Pilot beverage cartons

Extended technical report

dr. E.U. Thoden van Velzen, Ir. M.T. Brouwer, Ir. E. Keijsers (Wageningen UR Food and Biobased Research), prof. dr. Th. Pretz, dr. A. Feil, dipl.-ing. M. Jansen (RWTH Aachen)

Report 1440

Colophon

Title	Pilot beverage cartons, extended technical report
Author(s)	dr. E.U. Thoden van Velzen, Ir. M.T. Brouwer, Ir. E. Keijsers (Wageningen UR Food & Biobased Research), prof. dr. Th. Pretz, dr. A. Feil, dipl.-ing. M. Jansen (RWTH Aachen)
Number	1440
ISBN-number	978-94-6173-980-3
Date of publication	December 20th 2013
Confidentiality	No
Approved by	J.E. de Kramer

Wageningen UR Food & Biobased Research
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 480 084
E-mail: info.fbr@wur.nl
Internet: www.wur.nl

Abstract

This report gives a technological description of the four common collection and recycling schemes that have been tested in the Netherlands as part of the pilot beverage cartons in 2013. During this pilot the collection and recycling of beverage cartons was tested in 37 different municipalities, with various separate collection systems and 2 recovery facilities.
The pilot demonstrated that it is technically possible to collect and recycle Dutch beverage cartons. The recycled pulp from all tested collection methods is relatively similar in properties. Also, the fibres are relatively strong and the microbiological load is relative high, this limits the applicability. Hence, corrugated boxes are a well-suited application for these pulps.
Four different collection and recycling schemes were tested; separate collection, co-collection with plastics, co-collection with paper & board and recovery. The efficiency of most schemes is limited by the net collection yields and for some schemes also the sorting yield. The net collection yields are determined by different factors, such as the percentage of high rise buildings, the execution of the collection system (service level, communication, etc.) and the space inside the houses to store and keep beverage cartons separate until collection.
The recovery recycling chains were most efficient, although one of the two chains suffered from a relative low sorting yield. Nevertheless, this sorting step can be improved.
Two different co-collection chains with plastic packages were studied; the Milieuzakken and the Kunststof Hergebruik chains. The Milieuzakken-chain is already established for several years and the collection retrieves almost all the beverage cartons that are expected to be present in its collection area. However, the collected material contains also relative large amounts of residual waste, which hampers the sorting and recycling and reduces the overall efficiency. The Kunststof Hergebruik co-collection chain was set-up specially for this pilot and suffered from low collection yields and low sorting yields. Although the rural area around Deventer already reached a near complete collection of all beverage cartons, for most other collection areas more time is necessary to mature the collection system and obtain higher collection yields. For improved sorting ideally an investment is required which would make the sorting process much more efficient, since the current facility was not designed and equipped for the efficient sorting of beverage cartons.
The separate collection scheme suffered from relative low net collection yields, varying from 3% to 57% with a weight-averaged mean of 20%. This collection system needs time to mature and obtain higher net collection yields. For a few municipalities (with relatively low collection yields) some adjustments to the system are necessary.
Also, the co-collection scheme with paper & board in general suffered from low net collection yields. Although in the high-rise area of Etten-Leur the largest net collection yield for a high-rise area was recorded of 50%. The subsequent sorting was inefficient, due to the similarity of the materials. In the future, an ideal co-collection chain would be constructed without a sorting facility. The mixture would be integrally pulped and recycled as is now the current operation in a new facility in Nortrup (Germany).

Samenvatting

Dit rapport geeft een technische beschrijving van vier inzameling en hergebruik ketens voor drankenkartons in Nederland. De pilot voor de inzameling en hergebruik van drankenkartons werd gehouden met 37 verschillende gemeenten en 2 nascheidingsinstallaties en heeft aangetoond dat het technisch mogelijk is om drankenkartons in te zamelen en her te gebruiken. De herwonnen pulp van alle hergebruikssystemen was vergelijkbaar in eigenschappen; de vezels zijn relatief sterk en de microbiologische belasting is relatief hoog, dit is beperkt de toepassingsmogelijkheden. Golf-kartonnen dozen zijn een geschikte toepassing voor deze pulp. Vier verschillende inzamel- en hergebruikssystemen werden getest; gescheiden inzameling, gecombineerd gescheiden inzameling met kunststof verpakkingen, gecombineerd gescheiden inzameling met oud-papier en nascheiding. De overall systeemefficiëntie werd beperkt door het netto inzamelrendement en in sommige systemen ook door het sorteerrendement. Het netto inzamelrendement wordt bepaald door verschillende factoren, zoals de stedelijkheidsklasse, de uitvoering van het systeem (service niveau, communicatie, etc.) en de plek in huis om de drankenkartons apart te bewaren voor inzameling.
De nascheidingsketens waren het meest efficiënt, ofschoon het rendement van één van de twee ketens werd beperkt door een laag sorteerrendement voor drankenkartons. Dit laatste kan echter worden verholpen door technische aanpassingen aan de sorteerinstallatie.
Twee verschillende ketens voor het gecombineerd inzamelen met kunststof verpakkingen werden onderzocht; die van de Milieuzakken en van Kunststof Hergebruik. De Milieuzakken-keten is reeds jaren operationeel en de inzameling haalt nagenoeg alle drankenkartons uit het inzamelgebied terug, die daar aanwezig worden geacht. Het ingezamelde materiaal bevat echter eveneens relatief grote hoeveelheden restafval, hetgeen de navolgende sorteer- en hergebruiksstappen bemoeilijkt en het totale ketenrendement verlaagd. De gecombineerde inzamelketen van Kunststof Hergebruik werd speciaal voor deze pilot opgezet en had te maken met lage inzamelrendementen en sorteerrendementen. Ondanks dat het landelijk gebied van de gemeente Deventer een nagenoeg volledig netto inzamelrendement bereikte, is er voor de andere inzamelgebieden meer tijd nodig om het scheidingsgedrag van de burgers te veranderen en hogere inzamelrendementen te bereiken. De sorteerinstallatie zou idealiter technisch worden aangepast met een aanvullende NIR scheidingseenheid ten behoeve van drankenkartons, aangezien de huidige installatie hier niet voor was ontworpen en toegerust.
De gescheiden inzamelketen had te maken met lage netto-inzamelrendementen, variërend van 3% tot 57% met een gewogen gemiddelde van 20%. Er zal meer tijd nodig zijn om dit inzamelsysteem te laten rijpen en hogere netto inzamelrendementen te verkrijgen. Bovendien zal er voor enkele gemeenten met afwijkend lage inzamelrendementen verbeteringen in het inzamelsysteem moeten worden doorgevoerd.
Het gecombineerde inzamelsysteem met oud-papier had ook last van lage netto inzamelrendementen. Opmerkelijk was dat deze rendementen laag waren voor het laagbouw inzamelgebieden en relatief hoog voor het onderzochte hoogbouwgebied van Etten-Leur. Hier werd 50% inzamelrendement gehaald, een record voor een hoogbouwgebied. De navolgende sorteerstap was inefficiënt door de grote overeenkomsten in materiaal en eigenschappen. Waarschijnlijk wordt deze sorteerstap in de toekomst overbodig omdat er inmiddels al een groot papierbedrijf in staat is om het mengsel integraal her te gebruiken.

Content

Abstract 3

Samenvatting 4

1 Introduction 7

2 Materials and methods 8

2.1 Sampling method and the origin of the samples 8
2.1.1 Studied recycling chains 8
2.1.2 Origin of samples 10
2.1.3 Sampling 11
2.1.4 Analyses of samples 11
2.1.5 Response data 12
2.2 Material analysis 13
2.2.1 Test method 13
2.2.2 The procedure to determine material content of beverage carton bodies 14
2.2.3 Issues 15
2.3 Residue potential and washed off residues 15
2.3.1 Test method 16
2.3.2 Issues 17
2.3.3 Washed off residues 18
2.4 Amount and division of beverage cartons present on the Dutch market 18
2.5 Mass balancing the recovery and sorting facilities 19
2.6 Mass balancing the beverage carton recycling plant REPA 21
2.7 More detailed description of sampling method per participant of the pilot 25
2.7.1 Definition of terms for sampling 25
2.7.2 Attero Noord, Groningen 25
2.7.3 Omrin, Oudehaske 28
2.7.4 Augustin Entsorgung, Meppen 31
2.7.5 Schönmackers, Kempen 34
2.7.6 Sita, Rotterdam 37
2.7.7 Repa Boltersdorf, Brohl-Lützing 41
2.7.8 Sorting facilities for co-collected mixtures of paper & board and beverage cartons 44
2.8 Cross contamination effects 44
2.9 Paper Analyses 44
2.9.1 Description of the samples and evaluation method 44
2.10 Heavy metal analysis in by-products 45
2.11 Microbial analysis papers 45
2.12 Mass flow diagrams 46

3 Results 48

3.1 Response data 48
3.2 Composition of separately collected beverage cartons 51
3.3 Composition of beverage cartons co-collected with PPW 57

3.4 Composition of beverage cartons co-collected with paper & board 62
3.5 Composition of recovered beverage cartons 66
3.6 Material composition of clean beverage cartons 68
3.7 Residue potential of beverage cartons 70
3.8 Beverage carton potential and composition for Dutch market 73
3.9 Mass balance per facility and type of product stream 76
3.9.1 Results recovery chain Attero-Noord, Augustin, Repa 76
3.9.2 Results recycling chain recovery Omrin, Repa 82
3.9.3 Results recycling chain co-collection with plastics via Sita Rotterdam 87
3.9.4 Results Schönmackers 91
3.9.5 Results separate collection of beverage cartons 94
3.9.6 Results of Kempenaars 97
3.9.7 Results of Sita Soesterberg 98
3.10 Recycling of by-products 99
3.11 Cross-contamination 100
3.11.1 Cross contamination between beverage cartons and plastic packages 100
3.11.2 Cross contamination between the beverage cartons and paper & board 103
3.11.3 Cross contamination between the beverage cartons and MSW 106
3.12 Pulp analysis 107
4 Mass flow diagrams 114
4.1 Mass flow diagram: separate collected beverage cartons 114
4.2 Mass flow diagram for the combined collection of beverage cartons and plastics 118
4.3 Mass flow diagram for the combined collection of beverage cartons and paper & board126
4.4 Mass flow diagram recovery at Omrin 130
4.5 Mass flow diagram recovery at Attero Noord 135
5 Comparison of systems 140
6 Discussion 144
6.1 Data quality 144
6.2 Factors determining collection yields 144
6.3 Regional variation 145
6.4 By-product recycling 146
6.5 Future scenario’s 147
6.6 Relationship between logistical lead-time and recycling results 148
6.7 Expected infrastructure changes per system and interaction with renewable energy policies 149
7 Conclusions 151
Acknowledgements 153
Definition of terms 154
References and endnotes 155

1 Introduction

This technological report is one of the five reports on the pilot beverage carton recycling in the Netherlands in 2013. This report describes the quantity and quality of beverage cartons that can be collected and recycled with all common collection and recycling techniques that are annually available in the Netherlands in 2013. This technical data report serves as input for the dedicated report on the expected environmental impacts.

The four common collection methods recycling chains are being studied from municipalities up to (but not including) the final users of the recycled products. This report describes the results of technical measurements performed at all relevant chain elements that are necessary to describe the recycling chain in sufficient detail. These chain elements comprise of municipalities, cross-docking stations, sorting facilities, recycling facilities and material recovery facilities. The performed technical measurements have been combined in mass flow mass flow diagram, which describe the flow of materials through the recycling chain from the households up to recycled products, including all side products, wastes and consumables.

In three of the four studied common collection methods the beverage cartons are collected in combination with plastic packaging waste, paper and board waste and MSW. For these recycling chains the interactions between the beverage cartons and the carrier stream has also been studied both in positive terms (e.g. larger responses) and in negative terms (cross-contamination, lower qualities). These interactions are studied as an integral part of the mass flow diagrams and are additionally clarified in a separate chapter.

The prime results of the mass flow diagrams are the quantity [kg products net] and quality [% purity] of the materials produced from the recovered beverage carton waste. These prime results are related to amount of inhabitants and households present within the pilot areas to obtain normalised output values such as [kg net/cap.a]. These results are subsequently interpreted in terms of recycling percentages [%], meaning the percentage of beverage carton material that is collected within a collection area of the total amount of beverage cartons that is present within that collection area. The latter parameter is deduced from the amount of beverage cartons that is placed on the Dutch market and a regional correction factor. With this recycling percentage also the amount of beverage cartons that is not-recycled but incinerated with the MSW can be estimated, which is vital input for the environmental analysis. Hence, in this report for all chosen recycling chains the quantity and quality of the collected and recycled beverage cartons are described in terms of [kg products dry matter/cap.a], recycling percentages [%].

2 Materials and methods

2.1 Sampling method and the origin of the samples

2.1.1 Studied recycling chains

In this pilot the four most common recycling chains for beverage cartons are studied, see Figure 1. These chains are separate collection, combined collection with plastic packaging waste, combined collection with paper & board waste and the combined recovery with plastic packaging waste from MSW. In general the recycling chain consists of three stages: collection and material recovery, sorting and recycling.

1. Separate collection of beverage cartons
   The separate collection of beverage cartons implies that civilians keep the beverage cartons separate from other wastes at home and offer the beverage cartons separately for collection. These beverage cartons are usually cross-docked within a municipality and / or a regional cross-docking centre and are directly transported from the cross-docking centres to the recycling facilities.

2. Combined separate collection with plastic packages
   In case of the combined separate collection of beverage cartons with plastic packages civilians will keep both plastic packages and beverage cartons separate and will offer this mixture for collection. This mixture is usually cross-docked at a regional cross-docking station and transported to a sorting facility, which will produce several plastic products and a beverage carton product (usually named FKN). This beverage carton product is subsequently transported to a recycling facility.

3. Combined separate collection with paper & board
   In case of the combined separate collection of beverage cartons with paper & board civilians will add the emptied beverage cartons to the paper & board collection vessel at home and will offer this mixture for collection. This collected mixture is usually transferred directly to a sorting facility, which will produce several paper and board products, including a beverage carton product. These beverage cartons are baled and transported to a recycling facility.

4. Combined recovery of beverage cartons and plastic packages from MSW
   Civilians discard their beverage cartons and plastic packages in their MSW container. The collection service empties these containers every 2 weeks and transports the MSW to a material recovery facility, which recovers a mixture of plastic packages and beverage cartons. This concentrate is sent to a sorting facility which produces several plastic products and a beverage carton product from this mixture. This beverage carton product is shipped to the recycling facility.

Recycling of the beverage cartons from all 4 chains results in a fiber product and a large amount of light-weight by-products (PE film, PO from caps and closures, etc.) and a very limited amount of heavy-weight by-products (glass pieces, metals, stones and other residual waste).

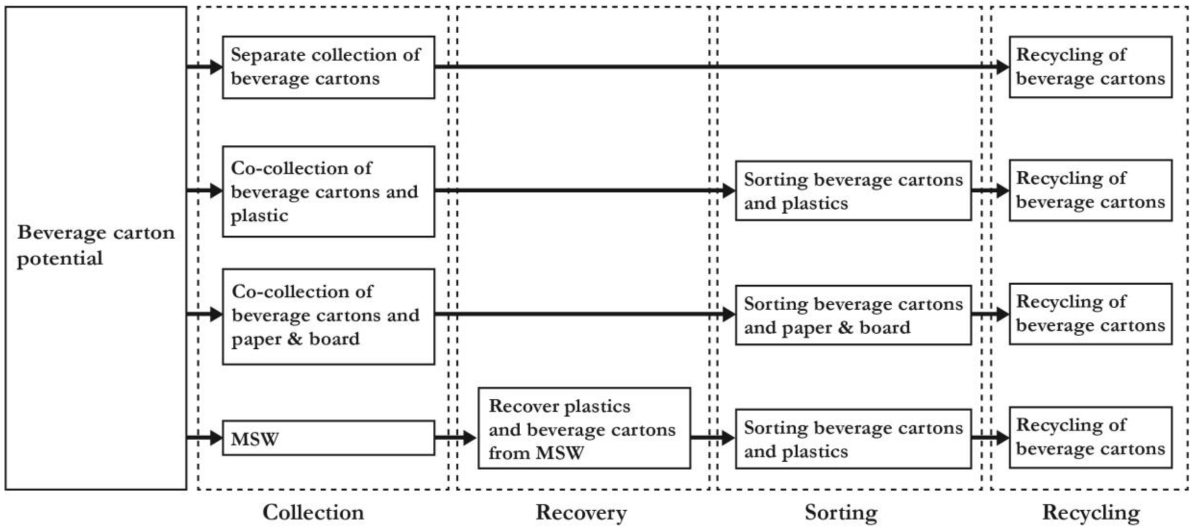

Figure 1: The four recycling chains for beverage cartons in the Netherlands studied within this pilot.

Table 1: Facilities that participated within the pilot beverage carton recycling 2013

Stage	System no.	Participants	Comment
I	1 Separate collection of BC	Municipalities in pilot region	Hedra as chain organiser
I	2. Co-collection with plastic	Municipalities in pilot region	Kunststof Hergebruik BV as chain organiser
I	2. Co-collection with plastic	Milieuzak municipalities	Hummel as chain organiser. Municipalities with milieuzakken are: Grootegast, Leek and Marum
I	3 Co-collection with P&B	Municipalities	
II	4 Recovery	Attero Noord	On behalf of Groningen, Bedum, Haren and Ten Boer
II	4 Recovery	Omrin, Oudehaske	On behalf of all municipalities in the Omrin service area
III	2 Sorting plant	Sita, Rotterdam	Sorting the material on behalf of Kunststof Hergebruik BV
III	2 Sorting plant	Schönmackers, Kempen	Sorting the Milieuzakken-material
III	3 Sorting plants	Kempenaars and Sita	Kempenaars manually sorts BC's from P&B of Etten-Leur Sita-Soesterberg semi-automatically sorts BC's from P&B of Vianen
III	4 Sorting plant recovered BC's	Augustin, Meppen	Sorting the packaging concentrate from Attero Noord
III	4 Sorting plant recovered BC's	Omrin, Oudehaske	Rekas sorting plant in Oudehaske
IV	1, 2, 4 Recycling	Repa Boltersdorf, Brohl-Lützing	Recycling of BC into fibre pulp and by-products

The recycling chains are analysed at all steps in the chain in the same sequence in which the material is treated. Since the dynamics of the recycling chains (such as variations in composition in time, duration of storage, etc.) are not included in this study this stepwise approach can result in differences in measured quality on the output side of one plant in the chain as compared to the measured quality of the input side of the next plant in the chain. In this study, all technical facilities were assumed to have static efficiencies (not dependant on material compositions) to correct for not matching data. Additionally, the sampling procedure followed the LAGA PN 98 norm and was adjusted by individual experiences.

2.1.2 Origin of samples

The matrix for the pilot beverage cartons is chosen to describe four common recycling chains, subdivided into collection areas with different amounts of high-rise buildings, collection systems (drop off / kerbside for the beverage cartons and the presence or absence of a pay as you throw scheme (PAYT) for MSW). This matrix is used to provide a representative overview for beverage carton recycling in the Netherlands. This subdivision is obviously not relevant for the recovery chain, which always is related to its complete service region. The studied types of collection systems and participating collection areas within municipalities are shown in Table 2. All municipalities listed in the matrix are studied.

Table 2: Matrix of the studied types of collection systems and participating collection areas within municipalities

Collection	Collection system	> 50% high rise buildings	10-50% high rise buildings	<10% high rise buildings
Separate	*Drop off, no PAYT*	Gorinchem Rotterdam Tilburg	Katwijk Zoetermeer	Roermond-Swalmen Son en Breugel Voorst
	Drop off, PAYT	Hengelo	Apeldoorn Beesel Oosterhout	Bernheze Bronckhorst Gennep Overbetuwe
	Kerbside	Schiedam	Deventer (centre) Oude IJsselstreek Stadskanaal	Leeuwarden Oldambt Zutphen
With plastic as carrier	*Kerbside/drop off, no PAYT*	Schiedam	Zeist	Binnenmaas Almere De ronde venen
	Kerbside/drop off, PAYT	Nijmegen	Vught Geldrop-Mierlo	Marum, Grootegast en Leek Deventer (rural area) Steenwijkerland
With paper & board as carrier	*Kerbside/drop off*	Etten-leur		Winsum Vianen Etten-leur
Recovery	*With MSW*	Omrin Attero Noord		

The pilot is executed in a limited time period of six months for practical execution, analysis and data collection. Therefore, the focus of research in the first months of this pilot was on the municipalities that already collect beverage cartons prior to the pilot and to study the newly established systems in the later months of the pilot.
Nevertheless, it is likely that the recorded responses during the pilot will be lower than what would be achieved after a few years of equilibration. This is, however, an inevitable effect of the condition that the pilot had to be executed during 2013.

2.1.3 *Sampling*

At all steps (collection, sorting and recycling) in the recycling chains the composition of the waste is analysed. Therefore samples are taken along the recycling chains.

At the collection step samples of the different recycling chains, samples of the collected waste are analysed. These samples are different for the different chains:

- Chain 1, separate collection: 1 bigbag (each 1 m^3) of collected beverage carton waste per municipality.
- Chain 2, collection with plastic as carrier: 2 bigbags (of 1 m^3) of collected combined beverage carton and plastic packaging waste per municipality.
- Chain 3, collection with paper as carrier: 1 bigbag (of 1 m^3) of collected combined beverage carton and paper & board waste per municipality.
- Chain 4, recovery from MSW: no ingoing MSW is sampled, the separate fractions of outgoing material from the material recovery plant are analysed.

At recovery, sorting and recycling facilities all products were sampled and analysed. Big garbage bags (of approximately 0,5 m^3) and bigbags (1 m^3) were used to sample these fractions. Samples of fibre material were obtained at the recycling facility by sieving the fibre containing stocked solution over 200 μm sieves and mechanically drying the pulp; about 30 litres of dewatered pulp was taken as sample for pulp analysis.

2.1.4 *Analyses of samples*

Samples that were highly contaminated and / or contained much non-beverage carton materials were first sorted by hand into the main material categories: organic and indefinable, paper & board, plastics, metals, glass and stones, textile and beverage cartons. The gross weight of all these material categories was determined after the hand-sorting was finished.
The sorted faction of beverage cartons was hand-sorted into 14 categories, which were chosen to describe Dutch beverage cartons, have different material composition and residue levels. These categories are listed in Table 3. After the hand-sorting the gross weights of the beverage carton categories were determined. Mass percentages were calculated by taking the gross weight of a beverage carton category and dividing that by the total gross weight of the complete sample (hence including all the gross weights of residual wastes).
For samples from the system in which beverage cartons and plastic wastes are co-collected, also the plastics were sorted in plastic types with NIR and subsequently manually in packaging type

(bottle, flask, thermoformed, other rigids, flexibles, laminated flexibles, and non-packaging objects).

