Summary: LCA REnescience

Comparison of wet and dry post-consumer municipal waste separation

CE Delft

Committed to the Environment

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Table of contents

Glossary

2D fraction	Plastic films, output: DKR 310.
3D fraction	Hard plastics and metals, output: HDPE (DKR 329), PP (DKR 328-1), PET (DKR 324), Mixed plastics (DKR 352), ferrous metals, non-ferrous metals.
CHP	Combined Heat and Power.
DKR Standards	Specifications for sorted recyclable plastic materials from household waste.
Endpoint	LCA damage category, in which midpoints are translated to damage to Human Health, Ecosystems and Resources.
Fine fraction of (solid) household waste	The fine fraction of (solid) household waste includes bio-waste, paper & cardboard, plastic, metals, textiles, beverage cartons, small chemical waste as well as residual waste.
Household waste (solid)	All (solid) waste produced by households including construction and demolition debris, bulky household waste such as furniture and the fine fraction of household waste.
Inashco technology	Technology to separate both ferrous and non-ferrous metals from bottom ash after incineration.
LCA	Life Cycle Assessment: method to assess environmental impact of a product or service.
Midpoint	LCA environmental impact category, such as climate change or acidification.
Municipal solid waste (MSW)	All solid waste (excludes sewage) that is produced in a municipality excluding industrial waste. This includes waste from maintenance of parks and public spaces as well as household waste.
Omrin	A facility with dry post-consumer separation treatment, currently established in Friesland.
OWF	Organic wet fraction.
Pt	Unit for ReCiPe Single score (point).
RDF	Refuse-derived fuel.
ReCiPe	LCA impact assessment method.
ReCiPe single score	Weighted score of the results on the three endpoints.
REnescience	A wet post-consumer separation treatment for household waste.
Residual household waste	The fine fraction of solid household waste which is not consumer separated.
Brine	Solution of salt in water.
AD Plant	Anaerobic digestion plant.
REC	Reststoffen Energie Centrale – Residual waste Energy Facility.
RPG	REnescience Process Group.
DST	Dry separation treatment.
WST	Wet separation treatment (REnescience).
Urbanization class 2	Average of 1,500 to 2,500 addresses per square km.

1 Executive summary

In this Life Cycle Assessment (LCA) different post-consumer waste separation methods are compared. The goal is to assess how the REnescience technology compares to the dry post-consumer separation treatment and to incineration (with metal recovery). This LCA gives insight into the potential environmental impact and some options for improvement. The geographical scope is the waste management for the municipality of Eindhoven and 's-Hertogenbosch. The temporal scope is 2017/2018.

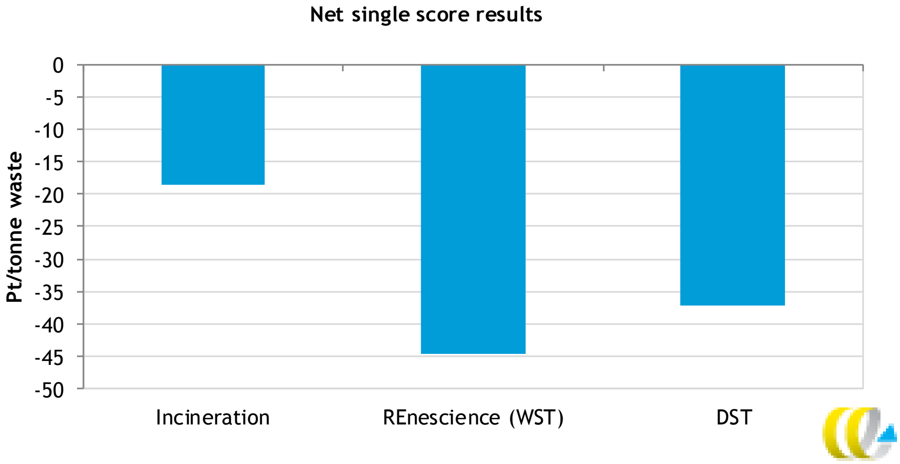
Box 1 Functional Unit

The treatment of 1 tonne of residual household waste (of given composition, see Annex A and the subsequent treatment of (valuable) recovered materials and final waste streams.

In this study we focus on three reference flows:
1. **Incineration**: incineration with energy recovery and metals recovery.
2. **Wet method/REnescience** (referred to as REnescience technology): treatment in the REnescience facility with enzymes.
3. **Dry method** (referred to as dry separation treatment/DST): treatment in a dry separation treatment installation, comparable with Omrin technology in 2017/2018.

In Figure 1 the single score (weighted score of 18 impact categories) is shown for the different treatment methods. All treatment options have a net environmental benefit, when expressed in single score. Compared to dry separation treatment, the REnescience technology has a higher plastics recovery, higher biogas production, as well as CO_2 capture. On the other hand, external electricity and heat requirements are higher, and an input of enzymes is necessary. Together, these aspects result in a net impact for the REnescience treatment in the Eindhoven/'s-Hertogenbosch region which is comparable to or better than dry separation treatment.

Figure 1 Net single score results (weighted score (Pt) per tonne waste)



This summary is based on an elaborate, confidential, LCA report (CE Delft, 2017).

2 Introduction

REnescience wants to enter the Dutch waste treatment market with a post-consumer waste separation method for household waste which has been proven on demonstration scale. The REnescience process is a wet, enzymatic post-separation technology developed by Dong Energy. The REnescience reactor converts food waste, paper and cardboard, the cellulosic part of diapers and the paper from beverage cartons into a 'bioliquid' from which biogas is produced. In addition, other fractions (plastics and metals) are separated out and washed.

Cure Afvalbeheer (waste management facilitator of the municipality of Eindhoven) and the municipality of 's-Hertogenbosch want to know if the REnescience technology is better than or equally environmentally friendly as source separation and other post-consumer waste separation methods (i.e. incineration and dry separation treatment).

