Waste Not, Want Not: Environmental Impacts of Sorting and Prevention of Household Waste

A case study of 100 Dutch households

Waste in the street of Sarajevo in the winter of (1992-1993) by Christian Maréchal

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Abstract

The Netherlands is performing quite well on waste treatment compared to other countries in Europe. However, only 51% of all Dutch household waste is collected as separately collected waste and the rest as residual waste. Reducing the amount of residual waste is important to improve recycling because the products and materials in separately collected waste can be recycled more easily. The Dutch waste management company ROVA organised the 100-100-100 project. This project was aimed to improve separation of waste, by reducing the amount of residual household waste. Four hundred households participated in the project and were coached by ROVA to decrease their residual waste.

The participating households reduced their residual waste through (1) improved waste sorting, (2) a changed consumption behaviour (i.e. buying products that can be recycled when wasted) and, (3) waste prevention. This thesis determined the environmental impact of the 100-100-100 project and related it to the average waste composition of Dutch households.

Four indicators were used to measure the environmental impact: (1) primary energy use, (2) GHG emissions, (3) absolute scarcity and, (4) critical materials. The waste of participating households was collected and analysed in order to determine the impact of the household waste. The environmental impact of the households was determined with a modified version of the iWaste model. Furthermore, the impact on scarcity was determined by looking how much of a material was wasted and how much could be recovered through recycling. The impact on critical materials in the waste was inferred from the product types that were found.

The increased share of sorted waste and reduction of overall waste resulted in a smaller impact for all four indicators. Personal coaching was more effective than collective coaching via an online platform in order to reach this goal. Households that were performing worse than the average household also realised a larger reduction. However, after the project those household still lagged behind the better performing households.

The sorting behaviour of the 100-100-100 participants is not comparable to the average Dutch household. The participants had a smaller amount of waste and also disposed a larger share of their waste as sorted waste. As a result, 100-100-100 participants already had a smaller environmental impact from household waste than the average Dutch household did. Therefore, the average Dutch household has a much larger reduction potential. A future project for Dutch households might thus result in larger environmental impact reductions.

Keywords: municipal solid waste (MSW), circular economy, waste sorting and prevention, primary energy, GHG emissions, resource scarcity, critical materials

Preface

This thesis is the result of the research I have carried out from November 2015 until June 2016 at Utrecht University as part of the master's programme Sustainable Development. Furthermore, this research was also performed as an internship at ROVA. This thesis is part of the research on the effects of the 100-100-100 project as designed by ROVA.

I was invited to participate in this research by my supervisor prof. Ernst Worrell. Immediately after I was introduced to the 100-100-100 project, I was attracted to the project. Household waste is something that everyone – consciously or unconsciously – encounters almost daily. The 100-100-100 project brought the challenge of waste sorting to the households themselves:

> *"Be the change you want to see in the world."*
>
> *- Mahatma Gandhi*

Before I started my research I thought that my housemates and I were behaving as responsible citizens by sorting our waste relatively well (to my great frustration there is no possibility to present sorted organic waste at my home, we separate all other possible waste streams). It was until the 100-100-100 project started that I realised that even good performing households still have a large potential for improvement. It was therefore not more than natural that this research also influenced me in my personal life. For example, cookies wrapped in multiple layers of plastic packaging are no longer an option during grocery shopping.

Over the course of the 100-100-100 project, I was regularly surprised by the enthusiasm, motivation and determination of the participants. Reading the short personal encouragements, tips and messages of participants on the project website always sparked my motivation and brought a smile to my face more than once.

I hope that you enjoy reading my thesis!

Bas van Zuijlen, Utrecht, June 25th 2015

Acknowledgements

There are several people that I want to thank for their contributions to this thesis and without whom this research would not have been possible.

First, I would like to thank my supervisors at Utrecht University for their advice and critical but encouraging feedback. I would especially like to thank Ernst Worrell for the invitation to the 100-100-100 project and the enthusiasm he brings along with his supervision. I would like to thank Lotte Visser for her near-instant responses to my emails, always having/making for me and her answer to my questions, which always helped me improving my work. Thirdly, I would also like to thank Wina Crijns-Graus in advance for being the second reader of this thesis her part in the assessment.

Then I would like to thank the two other students that did research in the 100-100-100 project. Robert Orzanna (UU) I would like to thank for his shared insights, critical thinking and unbounded positive energy. Additionally, I would like to thank Leonie Vrieling (RUG) for sharing insights from the behavioural sciences and the enthousiasm she brought to the project.

Special thanks to ROVA employees Huibert Boer, Natascha Spanbroek and Anne Oosterwijk for their part in the 100-100-100 project, the fruitful discussions we had and their feedback on my work.

Last but most definitely not least I would like to thank all the participating households for making this research possible.

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Glossary

Throughout this thesis various terms and abbreviations are utilized. To comprehend the thesis fully and correctly, readers might want to browse through the glossary of terms and abbreviations below.

Term/abbreviation	Meaning
CED	Cumulative (fossil) energy demand
DifTar	differentiated tariff for the varying waste streams. Waste stream that are considered to have a higher value (such as the organic waste stream) will be collected at lower costs than more undesirable waste streams.
GHG	Greenhouse gas
GKW	Garden and kitchen waste.
Gross Energy Requirement (GER)	all the energy that is required to produce a material. This includes the feedstock energy. An alternative name would be embodied energy. The GER values are also used in combination with emission factors to determine the amount of GHG emissions that are emitted to produce a material.
HHW	Household hazardous waste
PDF	Probability density function
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
pppy	an abbreviation for per person per year, for instance, kg pppy.
PS	Polystyrene
PVC	Polyvinyl chloride
RDW	Renovation and demolition waste

Term/abbreviation	Meaning
Reversed waste collection	can be applied to various waste streams. Normally, residual waste is collected at the households while sorted waste has to be brought to underground containers or other collection locations. With reversed collection, the sorted waste streams are collected at households while the residual waste needs to be brought to underground containers.
RPR	Reserves to production ratio
Sorted/separately collected waste stream	a waste stream that contains only waste of certain materials as defined by a waste management company. These waste streams, such as paper and organic waste, are generally easier to recycle and therefore more desirable.
Waste fraction	a fraction of a waste stream that can be uniquely determined by a description. For instance, diapers in the residual waste stream.
Waste stream	a flow of waste that is collectively collected by waste management companies. Examples of waste stream are: residual waste, organic waste, plastic packaging waste, paper waste etc.

1. Introduction

> *"The most difficult part was taking a hard look at myself, the environmental studies major, the shining beacon of sustainability, and realizing that I didn't live in a way that aligned with my values."*

This is a quote from Lauren Singer, a woman in her early twenties living in New York City, one of many. However, Lauren is different; she first banished plastic from her life and now has achieved a completely 'zero waste life'[1]*. Which* literally *means living without any waste that would be incinerated or landfilled whatsoever. To achieve this lifestyle she has made some changes in her life, among those changes are: making her own toothpaste, only buying second hand clothes and refusing receipts. More and more people follow this trend worldwide. The question is whether it is possible for everyone, if we are ready to change our lives drastically and if not, how far are we willing to go?*

1.1 Background

Our industrialised societies produce waste as a by-product of our material consumption. There are several options to dispose of waste. However, waste consists of valuable resources that are essentially lost while disposing the waste. All over the world, resources are being exploited to produce new goods because the old ones are discarded as waste. The exploitation of resources often goes at a rate that exceeds the rate of replenishment of those resources and is therefore an unsustainable practice. A considerable amount of energy is used to extract these resources and produce goods with them, along with the energy usage, greenhouse-gasses (GHGs) are emitted (Corsten, Worrell, Duin, & Rouw, 2010). Not having to extract these resources has a large energy savings and GHG emission reduction potential. Furthermore, it can prevent the increasing scarcity of resources.

The circular economy, a central concept in the field of sustainable development, is an alternative for our current wasting economy, named the linear economy. The current paradigm of the linear economy is inherently unsustainable. Resources are taken from the earth (input) and produce waste that is discarded (output). As long as this process is maintained, usable resources will be turned into unusable waste, eventually resources will be depleted. In a circular economy, there is no such thing as waste. The output (materials) of one process will merely serve as the input, with a similar or higher quality, for another process. Thereby creating a circle (hence the phrase circular economy) through which materials flow (see Figure 1).

The standard to manage waste sustainable is the waste hierarchy. It consists of five options to manage waste. From an environmental view the options are in order from most preferable to least preferable (Gertsakis & Lewis, 2003):

1. Prevention: reduce the amount of waste.
2. Reuse: use (parts of) a product again.
3. Recycle: reuse materials that were in the waste.
4. Incineration: produce energy from waste.
5. Landfilling: dumping of waste on a dedicated area.

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[1] Read more about Lauren at this blog: http://www.mindbodygreen.com/0-16168/i-havent-made-any-trash-in-2-years-heres-what-my-life-is-like.html

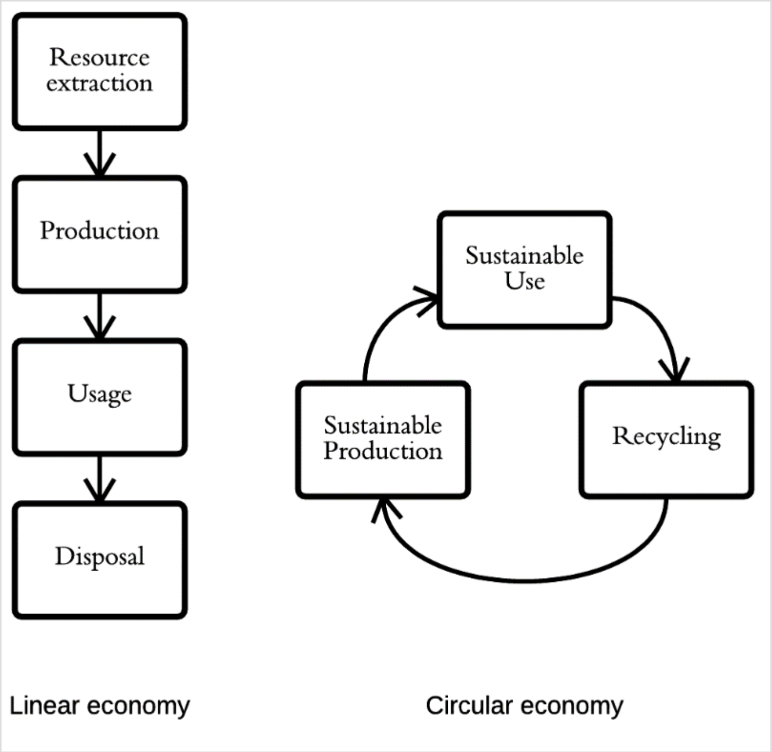

Figure 1. Linear economy (left) versus circular economy (right).

The Netherlands is one of the few countries in Europe that almost do not landfill any waste at all. Furthermore, the Netherlands is one of only five countries in Europe that are already recycling more than 50% of their municipal solid waste (EEA, 2013). Annually, all Dutch households together produce eight Mtonnes of waste. Only 51% of the total household waste is collected in a separately collected waste stream (CBS, 2014). However, the goal of the Dutch Government (2014) is to collect 75% of all household waste separately in 2020.

Several policy strategies exist to encourage households to act in line with the waste hierarchy.

(1) DifTar: This is an abbreviation for differentiated tariff and builds on the 'polluter pays' principle. The idea behind DifTar is that a household pays for waste that they produce (e.g. per kg of m^3), thereby giving the incentive to reduce the amount of waste that they produce. Additionally, a differentiation between the various sorted waste streams (e.g. plastic, paper etc.) and residual waste stream are possible, the former waste streams normally being cheaper since they are more desirable. With DifTar households receive a financial incentive to present the largest share of waste possible in a sorted waste stream.

(2) Reversed waste collection: With reversed waste collection the service for the households provided by the waste management companies will be higher for sorted waste than for residual waste. A higher service may be achieved by collecting the sorted waste streams at the households rather than at underground containers dispersed over the neighbourhood. The service for residual waste can then be lowered by only collecting it at those underground containers. The result is that a household has to put more effort into disposing residual waste than in disposing sorted waste. Thereby the households are given the incentive to sort more of their waste and dispose less of it in the residual waste stream. Hence, increasing the potential for recycling of their waste. The Municipality of Utrecht (2013) has conducted a pilot with reversed waste collection

which showed that households sorted a larger share of their waste as an effect of reversed waste collection.

The potential for environmental impact reductions of different waste management options has been studied more often, for example by Björklund & Finnveden (2005) and Corsten et al. (2010). However, these studies focussed on the management of the waste after it has left the households (or other locations where waste is produced). The focus is thus often on the difference between waste incineration, landfilling, recycling etc. However, the impact of household level waste sorting is neglected.

If it is considered, household waste management is often studied from the perspective of the behavioural sciences, such as in Barr et al. (2007; 2001) and Rousta et al. (2015). In those studies recycling, reusing and waste prevention are the preferable options for waste management. However, the effects of improved sorting and waste prevention are not quantified as environmental impact.

This thesis aims to close the gap between these two kinds of researches. In this thesis the effect of changed waste production and sorting by households is related to the environmental impacts of these behaviours.

1.2 Problem Definition

The current goal of the Dutch Government (2014) is to increase household waste sorting from 51% in 2014 to 75% by 2020. Thereby, the amount of waste that is incinerated will be decreased, in line with the waste hierarchy. In order to realise this increase in waste sorting, households need to increase their performance significantly. The amount of residual waste has only been decreasing slowly over the last twenty years (CBS, 2014). It needs to be studied if households can realise this improvement and how they can be stimulated to act upon this goal. Additionally, the environmental impact of this improvement needs to be studied.

ROVA is a Dutch waste management company, its operation is commissioned by 21 Dutch municipalities (ROVA, 2014). ROVA is collecting the household waste (and other municipal waste) and transporting it to waste processors such as recycling installations and waste incinerators. ROVA acknowledges that it can play a vital role in achieving the goal of the Dutch government to improve waste sorting, because it is responsible for large waste streams.

As part of their role, ROVA organised the 100-100-100 project[2] (100 households, 100 days, 100% free of residual waste) for households in the ROVA working area. The project had two goals:

(1) To reduce the amount of residual waste through improved sorting and changes in consumption behaviour;
(2) To reduce the overall amount of waste.

If the first goal is achieved the other, recyclable waste streams will become purer. The recycling of waste makes processing cheaper since the output of the waste processing can be used as input for new products. The second goal also clearly reduces the total costs for waste processing.

In the 100-100-100 project the scope is specifically on the household. What can households do themselves to improve sorting and prevent waste? The main part of the project will be the behavioural intervention in the households; households will be confronted with their own wasting behaviour and helped in improving it (i.e. prevention and improved sorting).

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[2] Website of the project: http://www.100-100-100.nl

Since waste prevention, reuse and recycling are at the top of the waste hierarchy, it is expected that the result of the 100-100-100 project will be a smaller environmental impact. Therefore, the environmental impact was studied in this thesis. The research question that follows from this problem is:

> *To what extent can a public behavioural intervention reduce the environmental impact of Dutch household waste in 100 days through waste reduction and improved sorting?*

Resulting in the following sub questions that need to be answered in order to answer the main research question:

(1) *What is the waste composition of the 100-100-100 participants?*
(2) *How does the waste composition of 100-100-100 households relate to the waste composition of average Dutch household?*
(3) *What is the possible improved waste sorting and waste reduction that the 100-100-100 households can achieve in 100 days?*
(4) *How does the improved waste sorting and waste reduction of the 100-100-100 project influence the life-cycle environmental impact from household waste?*
(5) *How does the life-cycle environmental impact change of the 100-100-100 project relate to the life-cycle environmental impact of waste of the average Dutch household?*

1.3 Outline

The next section will provide the general approach of the thesis and an overview of the methods that were used. Section 3 will describe the composition of the waste of the participating households. In the fourth section, the results of the environmental impact calculations will be presented and analysed for both primary energy and GHG emission savings as well as the problem of scarcity of materials and critical materials. In the fifth section, the results will be related to the average Dutch household waste sorting and environmental impact from waste. This will finally lead to a conclusion and a discussion of the results.

1.4 The Bigger Picture

As mentioned before this thesis is part of the 100-100-100 project. The project aimed to bring household waste a step closer to the circular economy. Because the residual waste is perceived as an impossible constituent of the circular economy, the ultimate goal of this project is to reduce the amount of residual waste to 0 kg. If applicable, the outcomes of the project were meant to indicate which factors would make it impossible for households to reach this goal. The results of the project will be studied scientifically.

This thesis elaborates on the results of the project and their implications for the environmental impact. However, scientific research within this project is not restricted to this master's thesis. Additionally, the environmental impact of food waste and the possibilities to eliminate food waste were studied in more detail. The food waste was linked to the daily practices of households. This research was based partly on the waste composition results that were also used in this thesis and three questionnaires were sent out to the participants to assess their daily practices. Furthermore, the environmental self-identity of the households was studied over the course of the project. This was studied to find the behavioural impact that the 100-100-100 project had. The main source of data for this research were the responses to the questionnaires.

2. Methodology

Within the greater 100-100-100 project, this thesis will provide insight in the environmental impact of household waste. In order to determine the impact of households waste, the residual waste stream and the three separately collected waste streams that are collected at home with reversed waste collection (ROVA, 2013) were studied. In total the following four waste streams were analysed, (1) residual waste, (2) organic waste, (3) plastic packaging waste and (4) paper waste. The waste was collected when it left the household.

The research steps are shown in Figure 2. The grey boxes show the major steps in the 100-100-100 project; white boxes show the research steps that were taken during the research for this thesis; and black boxes represent the research questions that were stated above.

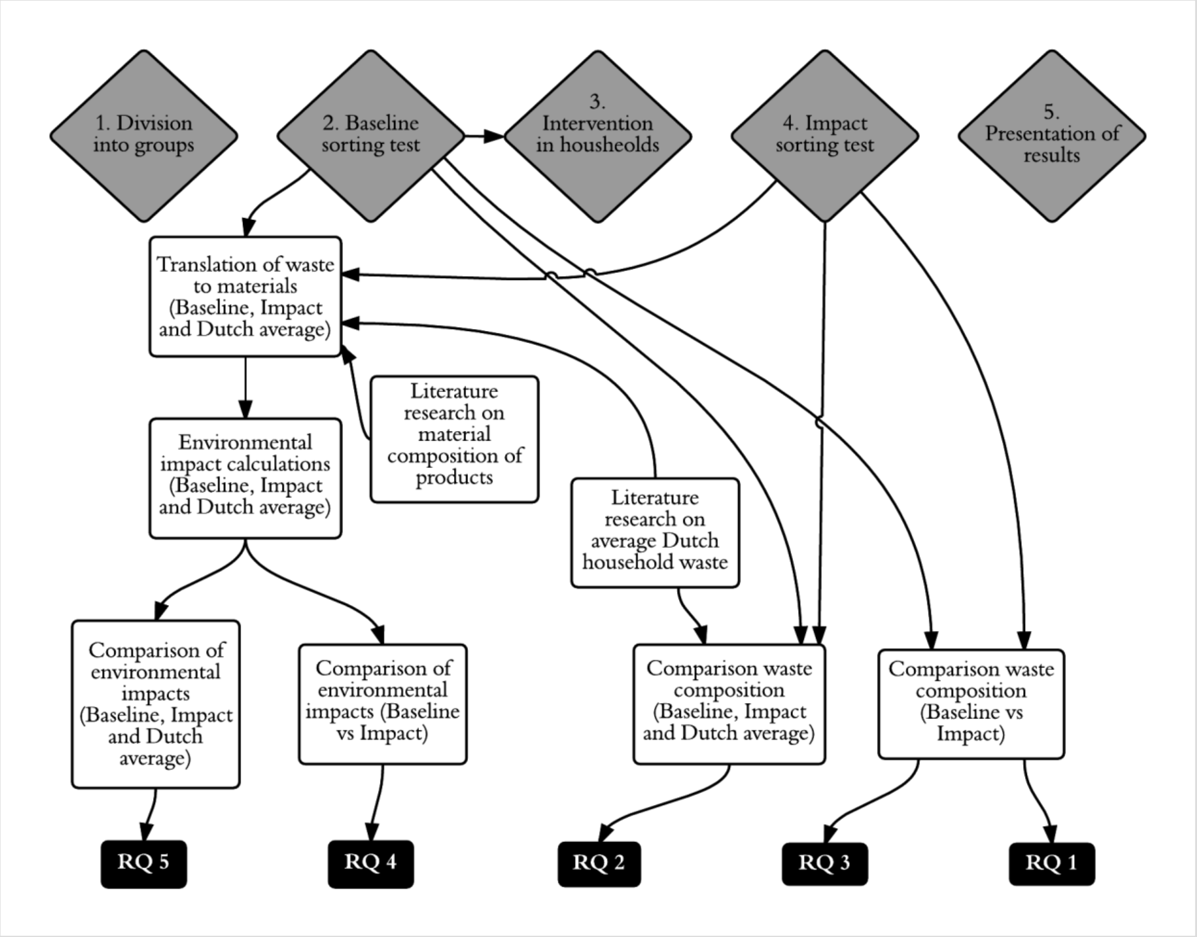

Figure 2. Research approach and answering of the research questions.

First, a division into different groups was made to compare the results of two types of interventions. For each group the waste streams then underwent baseline sorting tests. Thirdly, an intervention in the households took place. This intervention was based on the results from the baseline sorting tests. Fourthly, after the 100 days of intervention the impact sorting tests were executed for the same waste streams. Finally, the results were presented.

The results from both sorting tests allowed the answering of what the composition of waste was in the 100-100-100 project (research question 1) and what the possible reduction due to the 100-100-100 intervention was (research question 3). The literature review on the average Dutch household waste resulted in answering the question what the average waste composition of Dutch households was (research question 2). In order to determine the environmental impact reduction for both the average Dutch waste and the 100-100-100 participants, a translation key from products to materials was developed (e.g. a potato crisps bag was translated into plastic and aluminium). This translation key was developed based on a literature review. The translated data on materials then constituted the input for an analysis on how much primary energy and GHG emissions were related to the wasted materials. Additionally, it was studied how scarce these materials were and how much the wasting of those materials added to the scarcity problem. Also the amount of critical materials that was wasted was studied here. Comparing the results from the environmental impact analysis for both sorting tests resulted in the environmental impact reduction (research question 4). Also comparing the results of the environmental impact of the average Dutch household waste made it possible to relate these results to the possible impact for the Netherlands (research question 5).

For large parts of the research design, this research was dependent on the setup of the 100-100-100 project by ROVA. The division of the households in the various groups, the setup of the sorting tests and the waste streams that were analysed were already fixed.

2.1 System Boundaries

The scope of the research focusses on the households in the 21 municipalities that constitute the ROVA working area (see Figure 3). In these 21 municipalities ROVA serves about 900,000 inhabitants. The waste disposal was studied, but only to determine the environmental impact of the household waste with the current disposal system. Options to improve these processes were not studied in this report.

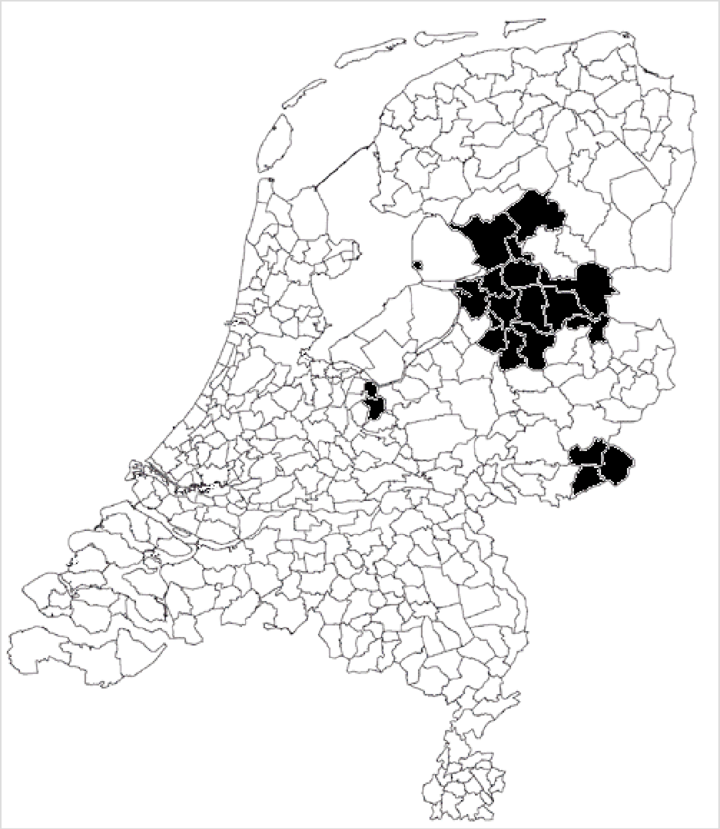

Figure 3. Working area of ROVA (in black) in the Netherlands.

The factors that were in the scope of the research were the factors that could be influenced by the members of the household. These factors were mainly (1) the products that were bought (or obtained otherwise) by the households and (2) the waste streams through which these products left the household as waste. The production of the materials and processing of the waste were in the scope of the research. These were assumed to stay constant and served to determine the environmental factors of household waste.

Other household waste streams – for instance separately collected glass or textile – were not in the scope of the research. These waste streams were not analysed in the sorting tests. Nonetheless, materials that belonged in these waste stream occurred in the studied waste streams (i.e. they were incorrectly sorted). A full overview of the system boundaries are depicted in Figure 4.

It is important here to make a distinction between the term 'waste stream' and 'waste fraction'.

- In this thesis a waste *stream* is meant as: a flow of waste that is collectively collected by waste management companies is meant. Examples of waste stream are: the residual waste stream and the plastic packaging waste stream.
- In this thesis a waste *fraction* means: a fraction of a waste stream or waste multiple waste streams that can be uniquely determined by a description. For instance, diapers in the residual waste stream or the incorrectly sorted waste of all waste streams.