The net material composition of beverage carton fractions was determined by randomly taking 10 beverage cartons per category and sample, weigh the gross weight, cutting the carton open and washing the carton clean, drying the carton in an oven at 75°C overnight and recording the dry net weight. The net material composition was calculated as the dry material weight divided by the gross material weight. Similarly for samples from the combined collection of plastics and beverage cartons 10 plastics packages from each 5 main plastic categories were weighted, washed, dried and weighted. These main categories are: PET bottle small clear, PE flasks, PP rigid others, PE film large and PET rigid others.

$$MDC, [\%] = \frac{m_{gross}^{BC\ category} - m_{net}^{BC\ category}}{m_{gross}^{BC\ category}}$$

Equation 1: The moisture and dirt content of category of beverage cartons equals the difference between the gross and the net weight divided by the gross weight.

2.1.5 *Response data*

Municipalities were obliged by contract to report their responses on a monthly basis to the pilot management and to add copies of recorded weights by official weighing bridges. This data was collected and forwarded to the researchers. The monthly recorded responses were added per municipality to obtain the total gross response of every municipality during the pilot period. This total response per municipality was extrapolated to an annual response number by multiplying the number by 12 and dividing it by the number of months the municipality participated in the pilot.

$$R_{extrapol.}^{mu\ 1}, [kg\ gross] = \frac{\{R_{m1}^{mu1} + R_{m2}^{mu1} + R_{m3}^{mu1} \ldots\} \times 12}{A}$$

Equation 2: The extrapolated response of a municipality [in kg gross] is the total response of all months that the municipality participated multiplied by 12 and divided by the amount of months this municipality participated.

The net amount of the collected material for a municipality was determined by taking the gross response, multiplying this with percentage of beverage cartons in the sample which originated from the sorting analysis and multiplying this with the net material composition percentage. The latter equals 100% minus the weight-averaged moisture and dirt content of the beverage cartons from that sample.

$$R_{net}^{mu1}, [kg\ net] = R_{extrapol.}^{mu1} \times X_{BC}^{mu1} \times \{100\% - MDC_{w-averaged}^{mu1}\}$$

Equation 3: The net amount of collected material for a municipality equals the extrapolated response multiplied with the percentage of beverage cartons in the sample and the net material content of the beverage cartons.

The net collection yield for a municipality (CY) was derived from net amount of collected material and divide this by the net potential of beverage cartons present in the collection area. The latter was derived from the total annual amount of beverage cartons placed on the Dutch market (70 kton) multiplied with the quotient of the amount of inhabitants in the collection area and the total population of the Netherlands and multiplied with a regional correction factor (RCF). This RCF equaled 115% for collection areas with less than 10% high-rise buildings and equaled 85% for collection areas with >50% of high rise buildings.

$$CY_{net}^{mu1}, [\%] = \frac{R_{net}^{mu1}}{\{\frac{AIC}{TAIN} \times TA \times RCF\}}$$

Equation 4: The net collection yield CY for a municipality equals the net collected amounts of beverage cartons divided by the amount of inhabitants in the collection area (AIC), divided by the total amount of inhabitants in the Netherlands (TAIN), multiplied by the total amount of beverage cartons placed on the Dutch market (TA) and a regional correction factor (RCF).

2.2 Material analysis

The material composition of every category of beverage cartons was determined by measuring the material content of at least ten, randomly selected, beverage cartons of that category. The material content is based on dry matter and described as a percentage of the total dry weight of the beverage carton.

2.2.1 Test method

First, the dry beverage cartons were weighed. Next, all detachable parts (caps, closures, straws, flow packs, etcetera) of the beverage cartons were detached, and glue or carton fibre was carefully removed from the parts. The separate parts were dried and weighted. The remaining weight is assigned to the body of the beverage carton (combination of carton fibre, PE and in some cases aluminium).

The mass-percentages of the materials in the body are determined by SEM-imaging and disintegration of the beverage cartons in combination with sieving. These procedures are described in the following section. The weight of the body is multiplied by the determined percentages, which results in an overview of the masses of all materials per beverage carton. The average material composition per category of beverage cartons is calculated as described in Equation 5.

$$\text{Average material content for a category } [\%] = \frac{\sum \text{Weight of material found in the category [g]}}{\sum \text{Weight of beverage carton [g]}} \text{ x } 100\%$$

Equation 5: Calculation method of the average material composition per category of beverage cartons

2.2.2 *The procedure to determine material content of beverage carton bodies*

Two different measurements are performed to determine the material content (%) of PE, aluminium and carton fibre from the body of the beverage carton. The first type is SEM imaging and the second type is disintegration in combination with sieving.

Firstly, SEM images were made of twelve different beverage cartons of different brand and types, an example is shown in Figure 2. From these images the thicknesses of the PE and aluminium layers are deduced. Together with the surface of the body and the density of the materials the mass of the PE film and aluminium are calculated. The weight of the carton fibre is determined by the weight of the body subtracted by the weight of the aluminium and PE film. The calculated weights are used to determine the material content in the body for the different materials.

Secondly, the material content of the bodies was determined by disintegrating and sieving the body material. The disintegration of the beverage carton is done with hot water (+/- 70˚C) at 70.000 rotations/minute. The suspension is fractioned with a Sommerville screen (machine for sieving fibrous material) for 30 minutes at water pressure 1.25 bar, with a sieve of 0.15 mm. The remaining PE(-aluminium) fraction is dried and weighted, which allows determining the PE (and aluminium) content. For the beverage cartons with a PE-aluminium layer an extra step is added. The PE was incinerated at 575 ˚C to render the remaining clean aluminium material. From the weight reduction the PE fraction was deduced. In later tests this procedure was repeated with only the parts of the body without folds and seals, to obtain as clean as possible PE-aluminium laminate structures without carton fibres.

As a verification some beverage cartons were incinerated as a whole to get insight in the aluminium content of the beverage cartons. The aluminium content seemed to be somewhat higher than expected based on the calculation made with the measured thickness and assumed density. Therefore, the aluminium content was adjusted based on the new insights. In the overall results this resulted in an increase of aluminium content from 5% to 6% for the categories containing small aseptic beverage cartons (UHT milk cartons < 1 ltr, Cartons with UHT mixes of juice & dairy < 1 ltr and Residual cartons < 1 ltr).

These calculations were done for several beverage cartons of common brands, types and volumes. This resulted in an overview of beverage carton types and the composition of their bodies. The percentages were generalised and were used to calculate the masses of all similar beverage cartons. For some specific beverage cartons there are no data for material composition of the body generated, and in such cases the data of the most similar beverage carton is used to calculate the composition.

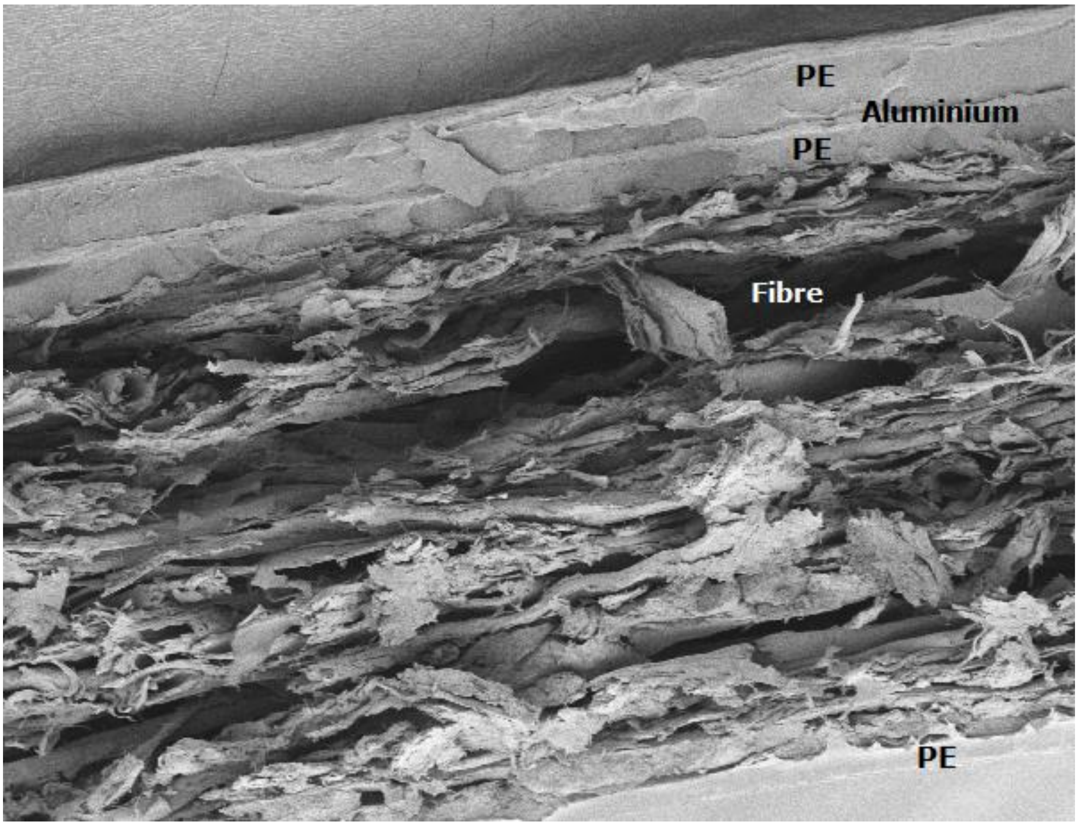

Figure 2: Example of SEM-image (SIG combibloc, 0.2 ltr, Taksi), topside is outside and bottom side is inside of the beverage carton.

2.2.3 Issues

In one of the milk cartons an EVOH layer was found in the SEM image. This resulted in a thicker PE layer, namely two layers of PE with an EVOH layer in-between. As the product in the beverage carton was a niche product and not representative for the category, the material composition of this beverage carton is not included in the average material composition of the category.

In the rest cartons < 1 ltr category some PS parts were found as part of the closure of cat milk cartons. As these parts figure up for less than 1% of cat milk cartons and cat milk cartons are pretty uncommon (<1 ‰ of the beverage cartons) these are not included in the average material composition.

The weight of the glue/hot-melt is not separated out in the analyses. This is included in weight of the carton fibre.

2.3 Residue potential and washed off residues

The residue potential was determined by measuring the moisture and dirt content in beverage cartons directly after consumption. To get insight in the moisture and dirt in the beverage cartons they were collected after consumption and rinsed in several steps. For every category at least ten beverage cartons were tested. These beverage cartons have been chosen randomly.

The beverage cartons used for this test were collected directly after consumption. Directly after consumption the beverage cartons have product residues on the inside of the packaging and the outside of the beverage cartons is clean. This test gives insight to the potential residue inside the beverage carton. Beverage cartons found in the waste are found to have moisture and dirt on the inside as well as on the outside of the carton. Comparing the residue potential and the moisture and dirt content of beverage cartons found in the waste streams this difference should be considered.

The time between emptying the beverage carton and the execution of the test varies from five minutes to one week. The aim of this test was to test the beverage cartons as soon as possible after consumption. The emptying techniques used for emptying the beverage cartons are listed. An overview of the most used emptying techniques of tested beverage cartons per category is given in Table 3.

Table 3: Most used emptying techniques of tested beverage cartons per category

Category of beverage cartons	Most used emptying technique
Milk cartons ≥ 1 ltr	poured out
Milk cartons < 1 ltr	poured out
UHT milk cartons ≥ 1 ltr	poured out
UHT milk cartons < 1 ltr	straw sipped
Yoghurt & dessert cartons ≥ 1 ltr	pressed
Yoghurt & dessert cartons < 1 ltr	pressed
Juice cartons ≥ 1 ltr	poured out
Juice cartons < 1 ltr	straw sipped
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	poured out
Cartons with fresh mixes of juice & dairy < 1 ltr	poured out
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	poured out
Cartons with UHT mixes of juice & dairy < 1 ltr	straw sipped
Residual cartons ≥ 1 ltr	poured out
Residual cartons < 1 ltr	poured out

2.3.1 Test method

The test was executed in several steps. First the received beverage cartons were weighed. Next, approximately 100 ml cold water (+/-18˚C) was added. The filled beverage carton was weighed. After shaking the beverage carton, it was emptied and the dirty water and the rinsed beverage carton were weighed. Subsequently, the same steps were executed with hot water (+/- 100 ml, +/- 69 ˚C). After the rinsing steps, the beverage cartons were checked on remaining dirt. If remaining dirt was found on the beverage cartons it was rinsed off. The clean beverage cartons were dried in an oven. The dry weight of the beverage carton was measured.

The data found by weighing the beverage cartons was used to calculate the average moisture and dirt content per category of beverage cartons. The moisture and dirt content was calculated as a percentage of the gross weight of the beverage cartons as shown in
Equation 6. This number represents the residue potential per category of beverage cartons.

$$\text{Moisture and dirt content [\%]} = \frac{\sum \text{weight dirty beverage cartons [gram]} - \sum \text{weight dry and clean beverage cartons [gram]}}{\sum \text{weight dirty beverage cartons [gram]}} \times 100\%$$

Equation 6: Calculation method of moisture and dirt content

The moisture and dirt content was calculated for every phase in the test (after consumption, after rinsing with cold water and after rinsing with hot water) to get insight in the effects of the rinsing steps. The percentage moisture and dirt was calculated in relation to the gross weight of the beverage cartons at the specific phase in the test.

2.3.2 Issues

In the set-up of this test the time between the consumption of the content of the beverage carton and the execution of the test was not measured and was not equal for all beverage cartons. In general it varied between 1 minutes and 2 weeks, but most were tested within 2 days. Dehydration or development of mould affect the results of this test, such effects are not taken into account in the calculation of the residue potential.

During the test the weight of some beverage carton increased after the first or second rinsing step. This occurred one or more times in the categories:

- Milk cartons ≥ 1 ltr
- Milk cartons < 1 ltr
- UHT milk cartons ≥ 1 ltr
- UHT milk cartons < 1 ltr
- Juice cartons ≥ 1 ltr
- Juice cartons < 1 ltr
- Cartons with fresh mixes of juice & dairy < 1 ltr
- Residual cartons ≥ 1 ltr
- Residual cartons < 1 ltr

This relative weight gain was probably the result of adding water to the beverage carton of which the content is dehydrated and an effect of the design of the beverage carton (e.g. placing of the caps, folded carton) due to which the beverage carton cannot be completely emptied after rinsing. The moisture and weight content per phase per category of beverage cartons was determined based on the sum of all beverage cartons. Due to the aggregation of the measured data the effect of individual packages is averaged out. Therefore, the weight gain was not visible in the aggregated results.

In some cases the beverage carton was not completely clean after the rinsing steps. In these cases the dirt was removed mechanically and the beverage cartons were weighed again. Where the weight difference was more than 0.1 gram this was noted. Notable weight differences were found one or more times in the following categories:

- UHT milk cartons ≥ 1 ltr
- Yoghurt & dessert cartons ≥ 1 ltr
- Yoghurt & dessert cartons < 1 ltr
- Juice cartons ≥ 1 ltr
- Residual cartons ≥ 1 ltr
- Residual cartons < 1 ltr

The weight of the beverage cartons after the rinsing step was used in the results of these analyses. Therefore, it should be noted that the moisture and dirt content after the second rinsing step is not only the weight of the moisture in the beverage carton, but can contain remaining product residue for the mentioned categories.

When analysing the results of this test it should be considered that the percentage moisture and dirt that is removed after the second rinsing step was not only a result of the temperature of the water, but also an effect of the fact that the beverage carton was rinsed twice. Both have an effect on the reduction of the moisture and dirt content.

2.3.3 Washed off residues

In order to estimate the amount of product residues that civilians wash off from the beverage cartons prior to collection at home we compared the residue potential (see paragraph above) with the residues observed in the samples. A smaller observed residue level than what would be expected based on the residue potentials would indicate washing off behavior by civilians. However, the determined residue levels not only include the residues inside the beverage cartons, but also the residues on the outside. Therefore, just a comparison between the residue potential and the observed residue level renders only an indication of the washing off behavior.

2.4 Amount and division of beverage cartons present on the Dutch market

According to the Hedra foundation (a co-operation of the three main producers of beverage cartons) about 70 kton of beverage cartons is annually placed on the Dutch market. This number is relevant for this study, since it allows us to estimate the amount of beverage cartons that is collected in the residual waste and incinerated. The compositional data of all the recovered waste fractions of both recovery facilities will be used to estimate the amount of beverage cartons present in the service areas of both recovery facilities and extrapolations to a national level will render to two estimations of the amount of beverage cartons which is placed on the Dutch market.

The same data is also used to estimate the composition of the beverage cartons on the Dutch market. However, here the composition of the beverage cartons present in the MSW of both recovery facilities is weight-averaged to obtain an estimation of the market division of beverage cartons which are present on the Dutch market.

2.5 Mass balancing the recovery and sorting facilities

The analyses of the processes within the recovery and sorting facilities followed the same methodology. Both process types have typically one input stream, one product containing most BC (> 50% of all BC), one or more residues containing BC and other products containing almost no BC (< 1% of all BC each), see Figure 3. Aim of each analysis was to find out what percentage of BC present in the input is transferred to the product containing most BC. To be able to calculate this figure the total mass of the product and the concentration of BC in it as well as the total mass of the input and the respective concentration of BC is needed. As sampling of the input material is difficult due to heterogeneity of the waste, especially MSW, all outputs where analysed for their concentration of BC and their total mass instead. However, certain products contain almost no BC because this product is subjected to manual quality control (e.g. PET, HDPE, PP, etc.) where the BC is removed. Alternatively the product is generated using separation techniques which BC are not responsive to (e.g. metal separation using magnets). These product where analysed by visual inspection for BC and/or by obtaining a small sample (approximately 5 kg). From all other outputs a set of three to nine samples was taken. The weight of these samples was supposed to be around 2% of the total mass of the respective output. All samples were brought to the RWTH Aachen University or the Wageningen UR and analysed for the composition (BC, paper and board, plastics, etc.).

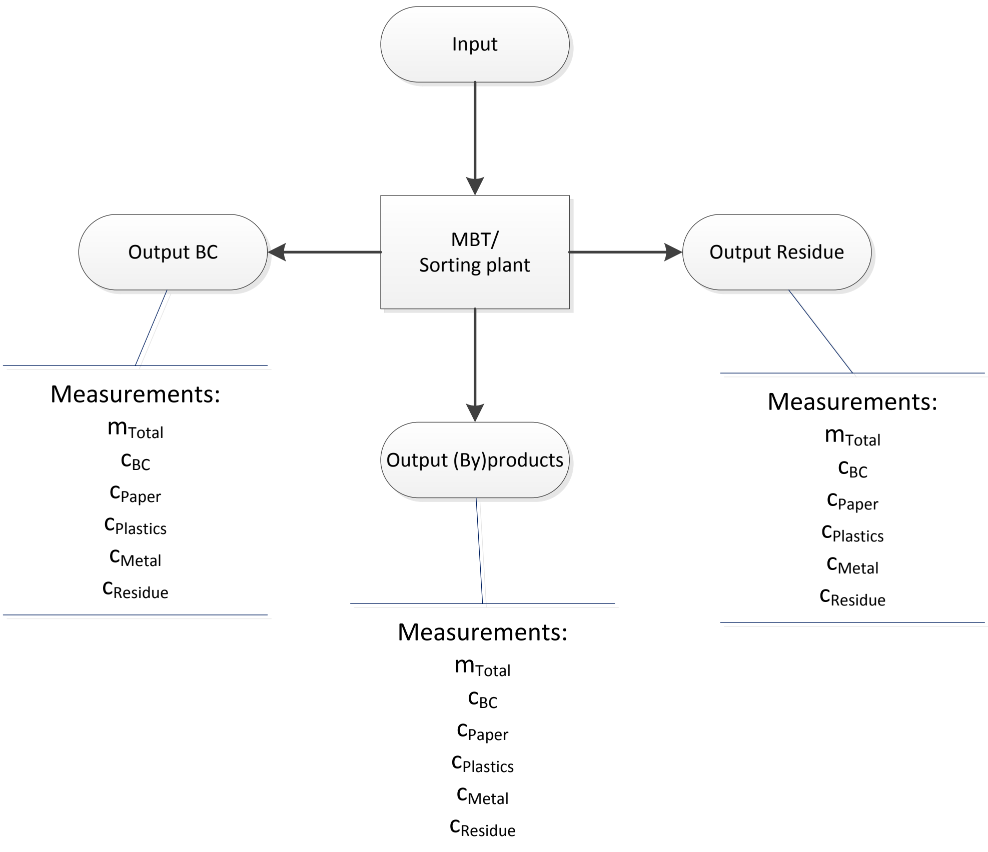

Figure 3: Methodology applied during the analyses of the recovery and sorting facilities.

The yield of BC into any fraction can be calculated from the masses of the output streams and the concentrations of BC in these streams, see Equation 7.

$$R_{w,i} = \frac{c_{BC,i} m_i}{\sum_{n=1}^{N} (c_{BC,n} m_n)}$$

Where:

$R_{w,i}$ is the yield of beverage cartons into the fraction i; i from 1 to N

$c_{BC,n}$ is the concentration of beverage cartons in the fraction n

m_n is the mass of the fraction n.

Equation 7: Yield of beverage cartons in a product fraction.

As previously mentioned the analysis of certain outputs was performed with much less effort. To be able to estimate the impact on the precision of this method three cases of one mass balance will be presented: a realistic case where all concentrations of BC where measured with similar precision, a simplified case where streams containing a small share of the total amount of beverage cartons are neglected and a worst case where the concentrations of streams which would be analysed with less effort are set to a relatively high value (half of the impurity content mentioned in the respective DKR specification was filled with BC). Table 4 shows the mass balance of a sorting process, the concentration of beverage carton in each output, the mass of each output and the respective yield of BC.

Table 4: Example of distribution of beverage cartons to the different outputs of a sorting process

Index	Fraction name	Concentration BC [%]	Mass total [Mg]	$R_{w,i}$ [%]
1	Beverage carton	97.7	2.45	50.7
2	Residue flat	22.3	8.18	38.7
3	Mixed plastics	7.3	5.90	9.1
4	PE	0.0	0.95	0.0
5	PET	0.0	1.19	0.0
6	PP	0.0	1.19	0.0
7	Residue fine	2.6	2.77	1.5
8	Residue manual sorting	0.0	1.20	0.0

The yield into the BC fraction has been calculated following formula:

$$R_{w,i} = \frac{c_{BC,i} m_i}{c_{BC,1} m_1 + c_{BC,2} m_2 + c_{BC,3} m_3 + c_{BC,4} m_4 + c_{BC,5} m_5 + c_{BC,6} m_6 + c_{BC,7} m_7 + c_{BC,8} m_8} = \mathbf{50.7\%}$$

Note that the residue fine contains 1.5% of all BC present in the input. The polymer fractions contained less than 0.0% of beverage cartons. An influence on the yield could not be measured.