The question of Eindhoven and 's-Hertogenbosch is two-fold and has therefore been divided into two parts; an assessment of post-consumer separation in comparison to source separation of household waste (CE Delft, 2016c) and a comparison of different post-consumer waste separation methods (this report).

Assessment of source separation vs. post-consumer separation

In a separate assessment, source separation and post-consumer separation were compared qualitatively. A summary of this assessment (CE Delft, 2016c) can be found in Chapter 3.

Assessment of post-consumer waste separation methods

This report focusses on answering the second part of the question of Eindhoven and 's-Hertogenbosch: *Is the REnescience technology better than or equally environmentally friendly as other post-consumer waste separation methods?*

LCA

To answer this question the life cycle assessment (LCA) methodology is used. LCA is a methodology that is used to determine the impact of a product or service on the environment throughout the entire life cycle. It can be used to compare the environmental impact of different products or services with each other that fulfil the same function.

A comparative LCA is carried out in four steps:
1. Goal and scope definition.
2. Life cycle inventory (LCI).
3. Life cycle impact assessment (LCIA).
4. Interpretation.

The goal and scope of the LCA can be found in Chapter 4, the LCI in Chapter 5 and the results (the LCIA) in Chapter 6.

Combined conclusion

The conclusion of the two parts is presented in Chapter 7.

3 Source separation vs. post-consumer separation

CE Delft was commissioned by the local authorities of Eindhoven and ‘s-Hertogenbosch to assess which combination of source separation and dry post-consumer waste separation is best from an environmental point of view. Wet post- consumer separation was not assessed in this study. This assessment (CE Delft, 2016c), is briefly summarized below.

Household waste treatment in the Netherlands

Almost everywhere in the Netherlands household waste is processed by a combination of source separation and post-consumer separation, with one or the other option dominating.

The technologies and processes involved in source separation and post-consumer separation are more similar than is often assumed. In all existing source separation and post-consumer separation options, multiple types of waste are collected together and then sorted as much as possible into mono-streams using optical recognition and blowing equipment. Whatever the route, there is always a certain degree of loss and contamination.

A combination of source separation and post-consumer separation

For the comparison between source separation and post-consumer separation, the following fractions of the waste are considered; food waste, plastics, paper, textile, glass and garden waste.

The main fraction in residual household waste is food waste. From an environmental impact perspective, this can be efficiently processed by post-consumer separation of the organic wet fraction and using it to produce biogas; the environmental footprint is similar to digestion via the food and garden waste route. A study for Stowa (CE Delft, 2015) indicates that, for food waste, post-consumer separation as performed by Omrin scores similarly, environmentally, in comparison to targeted source separation of food and garden waste.

The second fraction to be considered is plastic. Environmental studies and checks by the Netherlands Human Environment and Transport Inspectorate (ILT) show that post-consumer separation as performed by Omrin was already on a par with source separation in terms of quantity, quality and environmental impact in 2012. Since then Omrin has doubled separation efficiency. CE Delft and TNO have assessed that source separation will likely be twice as effective sometime between 2017 and 2020 compared with 2012, as more and more citizens start source separating (CE Delft, 2011a). Municipalities in ‘urbanization class 2’ like Eindhoven and ‘s-Hertogenbosch will probably lag somewhat behind with source separation. For these cities, post-separation using the Omrin technology is thus comparable with or slightly better than source separation.

For paper, glass and textiles there is no question that source separation is the best option. For garden waste, too, it is clear that source separation by households with a garden is the best option.

Conclusion: post-consumer separation is wise, but in what form?
The proposed choice of the Eindhoven and ‘s-Hertogenbosch regions to separate food waste, plastics, beverage cartons and metals via post-consumer separation, is sound environmentally if it is done with a process with an environmental impact similar to the dry post-consumer separation process (as currently done by Omrin). The earlier assessment (CE Delft, 2016c) has shown that dry separation treatment has a better or similar environmental score as source separation (for plastics, metals, food waste and beverage cartons). Therefore REnescience will be compared to dry separation treatment in this study.

4 Goal and scope

This report focusses on answering the question: *Is the REnescience technology better than or equally environmentally friendly as other post-consumer waste separation methods?* To answer this question the LCA methodology is used.

In this Life Cycle Assessment (LCA) different post-consumer waste treatment methods are compared. The LCA was done for DONG Energy, developer of the REnescience technology, Cure Afvalbeheer and the municipality of ‘s-Hertogenbosch. The goal is to assess the potential environmental benefit of the REnescience technology in the Eindhoven/’s-Hertogenbosch region, compared to incineration in this region and the benefits of a dry post-consumer separation treatment if located in this region.

4.1 Geographical scope

The geographical scope is (the residual household waste management for) the municipality of Eindhoven (5th largest city of the Netherlands with 225,000 inhabitants and a relatively high share of high-rise buildings) and ‘s-Hertogenbosch (152,000 inhabitants and also a substantial share of high-rise buildings). Residual household waste is generally not transported very far, and the geographical scope of the first step of the waste management is therefore the province of Noord-Brabant.

The incinerator as well as the REnescience plant and the dry separation plant are therefore assumed to be situated in the province of Noord-Brabant. Certain data are therefore adjusted to be regionally specific, such as the efficiency of incineration.

4.2 Temporal scope

The comparison between the REnescience treatment, dry separation treatment and the reference treatment (incineration) is based on a projection of the Omrin plant for 2017/2018 adjusted with regionally specific data, and a prediction for the REnescience installation for 2017/2018 (based on demonstration scale installation and full scale equipment supplier data).
In an optimisation analysis an assessment is made of potential future adjustments to the REnescience technology.

4.3 Function and Functional Unit

The following function is central to our assessment: the treatment of residual household waste.

Box 2 **Functional Unit**

The treatment of 1 tonne of residual household waste (of given composition, see Annex A), and the subsequent treatment of (valuable) recovered materials and final waste streams.