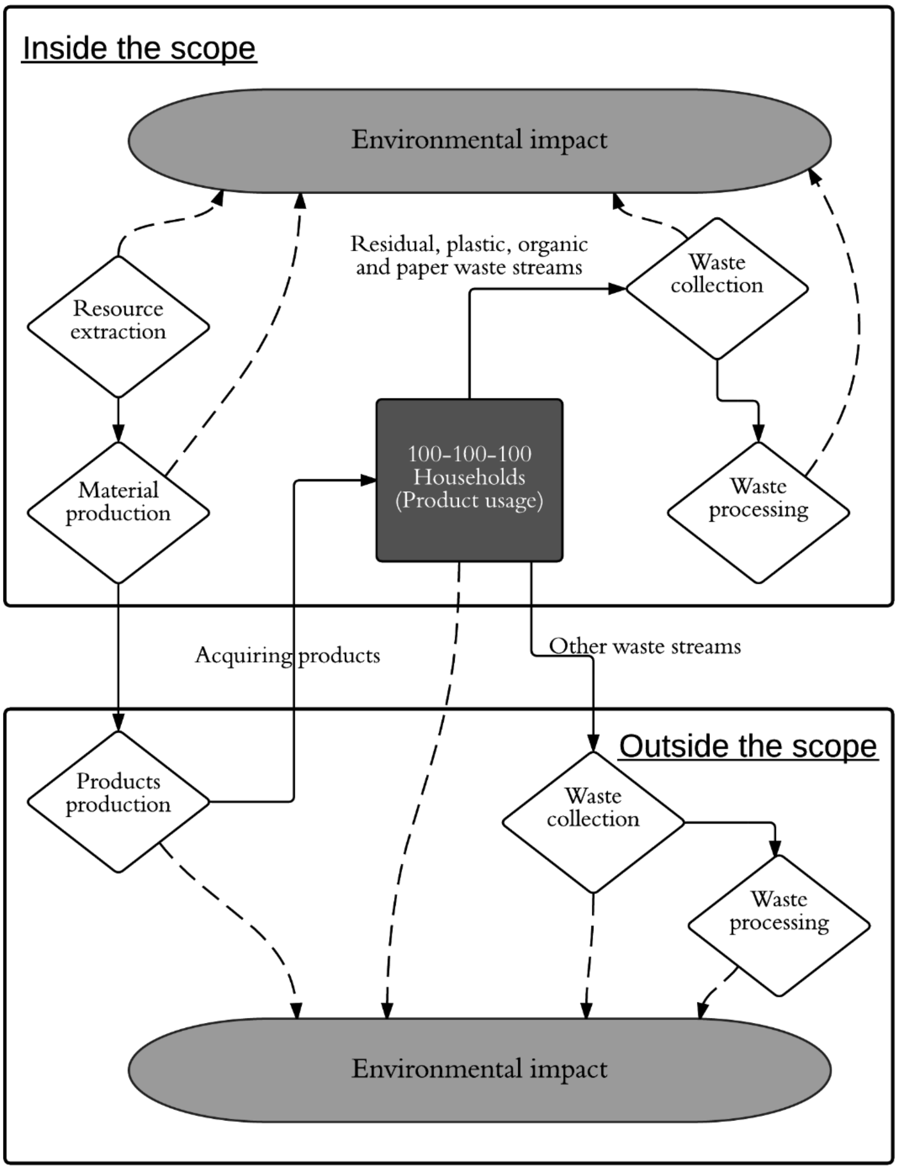

Figure 4. Scope of the research.

2.2 Groups and Clustering

Approximately 400 households signed up to participate in the 100-100-100 project. Originally, the project was designed for 100 households (hence the name of the project). Fifty households (hereafter called the *50+ group*) would receive extra personal guidance. The other fifty households (hereafter called the *50- group*) would only receive guidance through an online community that would also be available to the 50+ group. The unexpected high number of participating households resulted in a larger 50- group than was originally expected. The size of the 50+ group remained at 50 households.

Most households were randomly selected for the 50+ or 50- group. Some households did not register for pure intrinsic reasons; they were invited by ROVA to participate. Those households were of prominent figures in the region (mostly aldermen/alderwomen[3]). Hence, the composition of the 50+ group could no longer be assumed the same as the composition of the 50- group. Twelve of the 50 households in the 50+ group were selected as prominent figures.

Due to budget limitations, it was considered unfeasible to analyse the waste of all households on an individual basis. The plastic, residual and paper waste stream of the households that were in the 50+ group was analysed on an individual basis. For the organic waste stream of the 50+ group two clusters were formed. First, the group was divided in two subgroups. A subgroup that contained households located in high-rise buildings and a subgroup containing households located in low-rise buildings. For each of these subgroups, there was a sample of households randomly selected and clustered. This resulted in one cluster that contained only households living in high-rise buildings (cluster 1HB) and another cluster that contained only households living in low-rise buildings (cluster 1LB).

The waste of the 50 households that constituted the sample of the 50- group was analysed on an individual level for the paper waste stream only. For the plastic, organic and residual waste stream, the sorting tests were performed for all the waste of a cluster combined.

For the 50- group, a sample of 50 households was selected randomly. The sorting tests were only performed for the households in the 50+ group and this sample of the 50- group. The sample of the 50- group was separated into four clusters (2A, 2B, 2C and 2D) based on the area that they lived in. The areas were then combined based on the level of urbanism[4] and whether DifTar and/or reversed collection applied to those households. These combinations of households in similar areas were then defined as a cluster. A complete overview of the clusters can be found in Table 1. Note that the cluster names are unique identifiers of the cluster; some clusters are mentioned multiple times.

Households that were located in a reversed collection phase 1 area could dispose of their organic waste without costs. Residual waste was still collected at the household but only once in every four weeks (in areas without reversed waste collection this is once every two weeks). Households that were located in an area where the second phase of reversed waste collection was active had to bring their residual waste to underground containers shared with other households. Additionally, plastic waste, organic waste and paper waste was now also collected at the households (ROVA, 2013). These infrastructural factors influencing households to sort and prevent waste were already in place before the beginning of the 100-100-100 project. Households that are located in an area were reversed waste collection is active but do not participate in the 100-100-100 project had the same waste collection infrastructure.

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[3] The Dutch translation is ‘wethouders’.

[4] The level of urbanism is determined by measuring the number of addresses per square kilometre. Class 1 means very urban, class 5 means very rural.

Cluster 2D contained households that experienced a financial incentive to reduce and sort their waste because they were located in a DifTar area. Additionally, they also had a service incentive to sort their waste better through the reversed waste collection. Cluster 2C also had both a service incentive and a financial incentive. The service incentive for cluster 2C, however, was lower since the reversed waste collection for this cluster was only at phase 1. Cluster 2B only had the service incentive. Cluster 2A had no additional incentives to improve sorting or reduce waste. The clusters could alphabetically be sorted from lowest incentives (2A) to the highest incentives (2D).

Table 1. Clustering of households.

Waste stream	Cluster name	Group	Level of urbanism	DifTar	Reversed collection	Number of households
Residual	2A	50-	2	No	No	9
	2B	50-	2	No	Phase 2	9
	2C	50-	4/5	Yes	Phase 1	19
	2D	50-	4/5	Yes	Phase 2	13
Plastic	2A	50-	2	No	No	9
	2B	50-	2	No	Phase 2	9
	2C	50-	4/5	Yes	Phase 1	19
	2D	50-	4/5	Yes	Phase 2	13
Organic	1LB	50+	Mixed	Mixed	Mixed	6
	1HB	50+	Mixed	Mixed	Mixed	6
	2B	50-	2	No	Phase 2	9
	2D	50-	4/5	Yes	Phase 2	13

2.3 Determining Waste Composition

The main source of data was the waste that was disposed of by the participating households. The waste of the participating households was collected before the project and after the project. During two weeks, households that were participating in the 100-100-100 project collected their waste in a separate garbage bag that was collected by ROVA for analysis.

The waste streams were analysed in three different types of sorting tests: (1) a quantitative sorting test (2) a more qualitative sorting test and (3) weighting. A further distinction in the analysis – as discussed in the section above – was that some of the waste was analysed on an individual household level while other waste was analysed for a cluster of households together.

Both the quantitative and qualitative sorting tests were performed by EURECO[5], a company specialised in waste sorting and analysis. During these sorting tests, the occurrence of several (types of) products was measured. An overview of all the product types for the different waste streams can be found in appendix 9.1. The weighting was performed by ROVA during the collection of the waste.

At the quantitative sorting tests, the waste was sorted in the various product categories as specified in appendix 9.1. The weight of all the same products in the waste was then weighted. Before the waste was sorted by handpicking it first passed a vibrating sieve with a sieve opening of 40 by 40 mm. Objects that fell through the sieve were not handpicked but were put in the 'miscellaneous' category. This analysis was performed for the residual waste, plastic packaging

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[5] http://www.eureco-onderzoek.nl

waste and organic waste of the 50- group. Furthermore, the organic waste of the 50+ group was also analysed this way.

At the qualitative sorting test, the waste was again handpicked. But the occurrence of various product types was only recorded, not weighted. Both the correctly and incorrectly sorted waste were then separately bundled and weighted. Resulting in the weight of the correctly sorted fraction and the incorrectly sorted fraction. This type of analysis was performed for the residual waste and the plastic packaging waste of the 50+ group.

When the waste was collected at the households by ROVA, it was weighted as well. This means that the total weight of the waste stream is known. However, the composition of the waste could not be determined. For the paper waste stream of both the 50- and the 50+ group, the weight of the waste was the only information that was available. Therefore, it was assumed that the paper waste stream was completely correctly sorted.

Figure 5 gives a full overview of the different analyses per group and waste stream.

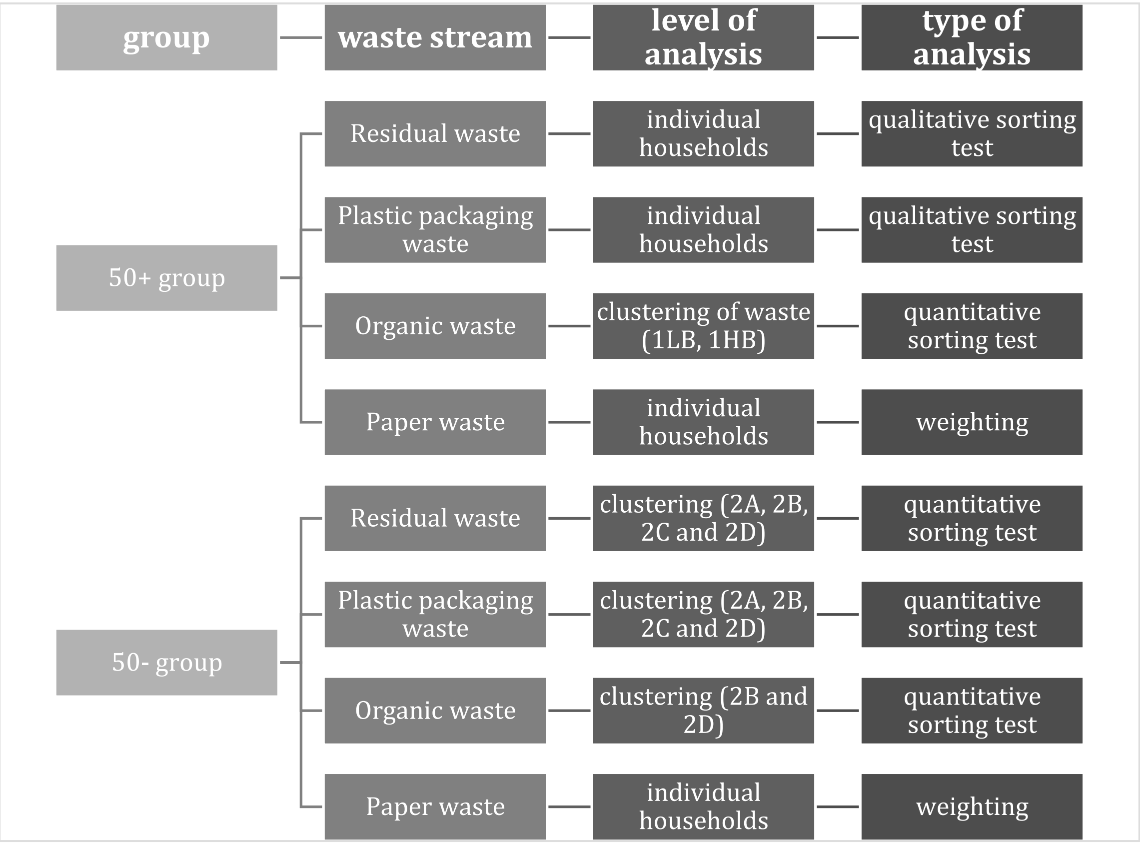

Figure 5. Overview of the waste composition analysis per group and waste stream.

At the baseline measurement, the plastic packaging waste was subjected to yet another analysis. All the correctly sorted plastic waste of the 50- group (clusters 2A, 2B, 2C and 2D) was combined per product type, i.e. all the plastic food packaging for all four clusters was collected in one pile. Then the average composition of types of plastic (PE, PP, PVC etc.) was determined per product type. The results of this analysis were used to determine the material composition of each plastic product type. The results of this analysis are shown in section 9.5 (in the table for plastic packaging waste).

Although literature, based on historical waste data of the Dutch municipality of Oostzaan (Linderhof, Kooreman, Allers, & Wiersma, 2001) and the Swedish locality Tvååker (Sterner &

Bartelings, 1999) does not suggest that the amount of household waste differs significantly between the months of the project (November and April). The composition of the waste might change in December due to the various festivities (Sinterklaas, Christmas and New Year's Eve). Therefore, it was a deliberate choice to let the first sorting tests already take place during the 27th of November and the 3rd of December. The waste that was analysed was produced by the participating households in the two weeks prior (thus almost solely in November) to the analysis.

The waste for the impact sorting tests was collected in the week between the 17th of March and the 1st of April. The waste collection infrastructure had changed in the period between the baseline analysis and this impact analysis. ROVA had expanded the types of waste that should be disposed of in the plastic packaging waste stream. The plastic packaging waste stream was transformed to the PMD waste stream in which, next to the plastic packaging, metal packaging and beverage cartons should be disposed. With this change, it became simpler for households to present their waste in a sorted manner. Furthermore, it was likely that the environmental impact of household waste would decline due to this change because the materials in the (larger) PMD stream could be recycled. However, it was not the intention to measure the impact of this infrastructural change in this study. To filter this impact out of the result the beverage cartons and metal packaging that were actually found in the PMD stream at the impact analysis were treated as if they had occurred in the residual waste stream. Implicit in this method is the assumption that the change in collection did not influence the consumption behaviour of the households (i.e. households did not buy extra metal packaging and beverage cartons now that they could be recycled better).

A minor negative effect of this assumption was that the metal packaging and beverage cartons that were found in the residual waste stream at the impact analysis were treated as if they were correctly sorted. However, in reality this metal packaging and beverage cartons should have been disposed of in the PMD stream and were therefore incorrectly sorted.

2.4 Intervention

The intervention took place over the course of the 100 days that the project lasted. As mentioned before, the intervention was more drastic for the 50+ group compared to the intervention for the 50-group. All the support that the 50- group received was also presented to the 50+ group, which then also receives additional support.

2.4.1 50- Group

The intervention was structured around several waste related themes. Each of the themes was the central focus point of the intervention during 1 or 2 weeks. Every week the participants received a small assignment. Examples of assignments are: (1) to report back on how many packages one participant has opened on one day; (2) to collect old and unused mobile phones and hand them in for recycling; (3) to take a picture of the waste resulting of preparation of one dinner, etcetera.

The assignments were communicated to the participant through the main source of information for the 100-100-100 project, the project website. This website additionally featured a community where participants could interact with each other and ROVA employees. On the website, the participants (and others) could also find a list of which product belongs in which waste stream.

2.4.2 50+ Group

After the baseline measurements, all participants of the 50+ group were visited by ROVA employees (waste coaches), which conducted a small semi structured interview during which waste management related information regarding the households in question was collected. In addition, during these interviews, the participants received some individual tips based on the results of the baseline sorting tests (e.g. if a household in the 50+ group would have presented batteries in the residual waste, this would be discussed during this meeting). Furthermore, the 50+ group received a binbang[6], a waste container consisting of multiple compartments meant for recycling. The binbang reduced the effort of waste sorting for households.

2.5 Unmeasured Waste Streams

The scope of this thesis (see Figure 4) did not include all the waste streams that leave the household. For instance, textile waste, household hazardous waste (HHW) and glass waste are not collected in this study. This means that there is not a full view on all of the waste that leaves the participating households. The contents of these waste streams and a possible change over the course of the project cannot be measured. However, these waste streams might have been influenced by some fractions in the residual waste stream. These waste fractions in the residual waste were:

- Glass packaging
- Textile
- Renovation and demolition waste (RDW)
- Electronic and electrical equipment (e-waste)
- Household hazardous waste (HHW)

When the amount of these fractions was smaller at the impact sorting analysis it could not simply be assumed that households prevented all of the waste. Part of the waste might have very well been correctly sorted in one of the waste streams outside the scope of the project. To deal with this uncertainty two scenarios were considered that represent the two possible extremes.

1. In the first scenario (prevention), it was assumed that the possible decrease in these fractions occurred because households had adjusted their consumption behaviour. This means that the abovementioned waste fractions, which were reduced between the baseline and the impact sorting tests, were assumed to be reduced. Therefore, they did not influence the waste streams in which they should originally have occurred. For instance, a reduction of glass packaging fraction in the residual waste stream was assumed not to lead to an increase of glass in the (correct) glass waste stream.
2. In the second scenario (improved sorting), it was assumed that the decrease of the abovementioned waste fractions did lead to a similar increase in the correct waste stream. For instance, a reduction of textile in the residual waste stream was assumed to lead to a similar increase of textile in the (correct) textile waste stream.

The first scenario would likely have the largest positive result regarding environmental impact since it represents the first step in the waste hierarchy. In the case where there is no reduction or even an increase the waste of the impact analysis was just treated as was done for the baseline.

2.6 Environmental Impact Calculation

Determining the environmental impact is a complex process. To analyse the impact of waste on the environment the impact of the lifecycle of the materials was taken into account. This approach assured a realistic and fair comparison between the materials in the varying waste streams (Björklund & Finnveden, 2005). However, since a large amount of different products

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[6] http://www.binbang.nl/?lang=en

were studied in this research, a full life cycle analysis for all of these products was not deemed feasible. Nonetheless, in this research some methods and concepts from life cycle assessment (LCA) were used to determine the environmental impact. Generally, for all the steps in the life cycle of the materials the impact were determined and added up. The steps of the life cycle are generally:

1. raw material extraction;
2. processing;
3. manufacturing;
4. distribution;
5. use and maintenance;
6. disposal

The impact from the usage and maintenance phase would likely be very hard to determine within this research project. The sorting tests of the waste were the main input of data but did not provide information on this level. Therefore, this phase was excluded in the analysis. It should be noted that for a large bulk of the waste (e.g. packaging), this phase was not even relevant since no actual usage or maintenance takes place for these goods.

A full LCA results in scores for a set of relevant indicators (ISO, 2006a, 2006b). In this research, the life cycle indicators that will be used are the primary energy that is required for a product (in Joules) the GHG emissions (in kgCO$_2$-eq) and a score for the impact on the scarcity of the material (no unit). Generally, the cumulative (or life-cycle) fossil energy demand (CED) has proven to correlate relatively well with other measures of environmental impact such as global warming, resource depletion, acidification, eutrophication, tropospheric ozone formation, ozone depletion, and human toxicity (Huijbregts et al., 2006). Since it can be foreseen that GHG emissions might differ significantly from the CED, they will be determined as well. GHG emissions and CED were expected to differ a lot when waste incineration is one of the waste treatment options. This was also found be Huijbregts et al. (2006). For several materials, energy can be recovered through incineration. This will result in a negative effect on the GHG emissions but a positive effect (i.e. less is needed) on the life-cycle primary energy that is required for those materials.

2.6.1 Waste Composition Estimates

To make calculations, quantitative data on the waste composition was required. Given this requirement, the results of the sorting tests for residual and plastic waste of the 50+ group were problematic because these results were not fully quantified. To resolve this problem, estimates of the weight of each product type in the waste stream for each of the 50+ households were made. Table 2 shows a hypothetical scenario that is used to explain the process of estimation. The first column (a) shows the different product types. Column (b) shows the average household waste from the 50- group. Column (c) shows if the material was present in the waste of household X, which was part of the 50+ group. The fourth column (d) shows the estimated waste in household X. The subtotals were measured and therefore do not have to be estimated. Finally, (e) shows the weights that were known. Grey cells hold values that were estimated, black cells hold values that were measured. For both the residual and the plastic waste, this will be the amounts of correctly sorted and incorrectly sorted waste and hence the total weight of the waste.

The underlying assumption is that the ratios in which the product types occur are similar for both the 50- and the 50+ group. This assumption, naturally, was only valid for the first (baseline) measurement. At the second (impact) measurement, the two groups had received different feedback. Hence, the composition of waste might have differed. However, due to the design of the 100-100-100 project, this was the best estimation that could be made.

Table 2. Hypothetical weight estimation for a household (X) in the 50+ group.

Product (a)	HH average (kg) (b)	Present in HH X waste (y/n) (c)	Estimated waste in HH X (kg) (d)	Measured waste in HH X (kg) (e)
		WELL SORTED		
a	5.0	y	*4.8*	N/A
b	1.0	y	*1.0*	N/A
c	2.0	n	*0.0*	N/A
d	3.0	y	*2.9*	N/A
e	1.0	y	*1.0*	N/A
Subtotal	12.0	N/A	9.5	9.5
		INCORRECTLY SORTED		
f	0.5	n	*0.0*	N/A
g	0.5	y	*0.7*	N/A
h	2.0	y	*2.9*	N/A
i	2.0	y	*2.9*	N/A
j	3.0	n	*0.0*	N/A
Subtotal	8.0	N/A	6.5	6.5
TOTAL	**20.0**	**N/A**	**16.0**	**16.0**

2.6.2 Primary Energy and GHG Emissions

To calculate the life cycle energy and the life cycle GHG emissions the iWaste model (Corsten et al., 2010) will be used. iWaste was originally developed to simulate various scenarios of development of the waste processing in the Netherlands. These scenarios were then assessed based on the amount of primary energy and emissions that could be saved due to waste processing.

2.6.2.1 Repurposing iWaste

The largest change in iWaste was to translate the results from the sorting tests to material data with which iWaste is compatible. The format of the results of the sorting tests can be found in appendixes 9.2 and 9.3. To translate the results of the sorting tests to materials, the weight of each product type was multiplied with the average shares of each material it consists of. For instance, metal packaging consists on average of 76% steel, 12% aluminium and 12% copper. If 1 kg of metal packaging is found, it was assumed that it consisted of 0.76 kg steel, 0.12 kg aluminium and 12 kg copper. A full overview of the breakdown from product to materials can be found in appendix 9.5.

For reasons of comprehensibility, the calculation of the life-cycle environmental impact was done for the 15 materials that represent by far the largest share of the waste. These materials were:

- Paper
- garden and kitchen waste (GKW)
- glass
- textile
- steel

- aluminium
- copper
- PE
- PP
- PS
- PET
- PVC
- beverage cartons[7]
- wood
- concrete.

When another material was used for the production of a product this was not considered at all.

iWaste distinguishes between the waste processing of separately and integrated collected materials. The materials that were correctly sorted in a non-residual waste stream constituted the separately collected share of the waste. All other occurrences of the material (i.e. either in the residual waste and/or incorrectly sorted) constituted the integrated collected materials. There was one exception to this rule, non-packaging plastic waste. Officially, non-packaging plastic is not supposed to be disposed of in the plastic packaging waste and should thus have been considered incorrectly sorted. However, in the plastic recycling process there is no distinction made between non-packaging and packaging plastic (J. de Groot, personal communication, May 6, 2015). Therefore, non-packaging plastic in the plastic packaging waste stream was recycled as well.

The output of the original iWaste model is, in line with the original purpose of the model, the amount of primary energy and GHG emissions that were used or abated by the waste processing. However, in this set-up the prevention of waste at the impact measurement (compared to the baseline measurement) would have been penalised. A reduction of waste at the impact measurement would have resulted in smaller amounts of primary energy and GHG emissions that could be saved because there would be a smaller amount of waste to begin with.

To account for this issue, the iWaste model was partially modified to meet the demands of this study. The impact of the production of the – eventually wasted – materials was also taken into account. This was done by using the GER values that were already used in the model to determine the primary energy and GHG emissions that were avoided by material recycling. A GER value is the amount of primary energy that was needed for material production (Corsten et al., 2010; Worrell et al., 1994). Standard emission factors per fuel type (IPCC, 1996) and the average grid emission factor for the Netherlands (CBS, 2015b) were used to convert from primary energy to GHG emissions. When prevention of waste was realised this was reflected in the decreased amount of primary energy and GHG emissions that were needed for raw material production.

To determine the amount of primary energy and GHG emissions that was needed for material production, the total amount of each material that was wasted was considered. This total amount was then multiplied with both the GER-energy value and the GER-emissions value. The results were the primary energy that was used and the GHG emissions that were emitted during material production.

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[7] Beverage cartons are an exception, they are clearly not materials, but products themselves. The recycling process for beverage cartons is very product specific. To model this process correctly the beverage cartons were not translated into different materials.

For almost all material categories in the iWaste model, recycling of the material is assumed to decrease the demand for the raw material, thereby saving primary energy and GHG emissions. Therefore, GER values were already used in the model and could be used to determine material production impacts.

Only for the organic waste category, such a GER value (or composition of GER values) was not readily available in the model because recycling of organic waste (composting or anaerobic digestion) does not reduce the demand for the raw material (organic products). Organic waste consists of various products with hugely varying impacts. To determine the impact of organic waste the impact factors for the various subcategories of organic waste were determined (FAO, 2013; Foster et al., 2006). Together with the ratios in which they occurred at the baseline and the results of the sorting tests by van Westerhoven (2013), this led to an aggregated GER value for organic waste. The derivation of the GER values for organic waste is given in appendix 9.6.

For each material in the waste the primary energy and GHG emissions that were needed for materials production could in this way be determined. To find the impacts of the waste processing, the original version of iWaste was used. Based on the amounts of materials that were integrated or separately collected, the primary energy and GHG emissions that were used or saved by the Dutch waste processing were calculated.

Finally, for each material the result for the waste processing and the material production was added up to find the total impact the disposal of this material had.

2.6.2.2 Updating iWaste

The iWaste model and the accompanying report (Corsten et al., 2010) were published in 2010. Therefore, some of the values that were used in the model were outdated. For some data in the iWaste model, more up to date versions were found. An overview of these updated values is shown in Table 3. Additionally some figures were deemed more appropriate in the modified version of iWaste. In the cases where there was a large difference, an explanation is given below the table.

Table 3. Overview of the values in iWaste that were updated

Updated figure	Unit	Old data	New data	Reference
Emission factor electricity	($kgCO2\text{-}eq/kWh_{elec}$)	0.51	0.48	(CBS, 2015b)
Electricity production efficiency	(kWh_{prim}/kWh_{elec}) [8]	2.26	1.97	(CBS, 2015b)
Post-separation of steel	(%)	65%	82%	(Otten & Bergsma, 2010)
Post-separation of aluminium	(%)	20%	75%	(Otten & Bergsma, 2010)
GER Cotton energy consumption	(GJ_{prim}/tonne) [9]	473	147	(Khabbaz, 2010)

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[8] Inverse of the efficiency of electricity production

[9] These values in the original version of iWaste were in kWh_{elec} the values in this table are converted to GJ_{prim}.

Updated figure	Unit	Old data	New data	Reference
GER Polyester energy consumption	(GJ_{prim}/tonne) [9]	649	217	(Khabbaz, 2010)
GER Cotton CO2-eq emissions	($kgCO_2$-eq/tonne)	31,991	4,000	(Khabbaz, 2010)
GER Polyester CO2-eq emissions	($kgCO_2$-eq/tonne)	43,924	9,000	(Khabbaz, 2010)
Recycling separately collected plastic (PE, PP and PET)	(%)	Varying between 33% to 80%	90%	(J. de Groot, personal communication, May 6, 2015)
Share of high grade recycling of separately collected plastic (PE, PP and PET)	(%)	0%[10]	45%	(J. de Groot, personal communication, May 6, 2015)
GER paper energy consumption	(GJ_{prim}/tonne)	6.04	32.14	(Worrell et al., 1994)
GER wood energy consumption	(GJ_{prim}/tonne)	10.5	19.8	(Worrell et al., 1994)

There are large differences in the values for textiles. The GER values in the original version of iWaste included all the primary energy required to produce final products (clothing that is ready for sale) while the new source only considers the energy that was required to produce the material. This is similar to the use of the GER values for the other materials in iWaste. For instance for plastic packaging, the energy that was required to produce the final packaging was not considered. Only the energy that was required to produce the plastic itself was considered in the model. The new values are also more in line with a review of textile that is used in the United Kingdom (Allwood, Ellebæk Laursen, Malvido de Rodriguez, & Bocken, 2006).