The simplified case is presented below.

$$R_{w,1} = \frac{c_{BC,1} m_1}{c_{BC,1} m_1 + c_{BC,2} m_2 + c_{BC,3} m_3} = \mathbf{51.5\%}$$

The concentration of BC in the polymer fractions and the residue fine was set to 0%. That means no analysis would have taken place as no beverage cartons could have been spotted in the products. The result deviates by 1.6% (1-50.7/51.5)from the realistic case.

The worst case is presented in Table 5. The concentration of BC in the polymer products is set to a value depending on the allowed impurity content specified in the respective DKR specification.

Table 5: Worst case scenario; following the DKR specifications the amount of residue in the PE, PET and PP fraction is limited to 3/2/3 %; those were assumed to be beverage cartons

Index	Fraction name	Concentration BC [%]	Mass total [Mg]	$R_{w,i}$ [%]
1	Beverage carton	97.7	2.45	**49.8**
2	Residue flat	22.3	8.18	38.0
3	Mixed plastics	7.3	5.90	8.9
4	PE	**3.0**	0.95	0.6
5	PET	**2.0**	1.19	0.5
6	PP	**3.0**	1.19	0.7
7	Residue fine	2.6	2.77	1.5
8	Residue manual sorting	0.0	1.20	0.0

Even in this worst case scenario a yield of BC of 49.8% is obtained. Therefore the worst case deviates from the simplified (best) case by only 3.3% (1-49.8/51.5).
This simple example shows that even if the analysis of certain outputs is done in a simplified way the mass balance can be seen as highly (>95%) precise. However, all analysed concentrations of BC will be presented as measured. In general, the variation of the concentration of BC in streams showing small shares of BC usually is greater as smaller samples were obtained.

2.6 Mass balancing the beverage carton recycling plant REPA

The analysis of the recycling process had to follow a different methodology as the process has two inputs, a beverage carton input and a water input. This implies that the input composition cannot be calculated from the sum of the output products.
Primary aim of the analysis was to measure the total dry matter content of both input streams and output products to allow for a plausibility check of the measurements. A high deviation of both measurements would originate from one or more measurement error on one side or both sides. Secondary aim of the analysis was to obtain information on the quality of the BC input and the outputs. Figure 4 shows where samples were obtained and which parameters were measured.
The mass of the BC input was measured on the lorry balance of the recycling plant. The dry matter content and the quality of the input is derived from a set of five to seven samples of 70 to 96 kg total.
The mass of the input water was not measured directly. Instead it was estimated by the volume of the buffered process water (density was assumed to be 1 g/cm^3). The dry matter content of the input water was measured from four samples of around one liter.
The mass of water in the storage vessel is estimated by the volume stored (density was assumed to be 1 g/cm^3). The dry matter content in the storage vessel is measured by obtaining samples from an outlet on the bottom of the vessel and by scooping from the surface of the stored process water. Six to twenty samples of approximately 10 litres each were taken and analysed in the laboratory of the I.A.R.

The mass of the light-weight by-product was measured by catching the material at the outlet of the press with a big bag and weighing of the bag. From each bag a sample of approximately 5 kg was taken to measure the dry matter content. The heavy by-products emerged after the process from a sink below in the pulper in a metal basket. Since this was only a few kilograms, this sample was dried and weighed completely.
A sample (ca. 400 litres) from the bottom outlet of the storage vessel was dewatered on a 200 µm screen. This sample was brought to the Wageningen UR for the quality analysis of the pulp.

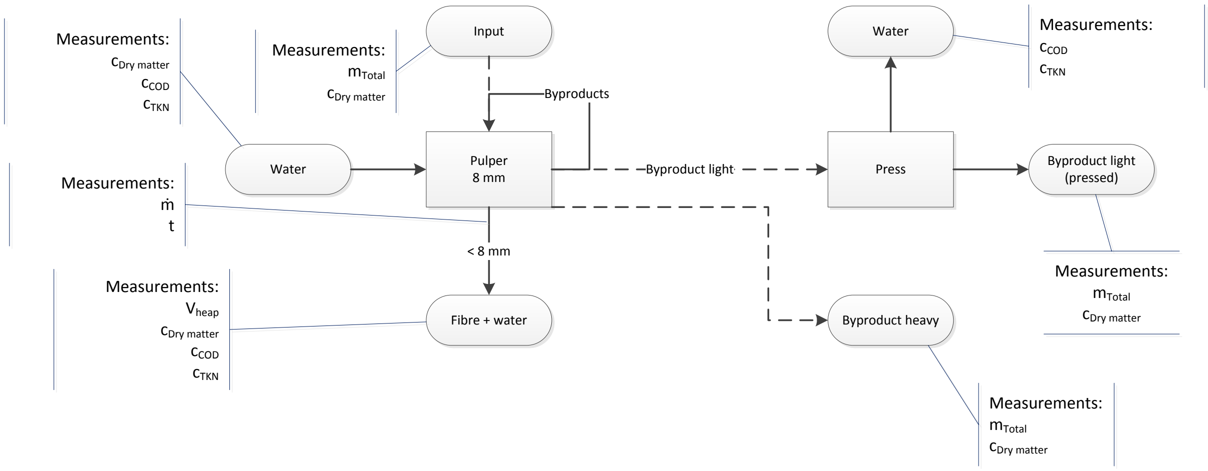

Figure 4: Process of the beverage carton recycling plant

Table 6 shows an example of a mass balance composed for a trial at the recycling plant. Note that the dry matter from the fibre-water-suspension contains not only fibres but also soluble substances which entered the process via the input water or adhered to the surface of the beverage cartons, fine non-fibre particles, e.g. ink from the beverage cartons or mineral particles and coarse non-fibre particles, e.g. plastic pieces which got comminuted during the pulping process.

Table 6: Example of a mass balance composed for the recycling process.

	Mass total [kg]	Dry matter [%]	Dry matter [kg]
Inputs			
Input BC	4500	75%	3375
Input water	ca. 450000	0.03%	135
Sum			3510
Outputs			
By-product light	1300	70%	910
By-product heavy	6	70%	4.2
Fibre-water-suspension	450000	0.58%	2610
Sum			3524.2

Due to uncertainties, variations between the analysis of inputs and outputs, additional measurements where performed to verify the plausibility of the results. The first option was a bypass (see Figure 5). That means a small percentage (ca. 0.5%) of the process water flow to the storage vessel was separated and dewatered constantly during the trial using a 200 µm screen. The

screen overflow was put approximately every eight minutes in a separate bag and analysed for its dry matter content in the laboratory. The screen underflow was caught in vessels. Approximately every 8 minutes a sub sample (ca. one litre) from the caught material was taken and analysed regarding its dry matter content in the laboratory.
The second option was to dewater the total fibre-water-suspension in the storage vessel (see Figure 6). A 200 µm screen was used. The screen overflow was caught and weight completely. A sample was taken to measure the dry matter content of the material. The screen underflow was not weighed. Instead it was calculated from the difference of the water contained in the storage vessel and the total mass of the screen overflow. A sample was taken from the screen underflow to measure the dry matter content.

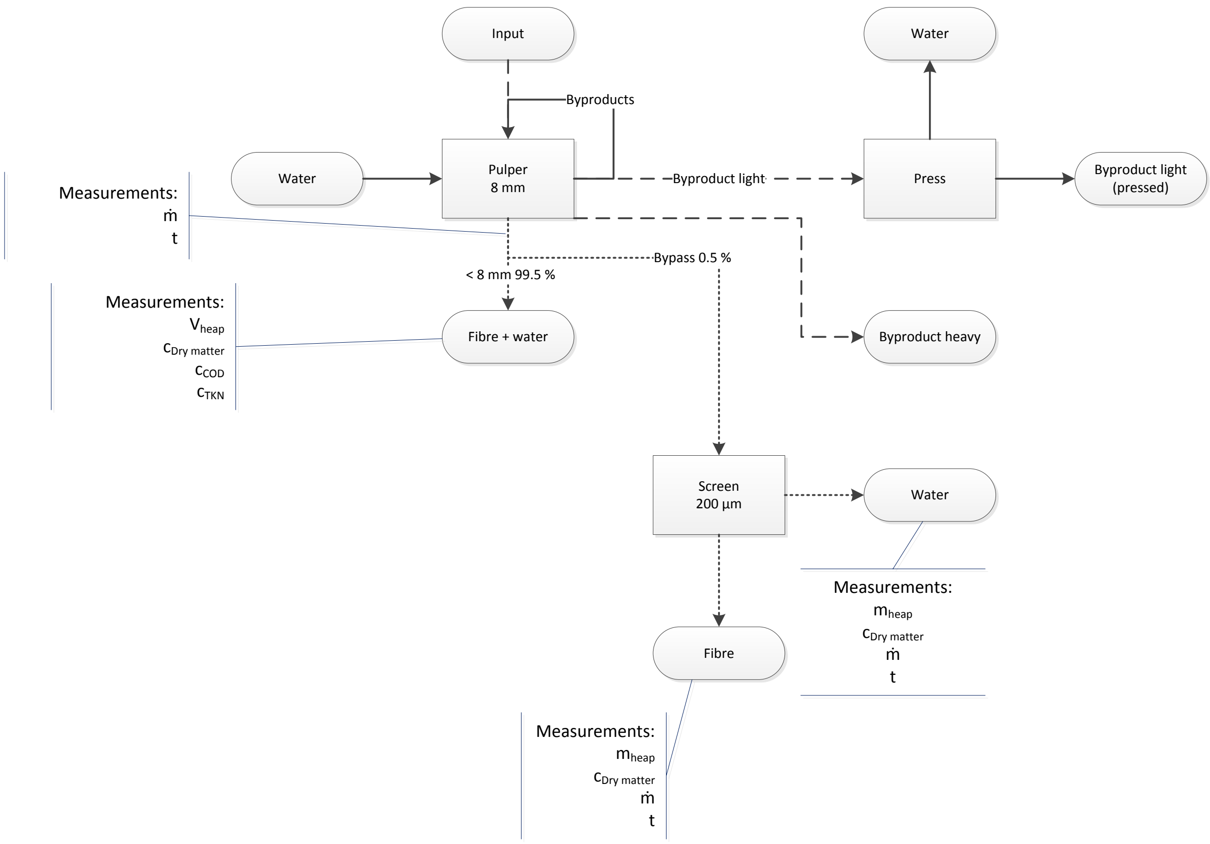

Figure 5: Optional configuration (by-pass) of the recycling plant.

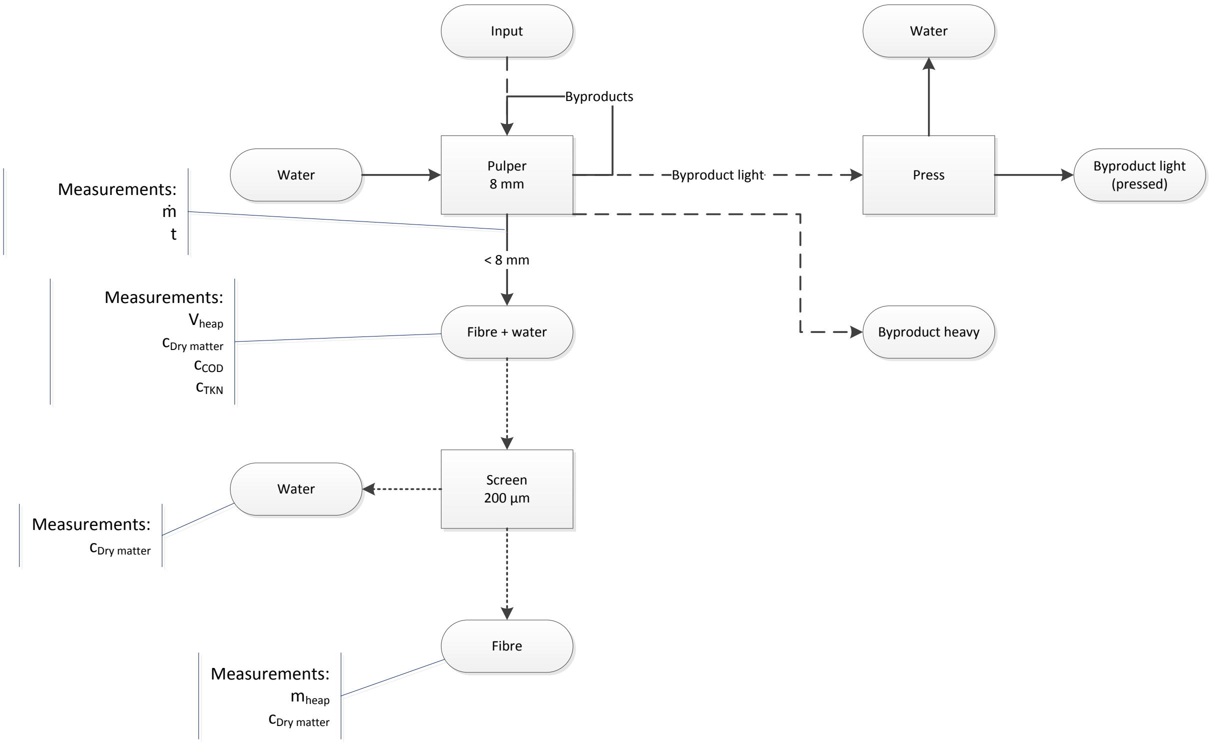

Figure 6: Optional configuration (dewatering) of the recycling plant.

2.7 More detailed description of sampling method per participant of the pilot

As many different parties (see Table 1) took part in the pilot the methodology described above had to be adjusted to the individual situation of each plant. Therefore details of each analysis (sample points, sample mass, total mass) will be presented in the following sections.

2.7.1 Definition of terms for sampling

The sampling method is an important aspect of each analysis. Different methods of sampling will result in different confidence intervals of the results. The methods used are the following (the description refers to the terms used in the info boxes in the flow sheets in the following sections):

- Drop-off: A sample was obtained from a falling material stream either at a belt-to-belt drop-off point or a belt-to-bunker drop-off point. The whole cross section of the falling material was caught using buckets, big bags, or similar vessels.
- Cross section: The full cross section of a conveyor belt was swept to obtain a sample.
- Press: If the material stream passed a press, it was possible to stop the press and sweep the chamber of the press completely.
- Grab (heap): A grab sample was taken from a material heap. For most materials a shovel was used. In some cases an excavator was used. This method was not applied if de-mixing effects could be spotted (e.g. round pieces rolling down the heap, flat pieces staying on top).
- Grab (conveyor): A grab sample was taken from running conveyor belt. Buckets, fishing nets or similar things had to be used to catch the material. It was not possible to cover the whole cross section of the belt applying this method.
- Hot spot: A material heap was actively searched for beverage cartons. If no beverage cartons could be spotted, the concentration of BC in the heap was assumed to be 0%. Usually no further analysis regarding the quality of the heap was performed (share of paper and board, plastics, etc.). This method was only applied in certain cases, e.g. if the respective product went through a quality control or the material was too fine for beverage cartons to be in the material (e.g. <30 mm, only if the process doesn't involve commination).

2.7.2 Attero Noord, Groningen

The recovery facility Attero Noord in Groningen treats MSW and recovers a mixture of plastics and beverage cartons which is forwarded to the sorting facility Augustin for further processing. Plastic films are not included in the mixture and form a separate fraction. Organic fine material and metals are recovered for further treatment. RDF, the sorting residue, is forwarded to an incineration facility. The process is shown in Figure 7.

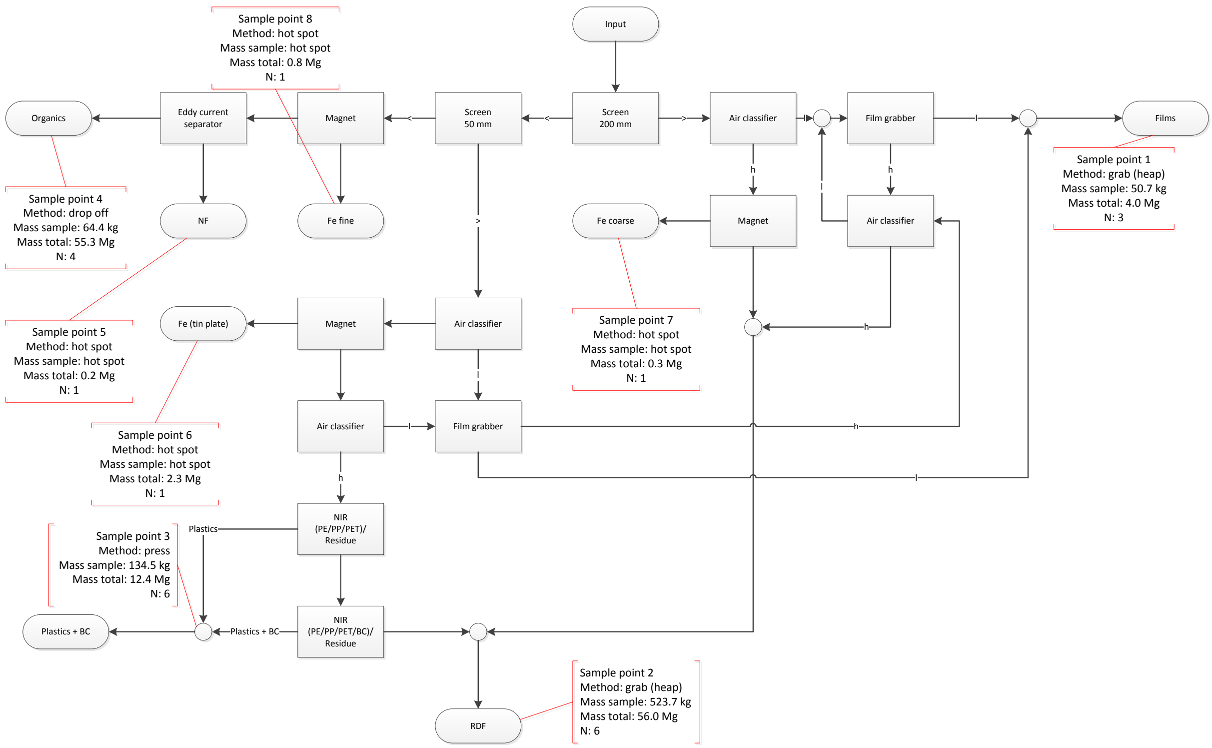

Figure 7: Process of the recovery facility of Attero Noord in Groningen.

Due to safety regulations personnel of the I.A.R. and WUR were not allowed to obtain samples. Instead personnel of Attero Noord performed the sampling under supervision of personnel of the I.A.R. The input MSW for the trial was delivered the day before the trial from municipalities of the province of Groningen. A total of 133 Mg were delivered and treated. All outputs of the process were weighed after sorting on a lorry balance with the exception of the organic fine material which had to be weighed using the built-in conveyor balance between the mechanical treatment plant and the biological treatment plant. It was found that the weight of the input and the sum of the weights of all outputs differ by 1.3%.
Figure 8 shows how the input material was stored on a dedicated place instead of the common MSW bunker of the plant. Figure 9 and Figure 10 show the pressed concentrate of beverage cartons and plastics and the sample point in the press. Figure 11 and Figure 12 show how the RDF was tipped from the press container after weighing and how a grab sample from the heap was obtained using an excavator. Figure 13 shows an example of a hot spot sampled material stream. No beverage cartons can be spotted.

Figure 8 Input material of the process

Figure 9 Concentrate of the plastic and beverage carton mix

Figure 10 Cleaning of the chamber of the press for the plastic and beverage carton mix

Figure 11 Tipping of the RDF

Figure 12 Obtaining a grab sample using the excavator

Figure 13 Example of an non-sampled output (here Non-ferrous metals)

2.7.3 *Omrin, Oudehaske*

The recovery facility of Omrin in Oudehaske treats MSW (see Figure: 14). Several products and residues are formed during treatment, e.g. ferrous and non-ferrous metals, organic fine material, etc. The beverage cartons are first separated as a mix of plastics and beverage cartons and as a mix of non-ferrous metals and beverage cartons. The mixed fractions are brought to a small sorting plant on the plant site, the so-called REKAS plant. This REKAS is comprised off a feeding conveyor belt, a ballistic separator and two NIR sorting units that process the 2D and 3D outputs of the ballistic separator. In this sorting facility the beverage cartons are then separated from the plastics or non-ferrous metals respectively. The produced beverage carton concentrate is directly sent to recycling facilities. No further purification in sorting plant is needed.

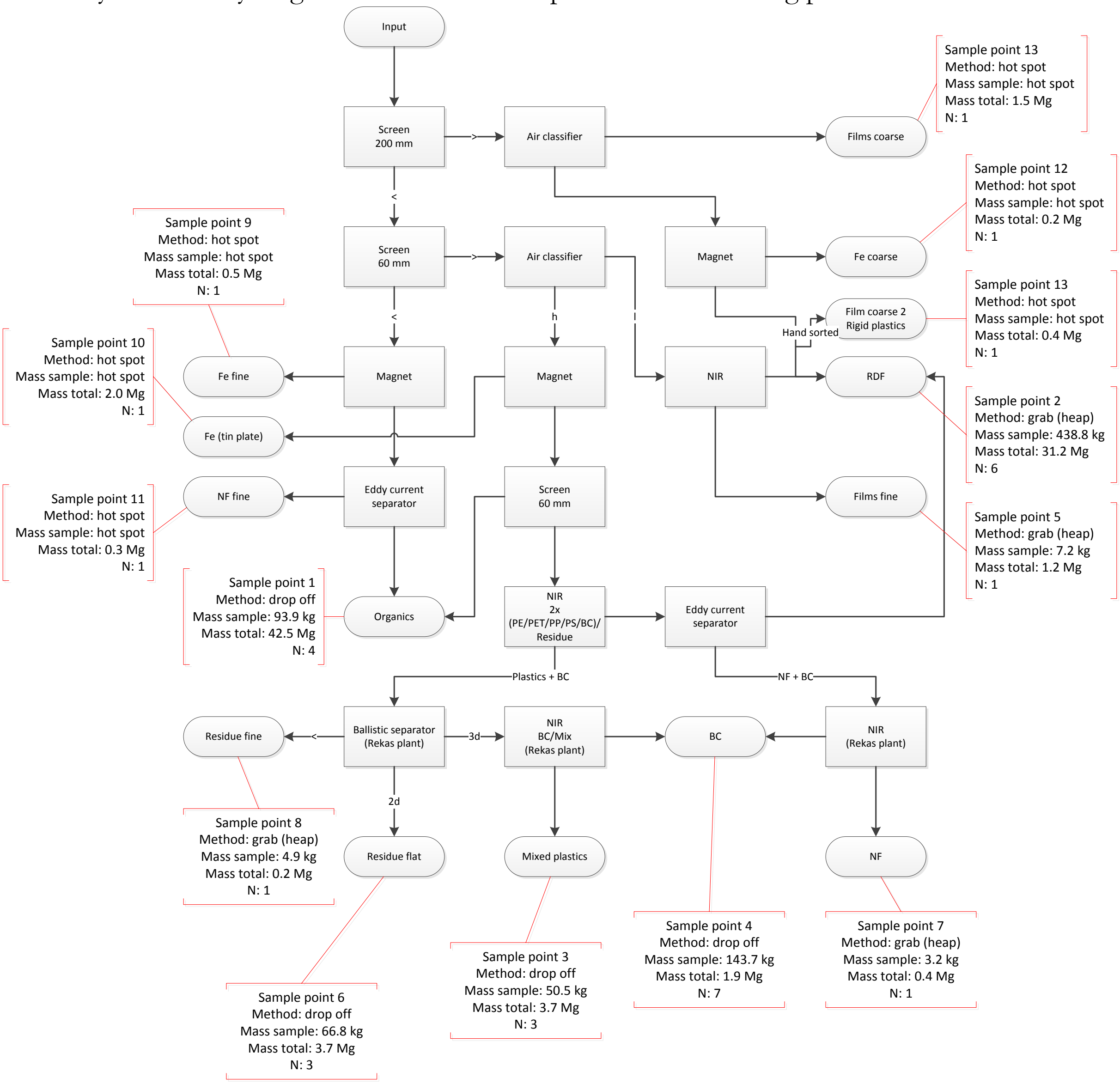

Figure: 14 Process of the recovery facility of Omrin in Oudehaske.