In this study we focus on three reference flows:

1. **Incineration**: 1 tonne of residual household waste (solid, fine fraction), at the incinerator gate, incinerated with energy recovery.
2. **Wet method/REnescience** (referred to as REnescience technology): 1 tonne of residual household waste (solid, fine fraction), at the REnescience gate, treated in the REnescience facility.
3. **Dry method** (referred to as dry separation treatment or DST): 1 tonne of residual household waste (solid, fine fraction), at the gate, treated in an installation with Omrin technology as projected for 2017/2018.

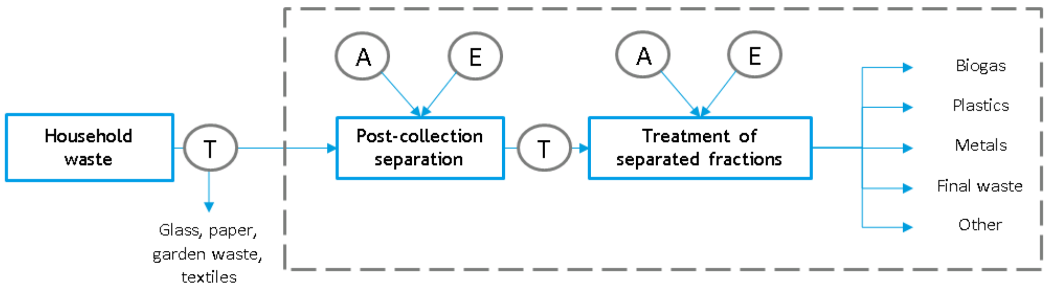
4.4 System boundaries

The LCA includes all inputs and outputs necessary to treat household waste from the facility gate to final treatment of the recovered fractions.

Rationale for system boundaries (Figure 2)
At gate: the fractions that are source separated are the same in all three treatment methods. It is assumed that transport of the residual household waste to the facilities considered in our assessment is similar because all treatment occurs within the province of Noord-Brabant, and that transport to the treatment facility will therefore not make a difference in the comparison.

Final treatment of recovered fractions: the assessment includes all steps necessary to completely treat all waste and recovered fractions. This includes further treatment of materials to a valuable material, e.g. plastics to a DKR-stream (specified as being able to replace virgin materials), and substitution of virgin materials.

Figure 2 **System boundaries: at gate to final treatment of recovered fractions**



T = Transport, A = Auxiliaries, E = Energy.

Composition of the fine fraction of solid household waste
It is common practice to source separate glass, paper, textile and garden waste in the Netherlands. As described in Chapter 3 this also makes sense environmentally. Therefore, for all three treatment routes we assume that some of the household waste has been source separated (data specific for the Eindhoven/'s-Hertogenbosch region).

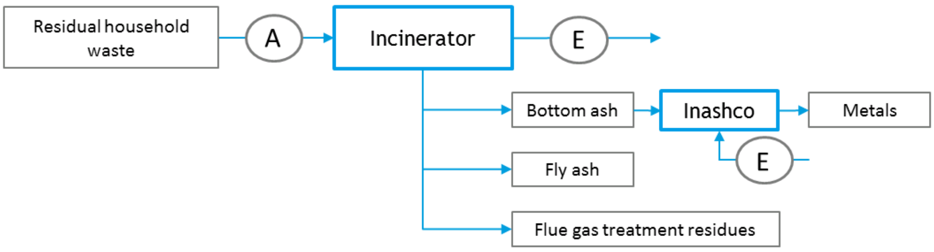
The composition of the residual household waste as used in this assessment is based on current compositions of the fine fraction of solid household waste in the municipalities of Eindhoven and ‘s-Hertogenbosch. The composition is specified in Annex A.

For all treatment options capital goods are excluded from the assessment.

Treatment Option 1: Incineration

Treatment of residual household waste by incineration is shown in a flow scheme in Figure 3. Residual household waste enters the incinerator. Auxiliaries such as charcoal and ammonia are included. The bottom ash is treated with the Inashco technology, to recover metals (this is becoming the standard in the Netherlands).