The large increase in the post-separation of aluminium was based on the forecast by CE Delft (Otten & Bergsma, 2010) that the waste incinerators will improve their post-separation of aluminium after the year 2010. CE Delft based this expectation on the intended improvement by the waste incinerators. The post-separation for aluminium was expected to lay in the range 70%-80%. The European Aluminium Association (EAA, 2011) also forecasts an aluminium post-separation of 75% in Western Europe. No reports could be retrieved in which the actual post-separation was communicated. Nonetheless, the forecasts were deemed reliable and the average value of 75% was used.

Based on contact with J. de Groot, manager resources and energy at ROVA (J. de Groot, personal communication, May 6, 2015) the figures for plastic recycling were updated. The separately

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[10] The value for PET was 98%; however, this was for the recycling of PET bottles, which are collected at supermarkets. This waste stream was not measured during the 100-100-100 project and therefore not relevant.

collected PE, PP and PET that ROVA collects were recycled for at least 90%. Of this 90%, 45% was recycled to replace virgin materials.

A more extensive explanation is required for the change in the model regarding paper waste and wasted wood. The reference used for the new value is from 1994 and was therefore clearly available when the first version of iWaste was developed. However, the GER value for both paper and wood were, in the original version of iWaste, lower than the caloric value for paper and wood. This was because the feedstock energy of paper and wood was not included in the GER value. This resulted in the fact that burning paper waste saved primary energy. Additionally, the iWaste model artificially accounted for the feedstock value of both paper and wood by assuming that recycled paper and wood would reduce the demand of wood from production forests. The production forests were then assumed to produce biomass that was used to fuel biomass power plants. The energy produced by the biomass power plant was then assumed to substitute for conventional power production. The reduced use of conventional power production was then attributed to the recycling of paper and wood. For the recycling of other materials, the scope for the recycling of materials is not that wide (an example would be that recycled plastic would free up the oil demand).

To maintain consistency, for this study it was decided to include the feedstock energy of both paper and wood the GER values and drop the assumption of freeing up production forests for biofuel production.

There was no need to update the values of CO_2 emissions of paper and wood. The GHG emissions of paper and wood incineration are considered to be short cycle emissions which means that they were only recently taken up from the atmosphere (during tree growth) and therefore, over a longer time horizon, do not contribute to a net increase of carbon in the atmosphere.

The results of these structural changes in iWaste were that recycling of paper waste uses less primary energy than incineration. However, the incineration of paper results in less life-cycle GHG emissions than recycling. The iWaste results for paper are still somewhat arguable and various studies have shown positive impacts while others have indicated negative impacts from paper incineration (Benner, Otten, Wielders, & Vroonhof, 2007).

The incineration of paper was used for energy production. Because it has no net GHG emissions, the energy from paper incineration has less GHG emissions than conventional energy production. Since the energy from waste incineration replaces conventional energy production, the incineration of paper reduces GHG emissions from energy production. However, with decreasing emissions in conventional energy production, the incineration of wasted paper will reduce a smaller amount of GHG emissions. If the conventional energy production would become carbon neutral, the incineration of wasted paper would have higher life-cycle emissions than conventional energy production (primary paper production results in the emission of GHGs, therefore the emissions over the whole life-cycle are higher). Therefore, it would result in extra GHG emissions, rather than GHG emissions savings. With an increasingly carbon neutral conventional energy production, the recycling of paper will also become preferable in reducing GHG emissions (Benner et al., 2007)

2.6.3 Absolute Scarcity and Critical Materials

The basic principle of circular economy is not the reduction of energy and GHG emissions related to waste, but to reuse materials in the same or at a higher quality. Therefore, scarcity of the materials in the waste is taken as a third indicator of environmental impact. The scarcity of materials is not necessarily linked to the use of energy or the emission of GHGs. However, generally increasingly more energy is required to extract resources that are becoming scarcer (Klinglmair, Sala, & Brandão, 2014).

The analysis of the scarcity of the materials in the household waste will be twofold since a distinction between two types of scarcity is made. The first type of scarcity is *absolute (or geologic) scarcity* (Henckens, Driessen, & Worrell, 2014) which only takes into account the global availability of a material (or its raw material inputs) and the extraction rates for that material. The other type of scarcity is also known as *criticality*.

2.6.3.1 Criticality of Materials

In this thesis the definition of criticality of materials by the European Commission (2014a). A material is considered critical when it is both of high economic importance and has a high supply risk (see Figure 6).

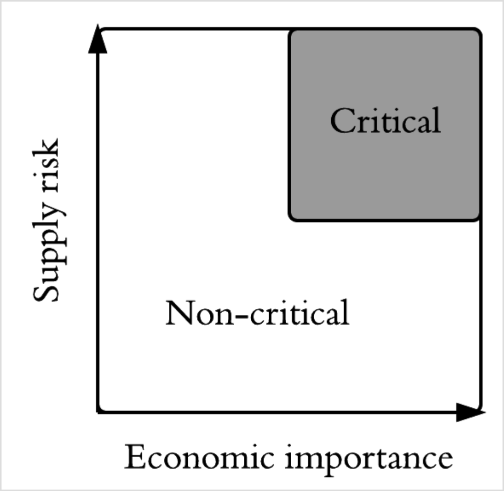

Figure 6. Criticality concept adapted from the European Commission (2014a).

For criticality the supply risk does not include the notions of the total available material on this planet since this will not be relevant on the timescale that the report was meant for (2014-2020, i.e. reserves will not run out on this short time scale). On the other hand, the supply risk is influenced by the dispersion of the resource over the globe. If a resource is concentrated in one or only a few countries the supply risk for that resource is higher. The other factor influencing criticality is the economic importance of a material. Criticality is of course different for the different countries/regions over the world. For example, Rare earth metals are almost solely produced in China and are therefore not critical for China itself. For other regions, however, rare earth metals are highly critical since they almost completely rely on China for their supply. In this thesis the view of countries in the European Union was taken in accordance with the report on critical materials by the European Commission (2014a). Because of the economic cooperation between the EU member states, it makes sense to view the economy of the whole of the EU as one importer of (potentially critical) materials. Additionally, European countries themselves produce very little raw materials and therefore have similar dependencies on raw material imports.

It was studied which materials that are deemed critical by the European Commission (2014a) occur in the household waste and in which quantities they occur. It could subsequently be determined how much of a material was used for products in household waste for both the baseline and the impact measurement. The difference between these measurements showed how much the import of critical materials imported to the European Union decreased.

2.6.3.2 Absolute Scaricity

When assessing the absolute scarcity of resources the potential of renewal or regrowth of a resource has to be taken into account. Generally a distinction between three types of resources can be made (Klinglmair et al., 2014; van Oers, de Koning, Guinée, & Huppes, 2002):

(1) Stock/deposit resources: exist as a finite and fixed amount in the natural environment and has no possibility of regrowth or the regrowth rate of the resources is too small to compare with the rate of human consumption of the resource.
(2) Fund resources: provide a renewable resource when the extraction rate stays below the renewal rate. Dependent on both the renewal and extraction rate a fund either can be expanded or depleted.
(3) Flow resources: are resources that cannot be depleted, the renewability rate of this resource is almost instantaneous. Locally or temporally, however, the resource may become scarce or even depleted.

An overview of the different types of resources and some examples is given in Figure 7.

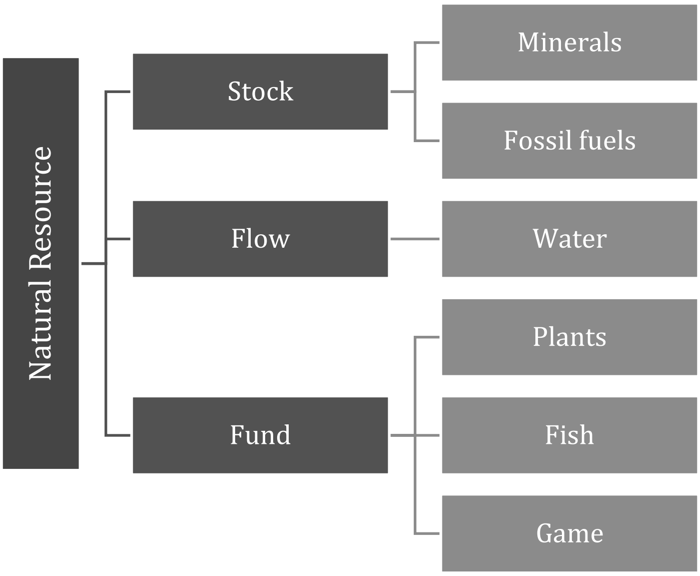

Figure 7. Resource classification, adapted from Klinglmair, Sala, & Brandão (2014).

When considering resource scarcity especially stock and fund resources are critical since they can easily be depleted. Here a more global approach was taken and materials were considered scarce when their global availability is becoming pressing.

It is important to make the distinction between resources and reserves. Resources are the actual occurrence of a material. The extractability – from either an economic or a technical perspective – of a material is not of importance to be classified as a resource. Furthermore, an occurrence of a material does not have to be discovered to be a resource. Because there might always be an occurrence of a material that has not yet been discovered the size of a resource can never be known with full certainty. A reserve, on the other hand, is an occurrence of a material that is known to exist (with large certainty) and of which the extraction can be economic. A price increase of a certain material will thus often result in an increased reserve. Parts of the resource might have been sub economic before the price increase, might then become economic. Resource classification is often done with a McKelvey diagram as shown in Figure 8. This diagram shows categories of resource classification with the increasing geological assurance (right to left) and increasing economic feasibility (bottom to top) (Rogner, 2012).

To analyse the absolute scarcity of the materials in the household waste, the same materials that were analysed with the iWaste model are used as a basis. Solely showing the amount of materials that was used for a product would not give a representative view in line with the LCA scope. Information on the remaining resource also has to be taken into account (Fang & Heijungs, 2014).

There are two kinds of indicators to describe the scarcity of a material, midpoint and endpoint indicators. Endpoint indicators try to capture the impact of the declined availability of a resource, midpoint indicators merely describe the scarcity of a resource (Klinglmair et al., 2014).

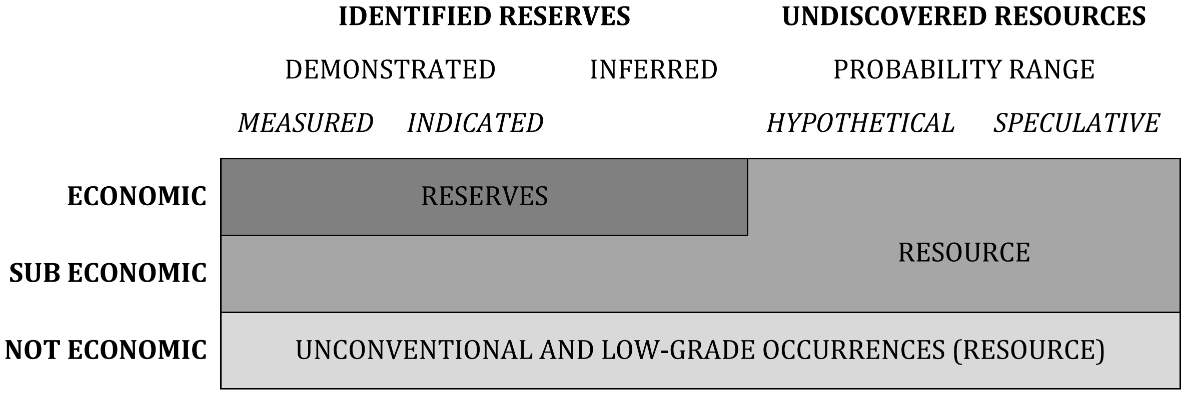

Figure 8. McKelvey Diagram adapted from Rogner (2012).

For this study, it was decided that a midpoint indicator was the most suitable. Trying to capture the impact of the scarcity of a material is value-laden and adds a new layer of uncertainty which was both deemed undesirable. A common midpoint indicator that is used to describe the scarcity of resource is the reserves-to-production ratio (RPR). In the RPR approach, the reserves are divided by the annual production of a resource resulting in the remaining years that a resource can continue to be extracted given that the annual production and the proven reserves remain the same. However, due to changes in both production figures and the resource the RPR is also constantly changing (Feygin & Satkin, 2004).

In this study, the methodology from Henckens et al. (2014) was followed. This approach differs from the RPR in that it is not using reserve figures but estimates for the total amount of a resource. These figures were taken from the UNEP Working Group on Geological Stocks of Metals (UNEP, 2011). It was assumed that 0.01% of the total resource in the earth's upper 1 kilometre crust can be extracted. Furthermore, the known extraction rate in the base year was taken from USGS (2012). Futhermore it was assumed that the extraction rate increases with 3% every year until 2050. Then the estimated remaining extractable amount of a resource is divided by the estimated extraction of the resource in 2050 to find the reaming production years, similar to the RPR.

The sources of data were expanded to include more materials than those that were discussed by Henckens et al. (2014). (ARI, 2013; BP, 2014; USGS, 2000, 2015). The new review by the USGS (2015) would allow for updated calculation compared to the data used by Henckens et al. However, there was no new data available on to total extractable resource. Therefore, the year 2010 remained as the base year in the calculations.

In the scarcity analysis, the amount of material that was wasted was considered as lost. However, only if the material was recycled with high quality and could thus substitute for the same virgin material (e.g. recycled copper substituting for virgin copper), then, that share of the material was not considered lost.

Improving recycling is an abatement option for both absolute scarcity and criticality (European Commission, 2014a; Wagner, 2002), because it will decrease the demand for virgin materials. Hence, the extraction rates that influence the absolute scarcity are lowered and the demand for imports from other countries decrease. The same argument holds of course for the prevention of waste production through reduced consumption.

3. Results

In this section the results of the various ways to determine the composition of the waste streams are presented. The results are compared among the different groups and clusters. The results are also compared between the baseline sorting tests and the impact sorting tests.

The sample size of the 50+ households was intended, in the original set-up of the analysis, to consist of 50 households. However, for 10 households, measurements were not completed during the baseline analysis. One household was deliberately left out of the results since this household was in the middle of moving and did therefore not present any waste to ROVA at the first measurement. Including this household in the analysis would therefore unfairly lower the average amount of waste. The waste of the other nine households was collected by ROVA but, due to a mistake at EURECO, thrown away before it was analysed.

Additionally, four other households did not submit their waste for the impact analysis because they stopped their participation or for other unknown reasons. The waste of an additional five households got lost in between the collection by ROVA and the analysis by EURECO. These events resulted in a remaining sample of 31 households (with only five households of prominent figures remaining). Households for which the analysis was only carried out during one of the measurements are filtered out of the results since the variability between households would then very likely influence the outcomes.

For the 50- sample, all waste was analysed at the baseline measurement but some of the households did not present their waste or again the waste was lost in between collection and analysis at the impact measurement. However, since the waste in this sample was analysed per cluster it was not possible to filter out the results for those households. For cluster 2A no data was missing at the impact sorting tests, for cluster 2B the waste for two households was lost. The waste of seven households in cluster 2C was not available during the impact sorting tests and the waste of one household in cluster 2D was lost. The total sample size for the 50- group shrunk from 50 households at the baseline sorting tests to 40 households at the impact sorting tests.

3.1 Baseline

The first sorting test showed that the categories for the varying waste stream were relatively well chosen. Waste for almost all fractions was found and the 'miscellaneous' fractions[11] were small. Only the 'non-renewable miscellaneous' fraction in the residual waste made up a large share of the residual waste. The size of the miscellaneous fractions was preferably small since it was hard to determine what the contents of those fractions were. The contents of other clearly indicated fractions could be more easily inferred.

A summary of the results for the first sorting test is shown in Table 4. The results shown in this table, however, are not the raw data that was provided by EURECO. The raw data only consisted of the weight for each product group per cluster, for the 50- group, or, for the 50+ group, the occurrence per product type per household and the weight of the well/incorrectly sorted fraction per household. In the table below the total weight for the entire group was aggregated and subsequently converted to the weight of the waste per person per year (kg pppy) using the data on the number of residents per household. With this knowledge, the raw data could be normalised in such a way that it is comparable and conclusions about differences between the groups could be drawn. The complete results can be found in appendix 9.2.

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[11] For example, non-packaging plastic and non-plastic contamination in plastic packaging waste or non-organic/contamination in the organic waste fraction.

Table 4. Summary amounts of waste in the baseline sorting tests.

(kg pppy)	Total	50+	50-	Cluster 2A	Cluster 2B	Cluster 2C	Cluster 2D
Residual Waste	40.54	46.59	36.56	38.43	36.83	27.41	47.86
Plastic Waste	12.81	13.61	12.28	9.70	11.60	12.17	13.99
Organic Waste[12]	65.04	49.46	72.60	-	-	-	-
Paper Waste	46.52	45.48	47.25	39.70	51.79	53.93	41.29
Total	**164.30**	**153.94**	**168.69**	**87.83**	**100.22**	**93.51**	**103.14**

The foremost objective of the 100-100-100 project is reducing the residual waste to zero. The 50- group scores better for this goal at the baseline measurement. However, along with reducing the residual waste the goal of the 100-100-100 project was also to improve the sorting of waste at household level (see Table 5). In the 50- group, the incorrectly sorted waste was smaller (both in percentage of waste and absolute weight). Therefore, the potential for this group to improve was also smaller. The 50+ group scored better on the total amount of waste. The 50- group had a bit more waste (9.6% more).

The results for the 50-group were split up in the different results for the four clusters. The results from the cluster do not include the results of the organic waste since this was only measured for the 2B and 2D cluster. To make the results of cluster 2B and 2D comparable with results of the clusters 2A and 2C the results of the organic waste are not considered here.

The results for the clusters are therefore not comparable with the results for the 50-, 50+ and total group. The results for the 50- group still consisted of the results of all clusters. Since the results for organic waste were only measured for cluster 2B and 2D, they were first normalised to kg pppy and only then included in the 50- group. A similar process was used for the 50+ group with cluster 1LB and 1HB.

Cluster 2B but especially 2A had substantial amounts of incorrectly sorted waste, both in relative and absolute amounts. However, cluster 2A also has the smallest total amount of waste. Cluster 2C scores very well, on both the absolute amount of waste and the amount of correctly sorted waste. Cluster 2D has the largest amount of waste, closely followed by cluster 2B.

As mentioned in section 2.2 and above, five households of the 50+ group were those of prominent figures that were actively recruited for the project. Because the enrolment of those households was different, the sorting behaviour of those households was also expected to be different. The amount of waste that was correctly/incorrectly sorted were weighted. Therefore, they can be presented without considerations. However, the waste composition was only determined qualitatively per household. This methodology is more reliable if it is used for a large sample of households, the outliers will then average out. The organic waste fraction was not analysed on an individual level for the 50+ households and could therefore not be analysed here.

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[12] Organic waste was measured for the cluster 2B and 2D but are not shown here to keep them comparable with cluster 2A and cluster 2C.

Table 5. Baseline sorting behaviour per group and cluster.

	Sorting	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Absolute	Correct (kg pppy)	154.40	142.61	159.71	74.75	89.06	87.81	95.94
	Incorrect (kg pppy)	9.90	11.33	8.98	13.09	11.16	5.70	7.20
Shares	Correct (%)	94.0%	92.6%	94.7%	85.1%	88.9%	93.9%	93.0%
	Incorrect (%)	6.0%	7.4%	5.3%	14.9%	11.1%	6.1%	7.0%

In Table 6 below, the differences between the groups are shown. The households of non-prominent figures sorted a larger part of their waste. However, the difference was very small, only 0.9%-point. The large difference between the groups was the amount of waste that they produced. The group of households of prominent figures produced a larger amount of waste (48% more) than the regular households in the 50+ group. The waste of the regular households was very comparable to that of the various clusters (Table 5).

Table 6. Baseline sorting behaviour of households of (non-)prominent figures in the 50+ group.

	Sorting	**Non-prominent figures**	**Prominent figures**
Absolute	Correct (kg pppy)	88.88	131.89
	Incorrect (kg pppy)	9.90	16.16
Shares	Correct (%)	90.0%	89.1%
	Incorrect (%)	10.0%	10.9%

3.2 Impact

A summary of the results for the first sorting test is shown in Table 7. The total amount of waste for the whole sample does not lie between the values for the 50- and 50+ groups although these two groups combined make up the whole sample. This can be explained by the fact that the samples of both groups (and hence the whole sample) differ per waste stream. The sample to determine the amount of organic waste for the 50+ group consists of only 11 households while the sample for the 50- group consists of 19 households with, additionally, (on average) more residents per household. Therefore, the results of the 50- group are weighed heavier in the results of the total sample. This weighing for other waste stream is more equally divided resulting in this anomaly.

The table again shows the normalised and comparable data. The 50+ group realised a large reduction in the residual waste of more than 10 kg pppy. The 50- group that was already performing better and received less help realised a reduction of 4 kg pppy. Similar reductions were found for the paper waste. The plastic packaging waste subject to only small changes. The results for the organic fraction were the most striking. For the 50- group there was a substantial reduction. However, the organic waste stream of the 50+ group increased over the course of the project with 23.4 kg pppy, an increase of almost 50%. The complete results are shown in appendix 9.3.

Table 7. Summary amounts of waste in the waste streams during the impact sorting tests and the change compared to the baseline (grey and italic).

(kg pppy)	Total	50+	50-	Cluster 2A	Cluster 2B	Cluster 2C	Cluster 2D
Residual Waste	30.47	27.93	32.56	41.84	19.66	21.09	44.64
	-10.07	*-18.66*	*-4.00*	*+3.41*	*-17.17*	*-6.32*	*-3.22*
Plastic Waste	12.87	12.63	13.07	9.48	13.71	13.52	14.28
	+0.06	*-0.98*	*+0.79*	*-0.22*	*+2.11*	*+1.35*	*+0.29*
Organic Waste	58.55	72.86	51.52	-	-	-	-
	-6.49	*+23.40*	*-21.08*	*-*	*-*	*-*	*-*
Paper Waste	38.39	30.30	44.87	33.24	41.51	55.62	41.40
	-8.13	*-15.19*	*-2.38*	*-6.46*	*-10.28*	*+1.69*	*+0.11*
Total	**140.29**	**143.71**	**142.02**	**84.56**	**74.88**	**90.22**	**100.31**
	-24.01	***-10.23***	***-26.67***	***-3.27***	***-25.34***	***-3.29***	***-2.83***

Combining the results from the baseline and the impact sorting tests results in the reduction per group (see Table 8). For all groups the total amount of waste decreased. However, for cluster 2A the amount of correctly sorted waste increased marginally as did the incorrectly sorted waste for cluster 2C. The row with relative values in Table 8 shows the new shares of correctly and incorrectly sorted waste. The change in the share of correctly and incorrectly sorted waste (in %-points) is also given. Both groups and all clusters, additionally to reducing the total amount of waste, also succeeded in decreasing the share of incorrectly sorted waste.

The same steps can also be taken for the regular household and those of prominent figures in the 50+ group (see Table 9). The households of prominent figures did manage to reduce the amount of waste that they with more than 40 kg pppy. By far the largest reduction of any of the subgroups/clusters. However, the largest reduction was realised for correctly sorted waste. The incorrectly sorted waste only decreased marginally. This resulted in the fact that the share of incorrectly sorted waste actually increased for this group. The other households in the 50+ group were already performing better at the baseline and realised larger savings than any of the clusters of the 50- group did. Additionally, they also managed to decrease the share of incorrectly sorted waste and ended up with only 3.6 kg pppy of incorrectly sorted waste.

Table 8. Impact sorting behaviour and change compared to the baseline per group and cluster (prevention scenario).

	Sorting	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Absolute	Correct (kg pppy)	133.07	136.57	134.56	75.60	69.56	84.29	95.35
	Change (kg pppy)	*-21.85*	*-7.12*	*-25.14*	*+0.85*	*-19.51*	*-3.52*	*-0.59*
	Incorrect (kg pppy)	7.22	7.14	7.46	8.96	5.33	5.93	4.96
	Change (kg pppy)	*-2.76*	*-4.31*	*-1.53*	*-4.13*	*-5.83*	*+0.23*	*-2.24*
Shares	Correct (%)	94.9%	95.0%	94.7%	89.4%	92.9%	93.4%	95.1%
	Change (%-point)	*+0.9%*	*+2.4%*	*+0.1%*	*+4.3%*	*+4.0%*	*-0.5%*	*+2.0%*
	Incorrect (%)	5.1%	5.0%	5.3%	10.6%	7.1%	6.6%	4.9%
	Change (%-point)	*-0.9%*	*-2.4%*	*-0.1%*	*-4.3%*	*-4.0%*	*+0.5%*	*-2.0%*

Table 9. Impact sorting behaviour and change compared to the baseline for the (non-)prominent figures (prevention scenario).

	Sorting	**Non-prominent figures**	**Prominent figures**
Absolute	Correct (kg pppy)	61.36	93.76
	Change (kg pppy)	*-27.53*	*-38.12*
	Incorrect (kg pppy)	3.57	13.48
	Change (kg pppy)	*-6.33*	*-2.68*
Shares	Correct (%)	94.5%	87.4%
	Change (%-point)	*+4.5%*	*-1.7%*
	Incorrect (%)	5.5%	12.6%
	Change (%-point)	*-4.5%*	*+1.7%*

Considerable dispersion was found between the waste streams of the varying households, even after correcting for the number of residents per household. The dispersion of the decreases per waste stream and household, however, was smaller. It should be noted that due to the methods of data collection varied per group of households. For the 50- group the dispersion of the results could not be determined since the waste was only measured in four clusters. However, a similar dispersion could be expected for this group.

4. Analysis

In this chapter the waste will be analysed using iWaste to find the environmental impact of the waste for the total sample, the 50+ and the 50- group and the four clusters of the 50- group. Furthermore, the influence of the waste on the problem of resource scarcity and critical materials will be analysed.

4.1 Waste sorting

From the baseline sorting tests it could be seen that the 50+ group had a lower amount of total waste (per person per year, pppy) compared to the 50- group, but also had a larger share of incorrectly sorted waste. At the impact sorting tests, the roles were switched. Both groups reduced their total amount of waste, but the 50- group did this so drastically that it overtook the 50+ group. However, the 50+ group was sorting their waste considerably better at the impact sorting tests, even better than the 50- group. Nonetheless, the 50- group also realised an improvement. This might be explained by the fact that the 50+ group received individual feedback on their sorting behaviour. This feedback might have helped them to improve sorting even further than the 50- group.

The minimum amount of waste that the 100-100-100 participants produced solely by improving their wasting behaviour was on average 140 kg pppy for the residual waste, plastic packaging waste, organic waste and paper waste combined. The ultimate goal of the 100-100-100 project was to reduce the amount of waste in the residual waste stream. At the baseline analysis, it consisted of, on average, 41 kg pppy. At the impact measurement, it consisted of the 30 kg pppy, a reduction of 25%.