All sample were taken by personnel of the WUR and I.A.R. The analysis of the quality of the samples was done by the WUR. Due to logistical issues it was not possible to store an amount of MSW separately from the MSW in the common bunker. Therefore the weight of the input is

unknown. All outputs were weighed after sorting (90 Mg combined). It is unknown to what extent the weight of the input and the weight of all outputs differ as no measurement of the input was performed. The REKAS plant which was used to sort the mixed fractions containing beverage cartons was not balanced separately. That means no samples were taken from the mixed fractions themselves but only from the outputs of the REKAS plant.
Figure 15 shows the input material to the recovery plant of Omrin. Figure 16 and Figure 17 show the dosing unit and the NIR cascade used to recover beverage cartons. Figure 18 shows how the fine material was sampled. De-mixing effects were observed while the material piled up on the heap in the container. Therefore material was caught from the falling material flow. Figure 19 shows an example of a "hot spot" sampled output. No beverage cartons were found in the fine ferrous metals.

Figure 15: Input material to the process (Omrin)

Figure 16: Dosing unit used to feed the NIR sorters

Figure 17: A two stage NIR sorter cascade used to recover beverage cartons

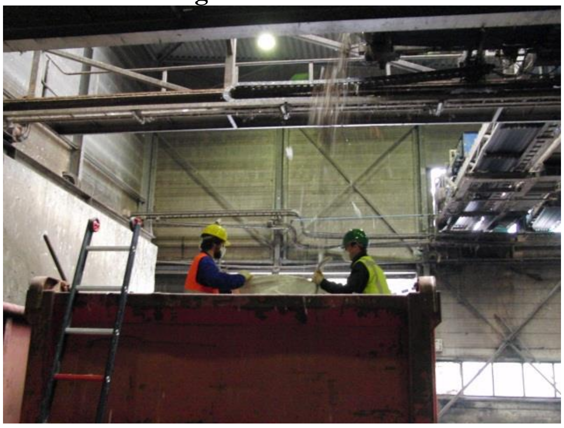

Figure 18: Sampling of the fine material

Figure 19: Fine ferrous metals recovered from the MSW

2.7.4 Augustin Entsorgung, Meppen

The sorting facility of Augustin in Meppen generates a beverage carton product from the recovered mixture of Attero-Noord mainly by NIR sorting with an additional manual quality control. Four other main products are generated: PE, PP, PET and a mixed plastic product. Two residues are formed; sorting rest flat and sorting rest fine. Figure 20 shows the sorting process for the recovered mixture of beverage carton and plastic packages generated by Attero Noord. The shredder showed in the flow sheet was not used during the trial as the material's top particle size is 200 mm. During separation in Attero's recovery facility the material stream larger are separated off and do not contribute to the mixture of beverage cartons and plastic packages that is sorted at Augustin.

All samples were taken by personnel of the I.A.R. The analysis of the quality of the samples was performed in the laboratory of the I.A.R. The input material for the process was weighed on a lorry balance of the sorting plant during delivery of the material. 24.6 Mg were supplied for the trial. After sorting all outputs were weighed. It was found that the weight of the input and the weight of all outputs differ by 3.2%.

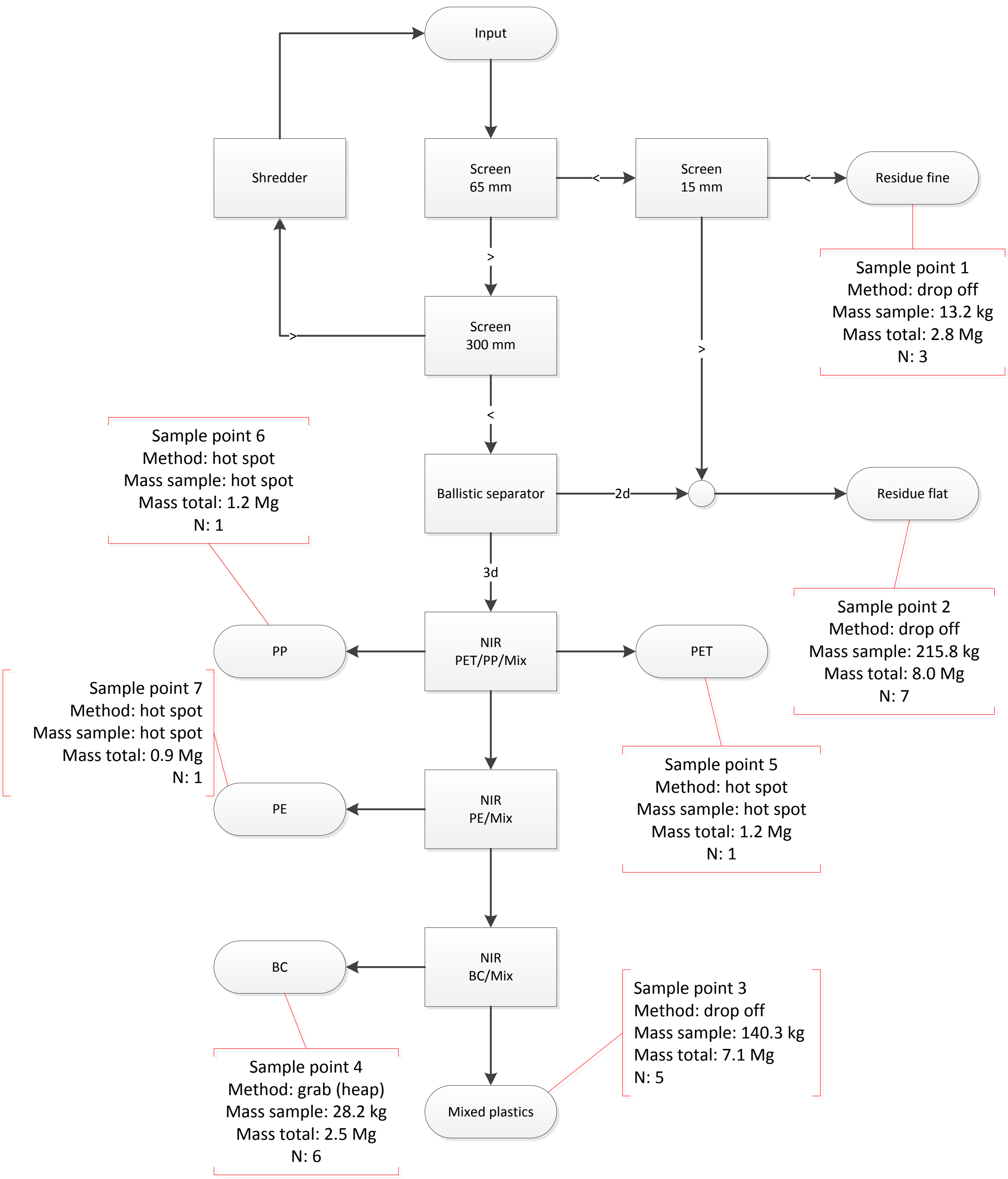

Figure 20: Process of the sorting facility Augustin in Meppen.

Figure 21 shows the beverage carton fraction generated in Meppen. Figure 22 and Figure 25 show the HDPE and PP product in which no beverage cartons can be spotted. Figure 23 shows the sampling method “drop-off”, here applied to the residue flat. Figure 24 shows the sampling method “grab (heap)”, here applied to the mixed plastics. An excavator was used to take a sample from the container which held the mixed plastics. Figure 26 shows the fine material (<15 mm). Due to a broken screen deck coarser material was allowed to pass the screen. Because of the ill-defined particle size the “hot spot” method was not applied.

Figure 21: The beverage carton product generated in Meppen.

Figure 22: The HDPE fraction generated in Meppen.

Figure 23: Obtaining a sample from the flat residue.

Figure 24: Obtaining a sample from the mixed plastics using an excavator.

Figure 25: The PP fraction generated in Meppen

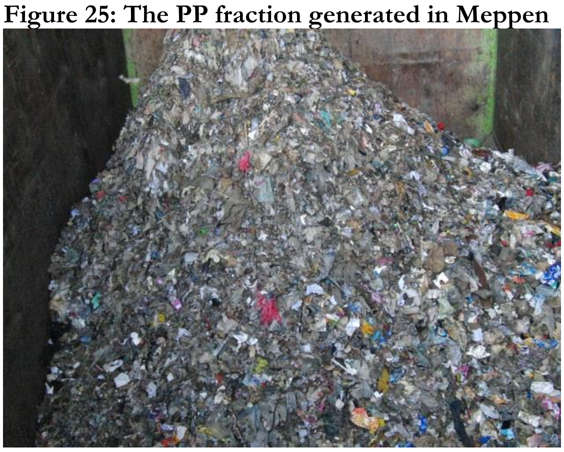

Figure 26: The fine residue generated in Meppen.

2.7.5 *Schönmackers, Kempen*

The sorting facility of Schönmackers in Kempen treats the co-collected mixture of beverage cartons, plastic packages and metal packages named Milieuzak, see Figure 27. The Milieuzak collection is a combined collection of paper & board in mini-containers with a separate plastic collection bags for plastic packages, beverage cartons and metal packages. At the cross-docking facility Hummel a hand-picking group removes the plastic bags from the collected mixture. Schönmackers produces several products like PET, PE, PP, paper and board and beverage cartons from the Milieuzakken. The process generates a fine residue, a residue from the manual quality control of the beverage cartons, a sorting residue and a coarse residue. The coarse residue is comminuted and re-fed to the plant after all other input material has been used. The coarse residue from treatment of the coarse material is not fed to plant again.

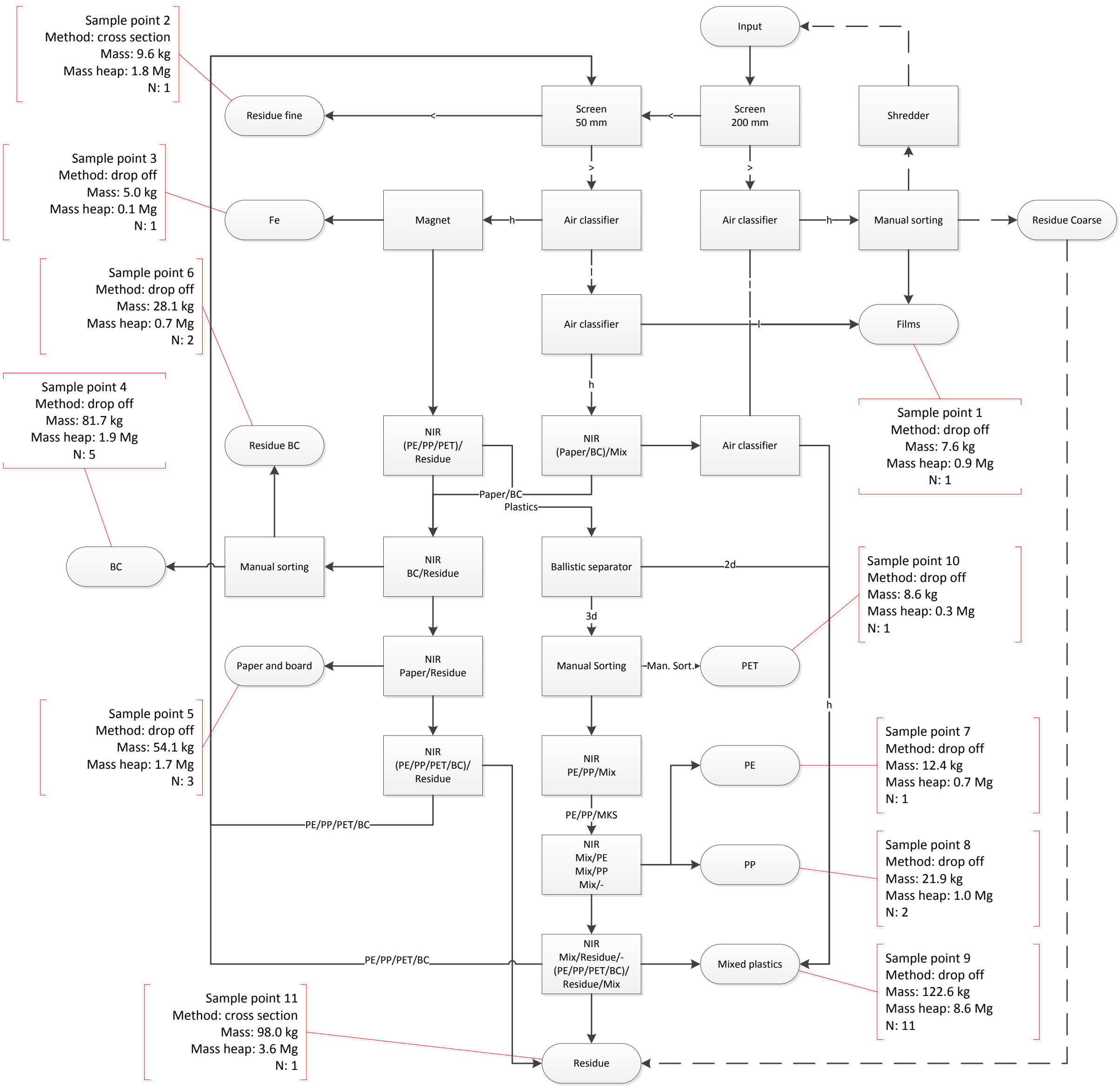

Figure 27: Process of the sorting plant of Schönmackers in Kempen.

The analysis of the quality of the outputs took place on 13th of June. Weighing of the input and outputs took place on the 25th of October. The difference is due to organisational aspects. The

personnel of the plant was not instructed to weigh the outputs on the 13th of June. In order to make sure that the outputs of the trial in June and the trial in October are comparable certain streams (mixed plastics, residue, residue coarse) were analysed twice. A total of 23.7 Mg was provided for sorting. The weight of the input and the weights of the outputs differ by 10.7%.
As the quality of the products from treatment of the coarse material might differ from the quality of the products from treatment of the untreated Milieuzak it was decided to take samples from the residue, residue coarse and mixed plastics. The quantity produced was estimated by the total time of processing of the untreated material and coarse material. However, it turned out that there was not enough time to take a sample from the mixed plastics during processing of the coarse material as the total amount of coarse material was quite small (approximately 6% of the total mass of the input). The influence of the difference of the quality can therefore effectively be neglected. However, if there were measurements regarding quality and mass flow of products originating from treatment of the coarse material available they were taken into account. If no data was available the total mass measured was assumed to have constant quality during processing of the untreated and coarse material.
Figure 28 shows the beverage carton fraction generated in Kempen. It can be seen that the fraction is polluted with paper and board. Figure 29 shows the paper and board fraction. Figure 30 and Figure 33 show the PET and PP fractions in which no beverage cartons could be detected. Hence hot spot samples were obtained. Figure 31 shows the sampling method "drop off" in the case of a belt-to-bunker drop off point. Figure 32 shows he untreated input material.

Figure 28: The beverage carton fraction generated in Kempen.

Figure 29: The paper and board fraction generated in Kempen.

Figure 30: The PET bottle fraction generated in Kempen.

Figure 31: Obtaining a sample from the mixed plastics fraction in the bunker in Kempen.

Figure 32: Input material of the milieuzak sorting process.

Figure 33: The PP fraction generated in Kempen.

2.7.6 Sita, Rotterdam

The Sita facility in Rotterdam treats the co-collected mixture of plastic packages and beverage cartons originating from the group of municipalities which are represented by Kunststof Hergebruik BV. The process is shown in Figure 34. The main products are PET, PE, PP, films, mixed plastics. Also two residues, a fine residue and a residue from the infrared sorting, are formed. The process is not equipped to produce a beverage carton fraction from its regular operation, i.e. no NIR sorter is present to sort out beverage cartons. Therefore, the last NIR sorter was re-programmed to sort out mixed plastics and beverage cartons in a first run. In addition all beverage cartons found during quality control of all outputs were added to this mixed plastics fraction. The mixed plastic fraction was then fed a second time to the plant (22.9 Mg). During processing of the mixed plastics the beverage cartons were sorted out manually from the mixed plastics. In addition the beverage cartons from the manual quality control of all output product streams were added to the beverage carton product.

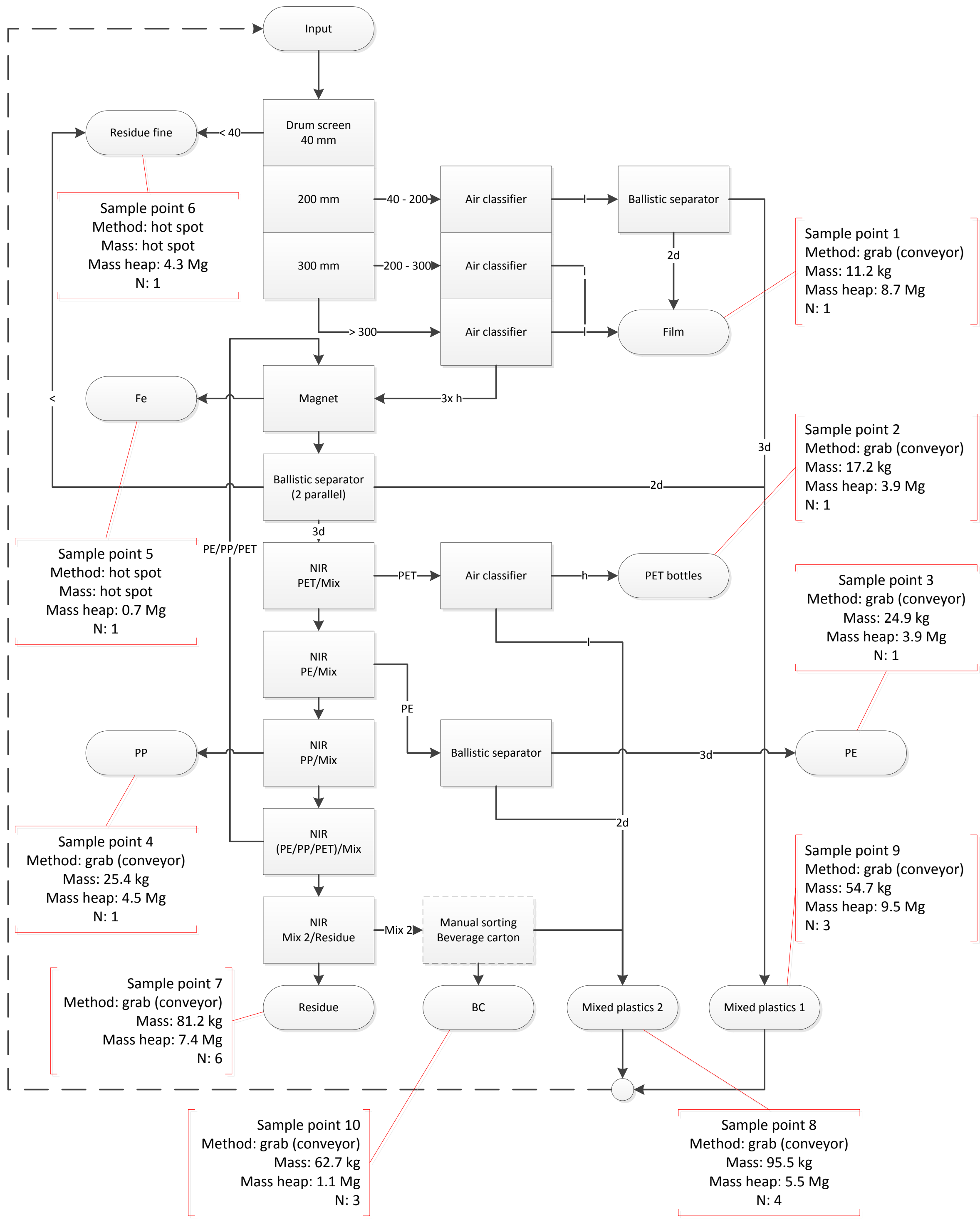

Figure 34: Process of the sorting facility Sita in Rotterdam.

All samples were taken by personnel of the I.A.R. Due to safety restrictions it was only possible to take samples as grab samples (with exception to the fine residue and ferrous metals) from the conveyor belt which connects the bunker system with the press. That means the material was buffered in the bunker. While emptying the bunker material was grabbed from the belt. The input material was weighed before sorting (52.3 Mg). All products were weighed after sorting. It was found that the weight of the input and the weight of all outputs differed by 5.5 %.

Figure 35 shows the applied sampling method in Rotterdam. A fishing net was used to grab material from the conveyor belt. Figure 36 shows the loose input material. Figure 37 shows the manual sorting from beverage cartons from the mixed plastics. Two to three workers shared the space in the sorting station to remove the beverage cartons. Figure 38 shows the fine material of the process, in which some beverage cartons can be spotted. However, even though some are present, the total amount in the heap was found to be negligible. Figure 39 and Figure 40 show the HDPE and PET fraction of the process. It was not possible to search these products as the material leaves the process baled. However, the samples obtained by the I.A.R. and reference samples of the WUR taken directly after the sorting cabinets indicate that no beverage cartons were present in these fractions.