Figure 3 Flow scheme for treatment by incineration

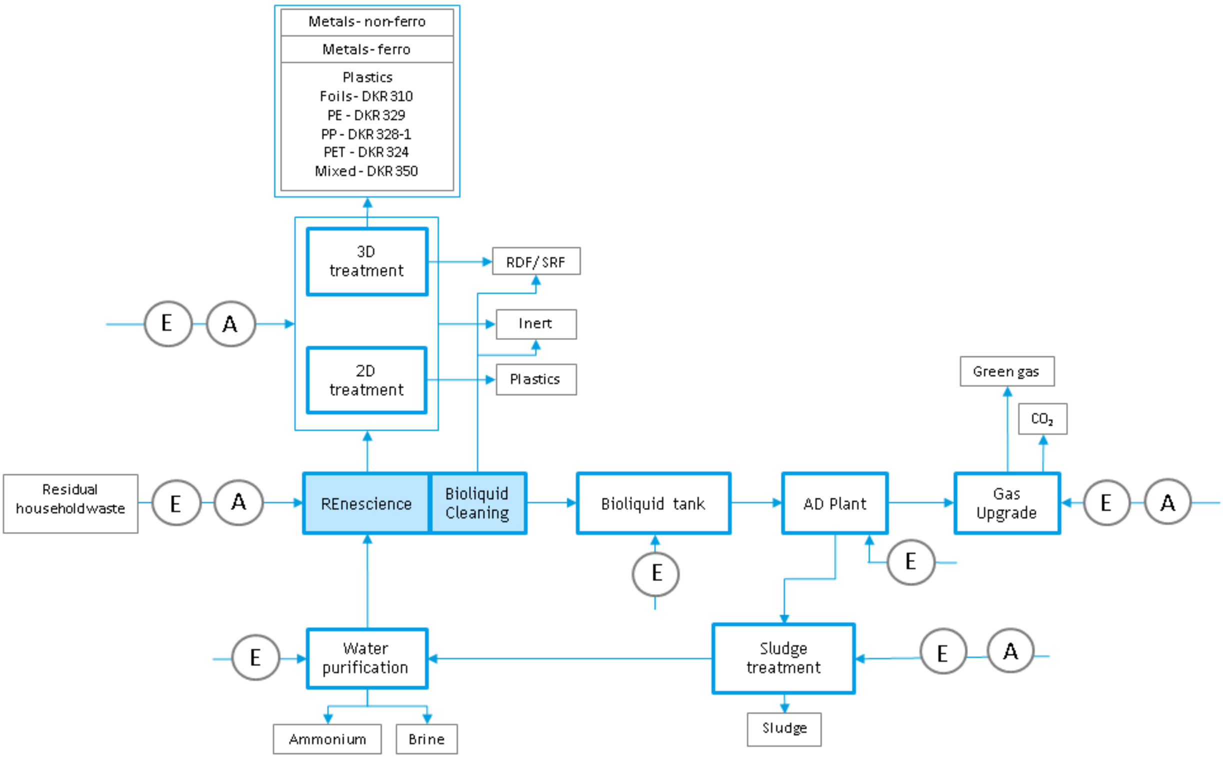


A = Auxiliaries, E = Energy.

Treatment Option 2: REnescience technology

The REnescience treatment is shown in a flow scheme in Figure 4. Household waste enters the REnescience reactor, together with water and enzymes. Final outputs are plastic fractions of different DKR values, metals, green gas, RDF and also an inert fraction, ammonium, brine and sludge.

Figure 4 Flow scheme for REnescience treatment



A = Auxiliaries, E = Energy, blue boxes are the REnescience Process Group (RPG).

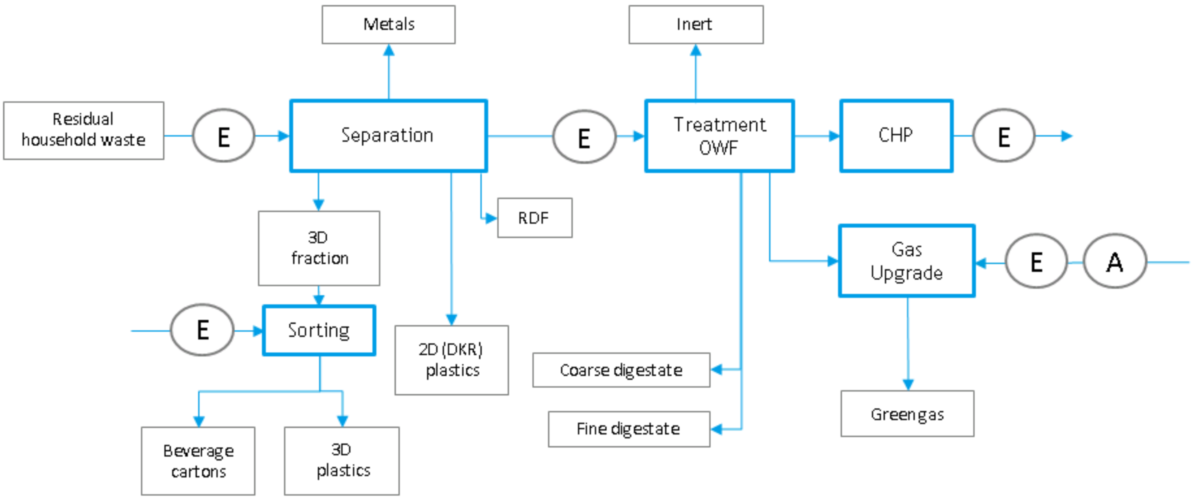
REnescience technology includes:

- Separation of metals, 3D plastics (sorted into monostreams) and 2D plastics for recycling.
- Separation of food and organic cellulosic matter, which is converted into bioliquid with the use of enzymes. Bioliquid consists of liquefied food waste, paper and cardboard, and the cellulose part of packages and sanitary paper. The digestion of bioliquid produces biogas.
- Two products from the biogas upgrading system: green gas and CO_2 for greenhouses.

Treatment Option 3: Dry separation treatment

The dry separation treatment is shown in Figure 5. Household waste is separated into different fractions, which are treated separately. Final outputs are metals, 2D plastics (foils DKR), 3D plastics, beverage cartons, green gas, digestate and RDF.

Figure 5 Flow scheme for dry separation treatment (DST) technology



A = Auxiliaries, E = Energy.

DST includes:
- separation of metals, beverage cartons, 3D plastics and 2D plastics for recycling;
- the digestion of an OWF consisting of bio-waste, sanitary paper and paper and cardboard, producing biogas;
- biogas being used in the CHP for energy production or treated in the gas upgrade for green gas production.

4.5 Allocation and cut-off

Attributional LCA
The LCA in this study is an attributional LCA. This means that:
- the assessment includes all the impacts related to treatment of 1 tonne of the residual household waste, assuming all treatment options function optimally (e.g. full capacity is utilized);
- major changes to external systems in case of shifts in current treatment are excluded; e.g. changes to treatment of bio-waste because of changes in composition of waste.

Substitution method
The material outputs are assessed environmentally by using the substitution method. This means that recycled outputs are accounted for as replacing virgin materials.

4.6 Software, database and environmental impact categories

In this analysis the LCA-software SimaPro is used, version 8.1.0. For most processes in the data inventory the Ecoinvent database 3.3, recycled content database is used (Ecoinvent, 2016). CE Delft has more up to date data for both electricity production and transport, in those cases CE Delft data are used.

The environmental effect of the different treatment methods is expressed by means of the ReCiPe-methodology. The ReCiPe-methodology presents environmental effect on three different levels:

- the environmental impact (e.g. climate change impact);
- the environmental damage (e.g. in species lost per year);
- an aggregated score (the single score) combining sixteen different environmental impacts.