The households did reduce the amount of residual waste, the correctly sorted fraction but especially the incorrectly sorted fraction. However, with reducing the amount of waste in the residual waste stream the incorrectly sorted waste in the plastic packaging and organic waste stream did increase. This effect could be due to overenthusiastic participants that started sorting waste, which should actually be disposed of in the residual waste.

The improved sorting of waste, the reduction of waste and especially the reduction of residual waste can be attributed to three aspects:

(1) The first aspect was the prevention of waste. For example, the amount of paper in the paper waste stream was reduced but no increases in waste could be related to this decrease.
(2) The second aspect was a changed consumption behaviour. The amount of non-renewable packaging decreased, but the amount of metal packaging increased.
(3) The third aspect was improved sorting. For example, the amount of organic waste in the residual waste (incorrectly sorted) decreased and the amount of organic waste in the correct waste stream did increase.

Often these aspects interacted and it could therefore not be determined which aspect was responsible for which change. For instance, the amount of paper waste in the residual waste decreased. However, the total amount of paper waste also decreased. The decrease of paper waste in the residual waste could be the effect of waste prevention (i.e. the paper products that were normally disposed of in the residual waste were no longer wasted.) or of improved sorting (i.e. the paper products that were normally disposed of in the residual waste were now disposed of in the paper waste stream).

There were considerable differences between the clusters. The fact that the 2A cluster, which had no additional incentives to sort and reduce their waste, had the lowest amount of waste and vice versa for cluster 2D, cannot be explained at this time. At the impact measurement, cluster 2B had surpassed cluster 2A as the cluster with the lowest amount of waste. However, cluster 2D was still performing substantially worse than the other clusters. It generally seems like the clusters that already had the highest incentives to sort their waste had the smallest reduction potential.

Contrastingly, the share of incorrectly sorted waste aligned quite well with the incentives that the varying clusters already had before the project began. The higher the incentive to sort waste, the smaller the amount of incorrectly sorted waste. At the baseline sorting tests Cluster 2C was performing a little bit better than Cluster 2D. However, cluster 2D was performing better at the impact sorting tests.

The difference between the prevention scenario and the improved sorting scenario was very small. The amount of waste that was incorrectly sorted in the residual waste and should not be sorted in one of the other three waste streams was already very small. Nonetheless, the households did still realise a reduction in this fraction.

4.1.1 Mass Flow Analysis

Some products that should have been disposed of in other waste streams than the four that were selected for this thesis (residual, plastic, organic and paper) were still found in the residual waste. For all of these products a reduction was found over the course of the project (see Table 10). As described in the methodology section (2.5), either the wasting of these materials decreased or they were correctly sorted at the time of the impact analysis. For all groups, all of these materials did either decrease or stayed at the same level of waste production. Considerable savings in absolute values were achieved for textile and glass packaging. There was little HHW found during the baseline sorting tests and none at the impact sorting tests. RDW was not found during any of the sorting tests. Also for electronic and electrical equipment, reductions were achieved. The only electronic and electrical equipment that was found at the impact analysis was a bicycling lamp in the waste of one household in the 50+ group.

Table 10. Reduction per product type (baseline to impact)

(kg pppy)	Total	50+	50-	Cluster 2A	Cluster 2B	Cluster 2C	Cluster 2D
Glass packaging	-0.27	-0.33	-0.24	-0.05	-0.02	-0.07	-0.67
Textile	-0.97	-1.17	-0.84	-0.92	-2.40	-0.31	-0.81
Renovation and demolition waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electronic and electrical equipment	-0.04	0.00	-0.06	-0.03	-0.01	-0.10	-0.06
Household hazardous waste	-0.01	0.00	-0.02	0.00	0.00	0.00	-0.05

As explained before, the decrease of the abovementioned materials were taken for granted in the prevention scenario. In the improved sorting scenario, the amount of decrease of the materials in the residual waste was assumed to increase the correctly sorted amount of this waste (see appendix 9.4). In this scenario, the total amount of waste was thus higher. All the extra waste was attributed to the correctly sorted category. Therefore, the share of correctly sorted waste increased (but the amount of incorrectly sorted waste did not decrease).

The amount of materials that disappeared from the scope of the analysis is very small compared to the total amount of waste that was measured. Therefore, the difference between the improved sorting scenario (see appendix 9.4) and the prevention scenario is marginal as well.

4.2 Primary Energy

4.2.1 Baseline

According to the iWaste model an average primary energy use of all households was 2,537 MJ pppy. The production of the wasted materials accounted for an energy consumption of 4,076 MJ pppy. The waste processing resulted in a primary energy recovery of 1,539 MJ pppy. The waste that was incorrectly sorted had a primary energy use of about 330 MJ pppy while it made up only 6% of the weight of the total amount of waste. The remaining 94% of the weight had a primary energy use of 2,200 MJ pppy. This implies that correctly sorted waste had per kilogramme, on average, only less than half the primary energy impact of incorrectly sorted waste.

The energy impact of the varying materials (see Figure 9) showed some remarkable spikes. Paper was responsible for the largest share of primary energy mainly due to the high amount of paper in the household waste (mostly correctly sorted in the paper waste). In addition, the organic waste had a large impact. Again, this was mainly due to the large share of organic waste. There was not much textile found in the household waste. Nonetheless, it was responsible for a large share of the primary energy use. Textile (cotton and nylon) had the highest GER-energy value of all materials in iWaste. Therefore, the reduction of primary textile production, through either prevention or recycling, would result in large energy savings. The other materials with a high energy impact were the plastics.

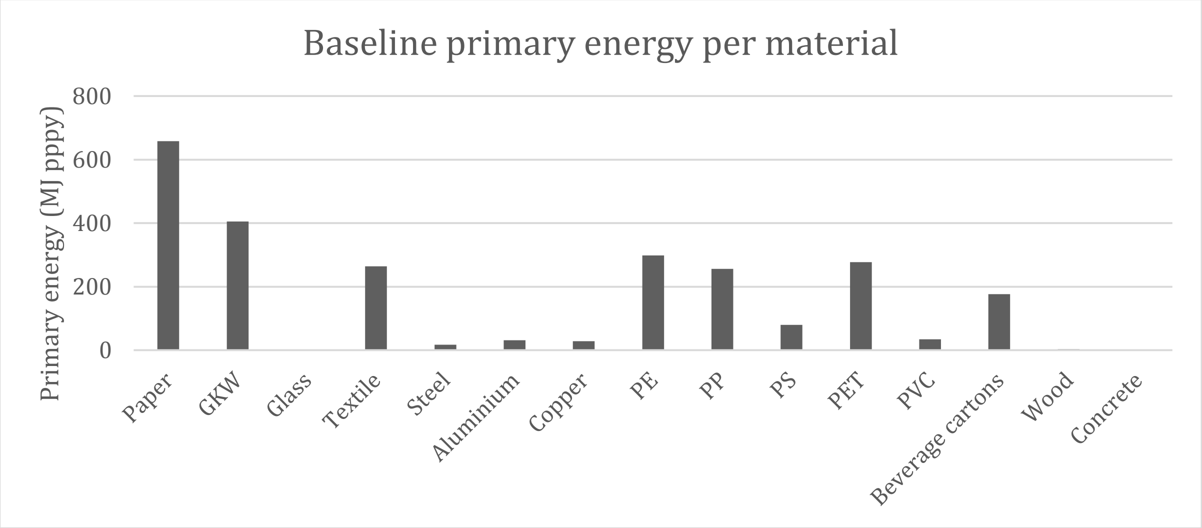

Figure 9. Primary energy use per material.

When comparing between the 50- and the 50+ group (see Figure 10) there were no major differences. The graph shows the aggregated primary energy where the primary energy use of waste processing and material production are combined. The three subcategories in the graph are (1) incorrectly sorted waste, which is all the waste that was produced by the households but disposed of in the incorrect waste stream; (2) waste that was correctly sorted in the residual waste; and (3) waste that was correctly disposed of in any other waste stream than the residual waste. From the graph, it can be concluded that the 50- group already had a smaller share of the primary energy use originating from correctly sorted residual waste and incorrectly sorted waste. The impact from correctly sorted waste, however, was higher for the 50- group.

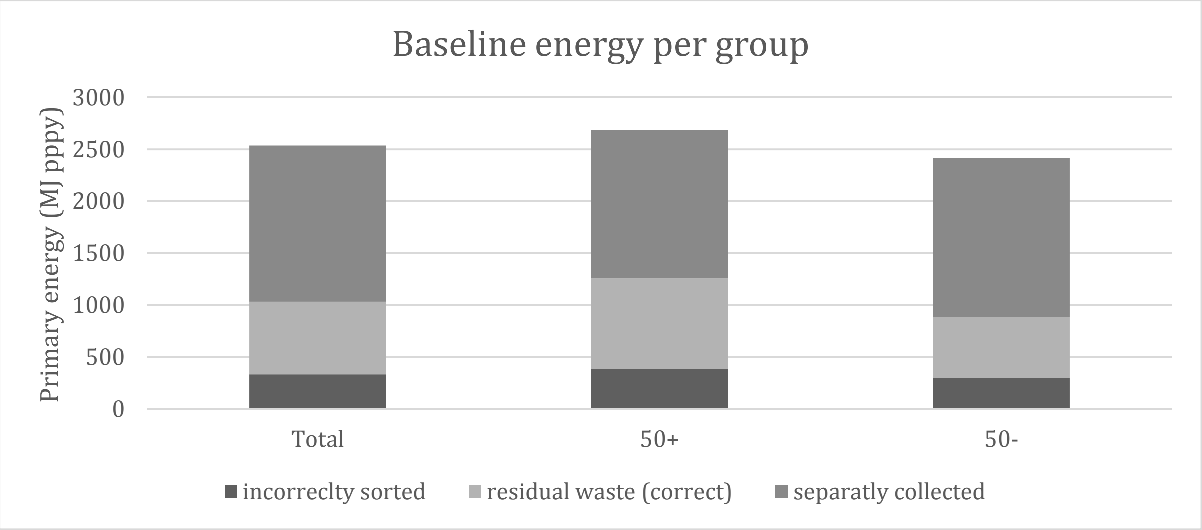

Figure 10. Baseline primary energy use for the groups.

One explanation for the difference between the 50+ group and the 50- group was the role of the households of prominent figures. The prominent figures were actively recruited. Therefore, their wasting and sorting behaviour might have differed from the households that enrolled themselves.

Since the waste of the households in the 50+ group was analysed individually, the results could be corrected for this aspect. However, the results for the organic waste fraction were then also excluded since these were not included in the individual analysis. After the exclusion of organic waste, the 50+ group had a waste related primary energy impact of 2250 MJ pppy and the 50- group (this is the weighted average of the four clusters) 1960 MJ pppy. The 50- group thus still had a lower impact. The difference, however, was smaller. The energy impact related to waste of the group of prominent figures was considerably larger with 3380 MJ pppy.

However, these results should be treated very carefully. The waste of the prominent figures was analysed using the more qualitative sorting test. The determination of the waste composition relied on the assumption that the share of materials in the waste would be comparable to those of the 50- group (see section 2.6). If the process would be performed for a large sample of households, the results can be expected to average out. However, there were only five households of prominent figures remaining in both sorting tests. The results of the prominent figures are used as an indication for the actual primary energy usage. Because the exact results could not be given they will also not be shown in the graphs.

The results from the four clusters of the 50- group are shown in Figure 11. Analogous to the situation described above, the organic waste was not analysed for cluster 2A and 2C. Therefore, the results for the organic waste stream were excluded from all the clusters in the primary energy impacts. The clusters display some differences in impact. The values in Figure 11 are therefore also not comparable to those in Figure 10. Cluster 2A that has the lowest externally provided incentives (no DifTar and no reversed waste collection) has the lowest primary energy use. Cluster 2D (with DifTar and with reversed collection phase 2) with households that had the highest incentives to sort and reduce their waste had the highest energy impact along with cluster 2B. Cluster 2C had a very small impact from incorrectly sorted waste but still a considerable impact from residual waste. Despite the fact that households with high incentives sorted their waste better, their total primary energy impact was higher. Households with high incentives also produced more waste. This means that a larger total amount of waste weighs heavier than the amount of correctly sorted waste in the determination of the primary energy impact.

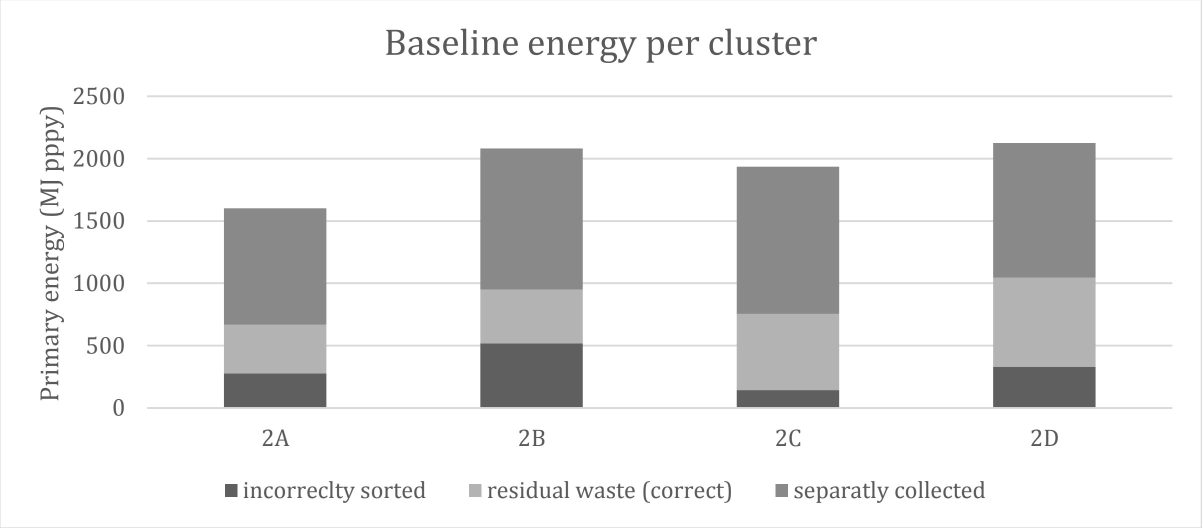

Figure 11. Baseline primary energy use for the clusters.

When looking more specifically from which waste stream the primary energy use originated (see Figure 12), it was found that the organic waste fraction had the smallest impact. Additionally, the impact from incorrectly sorted waste in the organic waste fraction is very small. The largest amount of energy use came from the residual waste stream, which also had a considerable impact from the incorrectly sorted fraction. The plastic packaging waste also had a high impact. However, the impact from incorrectly sorted fraction in the plastic waste was relatively small. This was partly the case because plastic waste had a small incorrectly sorted fraction. Additionally, the materials that were incorrectly sorted in the plastic packaging waste had a lower energy impact per kilogramme than the correctly sorted plastic waste.

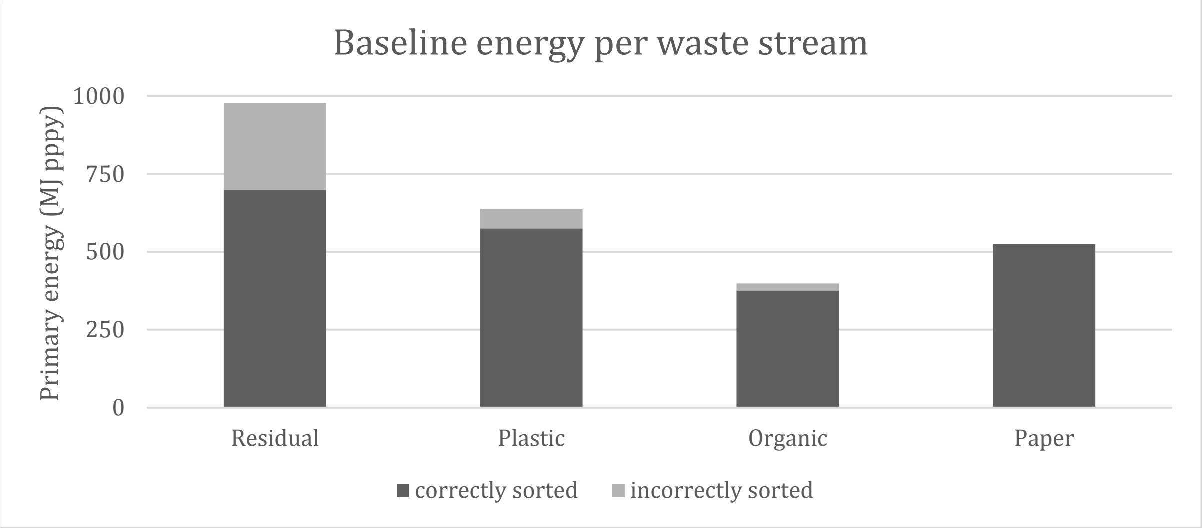

Figure 12. Baseline average primary energy use per waste stream for all participants.

4.2.2 Impact

The second sorting test showed a considerable reduction in amount of both correctly and incorrectly sorted waste. Additionally, the waste at the impact measurement had a smaller share of incorrectly sorted waste compared to the waste at the baseline measurement. Therefore, a reduction in primary energy use was expected. Both groups and all clusters, except cluster 2D, did realise a reduction (see Figure 13 and Figure 14). The total sample reduced their primary energy use related to waste, with 351 MJ pppy (a reduction of 14%). The total primary energy that was required for material production was 3,564 pppy. But through waste processing 1,379 MJ pppy was recovered.

The 50+ group did even better with 560 MJ (21%). The 50- group already did better at the baseline analysis but realised a saving of only 156 MJ (6%). This indicates that more extensive coaching on an individual level was effective in order to reduce the primary energy use. At the impact analysis, the energy impact from incorrectly sorted waste – even though it had more than halved – still was not zero. Therefore, there was an even further reduction potential for the households there. The impact from residual waste was even larger. However, here it is harder to allocate this potential to the households. Some products that are correctly sorted in the residual waste may be indispensable for households (e.g. diapers).

Figure 13 and Figure 14 are comparable to those shown before (Figure 10 and Figure 11 respectively) with the addition of the improved sorting category. The amount of primary energy in the improved sorting category arose from the waste category that was discussed in section 4.1.1 (e.g. textile, glass etc., also see section 2.5). If the primary energy of the improved sorting category is included, this results in the improved sorting scenario. Excluding the primary energy of the improved sorting gives the prevention scenario. The actual impact was somewhere in between these two scenarios.

The difference between the prevention scenario and the improved sorting scenario was small for the waste composition. The only substantial reduction was found for textile and glass. The primary energy impact per kilo of textile is the largest of all materials. Therefore, the difference between the prevention and the improved soring scenario was almost solely determined by the reduction of textile in the residual waste.

For instance, the amount of textile was relatively high in the baseline measurement of cluster 2B (2.55 kg pppy). Consequently, the energy impact for the incorrectly sorted fraction was high for this cluster. However, during the impact measurement the amount of textile was reduced considerable (to 0.15 kg pppy). In Figure 14, the effect of this reduction is clearly visible. The primary energy impact of the incorrectly sorted waste (of which textile in the residual waste was a part) was very large at the baseline. The energy impact from this fraction was decreased largely at the impact analysis. A large share of this decrease can be attributed to the decrease in incorrectly sorted textile. With the assumption underlying the improved sorting scenario, it was assumed that this textile was (correctly) disposed of in the textile waste stream. The impact from textile in the textile waste stream was considerable but smaller than the impact would have been if the textile were still thrown away in the residual waste.

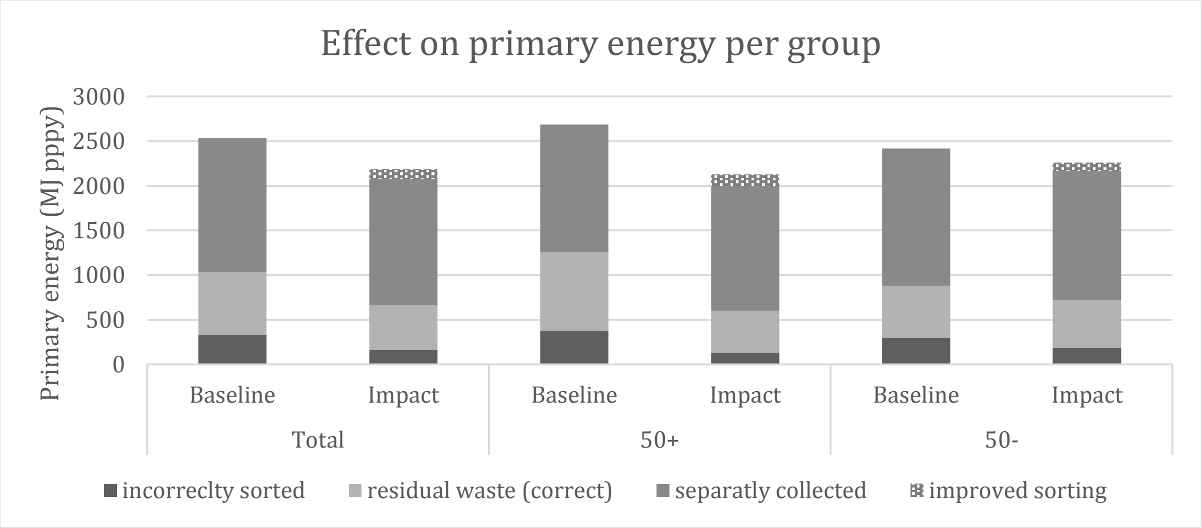

Figure 13. The primary energy effect for the different groups.

For the total sample, the energy impact from the incorrectly sorted fraction decreased with 172 MJ pppy. The impact of the correctly sorted residual waste decreased with almost 200 MJ. Even the impact from the correctly sorted fraction decreased with almost 100 MJ. However, this last saving was completely offset by the primary energy in the improved sorting category (naturally, this was only the case in the improved sorting scenario).

Although the 50+ group did a bit worse at the beginning of the project it was found that the group scored a lower primary energy impact at the second analysis. Especially when the households of prominent figures were left out of the analysis, the difference (again without the organic waste stream) between de 50- group (1880 MJ pppy) and the 50+ group (1510 MJ pppy) was even larger. However, it is also fair to note that the group of prominent figures reduced their primary energy use related to waste to 2330 MJ. This is a saving of almost 40%.

Between the various clusters in the 50- group, there were considerable differences (see Figure 14). Cluster 2A had the lowest energy impact at the baseline and again at the impact measurement. Still reasonable savings were realised, an 8% reduction. Cluster 2B realised a large reduction in the impact from the correctly sorted fraction in the residual waste. As mentioned before this reduction largely comes back in the improved sorting scenario. A large reduction of wasted textile in the residual waste fraction was found, in the improved sorting scenario this textile was assumed to be correctly sorted. At the impact analysis, in the prevention scenario, cluster 2B had the second largest primary energy impact. However, in the improved sorting scenario cluster 2B had the third lowest primary energy impact, a reduction of 5% was realised. Cluster 2C maintained a constant primary energy impact from the incorrectly sorted and separately collected waste, but reduced the impact of the residual waste. This resulted in a total reduction of 9%. Cluster 2D was the only cluster which did not realise savings but a small increase in primary energy impact (4%). However, small savings were found for this cluster in the prevention scenario.

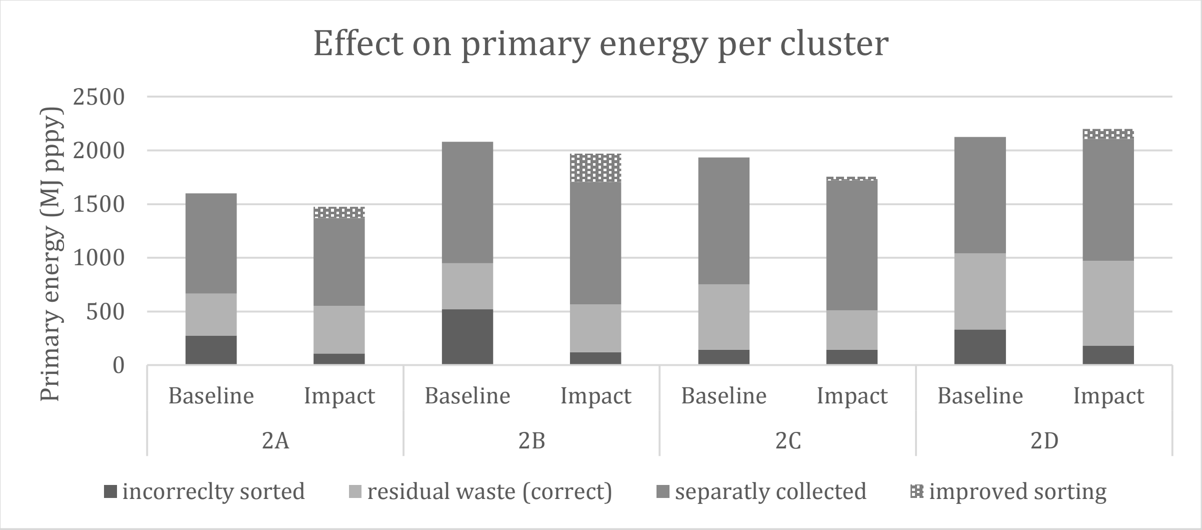

Figure 14. The primary energy effect for the different clusters.

The relative impact of the varying waste streams did also change (see Figure 15). The largest reduction in impact was for the residual waste stream. The impact of both the correctly and incorrectly sorted fraction of the residual waste decreased. More than a threefold reduction in the impact from incorrectly sorted residual waste was realised. The impact arising from the plastic stream also decreased but only with a very small amount. The savings were realised by a decrease in impact of the correctly sorted fraction. The incorrectly sorted fraction of the plastic waste stream did actually increase over the course of the project. This increase could mainly be explained by an increase in aluminium laminated plastic packaging and non-packaging plastic in the plastic waste stream. The impact from the organic waste fraction increased marginally, both the impact from the incorrectly and correctly sorted fraction increased. This could partially be explained by the decrease of organic waste in the residual waste stream. Furthermore, seasonal influences cannot be ruled out.

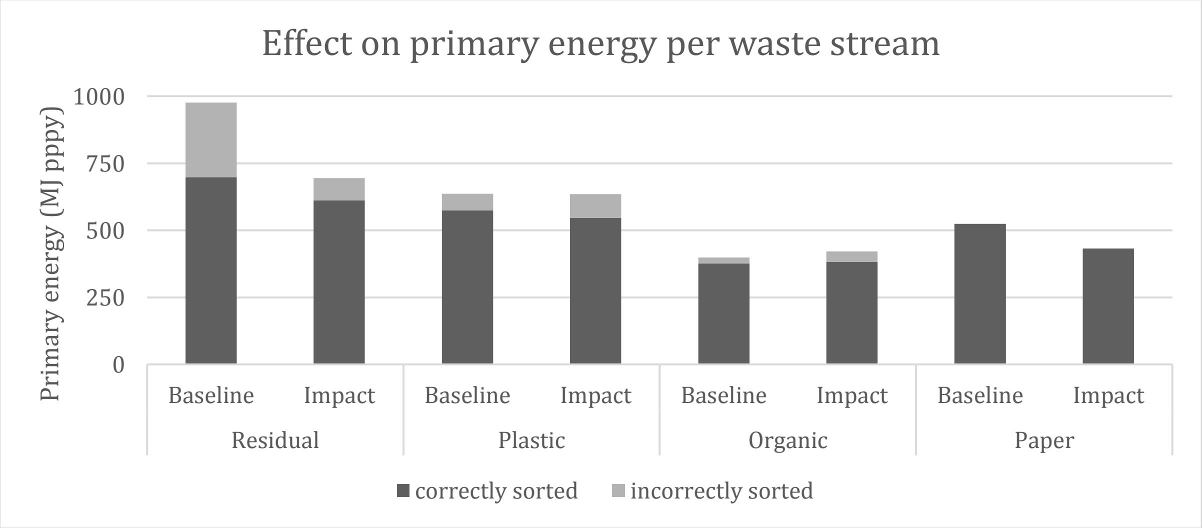

Figure 15. Effect on the primary energy impact per waste stream.