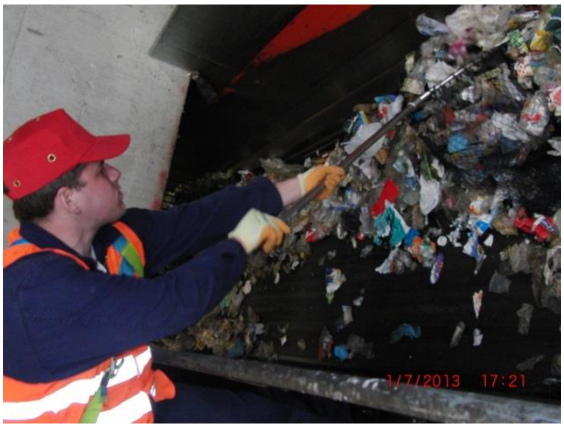

Figure 35: Obtaining a grab sample in Rotterdam


Figure 36: The input material to the Nedvang material sorting process

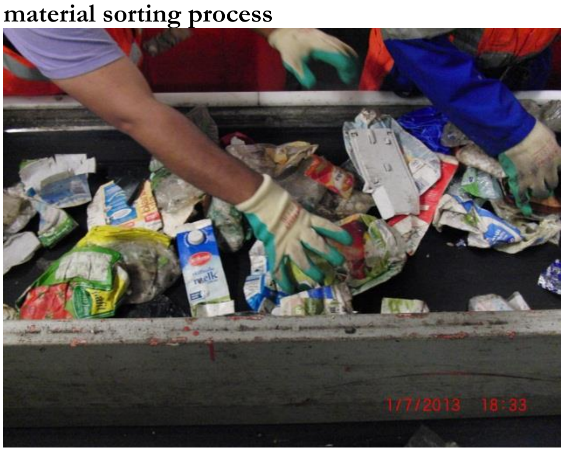

Figure 37: Manual sorting of beverage cartons in Rotterdam


Figure 38: The fine residue generated in Rotterdam


Figure 39: The pressed HDPE fraction generated in Rotterdam


Figure 40: The pressed PET bottle fraction generated in Rotterdam

2.7.7 Repa Boltersdorf, Brohl-Lützing

The beverage carton products generated in the sorting facilities and separate collected beverage cartons were transported to the recycling plant of Repa. The core device of the plant is the Codukte recycler, a dedicated pulper working device.

For each trial three batches of approximately 1.5 Mg were processed (with one exception). The reason for this limit is the capacity of the storage vessel (500 m^3) and that no water was re-circulated during the trials, i.e. around 100 m^3/h water had to be stored. The use of the press for the light by-product was experimental but necessary as it was not possible to weigh the wet heap of light by-product due to water trickling from the heap. The dry matter content in the input water was measured once for all trials as the fresh river water passes several settling basins and a coarse screen is used to remove impurities. Hence it was assumed that the quality of the water delivered was constant. However, one exception had to be made as the day before one trial a storm occurred. The coarse screen after the settling basins was blocked with leaves. Therefore the previously made assumption could not be applied. The COD and TKN of the input water was, as well, measured once for all trials with the above mentioned exception.

The fibre sample for the quality analysis at the WUR was generated on a 200 μm screen. The underflow from screening was drained and the overflow taken as sample.

Figure 41 shows the recycler unit in the plant. Figure 42 shows the screw feeders used to circulate the material (front and left) and the screw feeder which feeds new material to the plant (right). Figure 43 shows the inside of one part of the storage vessel. Some fibre samples were taken here by scooping. Figure 44 shows the discharged light-weight by-products. It can be seen that water is still trickling from the heap. Figure 45 shows the heavy-weight by-product discharge. Figure 46, Figure 47 and Figure 48 show how the light-weight by-products were pressed, caught in a big bag, weighed and poured out to take a sample. Figure 49 shows how a fibre sample was obtained by scooping. Figure 50 shows the beverage cartons while they are being processed.

Figure 41: The Codukte recycler used to produce the fibre pulp.

Figure 42: Screw feeders in the recycling plant.

Figure 43: Storage vessel for the process water containing the fibres.

Figure 44: Discharged light by-products.

Figure 45: The heavy by-product discharge

Figure 46: Pressing of the light by-product

Figure 47: Weighing of the light by-product.

Figure 48: Obtaining grab samples to measure the dry matter of the light by-products.

Figure 49: Obtaining a fibre sample from the storage vessel.

Figure 50: Beverage cartons during the pulping process.

.

2.7.8 *Sorting facilities for co-collected mixtures of paper & board and beverage cartons*

Three municipalities decided to test the combined collection of paper & board and beverage cartons. The amounts of beverage cartons that would be generated from these municipalities each month were too small for a recycling test at Repa. Moreover the amounts were also too small for a complete analysis of the sorting plants. It was therefore decided to perform an exploratory analysis of the two sorting plants; Kempenaars for manual sorting of the co-collected mixture from the municipality of Etten-Leur and Sita Soesterberg for partially mechanical and partially manual sorting of the co-collected mixture of the municipality Vianen. Samples of 1 m^3 were taken from the input material and from the sorted products. These samples were manually sorted in Wageningen. Additionally information on the weight of the input mixture and output products were determined at Sita with an industrial balance and at Kempenaars deduced from the weight of the delivering truck and by taking all the manually sorted beverage carton material from Kempenaars to Wageningen and weighing the total sorted product.
During manual sorting at Kempenaars and sampling of the input material at Sita, it was noticed that the beverage cartons were very unevenly spread over the mixture. The beverage cartons appear to be concentrated in pockets. This could indicate that the participation behavior in these co-collecting municipalities is very uneven; some civilians do and others do not participate.

2.8 Cross contamination effects

For the three collection systems with a carrier stream (co-collection with plastic, paper & board and MSW) the potential cross-contamination effects are explored. For the co-collection with plastics the emphasis lied on the moisture and dirt levels of the plastics, the dispersion of beverage cartons over the valuable plastic fractions and the sorting efficiencies of the valuable plastic packages in the presence of beverage cartons. For the co-collection with paper & board the emphasis lied on the microbial cross-contamination. For the recovery systems the emphasis lied on the quality of the recovered beverage cartons and the suitability for recycling plants.

2.9 Paper Analyses

2.9.1 *Description of the samples and evaluation method*

In total six different pulp samples were obtained.

- German reference: Pulp from reference material (German beverage cartons collected in combination with plastic and metal after sorting, FKN from DKR LVP)
- Hedra: Pulp from separate collected beverage cartons (Hedra, Oost-Brabant)
- Schönmackers: Pulp from beverage cartons from combined collection with plastic, Schönmackers (Milieuzakken)

- Attero: Pulp from beverage cartons from MSW, recovered by Attero-Noord and sorted by Augustin
- Omrin: Pulp from beverage cartons from MSW, recovered by Omrin
- Sita: Pulp from beverage cartons from co-collection with plastic, sorted at Sita Rotterdam

Paper without additives was produced from mixed paper & board waste. This was used as a reference material. This is a homogenous resource, since this pulp does not contain larger sized impurities, such as plastic flakes.

The pulps were received as wet pulps. They were frozen and stored at -19 °C. The evaluation of the pulps consisted of four different elements.

- Determination of the impurities, size distribution and chemical properties of the pulps
- Determination of the mechanical properties of the pulps as obtained
- Determination of the mechanical properties of a mix of recycled paper and the pulps
- Determination of the mechanical properties of the pulps after additional cleaning and refining

2.10 Heavy metal analysis in by-products

The environmental study revealed that "marine aquatic toxicity" is a relatively important environmental impact of beverage cartons and that this impact is associated with (heavy) metals in the plastic parts of the beverage cartons. To verify if these plastic parts do contain heavy metals an exploratory analysis of the four types of separable plastic components were performed; lids and closures, PE-aluminum laminate films, flakes of unprinted film and flakes of printed film. These measurements were performed with X-ray fluorescence spectroscopy by Alan Campbell in Brussels. The used machine was a ThermoScientific Nikon XL3t GOLDD+, which has a detection limit of 1 ppm.

2.11 Microbial analysis papers

Three types of samples were send in for microbial analysis by KBBL in Wijhe, with as objective to explore the present microorganisms in the recycled papers in a qualitative and where possible a quantitative manner.
The samples studied were:

- Reference 1, graphical white paper
- Reference 2, corrugated board, made from recycled paper & board
- Reference 3, Industrial brown paper made from recycled beverage cartons and paper & board by Delkeskamp.

- Four types of recycled paper made from paper & board that has been in contact with beverage cartons (Vianen, Etten-Leur).
- Six types of hand-sheets made from the six types of pulps produced by Repa during this pilot.

The paper was pre-treated with a disinfected food-blender in phosphate buffer solution. Subsequently the suspension was plated out. The total aerobic count was determined with PCA plates after 3 days at 30°C. The total aerobic spore formers count was determined with PCA plates which were treated at 80°C for 10 minutes and were left for 3 days at 30°C. The total yeasts and fungi count was determined with OGGA plates for 5 days at 25°C. The anaerobic count was determined with PCA plates after 3 days at 30°C under nitrogen gas. The anaerobic spore former count was determined with PCA plates which were treated at 80°C for 10 minutes and were stored for 3 days at 30°C under nitrogen gas.

2.12 Mass flow diagrams

The results of all the technical measurements were combined to form four mass flow diagrams for the four main recycling schemes.
Since almost all input data (measured results) were merely data points in time, frequently data incompatibility issues had to be resolved. The input material composition for one facility did not match the output material composition of the previous facility, etc. We resolved those issues by applying linear corrections.

The potential of available materials in the collection area was derived from the national consumption volume of 70 kton/a, the fraction of population present in the collection area and a regional correction factor. This regional correction factor amounted +15% for collection areas with less than 10% high-rise buildings and -15% for collection areas with more than 50% high rise buildings.
The breakdown in the amount of fiber, aluminum, PE-film, PE rigid, PP rigid and PP film was obtained from a cross-calculation of the market division per category and the composition per category (Table 25 and
Table 28). The imaginary amount of attached moisture and dirt to the potential was deduced from the potentially available moisture and dirt levels (paragraph 3.7) in freshly emptied beverage cartons.

The composition of the collected materials were calculated per municipality based on the response data and the results of the sorting analysis. This composition was described for each municipality to the level of fibre, aluminum, PE film, PE rigid, PP rigid and PP film, attached moisture and dirt, paper & board, plastics, organic waste, textiles, metals and glass.

The description of the mass flow in recovery, sorting and recycling facilities followed the results of this pilot study.

The amount of product residues that people wash off from the beverage cartons prior to collection was estimated per municipality. It was deduced from the difference between the potentially available amount of residues in the beverage cartons of the collection area, the amount of residues that is incinerated with the MSW (estimated from the residue potential and the net collection yield) and the observed amount of residues in the collected material.

The decision to accept or reject separate collected beverage cartons at the cross-docking facilities was also modelled. Based on the information of which municipalities the material had been rejected and was subsequently sorted by hand and our own sorting analysis, it was obviously that this decision is not taken at a 10% threshold level for residual waste, but at 20%. Therefore, it was modelled to accept beverage carton material with up to 20% residual waste and sorted collected material that contains more.

The amount of product residues pressed out of the beverage cartons during baling at the cross-docking facility was estimated from the difference between the percentage of product residues in the collected material and a 25% residue level for pressed Dutch beverage cartons.

3 Results

3.1 Response data

The crude response data were reported by the municipalities on a monthly basis. These monthly responses in kg gross/month are listed in Table 7 for the municipalities that operated a separate collection system. Additionally, the extrapolated annual response is presented, which was estimated from the total amount of collected material multiplied by 12 and divided by the amount of months the municipality participated to the pilot. Other extrapolation methods failed, since the monthly response data often lacks a clear pattern.

Table 7: Response data per municipality per month [kg gross/ month] and the extrapolated response number [kg gross/a]

		Municipality	May	June	July	Aug.	Sept.	Oct.	Extrapolated
					[gross kg]				[gross kg/a]
> 50% high rise buildings	*Drop off, no PAYT*	Gorinchem			480	360	340	580	**5280**
		Rotterdam		620	1200	840	1000	1080	**11376**
		Tilburg				950	640	1960	**14200**
	Drop off, PAYT	Hengelo		440	1440	440	140	1280	**8976**
	Kerbside	Schiedam	20	70	180	200	170	104	**1786**
10-50% high rise buildings	*Drop off, no PAYT*	Katwijk		1520	3060	3600	3320	2460	**33504**
		Zoetermeer		480	640	960	1200	1400	**11232**
	Drop off, PAYT	Apeldoorn			7160	7320	6820	14200	**106500**
		Beesel	4660	1640	4020	2580	2680	3380	**37920**
		Oosterhout		4020	3860		4140		**24040**
	Kerbside	Deventer	11900	18160	4900	17800	15740	8240	**153480**
		Oude IJsselstreek		2210	7840	6300	6950	6530	**68838**
		Stadskanaal		580	720	640	720	1060	**3720**
<10% high rise buildings	*Drop off, no PAYT*	Roermond-Swalmen	1700	1380	1640	1260	1300	1440	**8720**
		Son en Breugel		480	720	620	805	620	**3245**
		Voorst	160	365	325	440	380	550	**2220**
	Drop off, PAYT	Bernheze				300	600	1280	**7540**
		Bronckhorst	9940	11040	13460	z	9160	12920	**134860**
		Gennep	1300	3870	1635	1860	1040	2540	**24490**
		Overbetuwe	10000	8900	8620	5400	10200	6520	**103940**
	Kerbside	Leeuwarden	1140	1440	1960	1180	1620	1260	**8600**
		Oldambt		920	2410	1820	1960	920	**8030**
		Zutphen	17710	2450	9180	11850	13660	4690	**59540**

In case of Tilburg the collection system was altered in September, since too much residual waste was collected up to that moment, self-adhesive labels were placed from September on, with as text “Beverage cartons only”. From that moment of time a purer fraction was obtained, but it also implied that only two months of response data are available for Tilburg.
The reported responses for municipalities that operated a combined collection of plastic packages and beverage cartons are listed in Table 8. These responses are the gross weight of plastic packages, beverage cartons and concomitant residual wastes.

Table 8: Response data per municipality of combined collection plastic and beverage cartons per month and extrapolated to [kg gross/a]

		Municipality	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Extrapolated**
			[gross kg]						[gross kg/a]
> 50% high rise buildings	*Kerbside/ drop off, no diftar*	Schiedam	20	380	180	180	180	180	**2688**
	Kerbside/ drop off, diftar	Nijmegen		80	4740	5220	5400	8860	**72900**
10-50% high rise buildings	*Kerbside/ drop off, no diftar*	Zeist			3880	3880	3660	4380	**47400**
	Kerbside/ drop off, diftar	Geldrop-Mierlo		11080	10320	7800	10980	10420	**121440**
		Vught	13880	29280	26640	30760	36400	39040	**352080**
<10% high rise buildings	*Kerbside/ drop off, no diftar*	Almere		8420	10940	8840	8380	12220	**117120**
		Binnenmaas	4672	4880	4672	4672	4672	2320	**56483**
		De ronde venen	13640	10290	9400	8320	9340	13940	**128182**
	Kerbside/ drop off, diftar	Grootegast	32070	32070	32070	32070	32070	37900	**396500**
		Leek	50112	50112	50112	50112	50112	50710	**602540**
		Marum	31942	31942	31942	31942	31942	30390	**380200**
		Deventer	19220	9720	8280	18560		10620	**198120**
		Steenwijkerland		4670	5240	5340	5100	5240	**61416**

The responses of municipalities that operated a combined collection system of paper & board and beverage cartons are listed in Table 9. These systems and the nature of the response numbers varied strongly.
In the municipality of Etten-Leur three different collection systems were tested. For low rise dwellings a kerbside collection system with 240 l mini-containers was tested, where the beverage

cartons were collected between the paper & board. For high rise buildings two drop off systems were tested: underground press containers before the entrance of the apartment building and 1100 ltr roll containers in the entrance hall of the apartment building. Etten-Leur reported the responses as total gross weights of the collected mix of paper & board and beverage cartons.
In the municipality of Vianen the mix of paper & board and beverage cartons were collected in mini-containers. This collected mix was transported to sorting company Sita Soesterberg and here the sorted weight of beverage cartons were reported as response figures for the municipality of Vianen.
In Winsum the beverage cartons had to be kept separate in a plastic bag and this bag had to be added to the paper & board. This mix was monthly kerbside collected by volunteers and additionally several drop-off containers were available in the village centre. Winsum reported the weight of separate bags of beverage cartons.

Table 9: Response data per municipality with combined collection with paper and board as carrier per month and extrapolated to [kg gross/a]

		Municipality	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Extrapolated**
						[gross kg]			**[gross kg/a]**
< 10% high rise buildings	*Kerbside/ drop off, with paper and board*	Etten-leur 1 (mini containers)		95380	154650	151970	177010	245090	**359064**
		Vianen		18	75	88	62	41	**852**
	Kerbside/ drop off, with paper and board in bag	Winsum		360	1164	2037	2681	751	**13986**
> 50% high rise buildings	*Kerbside/ drop off, with paper and board*	Etten-leur 2 (indoor containers; underground press containers)		9220	31040	32240	37830	39280	**1977840**

For Etten-Leur the total gross weight of paper & board and beverage cartons was reported, while for Vianen and Winsum only the weight of the beverage cartons was reported.

3.2 Composition of separately collected beverage cartons

All the results of sorting the samples of separately collected beverage cartons are listed in Appendix A per municipality. In this report the summarized, averaged results are given and an exemplary sorting result is given in Table 10.

Table 10: Composition of separately collected beverage carton material, Municipality Overbetuwe, sampling date June 11th 2013.

Category	Content based on gross weights, [%]	Content based on net weights, [%]
Milk cartons ≥ 1 ltr	19.5%	13.9%
Milk cartons < 1 ltr	0.4%	0.3%
UHT milk cartons ≥ 1 ltr	5.9%	4.6%
UHT milk cartons < 1 ltr	0.2%	0.1%
Yoghurt & dessert cartons ≥ 1 ltr	18.1%	6.4%
Yoghurt & desserts cartons < 1 ltr	0.1%	0.1%
Juice cartons ≥ 1 ltr	32.0%	24.0%
Juice cartons < 1 ltr	1.0%	0.7%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	9.4%	6.2%
Cartons with fresh mixes of juice & dairy < 1 ltr	0.1%	0.1%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	1.8%	1.2%
Cartons with UHT mixes of juice & dairy < 1 ltr	1.5%	1.0%
Residual cartons ≥ 1 ltr	2.1%	1.8%
Residual cartons < 1 ltr	2.6%	2.1%
Paper & board	1.6%	
Plastics	0.9%	
Organic waste and indefinable waste	1.4%	
Textile	0.0%	
Metals < 100 gram	0.4%	
Metals ≥ 100 gram	0.0%	
Glass	1.0%	
Total		62.6%

The average gross composition of the separately collected beverage carton material is shown in Figure 51. The collected material consisted predominantly of materials from beverage cartons. The most frequently found other materials were paper & board materials, followed by organic waste and plastics. In most municipalities these other materials were hardly present and in nine of the twenty three municipalities the total amount of other materials was more than 21%. These municipalities were in general the more urban municipalities, with: Hengelo, Schiedam, Rotterdam, Deventer, Gorinchem, Tilburg, Katwijk, Roermond and Zutphen.

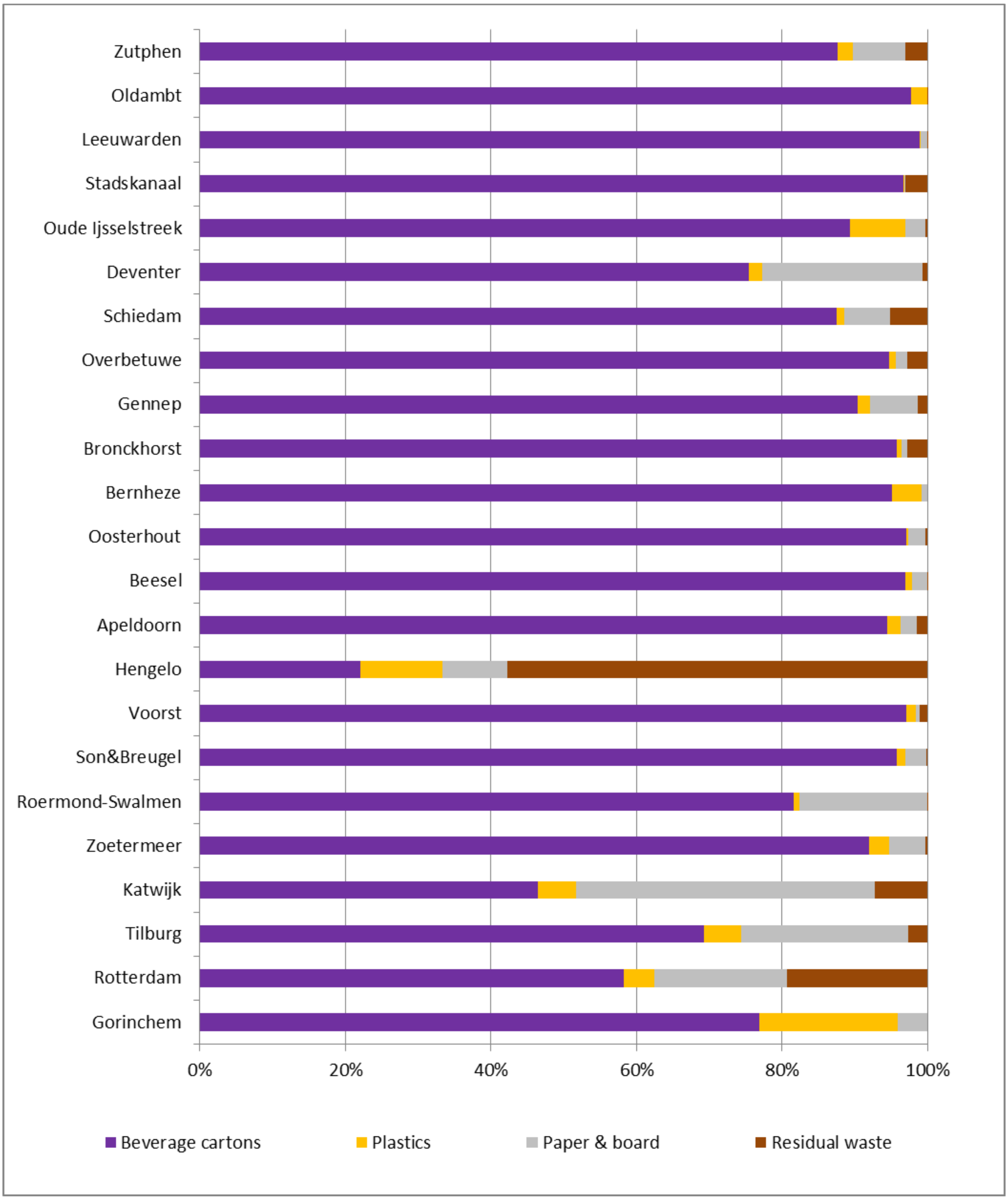

Figure 51: Composition of the separately collected beverage cartons in all municipalities

The normalised percentages of the beverage cartons are listed in Table 11. The largest categories are juice cartons, yoghurt cartons and milk cartons. The largest variance was also observed for these three large categories: milk cartons, yoghurt cartons and juice cartons. This would suggest that there is significant regional variation in consumption behavior. This can be understood for milk cartons, since here we see a smaller variance for the combination of the four types of milk cartons than for the individual milk carton categories. In most municipalities a preference for fresh milk cartons was observed, but for Beesel, Roermond-Swalmen, Oldambt and Stadskanaal a preference for UHT treated milk cartons was observed.