More information about the ReCiPe-methodology can be found in Annex B.

5 Inventory

The process descriptions, energy and auxiliary use as well as the produced quantity of outputs for REnescience are confidential, as is data used to model the treatment of bottom ash from incineration by means of the Inashco technology. Therefore, the inputs and outputs for the three treatment options are not included in this summary.

A description of the fate of the outputs and the replacements of outputs are summarized in 5.1**Fout! Verwijzingsbron niet gevonden.** and assumptions made for the incineration of waste (applied in all three treatment options) are described in Section 5.2.

5.1 Fates of outputs

The outputs from the treatment of municipal solid waste in the REnescience installation can be utilized in different ways. The green gas from REnescience and DST will be injected into the grid and Cure Afvalbeheer is planning on selling this to a party that ensures use of the green gas in the transport sector. Based on the price range of natural gas cars and taxation in the Netherlands a natural gas car is most likely to replace a car running on diesel. In this assessment, green gas therefore replaces the combustion of diesel in transportation.

The fate of the different outputs is given in Table 1. The table also shows the assumptions with respect to replacement.

Table 1 Fates of materials, R= REnescience, D = Dry separation treatment, I = Incineration

	Materials	Fate	Replacement
R D	2D, PET and mixed plastics 2D plastics	Send to recycler	PP, concrete and azobe wood[1]
R D	PE plastics 3D plastics	Send to recycler	PE granulate
R D	PP plastics 3D plastics	Send to recycler	PP granulate
R/D	Ferrous metals	Send to intermediary	Ferrous metal
R/D	Non-ferrous metals	Send to intermediary	Aluminum
R/D	Green gas	Injection into gas grid, used as transportation fuel	Diesel fuel combusted during transportation
R	CO_2 from gas upgrade	Sold to greenhouses	Fossil CO_2

[1] By weight 1/3 to PP (1:1 weight replacement), 1/3 concrete (1:1 volume replacement), 1/3 azobe wood (1:1 volume replacement). Based on (CE Delft, 2011a).

	Materials	Fate	Replacement
R D	Sludge Fine digestate	Production of bio-granulate, then incineration	Dutch Electricity mix in 2013[2]
R R/D	Brine Inert material	Send to treatment	Sand
D	Beverage cartons	Sorted and treated	Paper: sulfate pulp
R/D D I	RDF Course digestate Residual household waste	Send to incineration	Dutch Electricity mix in 2013[3] Heat production from natural gas

5.2 Incineration of waste

In the different treatment options, different fractions of waste are incinerated as shown in Table 2. For each of fractions being incinerated the composition is determined (e.g. bio-waste, PET).

For each waste type the Ecoinvent process for incineration of that particular substance is chosen. For two waste types, i.e. beverage cartons and sanitary paper, a set of processes is chosen to best describe the composition of the waste type. All auxiliaries needed for proper incineration are included in the Ecoinvent processes, as well as the emissions from incineration and treatment of final waste.

Table 2 Incinerated waste per treatment option

Route	Fraction incinerated
Treatment Option 1: Incineration	Residual household waste
Treatment Option 2: REnescience technology	RDF
Treatment Option 3: Dry separation technology	RDF, Coarse digestate

Dutch municipal waste incinerators produce energy, usually a combination of electricity and heat. An important factor in the environmental impact of waste incineration is the electric and thermal efficiency. These efficiencies vary widely between installations. The Attero installation in Moerdijk to which Eindhoven sends its municipal waste claims that it has a high efficiency (Attero, 2016); we assume efficiencies of 11% electric and 52% thermal.

Electricity is assumed to replace the average Dutch electricity mix, as reported in (CE Delft, 2014b)[4]. Heat is assumed to replace central or small-scale heat from natural gas.

2 Based on (CE Delft, 2014b).
3 Based on (CE Delft, 2014b).

4 The Dutch electricity mix in 2013 contained 28% energy from coal, 17% from natural gas, 37% from combined heat and power installations on natural gas, 6% nuclear energy, 9% renewable energy and 3% remaining sources.

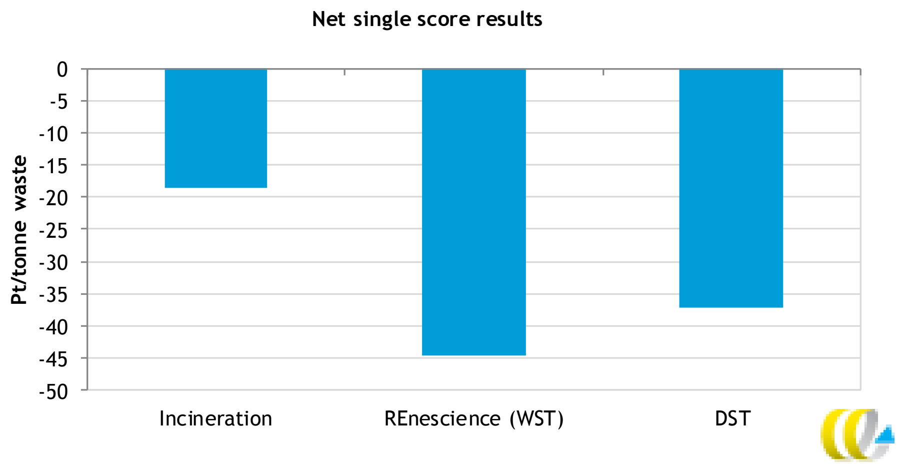
6 Results

This chapter describes the results of the assessment, and gives insight into the difference in environmental effects between the three different treatments options. The environmental effect expressed in the ReCiPe single score is shown in Section 6.1, the environmental effect at the damage category level can be found in Section 6.2 (endpoints) and at the individual environmental impact level in Section 6.3 (midpoints). The completeness and sensitivity of the results to assumptions made are discussed in Section 6.4.