4.3 GHG Emissions

4.3.1 Baseline

The average emissions related to waste for all households in the sample was 218 kgCO_2-eq pppy. An amount of 208 kgCO_2-eq pppy was needed for material production. An additional 10 kgCO_2-eq pppy was needed for waste processing. This immediately presents a remarkable result. The waste processing of the waste of the participants resulted in net emissions. The GHG emissions that were emitted during waste processing could almost be fully attributed to paper waste. The waste processing of paper resulted in GHG emissions of 17 kgCO_2-eq pppy. Additionally, the processing of textile, glass, PS, PET and PVC also resulted in small net emissions. For other materials, the waste processing resulted in a decrease of GHG emissions (for example, through prevention of primary production by high grade recycling). However, it should be noted that waste processing was aggregated for both the correctly incorrectly sorted materials.

When looking at the aggregate (i.e. waste processing combined with material production) GHG emissions impact per material (see Figure 16), a different picture than for primary energy arises. Paper did not have the largest impact; the emissions impact of textile compared to the other materials was also smaller than for primary energy, however still considerable. The outlier was the organic waste (or garden and kitchen waste). Despite the fact that they were relatively well sorted, the plastics constituted a large fraction of the emission impact.

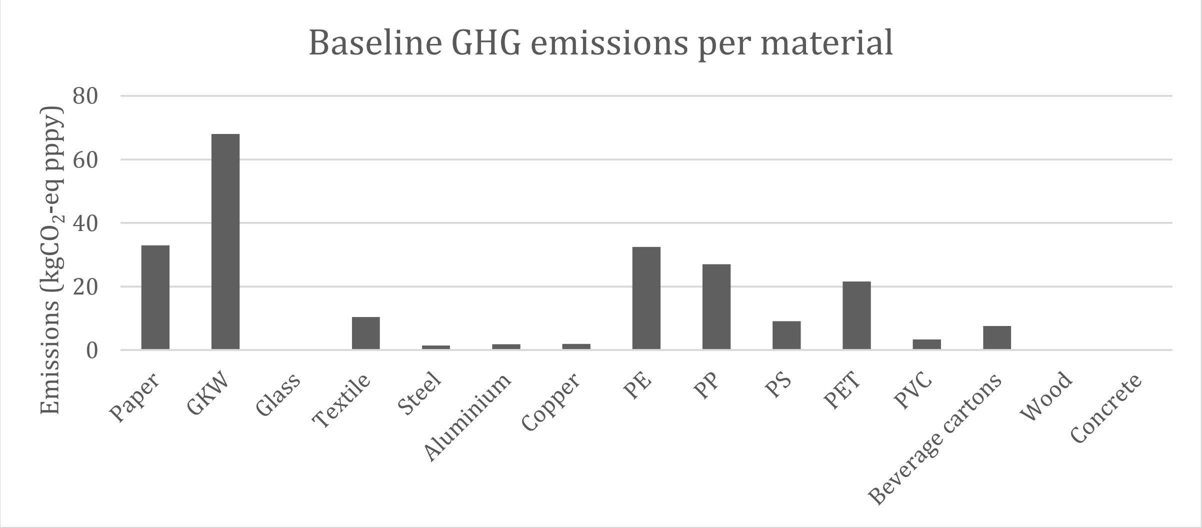

Figure 16. GHG emissions per material at the baseline.

In Figure 17, the difference between the two groups is shown for the emissions impact. The impacts per category shows similar results as for the primary energy. However, the sums of the categories showed that the emission impact was actually very similar for the two groups. The 50+ group still has a marginally higher GHG emissions impact 220 kgCO_2-eq versus 214 kgCO_2-eq for the 50- group. Given that the weight of the correctly sorted fraction (of all waste streams) was bigger than the weight of the incorrectly sorted waste fraction, the impact per kilogramme was twice as big for the latter fraction.

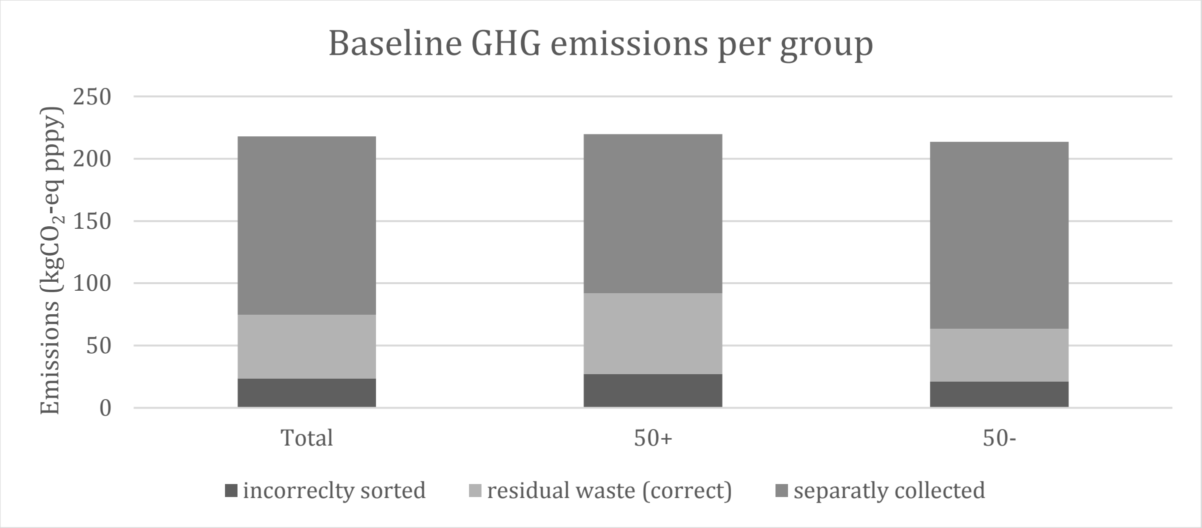

Figure 17. Baseline GHG emissions for the two groups.

Also for GHG emissions the 50+ group thus had a higher impact. Looking at the group of households of prominent figures in the 50+ group, the GHG emissions related to their household waste was 252 kgCO$_2$-eq pppy. For the other households in the 50+group the GHG emissions impact is only 162 kgCO$_2$-eq pppy. Both these values are higher than the average of the clusters of the 50-group. In Figure 17, however, the impact of organic waste was considered as well. This aspect brings the impact of the groups closer together.

For the varying clusters, the individual categories (see Figure 18) also followed a similar pattern for the relative impacts per category as was found for the primary energy values at the baseline analysis. However, the relative total impact per cluster was different from the primary energy results: cluster 2B has a lower GHG emission impact than cluster 2C. This could mainly be attributed to the impact from the incorrectly sorted fraction. The primary energy impact of cluster 2C's incorrectly sorted waste was much smaller than that of cluster 2B. This difference was less pronounced for GHG emissions.

GHG emissions from the incorrectly sorted waste in the 2D and 2C cluster were smaller than the GHG emissions of the other clusters, which was in line with the already existing incentives for those clusters. However, Figure 18 also shows that cluster 2C and 2D had the overall highest impact. The impact from correctly sorted residual waste for the 2B cluster was the smallest.

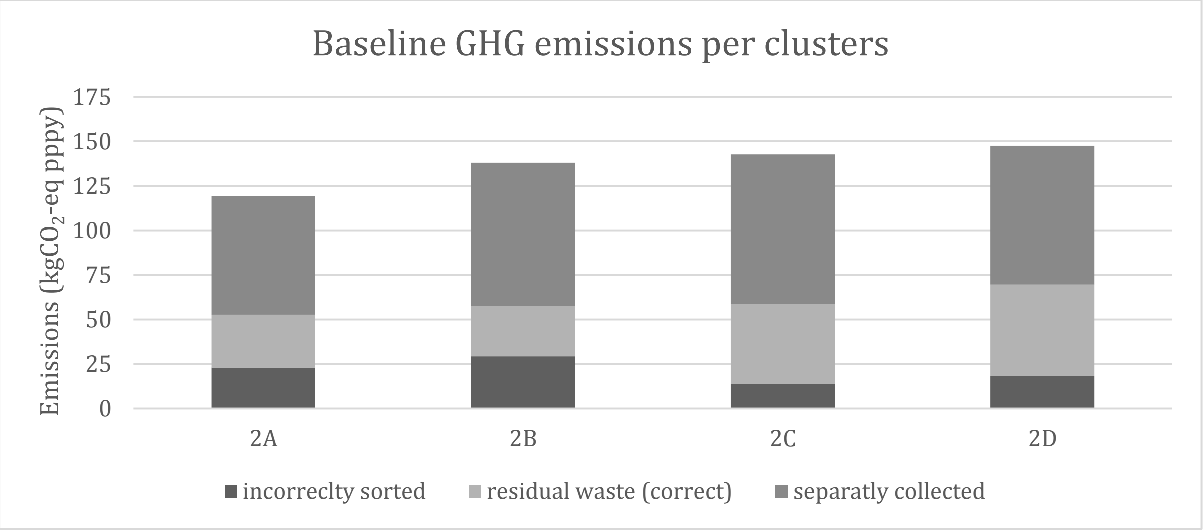

Figure 18. Baseline GHG emissions for the clusters.

GHG emissions mainly arose from the residual waste (70 kgCO$_2$-eq pppy), secondly from the organic waste (65 kgCO$_2$-eq pppy) and thirdly from the plastic packaging waste (49 kgCO$_2$-eq pppy), the paper waste stream resulted in the smallest amount of GHG emissions (34 kgCO$_2$-eq pppy). The GHG emissions from incorrectly sorted residual waste were large (both relative and absolute). Two fifths of the GHG emissions in the residual waste arose from incorrectly sorted waste. The other waste streams only had a small impact from incorrectly sorted waste.

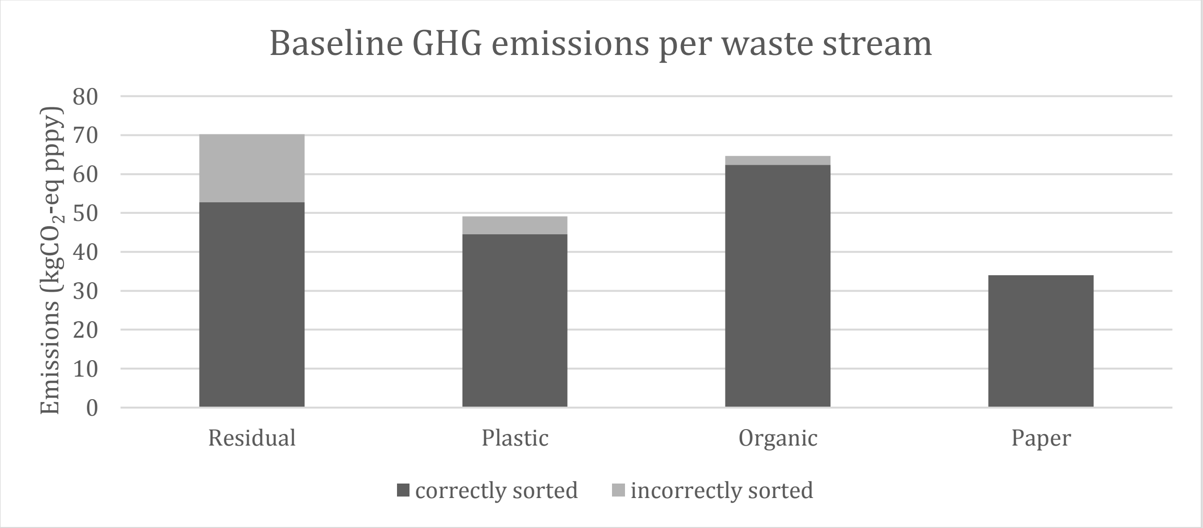

Figure 19. Baseline GHG emissions per waste stream.

4.3.2 Impact

Alongside with the weight of the materials and the primary energy use, the GHG emissions also generally declined over the course of the project (see Figure 20). The GHG emissions that related to the waste were now 193 kgCO$_2$-eq pppy and waste processing resulted in the prevention of 2 kgCO$_2$-eq pppy. Waste processing was not very important from an emissions point of view. For the 100-100-100 group only minor savings compared to the required GHG emissions for material production were achieved by waste processing. At the baseline analysis, the waste processing even resulted in net GHG emissions. Up until the impact tests, the pure reduction of waste was the most effective way to reduce the GHG emissions impact of household waste.

At the baseline, there were only small differences between the two groups and at the impact analysis the 50+ group did only marginally better when considering GHG emissions. The reduction of the total sample was 27.4 kgCO$_2$-eq pppy (a reduction of 13% to 191 kgCO$_2$-eq pppy). The 50+ group started a little bit worse and finished with a low GHG emissions impact (also 191 kgCO$_2$-eq pppy). This group realised a saving of 28.6 kgCO$_2$-eq pppy (13%). The 50- group had a smaller reduction of 19.4 kgCO$_2$-eq pppy (a reduction of 9% to 194 kgCO$_2$-eq pppy). The reduction in GHG emissions mainly came from a reduction of the impact of correctly sorted residual waste and, less so, from an impact reduction originating from the incorrectly sorted waste.

The improved sorting scenario and the prevention scenario were almost identical. As explained in the previous sections the two scenarios only differ marginally on the aspect of weight. The materials that did differ considerable were textile and glass. The primary energy impact of textile, however, was so high that the scenarios differed considerable for the primary energy impact. The primary energy impact of textile was an outlier compared to other GER values. However, the GHG emissions impact of textile is not such an outlier. Therefore, the difference between the improved sorting and prevention scenario was almost negligible.

As can be seen in Figure 20, the impact of the correctly sorted residual waste of the 50+ group was halved and the impact of the incorrectly sorted fraction was even more than halved. The 50- group also realised reductions. However, they were smaller.

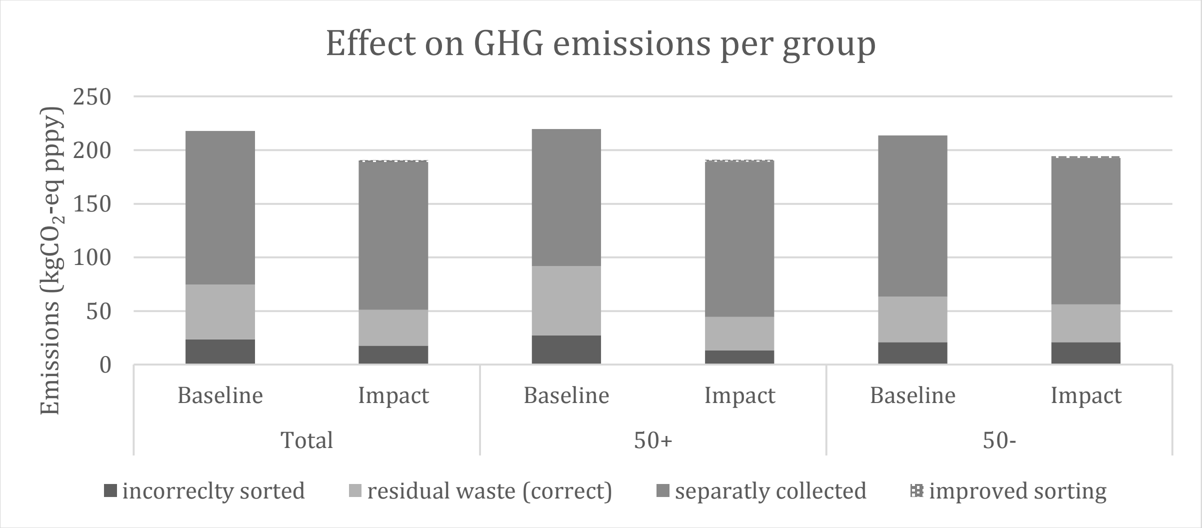

Figure 20. GHG emissions effect for the groups.

At the impact analysis, the group of households of prominent figures (note that this analysis is again without the results of the organic waste stream) had a waste related GHG emissions impact of 167 kgCO$_2$-eq pppy, a reduction of 38%. The other households in the 50+ group reduced their GHG emissions impact to 103 kgCO$_2$-eq pppy, a reduction of 32%.

In Figure 21, it can be seen that for cluster 2B and 2C the impact of the correctly sorted residual waste decreased over the course of the project. For the 2A and 2D cluster, however, the impact of this fraction increased. The impact of the incorrectly sorted waste did decrease for all clusters except for cluster 2C. Furthermore, cluster 2A was the only cluster that realised a decrease in impact resulting from correctly sorted waste. Assuming the improved sorting scenario, cluster 2A and 2C realised a reduction of 10%. 2B realised a reduction of 7% and 2D had an increase of 6% of GHG emissions over the course of the project.

Again, the 2B cluster was the only cluster where the difference between the improved sorting scenario and the prevention scenario became somewhat pronounced. The difference between the scenarios for cluster 2B was 4.1 $kgCO_2$-eq pppy. For the other clusters, the difference was less than 1.6 $kgCO_2$-eq pppy.

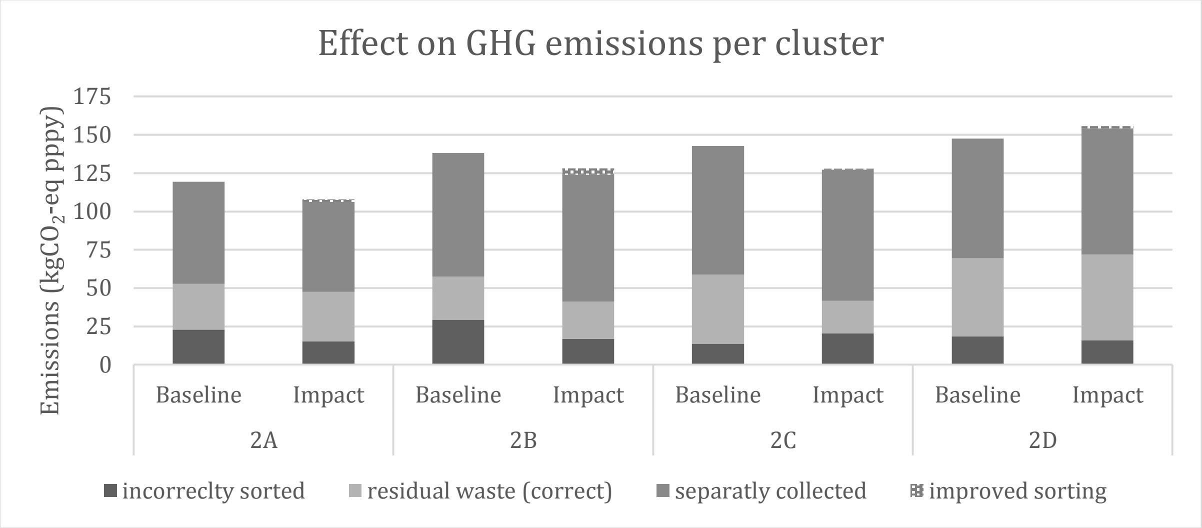

Figure 21. GHG emissions effect for the clusters.

The effects per waste stream (see Figure 22) are very similar to the effects on the primary energy use per waste stream. At the baseline analysis, a large share of the GHG emissions arose from the incorrectly sorted residual waste. Hence, the largest potential for improved sorting behaviour was with the residual waste stream. A big part of this potential was realised at the impact analysis. However, the incorrectly sorted fraction in the residual waste is still the incorrectly sorted fraction with the largest impact. On the other hand, the incorrectly sorted fractions of both the plastic and organic waste stream increased. The total GHG emission impact for the plastic and the organic waste stream increased as well.

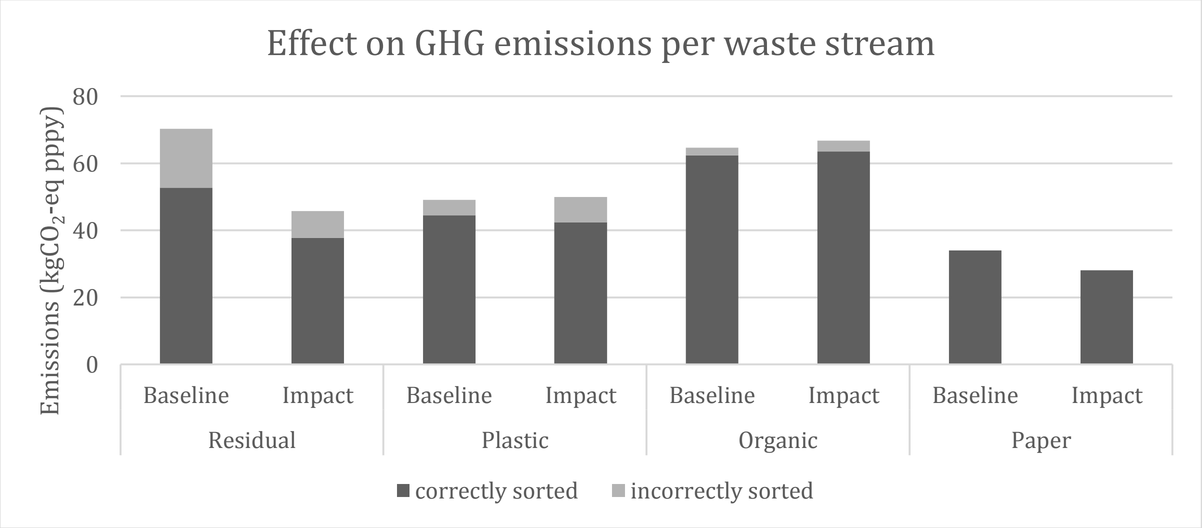

Figure 22. Effect on the emission impact per waste stream.

4.4 Absolute Scarcity

Since stock resources are the most vulnerable to depletion, they were the focus of the analysis. The stock resources that were considered in this analysis are crude oil, aluminium, copper, iron, soda ash and silicon. The iWaste materials that do not originate from these resources were not considered here. All plastics were assumed to consist solely of crude oil. In reality, a small share of plastics is produced from biomass. This share does therefore not influence the stock of crude oil. However, this share is so small (Shen, Haufe, & Patel, 2009) that it was not even considered here. Nylon was also assumed to consist solely of crude oil. Steel is mainly made up of iron; nonetheless, a small part of the steel may also be alloying elements and carbon. Here as well, the steel was assumed to consist solely of iron. For the materials copper and aluminium, the translation to the mineral copper and aluminium is obvious. For the beverage cartons, the composition from the iWaste model was followed: 78% paper, 19% PE/PP and 3% aluminium. For glass, a rough estimate was that it consists for 80% of silicon oxide and for 20% of soda ash (also called sodium oxide). A full overview of these assumptions is given in Table 11.

Table 11. iWaste materials translation to stock resources.

Material in iWaste	Materials for absolute scarcity	Material in iWaste	Materials for absolute scarcity
Paper and board	100% (-)	PP	100% Crude oil
Garden and kitchen waste	100% (-)	PS	100% Crude oil
Glass	80% Silicon 20% Soda ash	PET	100% Crude oil
Textile	50% (-) 50% Crude oil	PVC	100% Crude oil
Steel	100% Iron	Beverage cartons	78% (-) 19% Crude oil 3% Aluminium
Aluminium	100% Aluminium	Wood	100% (-)
Copper	100% Copper	Concrete[13]	100% (-)
PE	100% Crude oil		

The fact that stock resources can eventually be depleted is well established. The degree of scarcity, on the other hand, is still open for discussion. For the minerals iron, copper and aluminium the scarcity data were adopted from Henckens et al. (2014), which is based on data from the USGS (2012) and UNEP (2011). These sources also contain data for silicon oxide and soda ash. For oil a variety of sources was used to find the unconventional (ARI, 2013) and conventional global extractable resource (USGS, 2000) and the production rates (BP, 2014). The data is combined in Table 12 below.

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[13] Although concrete does not come from a renewable resource, it is not considered here since no concrete was found in either the baseline or the impact measurement.

Table 12. Absolute scarcity of relevant stock resources adapted from (Henckens et al., 2014; UNEP, 2011; USGS, 2012)

Material	Extraction 2010 (ktonnes)	Estimated Extraction 2050 (ktonnes)	Estimated total extraction 2010-2050 (ktonnes)	Extractable Global resources (Mtonnes)	Remaining resources 2050 (Mtonnes)	production years 2050 (years)
Aluminium	41,000	133,744	3,200,000	3,200,000	3,200,000	24,000
Copper	15,900	51,866	1,300,000	1,000	6200	120
Crude oil	4,146,930	12,975,702	312,906,090	1,106,204	793,297	61
Iron	1,218,824	3,975,848	96,000,000	1,400,000	1,300,000	330
Silicon	7,290	23,780	573,455	-	-	-
Soda ash	47,500	154,947	3,736,507	-	-	-

Both silicon and soda ash are so abundant that the USGS (2012, 2015) does not make a prediction of the reserve base. Also UNEP (2011) did, for similar reasons, not estimate the extractable global resource for both resources. Since silicon and soda ash are not considered scarce materials, usage of silicon and soda ash does not influence the scarcity of the material, not even on a longer time horizon (such as aluminium, which still has 24,000 production years ahead). Therefore, silicon and soda ash were not considered in the further analysis.

According to the classification scheme by Henckens et al. (2014), oil qualifies as scarce, copper and iron qualify as moderately scarce and aluminium qualifies as not scarce. The waste data from the original iWaste model is sufficient to do a calculation for the scarcity of the four materials that were chosen.

4.4.1 Analysis

As with the impacts on primary energy use and GHG emissions, the 50- group scores a little bit better than the 50+ group for both plastics and the three discussed metals. Less of those materials were lost due to the waste of those groups. For both iron and copper both groups waste 0.35 kg pppy. Aluminium wasting is considerably smaller with only 0.16 kg pppy. The use of crude oil is much larger: 15.4 kg pppy.

There were considerable differences found between the baseline measurement and the impact measurement. The amount of crude oil decreased with 2.5 kg pppy (see Figure 23). It was remarkable that the 50- group stayed at almost the exact same level as before the 100-100-100 project for oil. The 50+ group realised a saving of 4.1 kg crude oil pppy. The result of saved crude oil was realised by two effects:

(1) The pure reduction of plastic in the studied waste streams (i.e. not using virgin materials at all).
(2) The improved sorting through which the high-grade recycling would increase, therefore the amount primary materials that were required would decrease and less of the resource would be lost.

The results showed that on average the 100-100-100 households succeeded in both reducing the amount of plastics used (19.9 kg to 17.6 kg plastic pppy) while they still increased the amount of plastic that could be recycled high-grade.