Table 11: Average composition of separately collected beverage carton material, in normalised percentages based on gross weights. (n= 23)

Category	Average	St. dev	Median	Min	Max
Milk cartons ≥ 1 ltr	20.6%	7.8%	22.8%	5.9%	31.6%
Milk cartons < 1 ltr	0.5%	0.5%	0.3%	0.0%	2.3%
UHT milk cartons ≥ 1 ltr	12.3%	8.1%	9.2%	3.5%	30.5%
UHT milk cartons < 1 ltr	0.3%	0.3%	0.2%	0.0%	1.2%
Yoghurt & dessert cartons ≥ 1 ltr	22.1%	6.2%	21.5%	13.7%	36.7%
Yoghurt & desserts cartons < 1 ltr	0.7%	0.5%	0.6%	0.0%	1.6%
Juice cartons ≥ 1 ltr	26.9%	5.1%	26.6%	16.3%	33.8%
Juice cartons < 1 ltr	0.9%	0.4%	0.8%	0.3%	1.6%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	6.6%	2.2%	6.9%	2.4%	11.3%
Cartons with fresh mixes of juice & dairy < 1 ltr	0.4%	0.4%	0.3%	0.0%	1.3%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	1.9%	1.3%	1.9%	0.0%	5.7%
Cartons with UHT mixes of juice & dairy < 1 ltr	0.2%	0.4%	0.1%	0.0%	1.5%
Residual cartons ≥ 1 ltr	4.3%	2.7%	3.6%	1.0%	9.6%
Residual cartons < 1 ltr	2.3%	0.9%	2.2%	1.0%	4.4%
Total small cartons	5.3%	1.4%	5.2%	3.4%	9.2%
Total milk cartons	33.6%	4.6%	34.8%	23.2%	40.9%

Furthermore, the total normalised amount of small beverage cartons with an internal volume of less than 1 litre was 5.3%. This is clearly lower than the 12% of small beverage cartons which is placed on the Dutch market (see paragraph 3.8). This confirms that in a separate collection system the smaller beverage cartons are underrepresented, because either these small cartons are consumed and discarded out-of-home or civilians do less effort to keep the small cartons separate in comparison to the larger cartons.

The levels of attached moisture and dirt have been determined for all categories of beverage cartons in all municipalities. The averaged numbers are collected in Table 12.

Table 12: Average values for moisture and dirt percentages in separately collected beverage cartons, [%] (n=23).

Category	Average	St. dev	Median	Min	Max
Milk cartons ≥ 1 ltr	24%	5%	26%	15%	33%
Milk cartons < 1 ltr	20%	10%	19%	0%	43%
UHT milk cartons ≥ 1 ltr	27%	5%	27%	17%	38%
UHT milk cartons < 1 ltr	28%	11%	28%	0%	57%
Yoghurt & dessert cartons ≥ 1 ltr	50%	10%	51%	23%	64%
Yoghurt & desserts cartons < 1 ltr	37%	18%	31%	0%	70%
Juice cartons ≥ 1 ltr	24%	4%	23%	17%	32%
Juice cartons < 1 ltr	23%	7%	21%	13%	46%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	41%	8%	42%	27%	59%
Cartons with fresh mixes of juice & dairy < 1 ltr	39%	19%	43%	0%	83%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	34%	11%	35%	0%	47%
Cartons with UHT mixes of juice & dairy < 1 ltr	26%	15%	26%	0%	64%
Residual cartons ≥ 1 ltr	24%	7%	25%	12%	37%
Residual cartons < 1 ltr	28%	7%	26%	17%	40%
Weight averaged total	**32%**	**5%**	**31%**	**23%**	**41%**

The attached moisture and dirt levels differ largely per category of beverage cartons. In general, a similar pattern of residues can be observed in the collected material as in the freshly emptied cartons (see Table 26). The cartons with yoghurt, dairy and fruit mixes contained most residues, but the variance between municipalities was large, which indicates differences in emptying behaviour between the various municipalities.

The net material composition was calculated based on the gross material content per municipality and the attached moisture and dirt values. The average values of net material composition per category of beverage cartons are given in Table 13.

Table 13: Average net material composition per category of beverage carton, averaged for all separately collected beverage cartons, in percentages based on net material weights. (n= 23)

Category	Average	St. dev	Median	Min	Max
Milk cartons ≥ 1 ltr	12,7%	5,1%	12,6%	3,2%	19,9%
Milk cartons < 1 ltr	0,3%	0,4%	0,2%	0,0%	1,7%
UHT milk cartons ≥ 1 ltr	7,9%	6,1%	5,2%	1,0%	22,7%
UHT milk cartons < 1 ltr	0,2%	0,2%	0,1%	0,0%	0,8%
Yoghurt & dessert cartons ≥ 1 ltr	9,3%	4,2%	9,2%	2,4%	23,1%
Yoghurt & desserts cartons < 1 ltr	0,3%	0,2%	0,3%	0,0%	0,7%
Juice cartons ≥ 1 ltr	17,4%	5,5%	18,2%	3,5%	26,1%
Juice cartons < 1 ltr	0,5%	0,3%	0,5%	0,2%	1,0%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	3,3%	1,5%	3,6%	0,8%	6,5%
Cartons with fresh mixes of juice & dairy < 1 ltr	0,2%	0,1%	0,1%	0,0%	0,5%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	1,1%	0,8%	1,1%	0,0%	2,9%
Cartons with UHT mixes of juice & dairy < 1 ltr	0,1%	0,2%	0,1%	0,0%	1,0%
Residual cartons ≥ 1 ltr	2,6%	1,8%	2,1%	0,7%	6,5%
Residual cartons < 1 ltr	1,5%	0,7%	1,4%	0,3%	2,9%
Total	**57%**	**13%**	**61,3%**	**13,6%**	**70,5%**

The net material content of the separate collected beverage cartons varied between 70% and 18% for the municipalities, see Table 14. The highest net material contents were in general recorded for municipalities with a low percentage of high rise buildings and a high service level collection system.

Table 14: Net material composition of separate collected beverage cartons per municipality

Collection system	**> 50% high rise buildings**	**10-50% high rise buildings**	**<10% high rise buildings**
Drop-off no-diftar	Gorinchem 58% Rotterdam 40% Tilburg 47%	Katwijk 36% Zoetermeer 61%	Roermond 56% Son & Breugel 59% Voorst 67%
Drop-off, diftar	Hengelo 18%	Apeldoorn 63% Beesel 65% Oosterhout 70%	Bernheze 63% Bronckhorst 57% Gennep 64% Overbetuwe 63%
Kerbside	Schiedam 57%	Deventer 45% Oude IJsselstreek 66% Stadskanaal 69%	Leeuwarden 69% Oldambt 71% Zutphen 60%

From the net material composition (Table 13), the extrapolated annual response (Table 7) and the average net potential of beverage cartons per capita and annum the net collection yields have been calculated. These are listed in Table 15. The net collection yield equals the amount of beverage cartons that have been collected as a fraction of the total amount of beverage cartons that is potentially available within that collection area.

Table 15: Net collection yields for the municipalities with a separate collection system for beverage cartons

Collection system	**> 50% high rise buildings**	**10-50% high rise buildings**	**<10% high rise buildings**
Drop-off no-diftar	Gorinchem 17% Rotterdam 20% Tilburg 3%	Katwijk 5% Zoetermeer 8%	Roermond 24% Son & Breugel 19% Voorst 3%
Drop-off, diftar	Hengelo 12%	Apeldoorn 33% Beesel 44% Oosterhout 8%	Bernheze 4% Bronckhorst 43% Gennep 19% Overbetuwe 28%
Kerbside	Schiedam 13%	Deventer 18% Oude IJsselstreek 28% Stadskanaal 48%	Leeuwarden 47% Oldambt 57% Zutphen 32%

The highest recorded net collection yield was 57% for a kerbside collection system in an area with low rise buildings, whilst the lowest collection yield was 3% for two different municipalities with a drop-off collection system.
The general tendency of the net collection data is that areas with low rise buildings yield more than those with high rise buildings and that kerbside collection yields more than drop off collection. There are however many exceptions with lower recorded net collection responses than what would be expected based on type of buildings and the type of collection system. Four municipalities score less than 5% net collection response. Two of these (Voorst, Bernheze) were expected to yield much more beverage cartons based on the type dwellings in the area. Apparently there are other factors that have a larger impact on the final collection result than type of dwellings in the collection area and the type of collection system. These other factors are likely to involve the service level of the collection system and the communication effort of the municipality to encourage the population to recycle. This discussion is continued in chapter 6.
Another surprising result that becomes evident from Table 15 is that municipalities with existing collection systems do not perform better than municipalities that have recently started. Two newly started municipalities even reported the highest net collection percentages.

3.3 Composition of beverage cartons co-collected with PPW

The sorting results of samples taken from municipals that collect beverage cartons simultaneously with plastic packages are listed in Appendix B for every municipality in detail. The composition is schematically shown for all municipalities in Figure 52.

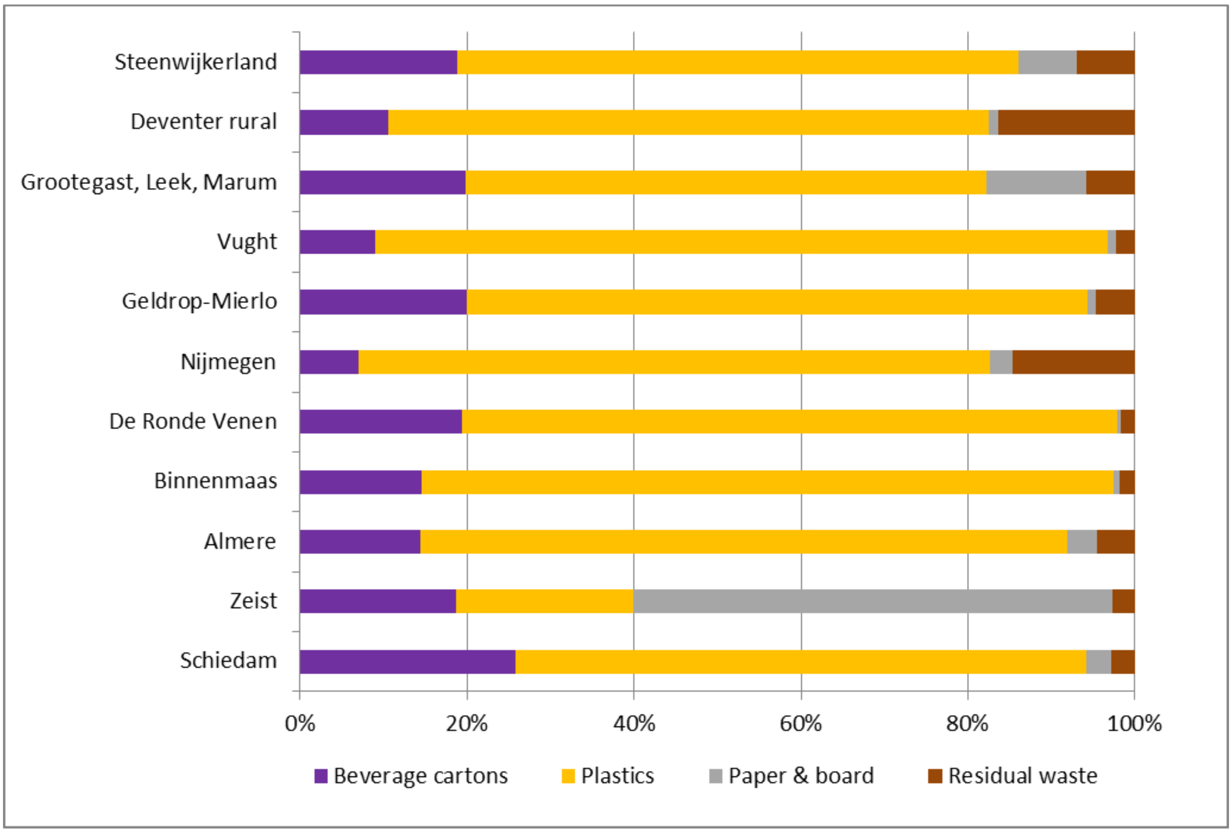

Figure 52: Composition of the combined collected of beverage cartons and plastic packages, [% gross weight].

The percentage of beverage cartons varied from 7% in Nijmegen up to 22% in Schiedam. The percentage was on average 16 ± 6% and the median value was 19%.
The share of plastics varied between 21 for Zeist and 88% for Geldrop-Mierlo, equalled on average 70 ± 18 % and the median value was 74%. The remarkable low share for plastics in Zeist and the surprising high contribution of paper & board is attributed to the used collection vessels; large re-painted collection containers, which have previously been used for glass collection and paper & board collection.

The composition of the collected beverage cartons is given in Table 16 and is shown as normalised percentages.

Table 16: Average composition of beverage cartons that can been co-collected with plastic packages, displayed as normalised percentages based on gross weights from the 11 municipalities that operated this co-collection system with plastic packages. (n= 11)

Category	**Average**	**St. dev**	**Median**	**Min**	**Max**
Milk cartons ≥ 1 ltr	19.1%	9%	15.5%	8.4%	41.7%
Milk cartons < 1 ltr	0.3%	0.2%	0.3%	0.0%	0.7%
UHT milk cartons ≥ 1 ltr	9.6%	6%	8.9%	2.5%	19.1%
UHT milk cartons < 1 ltr	0.6%	0.8%	0.4%	0.0%	2.8%
Yoghurt & dessert cartons ≥ 1 ltr	22.9%	6%	23.6%	13.5%	32.7%
Yoghurt & desserts cartons < 1 ltr	0.9%	0.6%	0.9%	0.0%	1.8%
Juice cartons ≥ 1 ltr	24.8%	9%	24.2%	8.0%	40.4%
Juice cartons < 1 ltr	2.1%	2%	1.7%	0.6%	7.9%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	7.5%	4%	7.5%	0.0%	12.5%
Cartons with fresh mixes of juice & dairy < 1 ltr	0.4%	0.4%	0.4%	0.0%	1.1%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	1.6%	2%	1.1%	0.0%	5.1%
Cartons with UHT mixes of juice & dairy < 1 ltr	0.8%	1.4%	0.1%	0.0%	4.4%
Residual cartons ≥ 1 ltr	3.3%	3%	1.8%	0.3%	10.4%
Residual cartons < 1 ltr	2.2%	1.1%	2.2%	0.8%	3.8%
Total small cartons	7.3%	2.1%	6.9%	4.1%	12.3%
Total milk cartons	29.6%	8.4%	28.6%	16.5%	47.3%

The composition of the collected beverage cartons is fairly comparable with the beverage cartons originating from the separate collection system. The categories of juice, yoghurt and milk are again the largest. The percentage of small cartons was on average higher, with a record value of 12% for the municipality of Almere.

The moisture and dirt percentages have been determined for the 14 categories of beverage cartons and 5 main categories of plastic packages. The averaged values for the 11 municipalities are listed in Table 17. The values tend to be slightly lower as compared to the separately collected beverage cartons, but the variance in the values is large and the difference in attached moisture and dirt levels between both collection systems is not significant.

Table 17: Average moisture and dirt percentages in beverage cartons and 5 main types of plastic packages from the combined collection of beverage cartons with plastic packages for the 11 different municipalities that operated this co-collection system with plastic packages, [%] (n=11).

Category	Average	St. dev	Median	Min	Max
Milk cartons ≥ 1 ltr	26.2%	5%	25.8%	20.5%	35.0%
Milk cartons < 1 ltr	22.3%	10%	19.6%	11.1%	44.9%
UHT milk cartons ≥ 1 ltr	25.0%	5%	25.4%	17.1%	33.2%
UHT milk cartons < 1 ltr	27.0%	15%	26.5%	11.1%	55.0%
Yoghurt & dessert cartons ≥ 1 ltr	26.2%	17%	28.9%	21.1%	71.1%
Yoghurt & desserts cartons < 1 ltr	37.4%	18%	40.3%	20.5%	65.6%
Juice cartons ≥ 1 ltr	24.6%	6%	23.5%	15.6%	35.0%
Juice cartons < 1 ltr	23.9%	3%	24.0%	19.2%	29.7%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	31.0%	8%	30.3%	21.1%	45.1%
Cartons with fresh mixes of juice & dairy < 1 ltr	31.9%	9%	29.6%	20.5%	51.4%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	24.5%	10%	24.9%	21.1%	35.0%
Cartons with UHT mixes of juice & dairy < 1 ltr	27.8%	5%	26.6%	20.5%	40.4%
Residual cartons ≥ 1 ltr	23.0%	7%	22.1%	11.1%	35.0%
Residual cartons < 1 ltr	26.1%	7%	25.8%	14.1%	36.3%
PET bottles clear < 1 ltr	11.6%	6%	10.0%	2.0%	23.0%
PE Flasks	14.7%	6%	15.0%	4.0%	23.0%
PET rigids	7.9%	6%	5.0%	2.0%	18.0%
PP rigids	11.3%	10%	7.0%	2.0%	28.0%
PE film > A4	10.4%	13%	6.0%	2.0%	45.0%

For this collection system the net content of desired materials equals the sum of the net beverage carton content and the net plastic packaging content. This value is listed per municipality in Table 18. Most municipalities reach values of 75% and higher. Only Zeist and Deventer show lower figures.

Table 18: Sum of the net material composition of the beverage carton and the net material composition of the plastic packages per municipality where beverage cartons are co-collected with plastic packages, in percentages. In the bottom two lines the averaged values of all municipalities are given. (n= 11)

Collection system	**> 50% high rise buildings**	**10-50% high rise buildings**	**<10% high rise buildings**
no-diftar	Schiedam 74%	Zeist 32 %	Almere 75% Binnenmaas 82% De ronde venen 90%
diftar	Nijmegen 78%	Geldrop-Mierlo 78% Vught 85%	Grootegast, Leek & Marum 70% Deventer 57% Steenwijkerland 76%

Average	St. dev.	Median	Minimum	Maximum
73%	16%	76%	32.4%	90.0%

The net collection yields for the beverage cartons were derived from the responses, the moisture and dirt values and the expected amount of beverage cartons available in the collection area, see Table 19.

Table 19: Net collection yields of the beverage cartons for the municipalities with a combined collection system for beverage cartons and plastics

Collection system	**> 50% high rise buildings**	**10-50% high rise buildings**	**<10% high rise buildings**
no-diftar	Schiedam 5%	Zeist 14%	Almere 61% Binnenmaas 16% De ronde venen 22%
diftar	Nijmegen 16%	Geldrop-Mierlo 31% Vught 18%	Grootegast 99% Leek 95% Marum 112% Deventer 96% Steenwijkerland 68%

The net collection yields for beverage cartons in a combined collection system with plastic packages vary greatly, from a 5% in Schiedam to almost 100% for Grootegast, Leek, Marum and Deventer. This spread in results is remarkably large. For collection areas with few high rise buildings and a pay as you throw scheme (diftar) the collection efficiency can be boosted to levels approaching the amount that is expected to be present in these areas.

One municipality (Marum) recorded a more than 100% net collection yield, which is obviously an outlier and could be understood as:

- The amount of beverage cartons put on the Dutch market is actually larger than 70 kton per annum, but the results in section 3.8 contradict this hypothesis,
- There is a larger than expected regional spread in consumption of beverages packed in cartons,
- Some of the collection systems attract packaging waste from neighbouring municipalities.

From these explanations, the regional spread in consumption behaviour appears to be the most likely. Since, there is no evidence for an attractive action of the collection systems and also not for a higher amount of beverage cartons that is put on the market.

3.4 Composition of beverage cartons co-collected with paper & board

Only 3 municipalities decided to test a combined collection of beverage cartons and paper & board; Etten-Leur, Vianen and Winsum. The area of Etten-Leur with high rise buildings was studied as a separate collection area with two different collection methods; underground press containers (UPC) and in-hall collection containers (ICC). The composition of the collected materials is shown in Figure 53. Unfortunately, no sample was taken from the crude collection mixture originating from the underground press containers. The complete sorting results are given in Appendix C. The composition of Etten-Leur and Vianen is fairly similar. For Winsum the collection of beverage cartons took place in a separate bag inside the collection vessel for paper & board and only the separate bags were inspected.

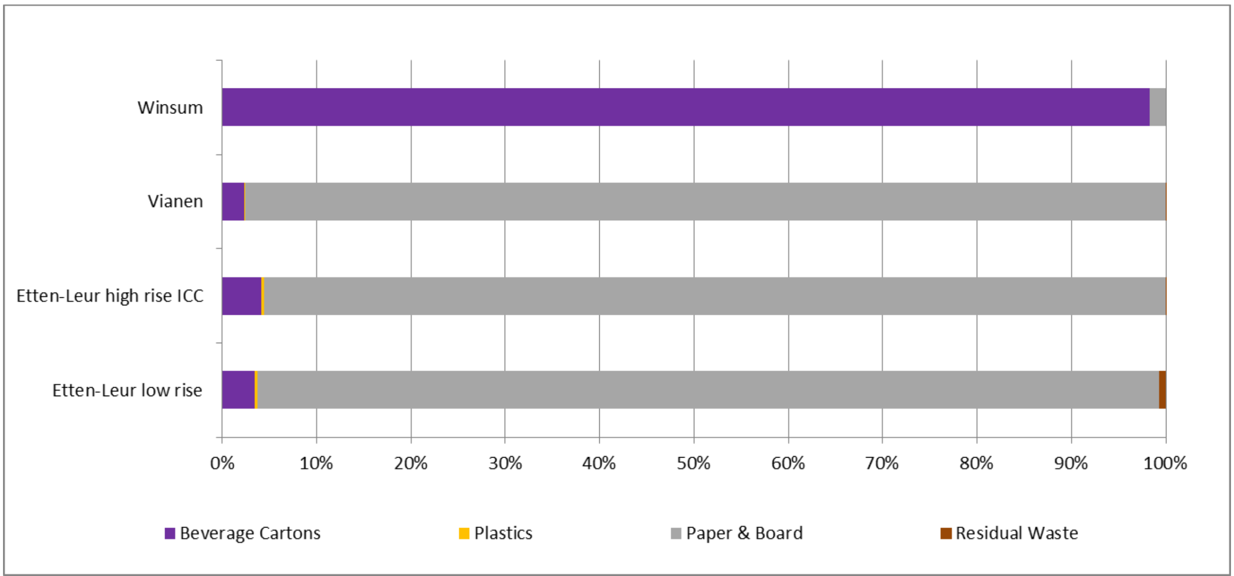

Figure 53: Composition of the collected materials in a co-collection systems of beverage cartons and paper & board

The collected mixtures of Etten-Leur were manually sorted and those of Vianen were sorted both automatic and manual means. The composition of the sorted products is listed in Table 20. There is hardly any residual waste present in the sorted beverage cartons and the composition of the beverage cartons is comparable to the compositions in other collection systems.

The sum of the normalized percentages for small beverage cartons varied between 3.6% for Vianen and 7.7% for Winsum. This indicates that civilians prefer to collect larger beverage cartons with this co-collection system.