6.1 Single score results

Figure 6 shows the single score results for the three different treatment options. A positive score means an environmental impact, a negative score an environmental benefit. All treatment options have a net environmental benefit, when expressed in single score. Based on these results it is very likely that the REnescience treatment has at least the environmental benefit of a dry separation treatment facility in the Eindhoven/’s-Hertogenbosch region.

Figure 6 Single score results per tonne of waste treated for the Eindhoven/’s-Hertogenbosch case



Note: WST = wet separation treatment, DST = dry separation treatment. Incineration of waste and RDF has a high energy recovery efficiency in all three cases.

Incineration has a relatively large environmental benefit, this is due to the high efficiency of energy recovery. The same efficiency value is also used for the incineration of RDF for both REnescience and dry separation treatment (DST).

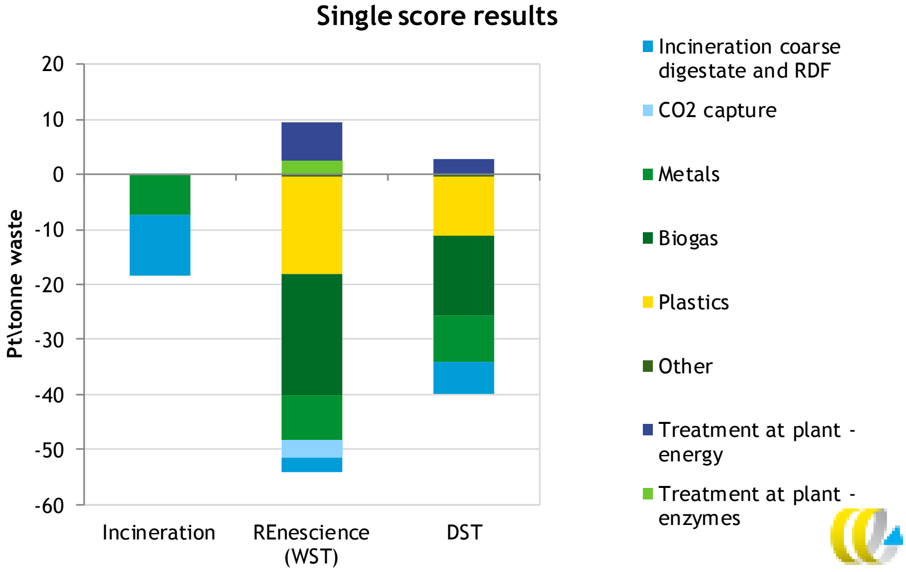
Figure 7 shows the breakdown of the single score results for the different treatment options. Relative to the dry separation treatment, REnescience has two main advantages. Relative to REnescience, DST has one main advantage.

Advantages of REnescience treatment:

+ the biogas production is approximately 1.5 times higher than future optimized DST separation;
+ a higher plastics recovery than the DST separation process.

Advantage of DST treatment:
- less inputs to treatment (e.g. lower electricity and heat consumption, no enzymes).

Figure 7 Single score results per tonne of waste treated for the Eindhoven/'s-Hertogenbosch case



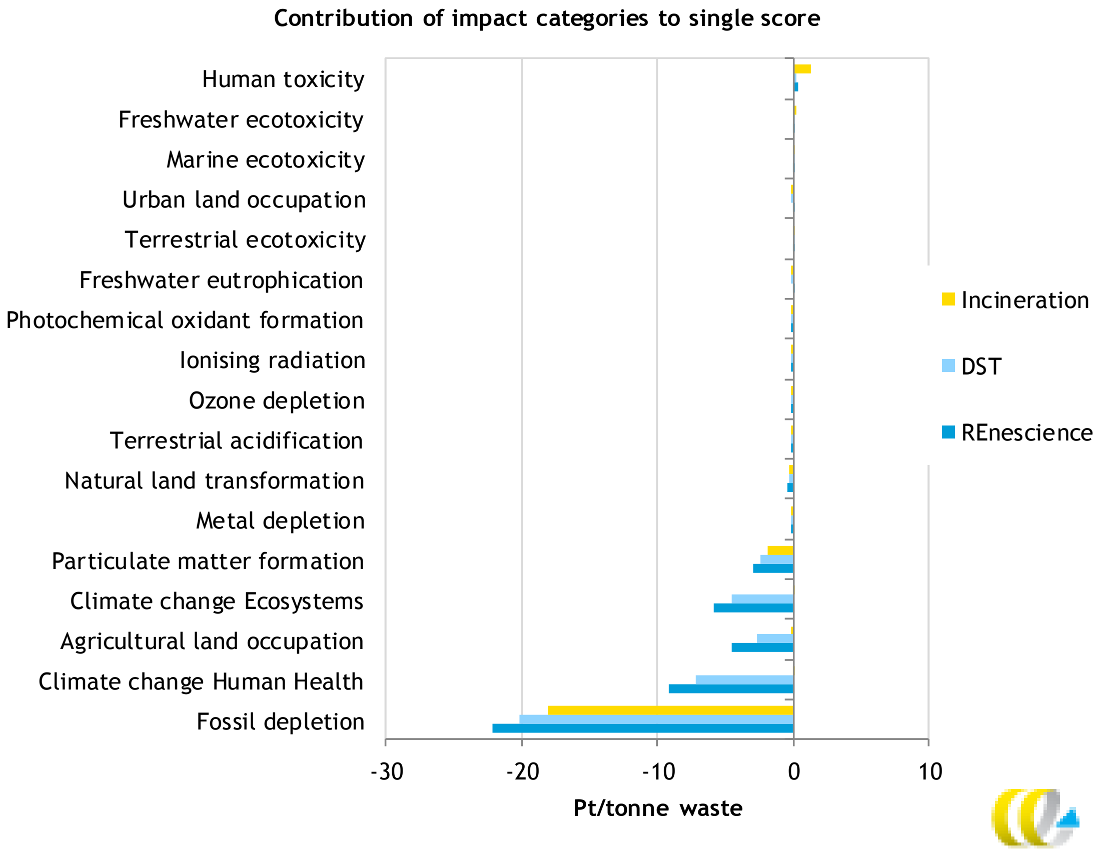
The environmental impact of the treatment at plant is higher for REnescience because:
- external inputs are used for energy (electricity and wood), as opposed to the DST where a certain share of the produced biogas is used internally for energy production;
- the REnescience treatment uses enzymes;
- more energy is needed to circulate the waste and water flow.