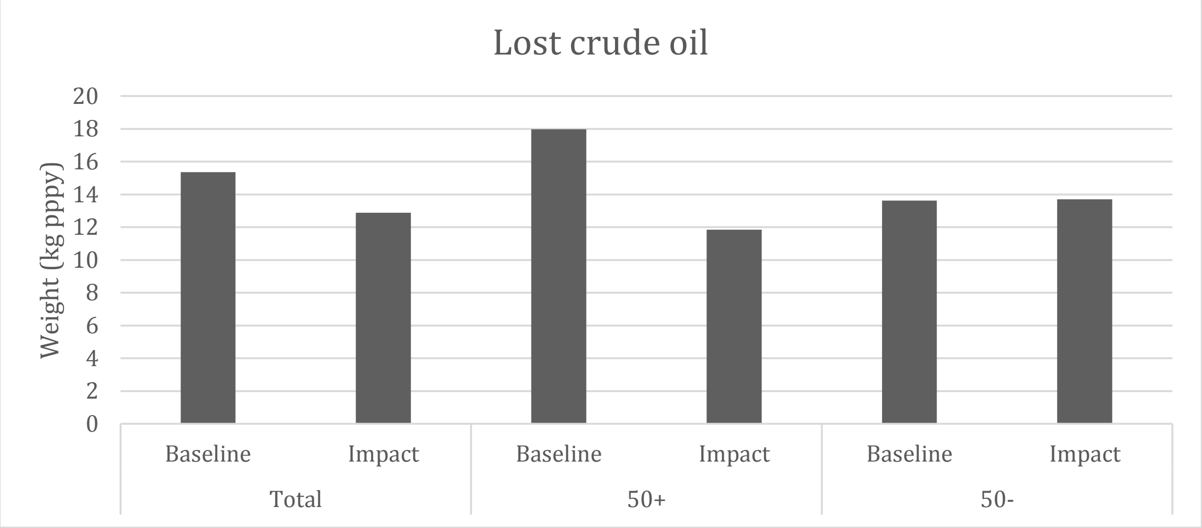

Figure 23. Effect of the 100-100-100 project on the amount of lost oil.

Figure 24 shows that the wasted aluminium increased marginally. However, the wasted iron and copper increased over the course of the project. The iron and copper use increased on average to 0.49 kg pppy (42% increase) and 0.37 kg pppy (9% increase), respectively. Since it was assumed that there was no separate waste collection for metals the only way that the households could realise a reduction would be to reduce the amount of metals in all of the considered waste streams. None of the groups succeeded in this goal. A factor that might be at play here might be the change in collection infrastructure (see section 7.1). Households might have decided to buy their food and other products no longer in non-renewable packaging (with a relatively small share of metals), but in metal packaging (with, of course a high share of metals) that could be correctly sorted.

At the baseline analysis, the 50- group was already performing better than the 50+ group. Despite the increase in metal use, the 50- group was still using less of the metals than the 50+ group at the impact analysis.

An important observation regarding the scarcity is that the materials in laminated packaging were always collected integrated. This makes recycling of the materials in laminated packaging harder than materials in packaging made of one material. Therefore, the reduction of lost materials could also be achieved by buying packaging made of one material rather than laminated packaging. However, this packaging then still needs to be correctly sorted.

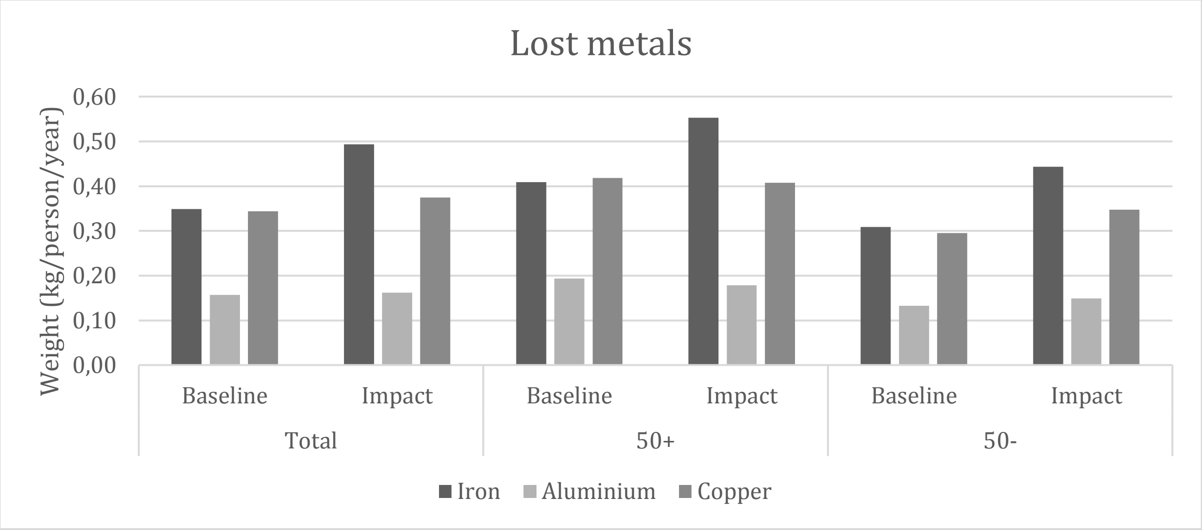

Figure 24. Effect of the 100-100-100 project on the amount of lost metals.

4.5 Critical Materials

Not all the materials that are considered critical by the European Commission (2014a) are used for products that are found in normal household waste streams. However, most of them are used (may it be as minor components) in a broad range of products. In Table 13 below an overview is given of all critical materials and usage of those materials in products that may be present in a household.

Most materials are used in electronics. The only electronics that were found during the sorting tests were in the residual waste. They made up the product category of e-waste. At the baseline measurement, the amount of e-waste was only 41 grams pppy. This was reduced to only 2.5 grams pppy at the impact measurement.

Batteries may also contain one or more of the materials antimony, cobalt, natural graphite and/or heavy rare earth elements (REEs). If they were found, batteries were classified in the HHW fraction. Nonetheless, this fraction likely consisted of more than just batteries. Batteries make up 41% of the HHW fraction in the average Dutch household residual waste (Rijkswaterstaat, 2013). The HHW fraction weighed only 11 grams pppy at the baseline measurement. The amount of HHW was reduced to exactly 0 grams at the impact measurement.

Furthermore, critical materials are also found in (or used for the production of) some more ordinary products, such as, for example, pencils, glass and steel. Reducing the amount of products in waste will also reduce the amount of critical materials used. The data did not allow to look for all these specific product types. As discussed above, the amount of steel did increase over the course of the project. The amount of glass (be it in the residual waste) did decrease over the course of the project from 310 grams pppy to only 20 grams pppy.

Table 13. Critical materials and their everyday use (European Commission, 2014a, 2014b)

Material	Everyday household use	Material	Everyday household use

Material	Everyday household use	Material	Everyday household use
Antimony[14]	Flame retardants Lead-acid batteries Plastics (PET) Glass Semiconductors Alloys	Magnesite	-
Beryllium	Consumer electronics and telecommunications products	Magnesium	-
Borates	Glass	Natural Graphite	Pencils Batteries (Li-Ion)
Chromium	-	Niobium	Steel production
Cobalt	Batteries (Li-Ion)	PGMs	Electronics
Coking coal	Steel (products and packaging)	Phosphate Rock	-
Fluorspar	-	REEs (Heavy)	Electronics Batteries (NiMH)
Gallium	Electronics (Integrated circuits) LED lighting	Silicon Metal	Ceramics Electronics
Germanium	Electronics (Semiconductors) Catalyst in PET production	Tungsten	-
Indium	Electronics (Semiconductors) LCD (Displays)		

It was hard to link the exact materials to the products that were found in the waste of the participants. Generally, some groups of products could be assumed to contain critical materials. Considering the criticality of these materials, recycling of e-waste is of the highest importance because various critical materials are used for all sorts of electronic equipment. Almost no waste that might have contained critical materials was found at the impact analysis. This can be expected to have helped reducing the Europeans dependence on other countries for the import of these (for Europe) critical materials.

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[14] Antimony is also the most absolute scarce metal (Henckens et al., 2014).

5. Relation to the Average Dutch Household Waste

The 100-100-100 project proved to be successful at reducing the environmental impact of the participating households. However, the impact will increase considerably if more households in the Netherlands would start sorting and producing their waste in similar manners as the 100-100-100 households did. This section will relate the findings to the average wasting and sorting behaviour in the Netherlands to those of the 100-100-100 project and the possible influences a similar project could have on the Netherlands.

5.1 Waste Sorting

Two sources were used to compare the waste of the 100-100-100 project with the average waste of the Netherlands. The first source was the data from the central bureau of statistics in the Netherlands (CBS, 2014), which was used to compare the data of the sorting analysis. This data consists of the amount of waste that was collected per waste stream. However, it did not contain any data on the composition of the waste. For this purpose, the original waste data from iWaste was used (Corsten et al., 2010). This data was compiled from various researches and statistics. The data was used to compare the results of the primary energy, GHG emissions and scarcity analysis. The amount of materials in the household waste of 2008 was available for all materials in iWaste. This data had the advantage that it was already expressed in materials rather than (types of products) in the waste.

The data from iWaste included all household waste streams. However, in this thesis only residual, plastic packaging, organic and paper waste were considered. To make the data from iWaste comparable with the data that was collected for this thesis, some waste was excluded. iWaste distinguishes between separately and integrated collected materials (see section 2.6.2.1). Therefore, it was possible only to include the waste streams that were analysed in this study as well. All integrated collected waste was considered (i.e. residual waste and incorrectly sorted waste in all other waste streams). Additionally, the separately collected materials that were supposed to be sorted in the plastic packaging, organic and paper waste stream. For instance, for glass (which should have been sorted in the glass waste stream), only the integrated collected glass was considered. However, for PP (which belongs in the plastic packaging waste) integrated collected as well as the separately collected materials were considered.

The amounts of waste in the two different sources were not equal, the amount of materials in iWaste was a bit smaller (5148 ktonne) than the amount of waste that the central bureau of statistics presented (5812 ktonne). This can be explained by the fact that some materials were weighted in the waste streams in the CBS data but were not considered in iWaste. A similar distinction was made in the assumptions of the original iWaste model (e.g. HHW is not considered at all). A full overview of the materials can be found in Table 14.

Table 14. Amount of materials and sort of collection in original in original iWaste model

Material (ktonne/yr)	Integrated collection	Separate collection	Total
Paper/cardboard	772.0	1240.0	**2012.0**
GKW	791.3	866.7	**1658.0**
Glass	185.0	0.0	**185.0**
Textile	153.0	0.0	**153.0**

Material (ktonne/yr)	Integrated collection	Separate collection	Total
Ferro	124.0	0.0	**124.0**
Aluminium	31.0	0.0	**31.0**
Copper	7.1	0.0	**7.1**
PE	374.9	1.3	**376.2**
PP	129.7	0.5	**130.2**
PS	53.4	0.1	**53.5**
PET	46.3	25.5	**71.8**
PVC	22.8	0.0	**22.8**
Beverage cartons	68.0	0.0	**68.0**
Wood	153.0	0.0	**153.0**
Concrete	102.0	0.0	**102.0**
Total	**3013.5**	**2134.1**	**5147.6**

At the baseline, all the households that participated in the 100-100-100 project performed substantially better than the average Dutch household did. The intervention in the shape of the 100-100-100 project improved the performance of the participants even further (see Table 15). At the impact measurement, the households only produced 30 kg pppy (still assuming that all metal packaging and beverage cartons were found in the residual waste), which is only 14% of the average amount of the Dutch residual waste, 210 kg pppy.

Furthermore, the households also produced a smaller paper waste stream. In addition, the paper waste stream was also reduced even further by the participating households.

The share of the plastic packaging waste of the household is larger than that of the average Dutch household. The Dutch average is lower for plastic packaging because the participating households sort their waste substantially better. The amount of plastic packaging in the residual waste of an average Dutch household is 8.3% (17.4 kg pppy) (Rijkswaterstaat, 2013). Additionally, the separately collected plastic packaging waste was also better sorted by the 100-100-100 participants. The plastic packaging waste of the participating households consisted of 13% incorrectly sorted waste[15]. The average composition of the Dutch packaging plastic waste stream consists for 24% of incorrectly sorted materials (Thoden van Velzen & Brouwer, 2014).

The value for the Dutch average of the organic waste fraction from the CBS included both garden and kitchen waste. For the households participating in the 100-100-100 project the organic waste was supposed solely to consist of kitchen waste (nonetheless, still some garden waste was found during the sorting test). The average composition of the Dutch organic waste stream consisted for one third of the kitchen waste and for two thirds garden waste (Vereniging Afvalbedrijven, 2010). The average Dutch household residual waste also consists of a large fraction of organic waste. On average 41% of the residual waste (86.1 kg pppy) was organic waste (Rijkswaterstaat, 2013).

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[15] This included non-packaging plastics that can be recycled but were not supposed to be collected via the plastic packaging waste.

Table 15. Amount per waste stream compared to the Dutch average.

(kg pppy)	Total Baseline	Total Impact	Dutch average 2013 (CBS, 2014, 2015a)
Residual Waste	40.54	30.47	210
Plastic Packaging Waste	12.81	12.87	7
Organic Waste	65.04	58.55	25 (75)[16]
Paper Waste	46.52	38.39	55
Total	**164.30**	**140.29**	**297 (347)**

A pilot with a similar aim as the 100-100-100 project in Horst aan de Maas showed that residual waste could be reduced to 22 kg pppy (Municipality of Amersfoort, 2014). The project in Horst aan de Maas was done for the whole community, not just for households that registered. Furthermore, it did not rely on a behavioural intervention but an extensive reversed waste collection system in combination with DifTar. The households in Horst aan de Maas received a very high service for more waste streams than even the 2D cluster (with the highest incentives of the 100-100-100 project). In Horst aan de Maas the households did have the possibility to dispose of their metal packaging and beverage cartons and diapers separately (Municipality of Amersfoort, 2014). When correcting for this factor the average households of the 100-100-100 project realised an amount of only 13 kg pppy of residual waste.

5.2 Primary Energy

If all people in the Netherlands would have a similar sorting behaviour as the average 100-100-100 participant, the total primary energy use would be 36.7 PJ[17]. The actual total primary energy use for these four waste streams of all Dutch households according to the waste data from the original iWaste model (see Table 14) is 110.3 PJ. If all households in the Netherlands would thus realize (on average) a similar waste sorting behaviour, primary energy savings of 73.6 PJ (a 67% reduction) would be achieved. However, only the four major waste streams were considered here. Considering that the participating households did very well in waste sorting, it is very probable that the participants presented larger amounts of waste in other waste streams (e.g. glass, textile, HHW waste streams etc.). If this was actually the case, the primary energy impact of the 100-100-100 participants would be larger for these waste streams. The total primary energy use for waste would then still be lower, but closer, to the Dutch average household.

The relevance of such savings can be shown by relating it to the Dutch energy efficiency target. The Netherlands is aiming to reach a primary energy use of 2,520 PJ (60.2 Mtoe) in 2020 as part of the European 20-20-20 targets (European Commission, 2015). Over the year 2012, the Netherlands still used 2,809 PJ (67.1 Mtoe) primary energy. Hence, a saving of 289 PJ of primary energy needs to be realised over in the eight years between 2012 and 2020. A quarter of this savings could be realised by improved waste sorting and waste prevention.

Given the large impact of the average Dutch household's waste, it can be concluded that there is a very large reduction potential. Generally, considerable primary energy savings were possible

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[16] The original CBS data was 75 kg pppy. However, as explained in the text only one third of this waste is kitchen waste while the rest is garden waste.

[17] $2{,}185\ [\text{MJ}\ pppy] \times 16.8 \times 10^6\ [people] \approx\ 36{,}7 \times 10^6\ [\text{MJ}/year] = 36.7\ [\text{PJ}/year]$

both through improved waste sorting and through prevention of waste. The participants of the 100-100-100 project were already performing much better than the average Dutch household was, but showed that further reductions were still possible.

The group of households of prominent figures was performing as the worst group at the beginning of the project but also realised a larger reduction of primary energy use (absolute as well as relative). It can be concluded that the more extensive coaching was more effective on households that score considerably worse than it was for already better performing households.

5.3 GHG Emissions

If all people in the Netherlands would have the same wasting patterns as the average 100-100-100 participant after the intervention, this would have resulted in emissions of 3.2 MtCO$_2$-eq[18]. These GHG emissions from waste may seem considerable. However, the actual emissions related to household waste in the Netherlands – again according to the waste data from the original iWaste model – are 8.4 MtCO$_2$. Just by sorting and producing waste in similar amounts as the participating households did, a reduction of 5.2 MtCO$_2$ (62%) in GHG emissions related to waste could be achieved.

The relevance of the emission savings can be explained by relating them to the carbon budget. The carbon budget is the notion of the maximum amount of carbon that can be emitted by anthropocentric sources while staying within the maximum of 2°C global warming increase, which is deemed relatively safe (IPCC, 2014). The amount of carbon that could be emitted since the year 1880 is 1000 PgC (3670 GtCO$_2$) of which already 515 PgC (1890 GtCO$_2$) was emitted by 2011. To place the emissions from waste within the carbon budget the global carbon budget needs to be translated to a Dutch carbon budget. This was done based on historic emissions figures[19] from the World Bank (2015). It was found that the Dutch emissions constitute 0.54% of the world wide GHG emissions. Hence, we could say that The Netherlands has an historic right to emit 0.54% of the remaining 485 PgC. That comes down to 2.63 PgC, which equals 9,632 MtCO$_2$-eq. If the emissions stay at the same level, 52.9 years remain before the Dutch carbon budget is spent, given the current Dutch GHG emissions of 182 MtCO$_2$-eq. If the savings due to the 100-100-100 project of 28 kgCO$_2$-eq per person were realised in the whole of the Netherlands (0.26% of Dutch emissions) this would give the Netherlands an additional 50 days before the carbon budget would be spent. However, if the average Dutch household would perform as the 100-100-100 group did after the project a saving of 5.7MtCO$_2$-eq would be realised (3.13% of Dutch emissions). This would result in an additional 20 months before the carbon budget would be spent.

The GHG emissions impact of the households of prominent figures was considerably larger at the baseline analysis. However, the amount of GHG emissions of this group was also reduced (both absolute and relatively) the most of all groups. Therefore, also for GHG emissions reduction, the groups that have a higher impact also had a higher reduction with personal coaching.

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[18] $191\ [\mathrm{kg}CO_2 - eq\ pppy] \times 16.8 \times 10^6\ [people] \approx\ 3.2 \times 10^9\ [\mathrm{kg}CO_2 - eq/year] = 3.2\ [\mathrm{Mt}CO_2 - eq/year]$

[19] It is acknowledged that this is a very simplified method and does in no way do justice to the political discussion of which country has a right to emit what amount of carbon. However, this discussion also falls outside the scope of this research. This method is merely chosen to make the impact of the emission savings of the 100-100-100 project more comprehensible.

5.4 Absolute Scarcity

The scarcest material discussed in this study was oil, the resource for the studied plastics and nylon. The weight of the plastic packaging waste stream was considerably larger for the 100-100-100 participants. However, on average the Dutch households produce more plastic waste and throw this away primarily in the residual waste stream. Hence, the amount of plastic that was lost is more than three times higher than the amount that the average 100-100-100 participant was wasting at the impact analysis.

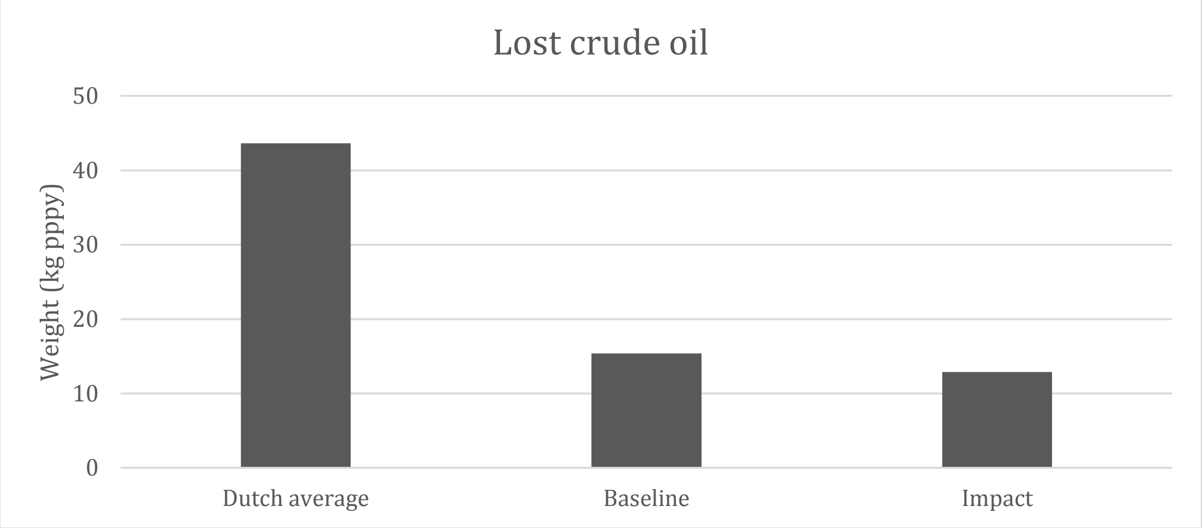

Figure 25. Lost plastics of 100-100-100 compared to the Dutch average.

The amount of metals that were used by the 100-100-100 participants increased over the course of the project. This might be the effect of the improved collection infrastructure for metal packaging. Nonetheless, the amount of metals that were used were lower than the Dutch average. Only the amount of copper exceeded the amount of copper used by the average Dutch household. At the impact analysis, three times less aluminium was wasted and two and a half times less iron.

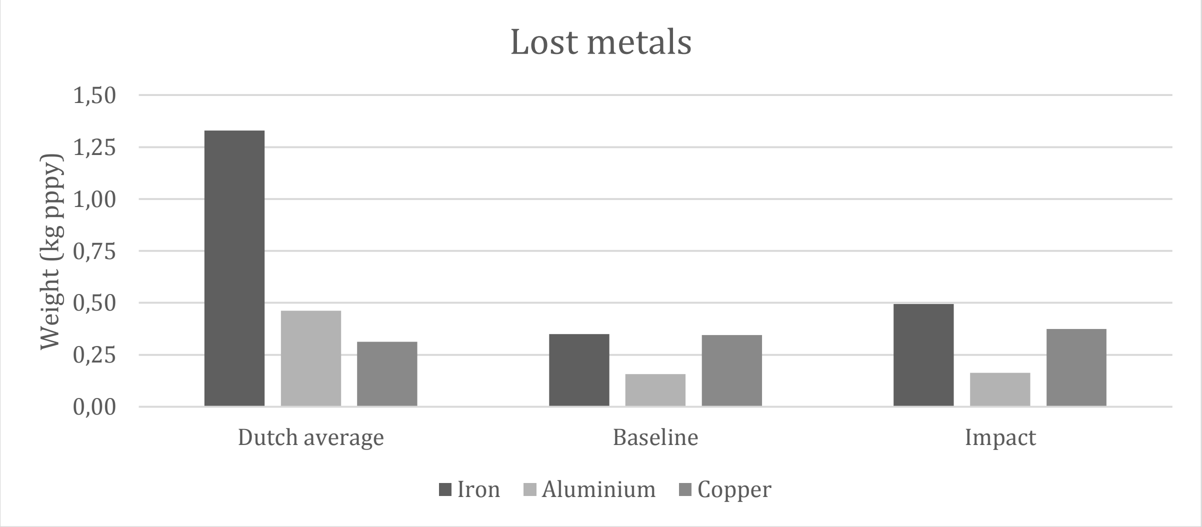

Figure 26. Lost metals of 100-100-100 compared to the Dutch average.

In comparison with the Dutch average, at both the baseline and the impact analysis the 100-100-100 participants were wasting considerably fewer materials. The lower amount of total waste and the better sorting of the 100-100-100 households did, as expected, also result in a smaller amount of lost scarce stock materials.

5.5 Critical Materials

As observed in section 4.5, critical materials are mainly found in the e-waste and the HHW fractions. For the 100-100-100 household these fraction made up smaller shares in the residual waste than the average Dutch household did (0.1% versus 1% for e-waste; and 0.03% versus 0.06% of HHW) already at the beginning of the project. Because the amount of residual waste of the 100-100-100 participants was also smaller, the total amount of HHW and e-waste in the residual waste was considerably smaller. Hence the amount of critical materials in the residual waste could also be expected to be considerably lower. At the impact analysis, the amount of HHW in the residual waste was reduced to completely zero. The amount of e-waste was reduced to 2 grams pppy (only 0.01% of the residual waste).

Since the 100-100-100 participants were sorting their waste well, it was also likely that they sorted their e-waste and HHW correctly (in the e-waste stream and HHW waste stream respectively). These waste streams were out of the scope of this thesis. Therefore, the actual amount of critical materials that was used by the 100-100-100 participants might have been higher and the results of the 100-100-100 participants and the average Dutch household might be closer together. Nonetheless, if this were the case, 100-100-100 participants would then be presenting their waste correctly sorted. This would allow for better recycling of this waste, resulting in less lost critical materials.

6. Conclusion

This section will present the conclusions that can be drawn from the findings of the research and answer the main research question. The main research question of this thesis was:

> *To what extent can a public behavioural intervention reduce the environmental impact of Dutch household waste in 100 days through waste reduction and improved sorting?*

The waste composition of the 100-100-100 participants was, based on weight:

- Organic waste (65 kg pppy);
- Paper waste (47 kg pppy) and;
- Residual waste (41 kg pppy);
- Plastic packaging waste (13 kg pppy).

The composition of the waste differed considerably between the different groups. The 50+ group had a larger residual and plastic packaging waste stream but also a smaller organic waste stream. Both groups sorted the largest part of their waste correctly. The 50+ group sorted 7.4% of their waste incorrectly. The 50- group only sorted 5.3% of their waste incorrectly. Furthermore, some had a considerably larger amount of waste. However, the share of incorrectly sorted waste was comparable to the share of the other households.

The 100-100-100 households managed to reduce their residual waste from 41 kg pppy to 30 kg pppy, a 25% reduction). Additionally, a reduction of the paper waste stream from 47 kg pppy to 38 kg pppy, a 17% reduction and the organic waste stream from 65 kg pppy to 59 kg pppy, a 10% reduction) was realised. The plastic packaging waste stream increased marginally. The share of incorrectly sorted waste decreased even further for both groups to 5.0% and 5.3% for the 50+ and the 50- group respectively. The household realised a larger correctly sorted share and a reduction of waste in three ways:

(1) Improved sorting;
(2) Changed consumption behaviour;
(3) Waste prevention.

However, over the course of the project the fraction of incorrectly sorted waste in the plastic packaging increased (mainly from non-packaging plastic). The amount of incorrectly sorted organic waste also increased (mainly cat litter). This might be attributed to overenthusiastic households that were separately sorting waste that was supposed to be collected in the residual waste stream.

The waste composition of the average Dutch households is considerably different from the waste composition of the 100-100-100 households. The amount of residual waste is much higher (210 kg pppy for the average Dutch household compared to 40 kg pppy for the participating households), mainly because the waste consists of a large incorrectly sorted fraction. The average Dutch household waste has a smaller plastic packaging and organic waste stream. This is due to the fact that large amounts of waste that are supposed to be sorted in the plastic packaging waste and organic waste are still disposed of in the residual waste. The average Dutch household produces more plastic packaging and organic waste than the 100-100-100 participants. Next to the residual waste, the total amount of waste for the measured waste streams is also considerably larger for the Dutch average household (297 kg pppy for the Dutch average household compared to 164 kg pppy for the 100-100-100 participants).