Table 20: Composition of the sorted beverage carton products from municipalities that operated a co-collection system for beverage cartons and paper& board.

Category	Winsum (A)	Vianen	Etten-Leur LR	Etten-Leur HR ICC	Etten-Leur HR UPC
Milk cartons ≥ 1 ltr	17.9%	7.9%	17.0%	19.8%	21.8%
Milk cartons < 1 ltr	0.1%	1.2%	0.2%	1.0%	0.8%
UHT milk cartons ≥ 1 ltr	9.5%	7.8%	17.4%	9.8%	13.9%
UHT milk cartons < 1 ltr	0.3%	0.2%	0.2%	0.0%	0.3%
Yoghurt & dessert cartons ≥ 1 ltr	25.2%	9.8%	15.0%	22.7%	14.3%
Yoghurt & desserts cartons < 1 ltr	0.5%	0.0%	0.7%	2.1%	1.1%
Juice cartons ≥ 1 ltr	30.1%	50.6%	34.6%	28.5%	31.5%
Juice cartons < 1 ltr	1.0%	0.3%	1.1%	0.1%	0.8%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	2.6%	6.9%	3.8%	5.8%	7.8%
Cartons with fresh mixes of juice & dairy < 1 ltr	0.1%	0.4%	0.3%	0.2%	0.4%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	2.7%	3.1%	1.7%	0.3%	0.3%
Cartons with UHT mixes of juice & dairy < 1 ltr	1.6%	0.1%	0.3%	0.0%	0.0%
Residual cartons ≥ 1 ltr	2.7%	6.1%	3.5%	6.5%	2.5%
Residual cartons < 1 ltr	3.9%	1.3%	2.0%	1.9%	3.1%
Paper & board	1.7%	4.2%	2.0%	1.1%	1.4%
Plastics	0.1%	0.0%	0.1%	0.0%	0.0%
Organic waste and indefinable waste	0.0%	0.1%	0.0%	0.0%	0.0%
Textile	0.0%	0.0%	0.0%	0.0%	0.0%
Metals < 100 gram	0.0%	0.0%	0.0%	0.0%	0.0%
Metals ≥ 100 gram	0.0%	0.0%	0.0%	0.0%	0.0%
Glass	0.0%	0.0%	0.0%	0.0%	0.0%

A: the collected mixture

LR: Low rise

HR: High rise

ICC: In-hall collection containers (1100-1300 ltr)

UPC: Underground press containers

The percentages of attached moisture and dirt have been determined for all sorted beverage cartons from these co-collection municipalities, see Table 21. The beverage cartons co-collected with paper and board are somewhat drier and less polluted with product residues than those separately collected or those collected with plastic packages. This would indicate that product residues from the beverage cartons have either been washed prior to collection or have transferred a part of their product residues to the paper & board fraction. An exception is

Winsum, where beverage cartons are collected in separate closed plastic bags and no transfer of moisture and dirt can be expected between beverage cartons and paper & board.

Table 21: Percentages of attached moisture and dirt for the sorted beverage cartons that originated from co-collection systems for beverage cartons and paper& board.

Category	Winsum	Vianen	Etten-Leur LR	Etten-Leur HR ICC	Etten-Leur HR UPC
Milk cartons ≥ 1 ltr	29.8%	16.0%	23.9%	21.4%	23.0%
Milk cartons < 1 ltr	14.3%	21.6%	14.4%	12.4%	12.0%
UHT milk cartons ≥ 1 ltr	27.5%	27.5%	23.3%	12.4%	30.9%
UHT milk cartons < 1 ltr	21.9%	27.7%	23.4%		29.7%
Yoghurt & dessert cartons ≥ 1 ltr	68.5%	57.3%	40.5%	46.6%	65.9%
Yoghurt & desserts cartons < 1 ltr	68.1%	0.0%	54.7%	60.3%	47.1%
Juice cartons ≥ 1 ltr	19.7%	18.2%	16.1%	13.0%	19.7%
Juice cartons < 1 ltr	19.4%	14.0%	15.1%	10.5%	15.6%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	51.2%	34.9%	32.2%	42.9%	28.8%
Cartons with fresh mixes of juice & dairy < 1 ltr	10.0%	44.3%	87.1%	43.8%	22.4%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	35.7%	29.7%	32.6%	32.6%	33.6%
Cartons with UHT mixes of juice & dairy < 1 ltr	31.4%	33.3%	36.8%		10.0%
Residual cartons ≥ 1 ltr	21.1%	16.3%	14.4%	16.9%	14.2%
Residual cartons < 1 ltr	28.0%	26.4%	22.8%	20.3%	28.0%
Weight-averaged total	**37%**	**25%**	**24%**	**26%**	**30%**

The net material content for this collection system is the sum of the net amount of beverage carton material and the net amount of paper & board. The latter has not been determined because the moisture and dirt levels of the carrier stream have not been determined. Nevertheless, given the small amounts of residual wastes present in the collected mixtures and the relative low levels for attached moisture and dirt, these net material content numbers are expected to be high for all the studied municipalities. This proves that these co-collections lead to the desired materials on the desired quality level.

The net collection yields for the beverage cartons from this collection system have been determined from the responses, net material contents and expected amounts of beverage cartons per collection area and are listed in Table 22. Remarkably, the highest net collection yield was achieved for the area with high rise buildings. Additionally, the variance in net collection percentages for the areas with low rise buildings was large. This shows that this collection system has potential in terms of collection efficiency.

Table 22: Net collection yields for beverage cartons in the municipalities that operated a co-collection system for beverage cartons and paper & board.

Collection system	**> 50% high rise buildings**	**10-50% high rise buildings**	**<10% high rise buildings**
With paper & board	Etten-Leur 50%		Etten-Leur 29% Vianen 3% Winsum 13%

3.5 Composition of recovered beverage cartons

Beverage cartons were recovered at two facilities during this pilot: Omrin and Attero-Noord. Both facilities first produced a concentrate of recovered plastic packages and beverage cartons named intermediate concentrate (IC), which was subsequentially sorted into a recovered beverage carton product (BC). This sorting occurred on-site at Omrin and for the material from Attero-Noord at the sorting plant Augustin. The composition of the intermediate concentrates and the final products of both recovery facilities is shown in Figure 54.

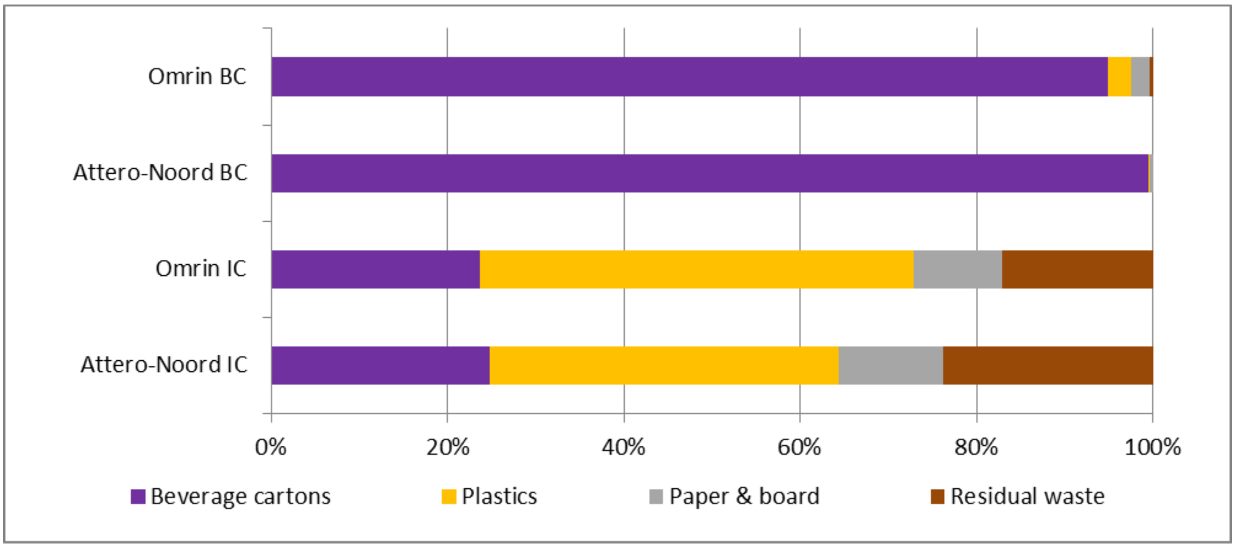

Figure 54:Composition of the recovered intermediate concentrates (IC) and finally sorted beverage carton products (BC) of Attero-Noord and Omrin.

The complete sorting results of the recovered products can be found in appendix D.
The normalised percentages of the two recovered beverage carton products are listed in Table 23. Also here the same categories: juice cartons, yoghurt cartons and milk cartons are the largest. The small cartons have a share of 7 to 9% of the total, which is less than the 13% which is put on the market. This results from the mechanical separation process which works more efficient with larger cartons. The smaller cartons are found to a larger extent in the recovery products ONF (organic wet fraction) and RDF (refuse derived fuels).

The levels of attached moisture and dirt for the two recovered beverage carton products are given in Table 24 and these are comparable. These levels are hardly higher than those from separate collection systems, as would be expected from a cross-contamination with MSW. The average values are slightly higher but are still well within the standard deviation, compare Table 12 and Table 24.

Table 23: Normalised percentages of beverage cartons in the final recovered beverage carton products.

Category	Attero-Noord	Omrin
Milk cartons ≥ 1 ltr	9.4%	13.3%
Milk cartons < 1 ltr	0.0%	0.2%
UHT milk cartons ≥ 1 ltr	17.7%	16.4%
UHT milk cartons < 1 ltr	0.3%	0.5%
Yoghurt & dessert cartons ≥ 1 ltr	22.1%	27.3%
Yoghurt & desserts cartons < 1 ltr	0.0%	0.6%
Juice cartons ≥ 1 ltr	32.0%	22.3%
Juice cartons < 1 ltr	1.6%	2.6%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	5.0%	7.3%
Cartons with fresh mixes of juice & dairy < 1 ltr	0.0%	0.3%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	4.7%	2.3%
Cartons with UHT mixes of juice & dairy < 1 ltr	0.0%	0.5%
Residual cartons ≥ 1 ltr	2.6%	2.2%
Residual cartons < 1 ltr	4.6%	4.0%
Total small cartons	6.5%	8.9%
Total milk cartons	27.4%	30.5%

Table 24: Percentages of attached moisture and dirt for the recovered beverage cartons products.

Category	Attero-Noord	Omrin
Milk cartons ≥ 1 ltr	33.3%	31.6%
Milk cartons < 1 ltr		32.5%
UHT milk cartons ≥ 1 ltr	43.9%	30.5%
UHT milk cartons < 1 ltr	33.3%	37.6%
Yoghurt & dessert cartons ≥ 1 ltr	45.7%	51.5%
Yoghurt & desserts cartons < 1 ltr		45.9%
Juice cartons ≥ 1 ltr	30.0%	26.5%
Juice cartons < 1 ltr	26.4%	26.7%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	42.1%	39.3%
Cartons with fresh mixes of juice & dairy < 1 ltr		41.8%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	48.8%	34.9%
Cartons with UHT mixes of juice & dairy < 1 ltr		33.6%
Residual cartons ≥ 1 ltr	31.7%	35.4%
Residual cartons < 1 ltr	44.0%	32.8%
Weight-averaged total	**38.4%**	**36.5%**

The net material content of the final beverage carton products equaled 61% for the sorted product of Attero at Augustin and 60% for the sorted product of Omrin.

The net collection yields are for recovered beverage cartons by definition equal to 100%, since the civilians will have only one waste bin available for used beverage cartons.

3.6 Density changes in carrier streams

As input for the economic research the density changes of the carrier stream due to the addition of beverage cartons have been analyzed.
Based on previous projects[i] the known density of separately collected plastics is between 20 and 40 kg per big bag (of 1m^3 volume). The density of such separately collected beverage cartons depends on the percentage of concomitant residual waste included, the more residual waste the heavier the fraction. The densities measured in this project of plastics combined with beverage cartons varied between 24 and 45 kg per 1m^3. There is no correlation found between the percentage of beverage cartons and the density. Therefore, there is concluded that there is no significant change in the density of the separately collected plastics due to the addition of beverage cartons to this stream.
The density of separately collected paper and board is not measured. The measurements of the combined paper and board and beverage cartons where for Etten-Leur 100 kg/m^3, and for Vianen 104 kg/m^3. However, in the collected paper and board combined with beverage cartons the percentage of beverage cartons was very low (between 2,3% and 4,1%). Furthermore, the beverage cartons are pressed by the weight of the paper and board, which makes their structure similar to board. This results in the conclusion that no significant differences can be indicated between the density of separate paper and board, and paper and board combined with beverage cartons.

3.7 Material composition of clean beverage cartons

The calculated average material composition per category of beverage cartons is shown in Table 25. This data gives an indication of and insight into the material content of beverage cartons. Around 73% of the beverage cartons consist of carton fibre, 19% PE-film and around 7% of rigid plastics. The beverage cartons which contain aluminium have a mass-percentage of around 5% of aluminium.

Table 25: Average material composition per category of beverage cartons [% based on dry matter]

Category of beverage cartons	Fibre	PE-film	PP - film	Aluminium	Rigid PE	Rigid PP
Milk cartons ≥ 1 ltr	79%	13%			8%	
Milk cartons < 1 ltr	75%	15%			10%	

UHT milk cartons ≥ 1 ltr	72%	17%		5%	5%	1%
UHT milk cartons < 1 ltr	67%	22%	1%	6%		4%
Yoghurt & dessert cartons ≥ 1 ltr	78%	12%			10%	
Yoghurt & desserts cartons < 1 ltr	79%	16%			5%	
Juice cartons ≥ 1 ltr	70%	20%		4%	3%	3%
Juice cartons < 1 ltr	67%	23%	1%	5%		4%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	78%	13%			9%	
Cartons with fresh mixes of juice & dairy < 1 ltr	72%	14%			14%	
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	71%	17%		5%	4%	3%
Cartons with UHT mixes of juice & dairy < 1 ltr	67%	22%	1%	6%		4%
Residual cartons ≥ 1 ltr	73%	17%		4%	4%	2%
Residual cartons < 1 ltr	67%	22%		6%	2%	3%

3.8 Residue potential of beverage cartons

The residue potential per category of beverage cartons is shown in Figure 55, accompanied by Table 26. This represents the average moisture and dirt content of beverage cartons directly after consumption (these percentages are based on gross weights of the carton). In addition, the variation of the dirt and moisture content directly after consumption is determined and also shown in Figure 55 and Table 26.

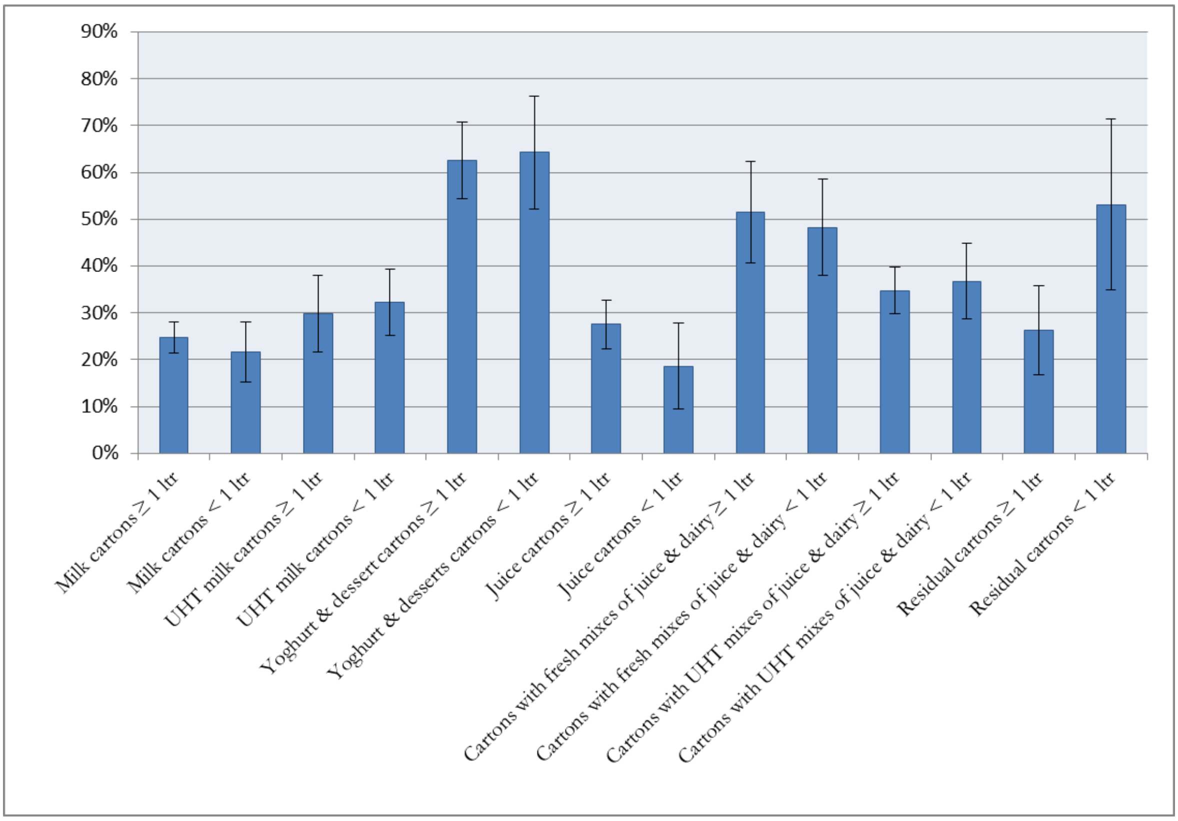

Figure 55: Average residue potential per category of beverage cartons

Table 26: Average residue potential per category of beverage cartons based on gross weights.

Category of beverage cartons	Moisture and dirt content [%]	STDEV
Milk cartons ≥ 1 ltr	25%	3%
Milk cartons < 1 ltr	22%	6%
UHT milk cartons ≥ 1 ltr	30%	8%
UHT milk cartons < 1 ltr	32%	7%
Yoghurt & dessert cartons ≥ 1 ltr	63%	8%
Yoghurt & dessert cartons < 1 ltr	64%	12%
Juice cartons ≥ 1 ltr	28%	5%
Juice cartons < 1 ltr	19%	9%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	52%	11%
Cartons with fresh mixes of juice & dairy < 1 ltr	48%	10%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	35%	5%
Cartons with UHT mixes of juice & dairy < 1 ltr	37%	8%
Residual cartons ≥ 1 ltr	26%	9%
Residual cartons < 1 ltr	53%	18%

The results show a large variation in residue potential for the different categories of beverage cartons. The moisture and dirt content varies from 19% for small juice cartons to 64% for small yoghurt and dessert cartons.

In Figure 56 the average moisture and dirt content per category is depicted for the different phases in the test. The graph shows the average moisture and dirt content directly after consumption (residue potential), after rinsing with cold water and after rinsing with hot water. This shows that rinsing beverage cartons with cold water reduces the moisture and dirt content strongly for most categories. A second rinsing step with hot water decreases the moisture and dirt content to a lesser extent.

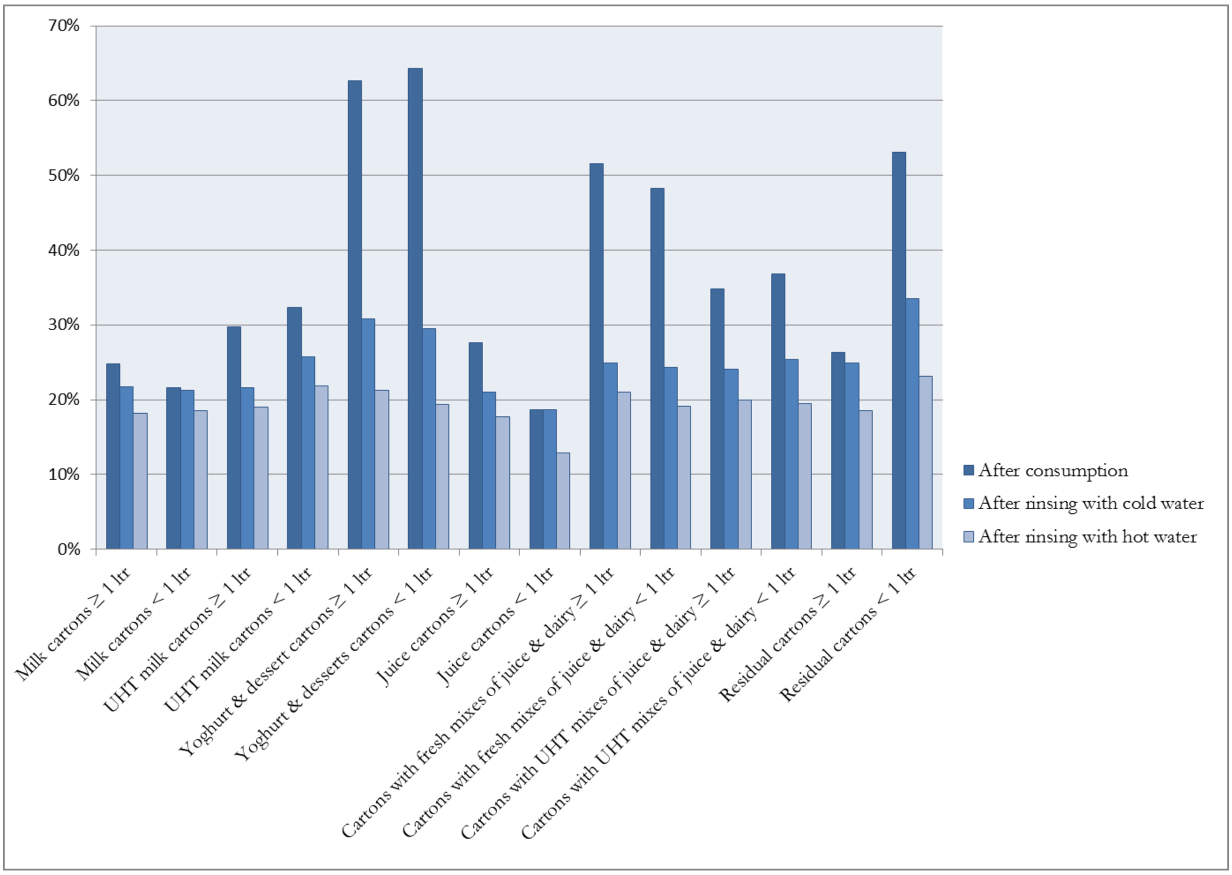

Figure 56: Average moisture and dirt content per category of beverage cartons in different phases of the test

3.9 Beverage carton potential and composition for Dutch market

The amount of beverage cartons placed on the Dutch market is according to the foundation Hedra 70 kton/a. This number was verified by analysing the total amount of beverage cartons present in the recovered products and extrapolating this figure to national levels on the basis of the total population and the total amount of treated MSW in the Netherlands (3752 kton in 2011). This calculation is shown in Table 27.

