	2,79E+00	-6,09E+01	2,57E+00	-3,65E+01
Mineral resource scarcity	kg Cu eq	6,72E-01	2,54E-02	2,73E-01	-3,25E-01	4,01E-01	-4,17E-02	3,71E-01	-3,23E-02
Fossil resource scarcity	kg oil eq	-3,51E+02	4,63E+00	5,10E+01	-1,62E+02	1,65E+01	-1,42E+02	1,53E+01	-1,34E+02
Water consumption	m3	-5,80E+00	3,68E-02	2,00E+00	-4,51E+00	3,85E-01	-2,24E+00	3,55E-01	-1,83E+00