In this thesis, four indicators were used to describe the environmental impact:

(1) Primary energy use
(2) GHG emissions
(3) Absolute scarcity
(4) Critical Materials

(1) The 100-100-100 households, on average, did reduce the primary energy use related to their waste from 2,537 MJ pppy to 2,185 MJ pppy, a 14% reduction. About one third of the primary energy that was needed for the production of the materials was recovered through the waste processing.

(2) The GHG emissions related to waste were reduced from 218 kgCO$_2$-eq pppy to 191 kgCO$_2$-eq pppy, a 13% reduction. The waste processing resulted in net emissions at the baseline measurement. Only at the impact analysis, when the waste was better sorted, the waste processing resulted in small GHG emissions savings. The reduction of waste was the most effective way to reduce the GHG emissions.

(3) The scarcity of four non-renewable materials was discussed in this thesis. First the degree of their scarcity was determined and second, the amount of material that could not be recovered was determined. The use of the ‘scarce’ crude oil decreased from 15.4 kg pppy to 12.9 kg pppy, a 16% reduction. The amount of materials that could not be recovered went up over the course of the project for the other materials. The use of the ‘moderately scarce’ iron goes up with 42% to 0.49 kg pppy. The use of the also ‘moderately scarce’ copper goes up with 9% to 0.37 kg pppy. The amount of lost aluminium increased marginally over the course of the project. However, aluminium is considered a ‘not scarce’ material.

(4) Quantitative data on the amount of critical materials (as defined by the European Commission) in the waste could not be retrieved. However, the waste fractions, of which it was likely that they contained considerable amounts of critical materials, were measured. The size of these fractions decreased over the course of the project. Hence, it is likely that the usage of critical materials has also decreased.

For primary energy use, GHG emissions and absolute scarcity the 50+ group performed worse than the 50- group at the beginning of the project. However, for all these three indicators the 50+ group also had a lower impact at the impact analysis. The extra support that the 50+ group received in improving their sorting and reducing their waste may have translated to a larger reduction for these indicators. Some dispersion in the decreases of waste per household was found. In further research the significance

Generally, the average Dutch household is performing considerably worse than the 100-100-100 participants were. This also means that the average Dutch household has a higher reduction potential. The research showed that with similar individual feedback, households that were performing worse realised a larger reduction. Therefore, a similar project could result in larger reductions of environmental impact of household waste than those that were achieved in the 100-100-100 project. However, this thesis also showed that household that were already performing better before the project were still performing better after the project. Therefore, the relative reduction of the average Dutch household would be larger than that of the average 100-100-100 participant. However, not so large that the absolute impact after the project would be smaller than that of the average 100-100-100 household.

From the results, it cannot be concluded if the average Dutch household has the same motivation to participate in a project similar to the 100-100-100 household. Nonetheless, the reduction potential for the average Dutch household is much larger than that of the average 100-100-100 participant was.

7. Discussion

The central tool of analysis in this thesis was the (modified) iWaste model. In this section the model as well as the rest of the research will be critically discussed. The outcomes of the sensitivity analysis of the model will be discussed. Furthermore, some limitations of the existing research design were found. Those limitations should be kept in mind while interpreting the results but also invite for further research. During the 100-100-100 project, the collection infrastructure changed. The effects of this change are also discussed here. Additionally, there are other options to reduce the impact of household waste. Also these options are discussed here.

7.1 iWaste Sensitivity

The iWaste model is a linear model, i.e. each additional kilogramme of a product type that was wasted has the same environmental impact. The change of the amount of product types was already covered in the previous sections. However, other figures in the iWaste model may have had consequences that were more complex. To determine the sensitivity of the iWaste model both a local sensitivity analysis and a global sensitivity analysis in the form of a Monte Carlo sampling were carried out. The Monte Carlo sampling was performed using @Risk software[20]. The first analysis was used to determine the impact of the various inputs factors. The second analysis was used to show how the model outputs behaved if the figures were varied simultaneously.

These sensitivity analyses were performed for two separate cases:

(1) To determine the impact of increasing efficiency in energy production, both the reference energy production (grid) and the energy production from waste incineration.
(2) To find the influence of the change in values that were updated (see section 2.6.2.2).

7.1.1 Setup

For both the cases the actual probability of the values were not the matter of discussion. The values that were used in the iWaste model were considered realistic. The sensitivity analyses were rather used to determine the influence of possible future developments and the impact of the updated values. Therefore, at the global sensitivity analyses the continuous uniform distribution was used for all variables in both analyses. In Table 16 and Table 17 the interval of the distributions per variable are shown. For the local sensitivity analyses the variables were changed one by one from their base value (the value that was used in this thesis) to the other extreme value of the previously described distribution. The sensitivity analyses were performed on the waste data of the total sample of participating households at the baseline.

In Table 16 the intervals for the continuous uniform distributions are given per variable. In this table only the variables for the sensitivity analysis with improved efficiencies are shown. The values of efficiency and the emission factor of electricity production were extrapolated 5 years into the future from the last known data point (i.e. extrapolated from the period 2000-2013 to 2018) (CBS, 2015b). In the iWaste model, it was assumed that heat was produced by a gas boiler with an efficiency of 90%. However, boilers with an efficiency of 95% have become available and will be used more often in the future (USDOE, 2015). For the expected future increases of efficiency of waste incineration the report accompanying the original iWaste model (Corsten et al., 2010) was used. Already when this report was published these values were achieved by one waste incinerator, these efficiencies can therefore be expected to be achieved by more waste incinerators in the future as well.

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[20] http://www.palisade.com/risk/

The variables for efficiency and the emissions factor of electricity production are somehow related. Nonetheless, in this analysis the distributions are independently defined since there is no fixed relationship between the two variables (i.e. an increase in efficiency of electricity production is likely to, but does not necessarily lead to, a lower emissions factor).

Table 16. Uniform Distributions over the Efficiency Variables for the Monte Carlo Analysis.

Variable name	Unit	Interval	Base value
Efficiency of electricity production	(kWh_{prim}/kWh_{elec})	[1.81 , 1.97]	1.97
Emission factor of electricity production	($kgCO_2$-eq/kWh)	[0.41 , 0.48]	0.48
Efficiency of heat production	(MJ_{th}/MJ_{prim})	[90% , 95%]	90%
Efficiency of waste incineration (thermal)	(MJ_{th}/MJ_{prim})	[7% , 9%]	7%
Efficiency of waste incineration (electric)	(kWh_{prim}/kWh_{elec})	[21% , 28%]	21%

Table 17 presents the intervals of the distributions. The first two variables were also used in the first sensitivity analysis. However, the interval over which they were varied in the analyses differed. The intervals for all variables were between the old and the new values (see Table 3). The new GER values for wood and paper production were not analysed in this sensitivity analysis. These values were not analysed because along with the change of those values the structure of the model was changed. Using the old data in the new model structure would be nonsensical.

Table 17. Uniform Distributions over the Updated Variables for the Monte Carlo Analysis.

Variable name	Unit	Interval	Base value
Efficiency of electricity production	(kWh_{prim}/kWh_{elec})	[1.97 , 2.26]	1.97
Emission factor of electricity production	($kgCO_2$-eq/kWh)	[0.48 , 0.51]	0.48
Post-separation of steel	(%)	[65% , 82%]	82%
Post-separation of aluminium	(%)	[20% , 75%]	75%
GER Cotton energy consumption	(GJ_{prim}/tonne)	[147 , 473]	147
GER Polyester energy consumption	(GJ_{prim}/tonne)	[217 , 649]	217
GER Cotton GHG emissions	($kgCO_2$-eq/tonne)	[4,000 , 31,991]	4,000
GER Polyester GHG emissions	($kgCO_2$-eq/tonne)	[9,000 , 43,924]	9,000
Recycling separately collected plastics (PE, PP and PET)	(%)	[30% , 90%]	90%
Share of high grade recycling of separately collected plastic (PE, PP and PET)	(%)	[0% , 45%]	45%

7.1.2 Sensitivity Analysis 1: Improved Efficiencies

From the local sensitivity analysis (see Table 18), it can be seen that an improved electric efficiency of waste incineration would have the largest decreasing impact on the total primary energy impact of household waste. Furthermore, the thermal efficiency of waste incineration does not have such a large impact because the efficiency does not increase that much. The improved efficiencies also have a decreasing effect on the amount of GHG emissions. Especially the improved electric efficiency of waste incineration and the emission factor of electricity production have large impact. Other improved efficiencies would also lower the impact use but very less so. This can be explained by the fact that an improved heat and power production decreases the amount of energy and emissions that were needed for material production. However, waste incineration also becomes less favourable. The reference heat and power production has become more efficient. Therefore, it uses less primary energy and emits less GHG emissions for each unit of final energy. The energy from waste incineration that substitutes for this final energy thus substitutes for less primary energy and GHG emissions as well.

Table 18. Results of the local sensitivity analysis for improved efficiencies.

Property	**Change in**	
	Primary Energy	**GHG emissions**
Efficiency of electricity production	-0.48%	-0.98%
Emission factor of electricity production	*No change*	-1.44%
Efficiency of heat production	-0.65%	-0.40%
Efficiency of waste incineration (thermal)	-0.49%	-0.32%
Efficiency of waste incineration (electric)	-3.04%	-2.39%

For the global sensitivity analysis, the Monte Carlo sampling was iterated 50,000 times to reach data convergence (see Figure 27 for the probability density function, PDF). Over the distributions of the improved efficiencies, the mean primary energy impact was 2340 MJ pppy (8.5% decrease) with a standard deviation of 23.35 MJ pppy. This means that the improved efficiencies would likely have a considerable effect on the total primary energy use related to household waste.

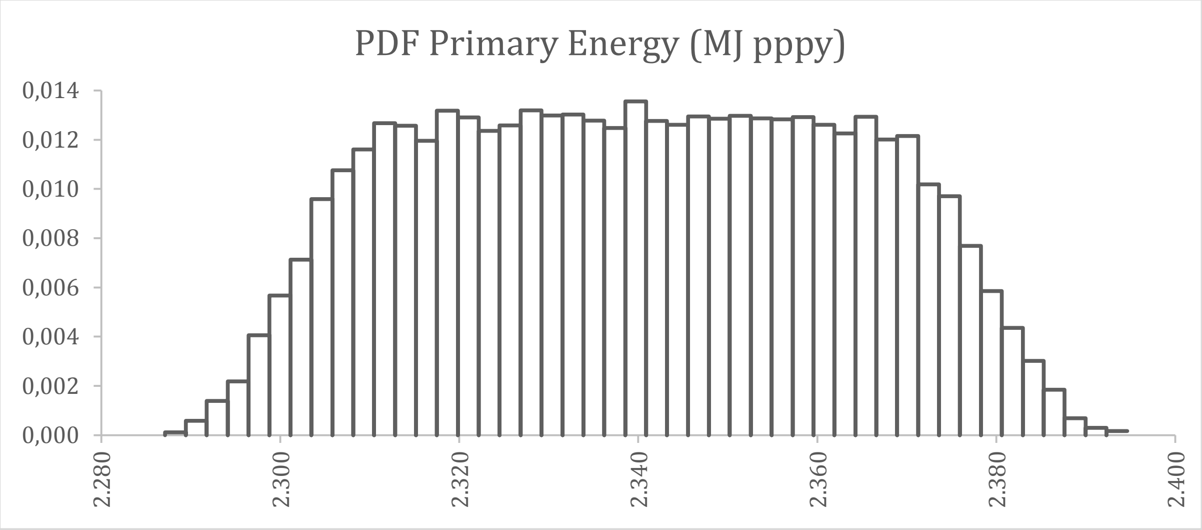

Figure 27. PDF of effect of improved efficiencies on primary energy.

The PDF for the effect on GHG emissions (see Figure 28) shows that the effect on emissions is smaller so. The average of the Monte Carlo sampling resulted in a mean of 215.6 $kgCO_2$-eq pppy (a decrease of 1.2%) with a standard deviation of 1.77 $kgCO_2$-eq pppy. Therefore, the model results for emissions seem to be robust.

The results of the iWaste model that was used for this thesis seem to be robust for anticipated future increases of efficiency. Especially GHG emissions are not influenced much by efficiency improvements. This means that improved sorting and waste prevention remain important options to reduce the environmental impact of household waste.

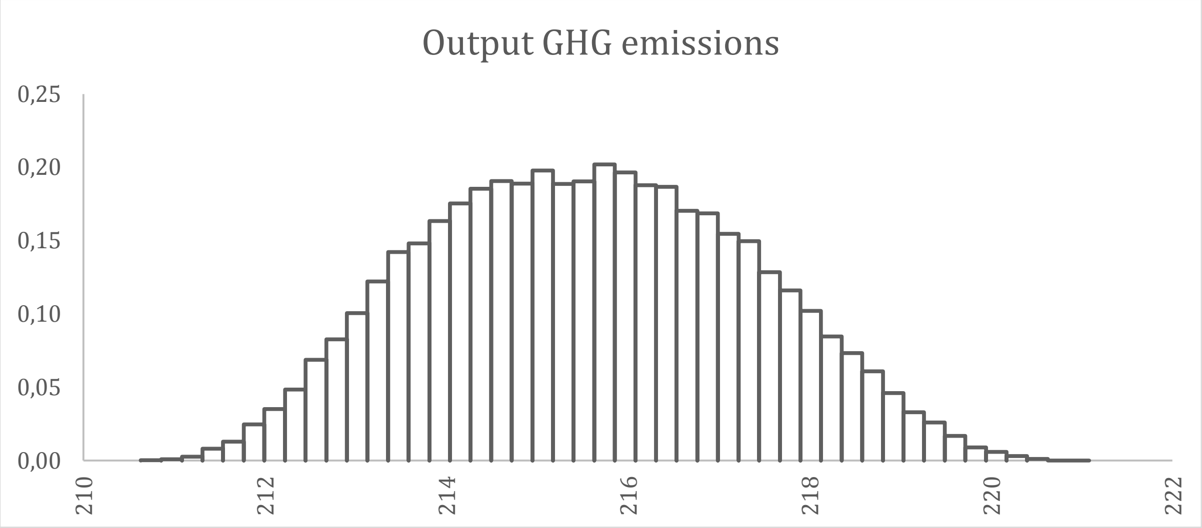

Figure 28. PDF of effect of improved efficiencies on GHG emissions.

7.1.3 Sensitivity Analysis 2: Updated Figures

The local sensitivity analysis for the updated values (Table 19) shows that some variables have a very large influence on primary energy and/or GHG emissions. Especially the GER values for cotton and polyester influence both the primary energy use and the amount GHG emissions. The values were changed largely and hence the influence of a very small waste fraction (1.17 kg pppy at the baseline for the total sample). The old value of the share of plastics (PE, PP and PET) that was recycled was the only value that would decrease the primary energy use. However, this value would also increase the amount of GHG emissions. This shows that the recycling of plastics (note that this also includes low-grade recycling) did not always save primary energy. However, this impact would have had negative effects on the GHG emissions. Additionally, the old value for share of high grade recycling of separately collected plastics (PE, PP and PET) would result in a higher primary energy use and GHG emissions.

Table 19. Results of the local sensitivity analysis for updated values.

Property	**Change in**	
	Primary Energy	**GHG emissions**
Efficiency of electricity production	+0.86%	+1.79%
Emission factor of electricity production	+0.00%	+0.62%
Post-separation of steel	+0.22%	+0.25%
Post-separation of aluminium	+2.35%	+1.64%
GER Cotton energy consumption	+10.13%	*+0.00%*
GER Polyester energy consumption	+13.42%	*+0.00%*
GER Cotton GHG emissions	*+0.00%*	+10.11%
GER Polyester GHG emissions	*+0.00%*	+12.62%
Recycling separately collected plastics (PE, PP and PET)	-5.31%	+2.13%
Share of high grade recycling of separately collected plastic (PE, PP and PET)	+8.15%	+6.94%

The PDF for primary energy resulting from the Monte Carlo sampling (again 50,000 iterations were used to reach data convergence) shows that the changed variables had a large impact on the output (Figure 29). The mean of the PDF was 2733 (a 7% increase) with a standard deviation of 132. Nonetheless, lower primary energy impacts were also possible.

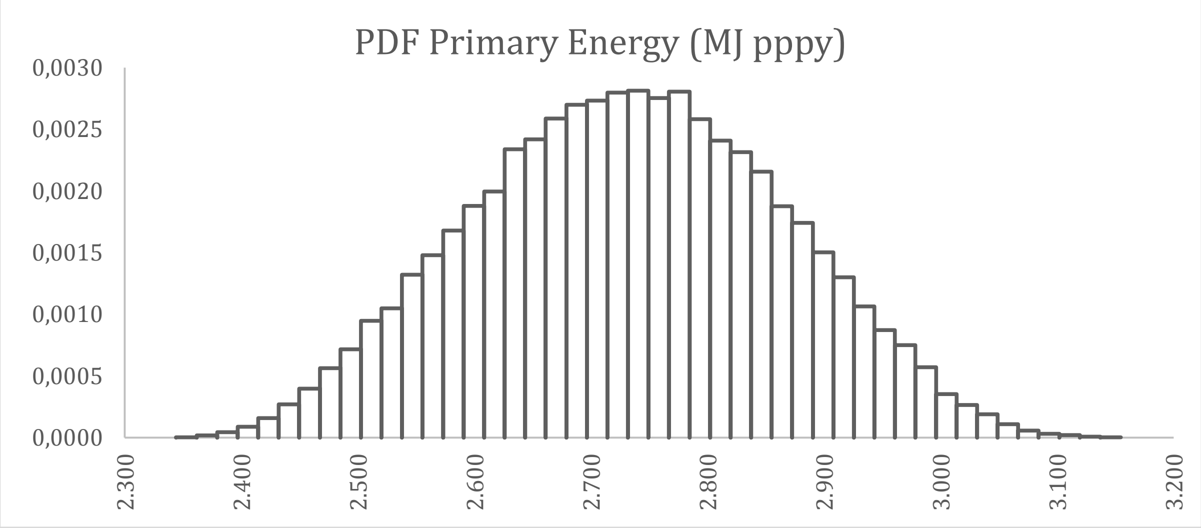

Figure 29. PDF of effect of updated variables on primary energy.

In Figure 30, it can be seen that also for GHG emissions the impact of the changed variables was considerably large. The mean of the PDF is 244.0 kgCO_2-eq pppy with a standard deviation of 11.2 kgCO_2-eq pppy.

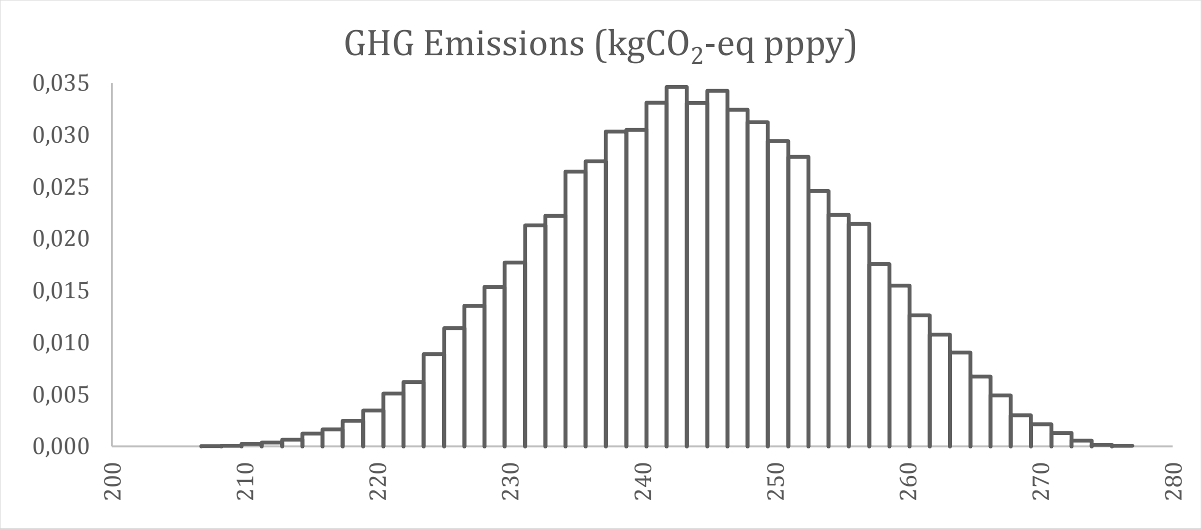

Figure 30. PDF of effect of updated variables on GHG emissions.

The changes of the abovementioned factors did influence the results considerable. The value changes that showed to have a large impact were mostly those for textile waste and the improved recycling of plastics (more recycling and more high-grade recycling). In section 2.6.2.2, the choices for the new values were extensively discussed and accounted for.

7.2 Limitations and Further Research

7.2.1 Simplified view on materials

Materials were central in the iWaste model. Some additional (primary) energy might be needed to produce a finished product (such as packaging) compared to the production of a material. This energy was not taken into account. This energy is generally small in comparison with the energy that was needed for the production of the raw materials as is apparent from the energy requirements for material processing (Heijningen, Castro, Worrell, & Hazewinkel, 1992). Prevention of waste is the only option for this energy to be saved (either through pure prevention or through product reuse). Therefore waste prevention potentially has a higher primary energy and GHG emission reduction potential. Nonetheless, the primary energy and GHG emissions that were needed for material production provided a reliable and revealing insight in the environmental impact of household waste.

7.2.2 Determining Waste Composition

Because the sorting tests were not solely used to determine the environmental impact of household waste, the set-up was also not ideal for this purpose. The quantitative sorting tests were better suited to determine the actual waste composition than the more qualitative sorting tests. However, the more qualitative sorting was more useful in providing specific feedback to the households in the 50+ group. Due to budget limitations, it was considered unfeasible to execute both types of sorting tests for all the analysed waste.

As a result of these different sorting tests the statistical significance of the results could not be demonstrated. In future research it is recommended to use similar ways to determine the waste composition in order to make the comparison more straightforward and reliable.

Furthermore, the households were aware when their waste was collected. They could potentially save up their waste to dispose it in another week. If this would be the case, the reduction as was shown in this project would be overestimated. Nonetheless, household did provide feedback about the total amount of their waste over the course of the project. It is unlikely that they would have saved up waste over the 100 days of the project.

Additionally, only four waste streams were considered here. Since the participating households were shown to perform well on waste sorting, it could be expected that the size of the other waste streams (e.g. textile waste, HHW, etc.) were substantially larger. The environmental impact of the 100-100-100 participants and the average Dutch household may thus be closer together. Nonetheless, the waste of the 100-100-100 participants would then be correctly sorted and would still have a smaller environmental impact.

7.2.3 Population of Households

The enrolment procedure for the participating households relied on the proactive registration of the households after minor publicity for the project. This might have influenced the population of participating households. The participants were already performing substantially better than the average Dutch household was. Ideally, a more diverse group would be randomly selected making the group more comparable to other Dutch households.

As discussed before, the selection procedure was different for some prominent figures in the region of ROVA's working area. They were actively recruited and all put in the 50+ group. This was a smart step from a PR perspective, but it influenced the group composition. Thereby making the 50+ and the 50- group less comparable.

Furthermore, the waste of some households that was not analysed for either the baseline analysis, the impact analysis or both. For the largest amount of waste, this was because it was lost somewhere between collection and the sorting analysis. It was assumed that the lost waste was randomly distributed over the households. Therefore, it could be expected that it did not influence the results too much. However, some households did not present their waste for the impact sorting analysis. It is unclear what the reason was that they did not present any waste. It might be the case that those households were not randomly distributed over the group of participating households. For the 50+ group the results could be corrected for the lost waste. For the 50- group this might have influenced the results.

Additionally, the participating households mainly lived in low-rise buildings. Households located in high-rise buildings generally do not have access to separate organic waste disposal. However, during this project the organic waste of households in high-rise buildings was collected separately. This might be more difficult for households since they were normally (and legitimately so) sorting their organic waste fraction in the residual waste.

7.2.4 Temporal Influences

The waste of the participating households was only measured twice, once before the project and once in the final week of the project. The lasting effect of the project is not known. Households may revert to old behaviours. Half a year after the end of the project (this is after the publication date of this thesis), a questionnaire will be sent out to all households that participated. The question will be if the 100-100-100 project influenced their wasting behaviour in the long term. The waste composition will not be monitored for these households.

Furthermore, seasonal influences (especially with organic waste) cannot be ruled out. The sorts of available vegetables changes during the year. This may have resulted in a different composition of organic waste. Similar changes that occur over the course of the year might have influence the wasting of other products. Also for this reason, a sorting test of the waste of the households may result in new insights in future research.

7.3 Metal Packaging and Beverage Carton Collection

As mentioned before, during the baseline analysis the households had no possibility to dispose their metal packaging and beverage cartons. However, since the 1st of January (2015) the households could (and should) sort their metal packaging and beverage cartons together with the plastic packaging waste. Recycling of these materials of course has a positive effect on the emission and primary energy impact as well as the scarcity of the materials (for the latter factor beverage cartons do not help since only the paper from these packages are recycled, the plastic and aluminium content is only used as a secondary fuel (Corsten et al., 2010)).

It is possible that the participating households chose products packaged in metal or beverage cartons because these materials could be separately collected during the project (and afterwards). Switching to these kinds of packaging would thus reduce the amount of residual waste. The share of residual waste might thus have went down for this reason. However, as explained before, the effect of the new collection infrastructure was explicitly filtered out of the results.

The actual amount of residual waste that was found was 23.60 kg pppy while in this research 30.47 kg pppy was assumed. Furthermore, the weight of the plastic stream was assumed to be 12.87 kg pppy but the weight of the PMD stream as collected by ROVA was 19.75 kg pppy.

These differences in waste composition were also reflected in the other results. The project and the new collection infrastructure together resulted in savings on both primary energy and GHG emissions compared to the results of the project by itself. The primary energy usage is brought down to only 2132 MJ pppy, an additional reduction of 53 MJ pppy. The reduction in GHG emissions is small, the GHG emissions ended at 190.4 kgCO2-eq pppy, (compared to 190.6 kgCO2-eq pppy originally). Considerable emission savings are achieved for the metal packaging (3.4 kgCO2-eq pppy) they are, however, largely undone by an increase of emissions arising from the sorted beverage cartons. Incineration of beverage cartons is a better option to reduce GHG emissions. This result arises from the assumption that paper incineration has no effective GHG emissions but it does substitute for regular power and heat production, which has GHG emissions (see also section 2.6.2.2).

The change in infrastructure was not expected to have an influence on critical materials. However, some absolute scarce materials can undergo high grade recycling due to the change in collection. In Table 20, it can be seen that the improved collection infrastructure did improve the recycling of metals even further. Only small amounts of metals are still lost during the waste processing.

Table 20. Change in lost materials due to improved (PMD) collection infrastructure.