For the REnescience treatment, the lower benefits of energy recovery of incineration of RDF are due to two aspects; the smaller amount of waste being incinerated and the lower biogenic content in the incinerated waste.

The REnescience energy requirements are based on guaranteed maximum consumptions for full scale equipment and may be overestimated for the REnescience treatment. Further optimisation of energy efficiency is probably possible.

In Figure 8 the contribution of the different impact categories to the single score is shown. Only five categories account for over 97% of all impacts of treatment with the REnescience technology: fossil depletion, climate change (both human health impacts and ecosystem impacts), agricultural land occupation and particulate matter formation. These are also the impact categories which account for the main share of the impact of incineration and treatment with DST.

Figure 8 Contribution of the impact categories to the single score. Values present net scores. Scores are the aggregation of all environmental impacts and benefits for that impact category.



Even though metals are recovered, the midpoint category metal depletion does not have a high contribution to the single score. This is because both steel and aluminium are not particularly scarce metals. The environmental benefit of the recovery (see Figure 7) is accounted for by the reduction in fossil fuel requirements and a reduction in climate change impact for the production of new metal.

6.2 Endpoint results

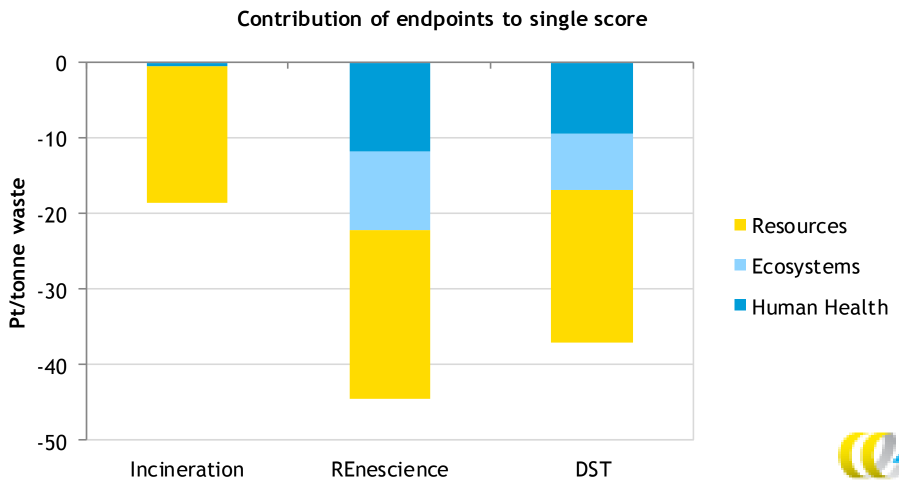
LCA single score results are quantified by weighting the three endpoint scores (damages). In the single score each of the damage categories receives a weight factor, the result of the single score is consequently a weighted average of the environmental damage.

The ReCiPe-methodology categorizes the damage into three endpoint-categories:

1. Damage to human health, contributes for 40% to the single score.
2. Damage to ecosystems, contributes for 40% to the single score.
3. Damage to resource availability, contributes for 20% to the single score.

Figure 9 shows how the scores on the three endpoints contribute to the single score for the three processes. As can be seen, the endpoint Resources contributes most to the scores on all three treatments. The score on this damage category is composed of: recovery of metals, recovery of plastics and energy recovery from incineration (of waste for incineration and of RDF and coarse digestate for the REnescience treatment and the DST treatment).

Figure 9 Contribution of the three endpoints to the single score



6.3 Midpoint results

The ReCiPe midpoint-level is a direct translation of emissions and resource use to environmental effects. There are 18 different environmental effects included in the ReCiPe-methodology. Figure 8 shows that the contribution of only five midpoints accounts for almost 100% of the single score. For these midpoints REnescience has a higher environmental benefit than dry separation treatment (DST). The main differences between the REnescience treatment and the DST are the higher plastics recovery and the higher biogas yield in the REnescience treatment.

Table 3 Midpoint results for the Eindhoven/'s-Hertogenbosch case, difference compared with incineration (per tonne of waste)

Midpoint category	REnescience	DST	Difference between REnescience and DST
Climate change (kg CO_2-eq)*	-326	-254	Plastics recovery and biogas production
Particulate matter formation (kg PM_{10})	-0.92	-0.84	Plastic recovery and biogas production
Agricultural land occupation (m^2a)	-238	-124	Plastic recovery and biogas production
Fossil depletion (kg oil eq)	-39	-20	Plastic recovery and biogas production

Note *: Aggregation of *climate change impact on human* health and *climate change impact on ecosystems*.

6.4 Completeness and sensitivity

The analysis has been carried out with the best possible data available. However, neither dry separation treatment nor REnescience treatment are currently applied in the Eindhoven/'s-Hertogenbosch region. Therefore, assumptions had to be made.

Sensitivity analyses related to food waste quantity, dry matter of food waste, and use of natural gas for heat in the REnescience treatment all have a relatively small impact on the results.

If it would not be possible to sell the green gas as transportation fuel, the gas will replace natural gas that is used as heat source. The influence of this shift was assessed in a sensitivity analysis. The sensitivity analysis showed that this shift has a relatively large impact on the result; the single score drops by about 15%.

Electric and thermal efficiencies of Dutch municipal waste incinerators vary widely. We have analysed the effect of both a higher and a lower efficiency of the incinerator for REnescience, DST and incineration. The sensitivity analysis shows that a lower efficiency would decrease the environmental benefit of both installations, by 10-15%. The influence of the efficiency is higher when more (final) waste is being incinerated after separation.