Metal (kg pppy)	Original impact analysis	PMD collection	Difference
Iron	0.35	0.15	-0.20
Aluminium	0.16	0.09	-0.07
Copper	0.34	0.16	-0.18

7.4 Improving Waste Processing

Especially for GHG emissions, the waste processing was not very effective. Compared to the required emissions for material production only minor savings could so far be achieved for the 100-100-100 group. If the sorting behaviour of households are kept constant, improvement of the waste processing itself could considerably reduce the environmental impact from waste as well (Corsten et al., 2010).

However, the problem with improving the waste processing is that it decreases the effect of improved sorting and waste prevention. Improving the efficiency of waste incineration reduces the environmental impact but also makes incineration more preferable compared to recycling. Improving recycling makes prevention less preferable compared to prevention. However, there is no way to reduce the environmental impact of waste prevention. Prevention of waste has no impact at all, the impact can therefore not be reduced further (see Figure 31). Improving the waste processing can be considered as the reinforcement the current sociotechnical regime (Schot & Geels, 2008). If the waste incineration was improved considerably, the difference in environmental impact between incineration of waste and recycling of waste may become small. The environmental incentive to sort waste further may therefore become smaller. This may result in a lock-in in a system with inferior technologies (Rammel & van den Bergh, 2003).

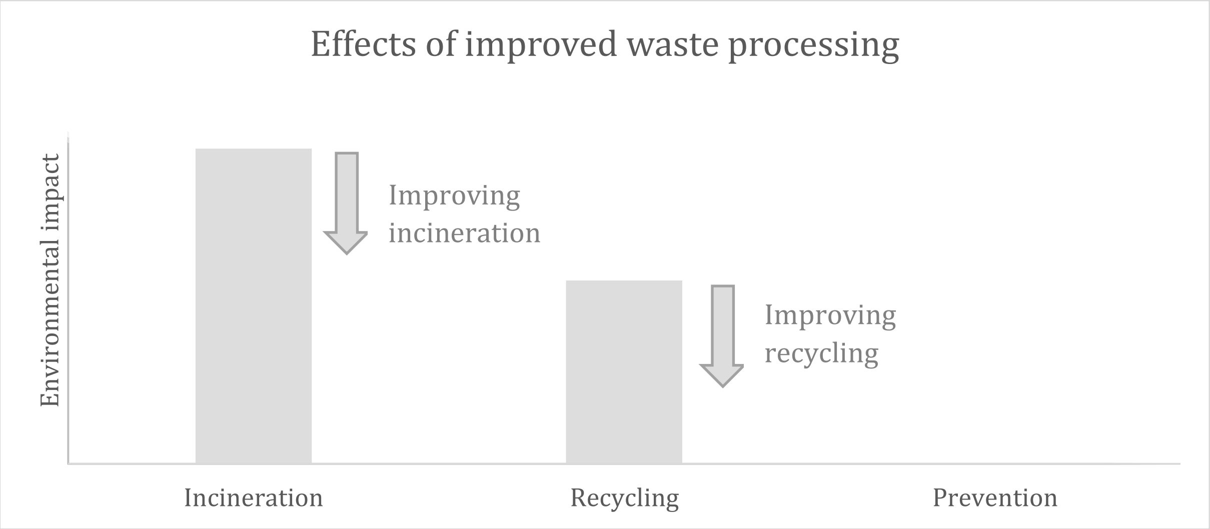

Figure 31. Effects of improved waste processing.

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9. Appendixes

9.1 Product Types for the Sorting Test per Waste Stream

9.1.1 Residual Waste

Dutch	English translation
- Goed gescheiden -	**- Well sorted -**
Luiers	Diapers
Niet herbruikbare voedselverpakkingen	Non-renewable food packaging
Niet herbruikbare verpakkingen non-food	Non-renewable non-food packaging
Kunststof voorwerpen	Plastic items
Drankkarton	Beverage cartons
Metaalverpakking	Metal packaging
Metaal niet verpakking	Metal non-packaging
Niet herbruikbaar overig	Non-renewable miscellaneous
Ondefinieerbaar	Undefinable
- Verkeerd gescheiden -	**- Incorrectly sorted -**
Snijresten organisch	Organic cut-offs
Voedselverspilling	Food waste
Kunststofverpakking	Plastic packaging
Oud papier/karton	Paper/cardboard
Glasverpakking	Glass packaging
Textiel	Textile
Verbouwingsafval	Renovation and demolition waste
Apparaten/kabels	Electronic and electrical equipment (e-waste)
Kca	Household hazardous waste

9.1.2 Plastic Packaging Waste

Dutch	English translation
- Goed gescheiden -	**- Well sorted -**
Portieverpakking	Single portion
Voedsel-drank-voer	Food-drink-feed
Schoonmaak, wasmiddelen	Cleaning
Persoonlijke verzorging	Personal care
Draagtasjes	Carrying bag
Overig	Miscellaneous
- Verkeerd gescheiden -	**- Incorrectly sorted -**
Aluminium laminaat	Aluminium laminated
Piepschuim	Styrofoam
Doordrukstrip	Blister strip
Kitkoker	Caulk tube
Niet verpakking kunststof	Non-packaging plastic
Vervuiling, niet kunststof	Non-plastic contamination

9.1.3 Organic Waste

Dutch	English translation
- Goed gescheiden (food) -	**- Well sorted (food) -**
Brood	Bread
Voedselresten - niet gekookt	Food - non-cooked
Voedselresten - gekookt	Food - cooked
Snijresten, botjes, koffiedrab, theezakjes	Cut-offs, bones, coffee grounds, tea bags
- Goed gescheiden (non-food) -	**- Well sorted (non-food) -**
Bloemen, kamerplanten	Flowers, houseplants
Stro en zaagsel van huisdieren	Straw and sawdust of pets
Tuinafval (blad)	Garden waste (leaves)
- Verkeerd gescheiden -	**- Incorrectly sorted -**
Voedselresten - aangebroken verpakking	Food – opened packaging
Voedselresten - ongeopende verpakking	Food – sealed packaging
Kattenbakkorrels - verpakt	Cat litter – packaged
Niet organisch, vervuiling	Non-organic, contamination

9.2 Results of the Baseline Sorting Test

All values except for the ‘average residents per household’ and ‘households in sample’ in this appendix are in [kg pppy]. The raw data was collected either per household (for the 50+ group) or per cluster (for the 50- group) over a period of two weeks. The values were all normalised using the resident per household data.

9.2.1 Residual Waste

Waste fraction (kg pppy)	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Average residents per household	3.11	3.23	3.04	2.44	2.44	3.26	3.54
Households in sample	81	31	50	9	9	19	13
		Well sorted					
Diapers	8.24	5.81	9.84	11.85	12.03	0.74	20.09
Non-renewable food packaging	1.59	2.10	1.25	2.01	1.19	0.74	1.62
Non-renewable non-food packaging	0.01	0.01	0.01	0.04	0.00	0.01	0.01
Plastic items	0.23	0.24	0.22	0.30	0.15	0.26	0.18
Beverage cartons	5.36	6.75	4.45	2.19	5.21	4.27	5.41
Metal packaging	1.72	2.05	1.49	2.49	3.38	0.75	1.12
Metal non-packaging	0.04	0.02	0.06	0.09	0.00	0.09	0.04
Non-renewable miscellaneous	15.64	20.15	12.67	5.63	4.09	16.38	15.16
Undefinable	0.22	0.00	0.36	1.18	0.27	0.31	0.08
Total	33.05	37.14	30.37	25.77	26.31	23.54	43.69

Waste fraction **(kg pppy)**	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
			Incorrectly sorted				
Organic cut-offs	4.12	4.56	3.14	10.01	4.54	2.29	0.32
Food waste	1.11	1.43	0.76	0.22	2.49	0.21	0.92
Plastic packaging	0.75	1.01	0.47	0.65	0.52	0.62	0.17
Paper/cardboard	0.58	0.72	0.41	0.58	0.39	0.23	0.58
Glass packaging	0.31	0.34	0.27	0.20	0.02	0.07	0.67
Textile	1.17	1.40	1.06	0.96	2.55	0.34	1.38
Renovation and demolition waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electronic and electrical equipment	0.04	0.01	0.06	0.03	0.01	0.10	0.06
Household hazardous waste	0.01	0.00	0.02	0.00	0.00	0.00	0.05
Total	8.09	9.45	6.19	12.66	10.52	3.86	4.16
GRAND TOTAL	**40.54**	**46.59**	**36.56**	**38.43**	**36.83**	**27.41**	**47.86**

9.2.2 Plastic Packaging Waste

Waste fraction **(kg pppy)**	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Average residents per household	3.11	3.23	3.04	2.44	2.44	3.26	3.54
Households in sample	81	31	50	9	9	19	13
		Well sorted					
Single portion	0.03	0.03	0.04	0.02	0.12	0.01	0.04
Food-drink-feed	7.86	8.38	7.63	6.70	6.99	7.61	8.42
Cleaning	0.53	0.43	0.61	0.46	0.86	0.67	0.47
Personal care	0.52	0.52	0.53	0.61	0.35	0.51	0.60
Carrying bag	0.29	0.29	0.29	0.25	0.21	0.33	0.29
Miscellaneous	1.42	1.55	1.36	1.24	2.43	1.20	1.13
Total	10.66	11.20	10.46	9.28	10.96	10.33	10.95
		Incorrectly sorted					
Aluminium laminated	0.06	0.04	0.08	0.01	0.06	0.09	0.11
Styrofoam	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Blister strip	0.00	0.00	0.01	0.00	0.00	0.01	0.01
Caulk tube	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-packaging plastic	0.69	0.56	0.79	0.25	0.21	0.94	1.13
Non-plastic contamination	0.79	0.61	0.94	0.16	0.37	0.80	1.77
Total	1.55	1.21	1.82	0.43	0.64	1.84	3.03
GRANDTOTAL	**12.21**	**12.41**	**12.28**	**9.70**	**11.60**	**12.17**	**13.99**

9.2.3 Organic Waste

Waste fraction (kg pppy)	**Total**	**50+**	**50-**	**Cluster 2B**	**Cluster 2D**	**Cluster 1LB**	**Cluster 1HB**
Average residents per household	3.06	2.75	3.23	2.44	3.54	3.83	1.67
Households in sample	34	12	22	9	13	6	6
Well sorted (food)							
Bread	2.38	3.54	1.82	0.62	2.39	4.51	1.30
Food - non-cooked	2.79	4.02	2.19	1.27	2.63	3.76	4.62
Food - cooked	3.20	3.36	3.12	3.19	3.08	4.68	0.35
Cut-offs, bones, coffee grounds, tea bags	44.18	25.88	53.07	41.44	58.63	24.72	28.56
Total	52.55	36.81	60.20	46.51	66.74	37.66	34.83
Well sorted (non-food)							
Flowers, houseplants	1.91	1.22	2.25	5.57	0.66	1.02	1.65
Straw and sawdust of pets	7.02	9.64	5.75	13.51	2.05	0.00	31.81
Garden waste (leaves)	2.68	1.13	3.43	9.54	0.51	0.00	3.74
Total	11.61	11.99	11.43	28.62	3.21	1.02	37.20

Waste fraction (kg pppy)	**Total**	**50+**	**50-**	**Cluster 2B**	**Cluster 2D**	**Cluster 1LB**	**Cluster 1HB**
	Incorrectly sorted						
Food – opened packaging	0.07	0.20	0.00	0.00	0.00	0.29	0.00
Food – sealed packaging	0.01	0.03	0.00	0.00	0.00	0.05	0.00
Cat litter – packaged	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-organic, contamination	0.79	0.43	0.97	1.88	0.53	0.09	1.23
Total	0.87	0.66	0.97	1.88	0.53	0.42	1.23
GRANDTOTAL	**65.04**	**49.46**	**72.60**	**77.02**	**70.48**	**39.11**	**73.26**

9.2.4 Paper Waste

Waste fraction **(kg pppy)**	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Average residents per household	3.09	3.23	3.00	2.44	2.44	3.19	3.54
Households in sample	78	31	47	9	9	16	13
		Correctly sorted					
Total	**46.52**	**45.48**	**47.25**	**39.70**	**51.79**	**52.68**	**41.29**

9.3 Results of the Impact Sorting test

9.3.1 Residual Waste

Waste fraction (kg pppy)	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Average residents per household	3.13	3.23	3.05	2.44	2.29	3.58	3.42
Households in sample	71	31	40	9	7	12	12
		Well sorted					
Diapers	9.60	8.03	10.89	20.20	0.56	6.14	14.90
Non-renewable food packaging	1.14	1.50	0.84	1.02	0.95	0.72	0.81
Non-renewable non-food packaging	0.10	0.04	0.15	0.18	0.17	0.13	0.14
Plastic items	0.10	0.09	0.11	0.12	0.15	0.12	0.08
Beverage cartons	4.58	4.38	4.75	3.15	6.16	4.13	5.72
Metal packaging	3.02	3.71	2.46	1.25	4.92	2.95	1.64
Metal non-packaging	0.03	0.01	0.04	0.08	0.10	0.00	0.04
Non-renewable miscellaneous	8.43	6.56	9.96	7.95	3.51	4.63	19.13
Undefinable	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	27.00	24.31	29.20	33.96	16.52	18.82	42.48

Waste fraction **(kg pppy)**	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Incorrectly sorted							
Organic cut-offs	2.53	2.94	2.19	6.90	1.80	1.15	0.91
Food waste	0.08	0.18	0.00	0.00	0.00	0.00	0.00
Plastic packaging	0.57	0.21	0.86	0.71	1.11	1.07	0.63
Paper/cardboard	0.05	0.04	0.05	0.09	0.08	0.03	0.05
Glass packaging	0.02	0.02	0.03	0.15	0.00	0.00	0.00
Textile	0.23	0.23	0.23	0.04	0.15	0.02	0.57
Renovation and demolition waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electronic and electrical equipment	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Household hazardous waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.48	3.62	3.36	7.89	3.14	2.27	2.16
GRAND TOTAL	**30.47**	**27.93**	**32.56**	**41.84**	**19.66**	**21.09**	**44.64**

9.3.2 Plastic Packaging Waste

Waste fraction **(kg pppy)**	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Average residents per household	3.13	3.23	3.05	2.44	2.29	3.58	3.42
Households in sample	71	31	40	9	7	12	12
		Well sorted					
Single portion	0.07	0.10	0.04	0.03	0.17	0.01	0.04
Food-drink-feed	6.83	6.22	7.33	5.69	8.80	6.66	8.33
Cleaning	0.77	0.87	0.69	0.66	0.39	0.70	0.83
Personal care	1.22	1.52	0.98	0.59	1.06	0.85	1.29
Carrying bag	0.39	0.48	0.33	0.28	0.23	0.52	0.20
Miscellaneous	1.49	2.11	0.99	1.15	0.88	1.12	0.79
Total	10.78	11.29	10.36	8.40	11.53	9.85	11.48
		Incorrectly sorted					
Aluminium laminated	0.22	0.14	0.29	0.11	0.12	0.65	0.07
Styrofoam	0.01	0.00	0.02	0.00	0.00	0.05	0.00
Blister strip	0.01	0.00	0.02	0.00	0.00	0.03	0.03
Caulk tube	0.01	0.00	0.02	0.00	0.00	0.05	0.00
Non-packaging plastic	1.22	0.89	1.48	0.38	1.73	1.84	1.60
Non-plastic contamination	0.62	0.30	0.89	0.58	0.34	1.04	1.10
Total	2.09	1.34	2.71	1.07	2.19	3.66	2.80
GRANDTOTAL	**12.87**	**12.63**	**13.07**	**9.48**	**13.71**	**13.52**	**14.28**

9.3.3 Organic Waste

Waste fraction (kg pppy)	**Total**	**50+**	**50-**	**Cluster 2B**	**Cluster 2D**	**Cluster 1LB**	**Cluster 1HB**
Average residents per household	2.83	2.55	3.00	2.29	3.42	3.60	1.67
Households in sample	30	11	19	7	12	5	6
Well sorted (food)							
Bread	4.81	10.68	1.92	0.51	2.47	14.67	3.51
Food - non-cooked	4.61	5.53	4.16	3.54	4.40	7.83	1.37
Food - cooked	6.25	8.74	5.02	14.07	1.49	9.16	8.00
Cut-offs, bones, coffee grounds, tea bags	37.85	39.40	37.09	53.10	30.84	46.04	27.45
Total	53.51	64.35	48.19	71.22	39.21	77.69	40.33
Well sorted (non-food)							
Flowers, houseplants	2.09	2.55	1.87	3.66	1.18	0.42	6.37
Straw and sawdust of pets	1.30	3.79	0.07	0.00	0.10	0.00	10.60
Garden waste (leaves)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.39	6.33	1.95	3.66	1.28	0.42	16.97

Waste fraction **(kg pppy)**	**Total**	**50+**	**50-**	**Cluster 2B**	**Cluster 2D**	**Cluster 1LB**	**Cluster 1HB**
Incorrectly sorted							
Food – opened packaging	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food – sealed packaging	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cat litter – packaged	0.33	1.00	0.00	0.00	0.00	1.55	0.00
Non-organic, contamination	1.32	1.18	1.38	2.67	0.88	1.37	0.83
Total	1.64	2.18	1.38	2.67	0.88	2.93	0.83
GRANDTOTAL	**58.55**	**72.86**	**51.52**	**77.55**	**41.37**	**81.04**	**58.13**

9.3.4 Paper Waste

Waste fraction (kg pppy)	**Total**	**50+**	**50-**	**Cluster 2A**	**Cluster 2B**	**Cluster 2C**	**Cluster 2D**
Average residents per household	3.13	3.23	3.05	2.44	3.58	3.58	3.42
Households in sample	72	31	41	9	8	12	12
		Correctly sorted					
Total	**38.39**	**30.30**	**44.87**	**33.24**	**41.51**	**55.62**	**41.40**

9.4 Sorting test Results (Improved Sorting Scenario)

Impact sorting behaviour per group and cluster (improved sorting scenario).

(kg pppy)	Sorting	Total	50+	50-	Cluster 2A	Cluster 2B	Cluster 2C	Cluster 2D
Absolute	correct	134.36	138.07	135.72	76.60	71.98	84.77	96.95
	incorrect	7.22	7.14	7.46	8.96	5.33	5.93	4.96
Relative	correct	94.9%	95.1%	94.8%	89.5%	93.1%	93.5%	95.1%
	incorrect	5.1%	4.9%	5.2%	10.5%	6.9%	6.5%	4.9%

Reduction per group and cluster (improved sorting scenario).

(kg pppy)	Sorting	Total	50+	50-	Cluster 2A	Cluster 2B	Cluster 2C	Cluster 2D
Change Absolute	correct	-20.04	-4.54	-23.99	+1.85	-17.08	-3.04	+1.01
	incorrect	-2.68	-4.19	-1.52	-4.13	-5.83	+0.23	-2.24
Change Relative (%-point)	correct	+0.9%	+2.5%	+0.1%	+4.4%	+4.2%	-0.4%	+2.1%
	incorrect	-0.9%	-2.5%	-0.1%	-4.4%	-4.2%	+0.4%	-2.1%

9.5 Breakdown to materials

Waste stream		Category	Reference	Model parameter[21]
Residual	**Well sorted**	Diapers	(Aumônier, Collins, & Garrett, 2008)	6% Paper, 1% PE, 3% PP, 90% Other[22]
		Non-renewable food packaging	*Own estimate based on* (Slater & Crichton, 2011)	45% Paper, 10% Aluminium, 45% PE[23]
		Non-renewable non-food packaging	*Own estimate*	45% Paper, 10% Aluminium, 45% PE
		Plastic items	(Thoden van Velzen & Brouwer, 2014)	37% PE, 29% PP, 15% PS, 6% PET, 13% PVC[24]
		Beverage cartons	N/A	100% Beverage cartons
		Metal packaging	(Corsten et al., 2010; Rijkswaterstaat, 2013)	76% Ferro, 12% Aluminium, 12% Copper
		Metal non-packaging	(Corsten et al., 2010; Rijkswaterstaat, 2013)	73% Ferro, 13% Aluminium, 13% Aluminium
		Non-renewable miscellaneous	*Own estimate based on qualitative data from EURECO*	10% Paper, 2% Textile, 3% Ferro, 2% Aluminium, 2% Copper, 10% PE, 10% PP, 5%PS, 2%PET, 3%PVC, 2% Wood 50% Other
		Undefinable	N/A	100% Other

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[21] All figures presented in this table are rounded to zero decimals

[22] Fluff pulp in 'Paper' Adhesives and SAP in 'Other', the largest share of 'Other' is urine and faeces

[23] Assumed that this consists of 50% Paper aluminium laminates and 50% Plastic aluminium laminates

[24] Same composition as plastic non-packaging in the plastic packaging waste (second table)

Waste stream		**Category**	**Reference**	**Model parameter**
Residual	**Incorrectly sorted**	Organic cut-offs	N/A	100% GKW
		Food waste	N/A	100% GKW
		Plastic packaging	*EURECO Data*	36% PE, 33% PP, 4% PS, 20% PET, 1% PVC, 7% Other
		Paper/cardboard	N/A	100% Paper
		Glass packaging	N/A	100% Glass
		Textile	N/A	100% Textile
		Renovation and demolition waste	*Own estimate*	25% Ferro, 25% PVC, 25% Wood, 25% Other[25]
		Electronic and electrical equipment	N/A	12% Glass, 2% Aluminium, 3% Copper, 48% Ferro, 3% PE, 3% PP, 30% Other
		Household hazardous waste	N/A	100% Other[26]

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[25] This will very likely be some of the materials in the demolition waste. The demolition waste fraction is very small, hence the assumption has little influence on the final result

[26] Household hazardous waste is not in the iWaste model

Waste stream		Category	Reference	Model input
Plastic packaging	**Well sorted**	Single portion	*EURECO data*	100% PP
		Food-drink-feed	*EURECO data*	28% PE, 40% PP, 4% PS, 24% PET, 4% Other
		Cleaning	*EURECO data*	46% PE, 23% PP, 3% PS, 26% PET, 3% Other
		Personal care	*EURECO data*	59% PE, 21% PP, 3% PS, 13% PET, 3% PVC, 3% Other
		Carrying bag	*EURECO data*	100% PE
		Miscellaneous	*EURECO data*	40% PE, 17% PP, 2% PS, 2% PET, 7% PVC, 33% Other
	Incorrectly sorted	Aluminium laminated	(Slater & Crichton, 2011)	10% Aluminium, 90% PE
		Styrofoam	N/A	100% PS
		Blister strip	*Own estimate*	10% Aluminium, 90% PE[27]
		Caulk tube	(Thoden van Velzen & Brouwer, 2014)	100% PE
		Non-packaging plastic	(Thoden van Velzen & Brouwer, 2014)	37% PE, 29% PP, 15% PS, 6% PET, 13% PVC
		Non-plastic contamination	(Thoden van Velzen & Brouwer, 2014)	30% Paper, 41% GKW, 3% Glass, 8% Textile, 13% Ferro, 2% Aluminium, 2% Copper

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[27] Assumed to be the same as aluminium laminated packaging

Waste stream		Category	Reference	Model input
GKW	**Well sorted (food)**	Bread	N/A	100% GKW
		Food - non-cooked	N/A	100% GKW
		Food - cooked	N/A	100% GKW
		Cut-offs, bones, coffee grounds, tea bags	N/A	100% GKW
	Well sorted (non-food)[28]	Flowers, houseplants	N/A	100% Other
		Straw and sawdust of pets	N/A	100% Other
		Garden waste (leaves)	N/A	100% Other
	Incorrectly sorted	Food – opened packaging	*Own estimate based on EURECO data*	60% GKW, 16% PP, 11% PE, 10% PET, 2% PS, 0% PVC, 2% Other[29]
		Food – sealed packaging	*Own estimate based on EURECO data*	90% GKW, 4% PP, 3% PE, 2% PET, 0% PS, 0% PVC, 0% Other[30]
		Cat litter – packaged	*Own estimate based on* (Afval Overleg Orgaan, 2002)	20% Paper, 80% Other
		Non-organic, contamination	*Own estimate based on* (Afval Overleg Orgaan, 2002)	40% Paper, 20% PE, 20% PP, 20% Other

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[28] This fraction was analysed, however the participants were instructed not to present this waste for sorting test. Additionally it is highly influenced by seasonal aspects. Therefore, this fraction was not considered in the modelling.

[29] Assumption that 60% by weight consists of actual wasted food and 40% of ‘average’ plastic food packaging (see table with plastic packaging waste)

[30] Assumption that 90% by weight consists of actual wasted food and 10% of ‘average’ plastic food packaging (see table with plastic packaging waste)

9.6 Origin of Organic Waste GER Values

The composition of the organic waste is based on the baseline findings. The composition of subcategories is based on (van Westerhoven, 2013). Cutting waste is assumed to have the same composition on average as the values found below.

Waste stream	**Category**	**kg product/kg waste**	**kg product**	**Energy (MJp_{rim}/kg product) (Foster et al., 2006)**	**Energy (MJ_{prim}/ kg waste)**	**eq / kg product) (FAO, 2013)**	**Emissions ($kgCO_2$-eq / kg waste)**
residual	food waste (cooked and uncooked)	10.80%	1.02	9.14	0.987	1.47	0.159
	bread	2.16%	0.20	9.70	0.210	0.80	0.017
	meal leftovers	1.08%	0.10	9.00	0.097	1.64	0.018
	leftovers (opened packaging)	2.38%	0.22	9.00	0.214	1.64	0.039
	leftovers (unopened packaging)	5.19%	0.49	9.00	0.467	1.64	0.085
organic	bread	25.14%	2.38	9.70	2.439	0.80	0.201
organic	leftovers (uncooked)	29.47%	2.79	2.72	0.801	0.95	0.280
	potatoes	9.82%	0.93	1.30	0.128	0.24	0.024
	fruits	9.82%	0.93	4.75[31]	0.467	0.27	0.027
	apples	3.70%	0.35	4.75	0.000	0.18	0.007
	bananas	3.54%	0.34	-	0.000	0.35	0.012
	Mandarin orange	1.45%	0.14	-	0.000	0.29	0.004
	oranges	1.13%	0.11	-	0.000	0.29	0.003
	vegetables (mixed)	9.82%	0.93	2.10	0.206	2.34	0.230
organic	leftovers (cooked)	33.79%	3.20	9.00	3.041	1.64	0.554
	carbs	13.21%	1.25	1.01	0.134	1.16	0.153
	potatoes	3.03%	0.29	1.30	0.039	0.24	0.007

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[31] There were no values found for other fruits so the figure for apples was used as an approximation for all fruits.

	rice	3.58%	0.34	9.80	0.351	2.60	0.093
	pasta	6.61%	0.63	8.57	0.566	0.80	0.053
	meat	1.32%	0.12	17.96	0.237	7.82	0.103
	pork	0.68%	0.06	17.00	0.115	4.48	0.030
	beef	0.28%	0.03	28.00	0.078	20.20	0.057
	poultry	0.36%	0.03	12.00	0.043	4.48	0.016
	vegetables (mixed)	9.63%	0.91	2.10	0.202	2.34	0.225
	sauce (oil crops)	9.63%	0.91	25.63	2.468	0.75	0.072
organic	leftovers (opened packaging)	0.69%	0.07	4.50	0.031	0.08	0.001
organic	leftovers (unopened packaging)	0.11%	0.01	6.75	0.007	1.23	0.001
TOTAL		**100%**	**9.47**	**-**	**7.31**	**-**	**1.20**