Combined impact of sensitivities

When all sensitivities are combined it is possible that REnescience and DST provide a comparable environmental benefit. It is probable that REnescience has a higher environmental benefit than DST, because recovery efficiencies are higher and energy use is possibly overestimated.

7 Conclusion

It can be concluded that the REnescience treatment is comparable or better than dry separation treatment in the Eindhoven/'s-Hertogenbosch region. Both the REnescience technology and the dry separation treatment (DST) can be optimised further. Both of these technologies are in different stages of development. The REnescience technology is in its early development and improvements in the process are still expected. They are economically optimised based on the current market situation. It is possible that the environmental benefit of both treatments methods will increase further in the future.

Because the earlier assessment has shown that dry separation treatment has a similar environmental score as source separation (for plastics, metals and food waste and beverage cartons), it can be concluded that the REnescience treatment also scores comparable or better than source separation in the Eindhoven/'s-Hertogenbosch region.

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Annex A Composition of residual household waste in Eindhoven and ‘s-Hertogenbosch

To ensure a fair comparison of the different waste treatment options, it is important to establish the basis for the functional unit, in this case the composition of the household waste to be treated. Because percentages of source separated wastes differ between municipalities, a generic composition may not reflect the situation adequately.

The residual household waste is the fraction of municipal solid waste that could end up in the REnescience installation and excludes large waste types such as furniture. This fraction includes all household waste collected by the municipality for treatment in an incinerator (with energy recovery) and excludes wastes which are source separated by households, such as textiles, glass, paper and food and garden wastes. Furthermore, large PET bottles (1 litre or larger), which are collected in the Dutch Deposit (statiegeld) system are excluded from the assessment.

Table 4 Scope - source separation now and assumptions for the future in Eindhoven/’s-Hertogenbosch, as basis for the functional unit in this study

	Currently source separated?	Source separated in future? (= basis for functional unit)
Food waste	Yes	No
Garden waste	Yes	Yes
Plastics	Yes	No
Glass	Yes	Yes
Textiles	Yes	Yes
Paper and cardboard	Yes	Yes

Note: Source separation does not amount to 100%. Source separated garden waste may include some food waste in the future.

The waste which would be treated in the REnescience reactor includes food waste and plastics, but excludes source separated glass, paper and cardboard, textiles and garden waste (Table 4). As plastics and food waste are currently source separated to a certain degree, no data is available on the exact composition of the residual household waste produced in the Eindhoven/ ’s-Hertogenbosch region, which fits the characteristics of the third column in Table 4.

The composition of the residual household waste produced in the Eindhoven/’s-Hertogenbosch assessed in this study was determined by combining two known fractions:

1. The composition of post-consumer separated household waste.
2. The source separated waste streams.

The current efficiencies of source separation for garden waste, glass, textiles and paper and cardboard were used to define the residual household waste composition from which some fractions are source separated (to different degrees).

Table 5 shows the composition after source separation that is used as a functional unit in this LCA study. The plastics sub-composition is based on an aggregation of plastics in post-consumer separated waste and in residual household waste (CE Delft, 2011b). It therefore approximates the composition of the plastics fraction in the waste composition used in this study.

Table 5 Composition of residual household waste used as functional unit

	% of total	Sub-composition
Plastics	14%	PET (3%) HDPE (1%) PP (3%) LDPE/foil (5%) Other (1%)
Paper & Cardboard (without beverage cartons)	6%	-
Beverage cartons	2%	-
Sanitary paper	11%	
Glass	3%	-
Bio-waste	45%	Food waste (39%) Garden waste (6%)
Metal	2%	Steel (2%) Non-steel (1%)
Textile	5%	-
Ceramics	1%	
Wood	2%	
Small chemical waste	<1%	-
WEEE	1%	
Other	9%	-

Annex B ReCiPe-methodology

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 three different levels: midpoint, endpoint and single score.

Midpoint-level (problem-oriented)
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.

Endpoint-level (impact-oriented)
At the endpoint-level the environmental effects are normalized and recalculated towards damage. For example the environmental effect 'ecotoxicity' has an impact on the amount of animal- and plant species (a decline) and thus causes 'damage to ecosystems'. The ReCiPe-methodology categorizes the damage into three endpoint categories: Damage to human health, Damage to ecosystems and Damage to resource availability.

Single score (weighted average)
The LCA single score result is the addition and weighting of the damages from the three endpoints. In the single score each of the damage categories receives a weight factor, the result of the single score is consequently a weighted average of the environmental damage.

Table 6 gives an overview of the ReCiPe-methodology.

Table 6 Environmental effect categories, units and weighting according to ReCiPe

Midpoints	Endpoints	Weight in single score
Climate change Human Health (kg CO_2-eq.)	Human Health (DALY)	40%
Ionising radiation (kBq U235-eq.)		
Ozone depletion (kg CFC-11-eq.)		
Terrestrial acidification (kg SO_2-eq.)		
Human toxicity (kg 1,4-DB-eq.)		
Photochemical oxidant formation (kg NMVOC)		
Particulate matter formation (kg PM_{10}-eq.)		
Marine eutrophication (kg P-eq.)	Ecosystems (species.year)	40%
Freshwater eutrophication (kg P-eq.)		
Climate Change Ecosystems (kg CO_2-eq.)		
Terrestrial ecotoxicity (kg 1,4-DB-eq.)		
Fresh water ecotoxicity (kg 1,4-DB-eq.)		
Marine ecotoxicity (kg 1,4-DB-eq.)		
Agricultural land occupation (m^2a)		
Urban land occupation (m^2a)		
Natural land transformation (m^2)		
Water depletion (m^3)		
Metal depletion (kg Fe-eq.)	Resources ($)	20%
Fossil depletion (kg oil-eq.)		

Source: (Goedkoop, et al., 2013).