Table 27: Extrapolation of the amounts of beverage cartons present in the waste treated by both recovery facilities to national levels.

	Attero-Noord	Omrin
Population in service area, [#]	229,569	786,071
Amount of MSW treated from this service area in 2012, [kton gross/a]	51.5	190
Total amount of beverage cartons present in recovered products, on annual basis, [kg gross/a]	1,063,226	6,009,873
Gross Potential, [kg gross/cap.a]	4.63	7.65
Net Potential, [kg net/cap.a]	2.85	4.85
Extrapolation based on population, [kton/a]	47.9	81.5
Extrapolation based on total amount of treated MSW, [kton/a]	47.7	75.4

(For Attero-Noord this calculation was based on the 4 municipalities that co-operated with this pilot)

The extrapolations for the Attero-Noord facility yields 48 kton and the extrapolation for the Omrin facility yields about 75 to 82 kton. The errors due to extrapolation are large and given the outcomes, they indicate that the 70 kton number given by Hedra is roughly correct. The large difference between the extrapolations of both facilities suggests that there is significant regional variation in the consumption of beverages packaged in cartons. This study found four different strong indications for such a regional variation:

- Retailers indicated that the sales numbers in rural regions are higher than in urban regions. This could be attributed to larger households with more children in the rural regions, which results in the use of more beverage cartons. They were unable to render accurate estimations of this variation, but expected it to be around 10%.

- This study revealed a large difference in the amount of beverage cartons present in the MSW treated at a recovery facility treating mostly urban waste and another facility treating mostly rural waste (see above). The difference found was overall 30%, meaning a variation parameter of 15%.
- Four rural municipalities that operate a co-collection system of plastic packages and beverage cartons report higher responses than what would be expected to be possible based on a national consumption of 70 ktons and an even distribution. These responses indicate that the regional variation between base-line and rural would be +15%.
- This study clearly shows that the composition of the collected beverage cartons varies between municipalities. Implying that there is not only regional variation in the amount of beverage cartons per inhabitant and year but also in types of products sold in beverage cartons. For example, in most municipalities predominantly fresh milk is consumed, while in some other mostly sterilised milk is consumed.

Therefore, it was decided for this study to set the national annual consumption at 70 ktonnes, and to apply a regional correction factor of -15% for collection areas with more than 50% high-rise buildings (mostly urban) and +15% for collection areas with less than 10% high-rise buildings (mostly rural).

Table 28:Market division of beverage cartons on the Dutch market derived from the total amounts of beverage cartons present in recovered products from the two facilities, extrapolated to annual levels.

Category	Attero	Omrin	Total	Division
Milk cartons ≥ 1 ltr	122116	839455	961571	13.2%
Milk cartons < 1 ltr	2127	24769	26896	0.37%
UHT milk cartons ≥ 1 ltr	174927	964125	1139052	16.2%
UHT milk cartons < 1 ltr	11433	68283	79716	1.08%
Yoghurt & dessert cartons ≥ 1 ltr	253638	1609079	1862718	26.1%
Yoghurt & desserts cartons < 1 ltr	12558	53641	66199	0.95%
Juice cartons ≥ 1 ltr	244231	1231510	1475741	21.2%
Juice cartons < 1 ltr	62364	258512	320876	4.58%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	70197	393817	464013	6.59%
Cartons with fresh mixes of juice & dairy < 1 ltr	9355	31395	40750	0.54%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	11555	105709	117264	1.69%
Cartons with UHT mixes of juice & dairy < 1 ltr	9721	89714	99435	1.40%
Residual cartons ≥ 1 ltr	23393	110366	133760	1.93%
Residual cartons < 1 ltr	55611	229498	285109	4.09%
TOTAL	**1063226**	**6009873**	**7073099**	

A market division of the beverage cartons was derived from the total amounts of beverage cartons present in all the recovered products on an annual basis and performing a weighted averaging of these numbers, see

Table 28. This market division suggests that 13% of the beverage cartons have a volume of less than 1 litre.

3.10 Mass balance per facility and type of product stream

3.10.1 Results recovery chain Attero-Noord, Augustin, Repa

The results of mass balancing the recovery facility Attero-Noord are given in Table 29. The quality [%] was a derived from the determined sorting analysis and the mass balance [kg] were the actual weights of the products formed. The recovery of mass [R_m] is directly derived from the mass balance. The yield of recyclable materials [R_w] was derived from the recovery of mass and the quality. The execution of the mass balancing of Attero-Noord was as planned. The only exception was the sampling of the metal products. These were only sampled as 'hot spot' samples, since visual inspection revealed the absence of beverage cartons.

The majority of the beverage cartons were recovered at Attero-Noord (87%) in the concentrate named 'plastics and beverage cartons' and only a limited loss occurred to the RDF and ONF fractions. Moreover, the input material was found to contain 2.1% beverage cartons.

The plastics and beverage carton product of Attero-Noord was subsequently sorted at Augustin. The results of mass balancing Augustin are listed in Table 30. A beverage carton product (named BC) was obtained that contained 50.7% of the beverage cartons from the input stream. The product is a mix of three streams: a BC stream originating from the NIR sorter, a BC stream from the quality control of the PE,PP and PET fraction and a stream recovered from the mixed plastics. As more than 94% of the BC originate from the NIR sorter the BC from the other sources where neglected. The mass of the BC fraction is therefore the sum of the three streams. The composition was derived from the stream originating from the NIR sorter. Most of the losses occurred to the 'flat sorting rests' and some to the mixed plastics. These beverage cartons are not recycled.
The mass balance of Augustin was conducted as planned. Only the composition of the manually sorted polymer products and residues should be treated as assumptions, since they were just sampled as 'hot spots'.

Table 29 Mass balance of the recovery plant Attero-Noord (generation of plastics and BC mix for Augustin, see next table, cursive values are hot spot sampled fractions)

Sorted fractions	Plastics + BC	Films	RDF	Organics	Fe coarse	Fe fine	Fe (tin plate)	NF	Input	
	Products									
BC	19.2%	0.0%	0.5%	0.1%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	2.1%	Quality [%]
Paper & Board	10.2%	9.2%	20.6%	2.5%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	11.1%	
Plastics	50.4%	90.8%	25.0%	2.1%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	19.1%	
Metal	1.8%	0.0%	5.0%	0.4%	*100.0%*	*100.0%*	*100.0%*	*100.0%*	5.2%	
Residue	18.3%	0.0%	48.8%	94.9%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	62.5%	
Sum	100%	100%	100%	100%	*100%*	*100%*	*100%*	*100%*	100.0%	
BC	2379	0	288	58	0	0	0	0	2726	Quality [kg]
Paper & Board	1268	367	11558	1370	0	0	0	0	14562	
Plastics	6240	3633	14018	1136	0	0	0	0	25028	
Metal	220	0	2792	247	340	760	2280	238	6877	
Residue	2267	0	27329	52488	0	0	0	0	82084	
Sum	**12374**	**4000**	**55984**	**55300**	**340**	**760**	**2280**	**238**	**131276**	**Mass balance**
BC	**87.3%**	0.0%	10.6%	2.1%	0.0%	0.0%	0.0%	0.0%	100.0%	Rw
Paper & Board	8.7%	2.5%	79.4%	9.4%	0.0%	0.0%	0.0%	0.0%	100.0%	
Plastics	24.9%	14.5%	56.0%	4.5%	0.0%	0.0%	0.0%	0.0%	100.0%	
Metal	3.2%	0.0%	40.6%	3.6%	4.9%	11.1%	33.2%	3.5%	100.0%	
Residue	2.8%	0.0%	33.3%	63.9%	0.0%	0.0%	0.0%	0.0%	100.0%	
Sum	**9.4%**	**3.0%**	**42.6%**	**42.1%**	**0.3%**	**0.6%**	**1.7%**	**0.2%**	**100.0%**	**Rm**

Table 30 Mass balance of the sorting plant Augustin

Sorted fractions	BC	Residue flat	Mixed plastics	PE	PET	PP	Residue fine	Residue manual sorting	Input	
	Products									
BC	97.7%	22.3%	7.3%	*0.0%*	*0.0%*	*0.0%*	2.6%	*0.0%*	19.8%	Quality [%]
Paper and Board	1.2%	14.3%	2.8%	*0.0%*	*0.0%*	*0.0%*	0.0%	*0.0%*	5.8%	
Plastics	0.7%	25.9%	85.5%	*100.0%*	*100.0%*	*100.0%*	0.0%	*100.0%*	49.1%	
Metal	0.0%	1.2%	0.2%	*0.0%*	*0.0%*	*0.0%*	0.0%	*0.0%*	0.5%	
Residue	0.4%	36.0%	4.2%	*0.0%*	*0.0%*	*0.0%*	97.4%	*0.0%*	24.8%	
Sum	100%	100%	100%	*100%*	*100%*	*100%*	100%	*100%*	100.0%	
BC	2.39	1.82	0.43	0.00	0.00	0.00	0.07	0.00	4.72	Quality [Mg]
Paper and Board	0.03	1.17	0.17	0.00	0.00	0.00	0.00	0.00	1.37	
Plastics	0.02	2.12	5.04	0.95	1.19	1.19	0.00	1.20	11.70	
Metal	0.00	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.11	
Residue	0.01	2.95	0.25	0.00	0.00	0.00	2.70	0.00	5.92	
Sum	2.45	8.18	5.90	0.95	1.19	1.19	2.77	1.20	23.81	Mass balance
BC	**50.7%**	38.7%	9.1%	0.0%	0.0%	0.0%	1.5%	0.0%	100.0%	Rw
Paper and Board	2.2%	85.6%	12.2%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	
Plastics	0.1%	18.1%	43.1%	8.1%	10.1%	10.1%	0.0%	10.3%	100.0%	
Metal	0.0%	90.8%	9.2%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	
Residue	0.2%	49.9%	4.2%	0.0%	0.0%	0.0%	45.7%	0.0%	100.0%	
Sum	**10.3%**	34.3%	24.8%	4.0%	5.0%	5.0%	11.6%	5.0%	100.0%	Rm

The mass balance of recycling the BC-product from Augustin at Repa is shown in Table 31. The major recovered product is the fibre product. Its composition is shown in Table 32. Most of the fibre product (77.3%) consists of fibres, about 3.6% are light by-products (pieces of plastic film) and 19% are soluble substances and fibre losses. The light by-products are removed in the paper making process and the latter category is the losses that occur during screening with 0.5 µm sieves.

Table 31 Mass balance of the recycling plant Repa using beverage cartons generated at Augustin

	Mass [kg gross]	DM [%]	DM [kg-DM]
Input	4944	69.87%	3454.2
Water	460000	0.03%	138.0
Sum Input			3592.2
By-product light	1330	69.69%	926.8
By-product heavy	6.0	66.57%	4.0
Process water + fibre	460000	0.597%	2748.5
Sum products			3679.3
Difference Input/output			-2%
Fibre via tumble screen (overflow)	28240	7.182%	2028.3
Water from tumble screen (underflow)	431760	0.182%	785.8
Sum products tumble screen			3744.9
Difference Input/output			-4%

Table 32 Quality of the fibre product from Attero-Noord / Augustin.

By-product light	**Fibres**	**Soluble substances and fibre losses**
3.6%	77.3%	19.0%

Table 33 Quality of the input material to the recycling process generated at Augustin

	Share	Dry matter
Milk cartons	29.7%	70.4%
Juice/water/ice tea	35.7%	73.2%
Yogurt & dessert cartons	16.9%	62.7%
Cartons with fresh mixes of juice & dairy	10.3%	69.9%
Residual cartons	4.5%	69.2%
Paper and board	0.7%	66.6%
Plastics	1.4%	80.5%
Metals	0.0%	100.0%
Residue	0.8%	43.3%
Sum	100%	

Based on this crude mass balance and composition of the recovered fibre product, the detailed mass balance -including the moisture content of the input stream- was calculated, see equations below and Table 34.

Calculation of the net fibre product, total by-products and amount of moisture in the input material.

$$2748.5\ kg\ (fibre\ total) * 77.3\% - 24\ kg\ (fibre\ from\ paper) = 2126\ kg\ (fibre\ from\ BC)$$

$$4944\ kg\ (total\ mass\ input) * 0.7\% * 66.6\%\ (share\ and\ dry\ matter\ of\ paper\ and\ board)$$
$$= 24\ kg\ (fibre\ from\ paper)$$

$$2748.5\ kg\ (fibre\ total) * 3.6\%\ (by-product\ in\ fibre\ product)$$
$$= 99\ kg\ (by-product\ loss\ to\ fibre\ product)$$

$$2748{,}5\ kg\ (fibre\ total) * 19.0\%\ (fine\ material\ in\ fibre\ product)$$
$$= 523\ kg\ (fibre\ losses\ and\ soluble\ substances)$$

$$926.8\ kg + 4\ kg\ (by-product\ light\ and\ heavy) - 73\ kg\ (plastics, metals, residues\ in\ by-product)$$
$$= 858\ kg\ (by-products)$$

$$4944\ kg * (1.4\% * 80.5\% + 0.0\% * 100\% + 0.8\% * 43.3\%)(share\ and\ DM\ of\ plastics, metals, residue)$$
$$= 73\ kg\ (plastics, metals, residue\ in\ by-product)$$

$$\frac{2102 + 24 + 99 + 523 + 858 + 73}{1 - 30.1\%} - (2102 + 24 + 99 + 523 + 858 + 73)$$
$$= 1587\ kg\ (moisture\ in\ input)$$

Table 34 Calculation of the share of fibre from BC in the fibre fraction and of the amount of by-product from BC and lost by-product for the calculation of the yield of fibre/by-product(values are derived from Table 31, Table 32 and Table 33)

		Mass [kg]		Comment
Fibre product	**Fibre from BC**	**2102**	39,9%	After removal of soluble substances/fibre losses
	Fibre from paper	24	0,5%	Fibre from paper (estimated on input analysis)
	By-product loss	**99**	1,9%	By-product light in fibre product
	Soluble substances and fibre losses	523	9,9%	Losses of fibre/dissolved impurities
By-product	**By-products**	**858**	16,3%	Aluminium and plastics from BC
	Plastics, metals residue in by-product	73	1,4%	Other fractions (estimated on input analysis)
Moisture	Moisture in input	1587	30,1%	Measured (DM input)
Sum		5266	100,0%	

The yield of by-products can be calculated from the loss of by-product to the fibre product and the actual part of by-product found in the by-product:

$$R_{w,by-product} = \frac{858\ kg}{858\ kg + 99\ kg} = \mathbf{89.6}\%$$

The yield of fibre can't be calculated directly as no information is available which part of the fibre loss and soluble substances fraction originates from fibres of the BC and which is derived from impurities adhering the BC. Information on the composition of the BC (fibre, plastics, aluminium, see table 25) and the composition of the input material to the recycling process (milk/juice/etc. cartons) has to be taken into account to estimate the amount of fibre from the BC in the input to the recycling process. This figure has then to be put in relation to the fibre from BC found in the fibre product (see table 34).
In detail the amount of input to the recycling plant (Table 31, 4944 kg) has to be multiplied with each beverage carton fraction of the input (see Table 33) and its respective dry matter content. For each beverage carton fraction the respective amount of fibre (see Table 25) has to be taken into account. The sum is then the amount of fibre from beverage carton in the input. Table 34 delivers information on the amount of fibre from beverage carton found in the fibre product. This figure in relation to the figure calculated above is then the yield of fibre.

However, that means that the calculated yield is very sensitive to measurement errors of the dry matter content measurement in the storage vessel (e.g. Table 31 difference input/output). It has to be considered that in some cases huge (15%) differences between dry matter in the input and dry matter in the output were experienced and that the results therefore shouldn't be taken to order the different systems but to get an understanding of the magnitude of the yield of fibre. Further the amount of impurities adhering to the surface of the beverage carton had to be neglected. Some of the beverage cartons were found in a state where contact with water would have caused not only the loss of the dirt on the surface but also of some fibres. As this affects mainly the calculation of the amount of fibres in the input a yield corrected for the amount of dirt in the input will be higher the dirtier the input material is.

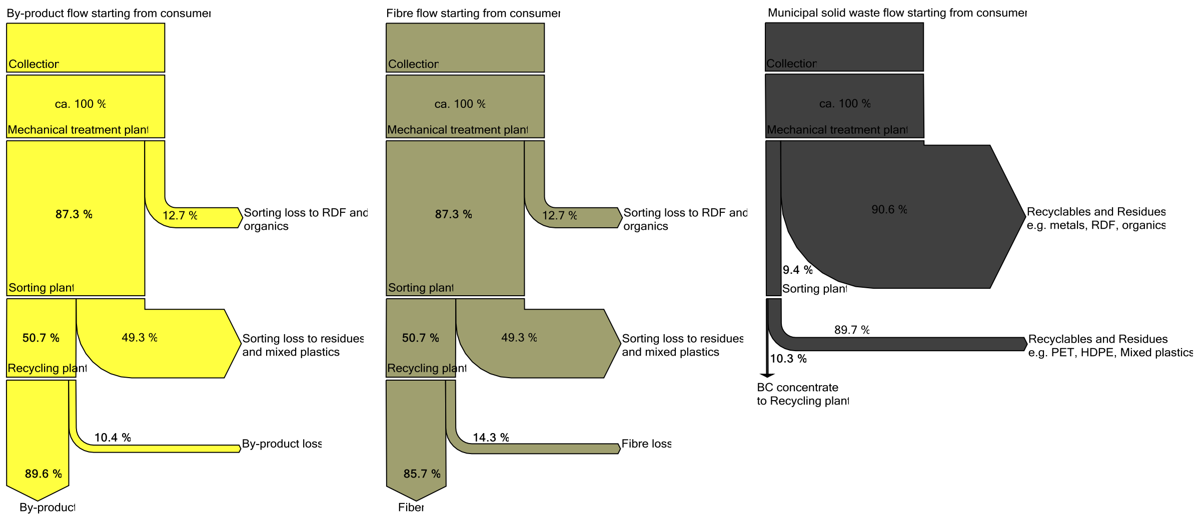

Figure 57: Material flow chart for the fibre and by-product originating from MSW of Attero-Noord (left and middle) and for the total MSW originating from Attero-Noord (right).

The mass balance data from the three facilities in the recovery chain Attero-Noord, Augustin and Repa have been combined into one material flow chart, see Figure 57. The data originates from the results in Table 29, Table 30 and Table 34.

3.10.2 Results recycling chain recovery Omrin, Repa

The results of the recovery and subsequent sorting of beverage cartons at Omrin is shown in Table 35. The Omrin facility has a recovery facility where MSW is separated in several products of which two fractions (the mixed plastics and the non-ferrous metals) are expected to contain beverage cartons. These two fractions are subsequently being sorted at the REKAS facility of Omrin, which is composed of a ballistic separator and two NIR sorting machines. The sorting of the mixed plastic fraction yields a beverage carton product, a plastic product, an RDF from the mixed plastics and an ONF fraction from the mixed plastics. The sorting of the non-ferrous metal fraction resulted in a negligible amount of beverage cartons (2.7 kg gross).

The main losses occur to the RDF fraction at the recovery facility and to the RDF at the Rekas sorting facility.

Table 35: Mass balance of the recovery facility and sorting facility at Omrin.

Sorted fractions	Mixed plastics	BC	BC from NF	Film	RDF	Organics	RDF from Mixed plastics	NF fine	Fe fine	Fe (tin plate)	Fe coarse	Film coarse	Film (manual)	Plastics (manual)	Organics from mixed plastics	NF	Input	
	Products																	
BC	1.8%	94.9%	100.0%	0.8%	1.5%	0.3%	10.2%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	3.2%	Quality [%]
Paper and Board	5.3%	2.1%	0.0%	6.7%	13.9%	4.9%	19.2%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	8.3%	
Plastics	81.1%	2.7%	0.0%	84.4%	10.9%	5.6%	43.6%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*100.0%*	*100.0%*	*100.0%*	*0.0%*	*0.0%*	14.9%	
Metal	1.6%	0.1%	0.0%	3.1%	2.1%	0.9%	1.1%	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*100.0%*	5.0%	
Residue	10.2%	0.3%	0.0%	5.0%	71.6%	88.3%	25.9%	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*100.0%*	*0.0%*	68.6%	
Sum	100%	100%	100%	100%	100%	100%	100%	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	100.0%	
BC	0.07	1.78	0.00	0.01	0.46	0.12	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.83	Quality [Mg]
Paper and Board	0.20	0.04	0.00	0.08	4.34	2.07	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.43	
Plastics	3.00	0.05	0.00	0.98	3.40	2.40	1.61	0.00	0.00	0.00	0.00	1.50	0.02	0.38	0.00	0.00	13.34	
Metal	0.06	0.00	0.00	0.04	0.67	0.37	0.04	0.30	0.52	1.98	0.16	0.00	0.00	0.00	0.00	0.36	4.49	
Residue	0.38	0.01	0.00	0.06	22.34	37.55	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	61.49	
Sum	**3.70**	**1.88**	**0.00**	**1.16**	**31.20**	**42.52**	**3.70**	**0.30**	**0.52**	**1.98**	**0.16**	**1.50**	**0.02**	**0.38**	**0.20**	**0.36**	**89.58**	Mass balance
BC	2.3%	**63.1%**	**0.1%**	0.3%	16.4%	4.4%	13.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	Rw
Paper and Board	2.6%	0.5%	0.0%	1.0%	58.4%	27.8%	9.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	
Plastics	22.5%	0.4%	0.0%	7.3%	25.5%	18.0%	12.1%	0.0%	0.0%	0.0%	0.0%	11.2%	0.1%	2.8%	0.0%	0.0%	100.0%	
Metal	1.3%	0.0%	0.0%	0.8%	14.8%	8.3%	0.9%	6.7%	11.6%	44.1%	3.6%	0.0%	0.0%	0.0%	0.0%	7.9%	100.0%	
Residue	0.6%	0.0%	0.0%	0.1%	36.3%	61.1%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	100.0%	
Sum	**4.1%**	**2.1%**	**0.0%**	**1.3%**	**34.8%**	**47.5%**	**4.1%**	**0.3%**	**0.6%**	**2.2%**	**0.2%**	**1.7%**	**0.0%**	**0.4%**	**0.2%**	**0.4%**	**100.0%**	Rm

The results of the recycling of the recovered and sorted beverage cartons from Omrin at Repa are shown in Table 36, Table 37 and Table 39. The recycled fibre product contains a little bit less light-weight by-products and the overall recycling yield is slightly higher than for Attero-Noord.

Table 36: Mass balance of the recycling plant Repa using beverage cartons generated at Omrin

	Mass [kg gross]	DM [%]	DM [kg-DM]
Input	4429	77.06%	3412.7
Water	427000	0.03%	127.3
Sum Input			3540.0
By-product light	937	81.21%	760.9
By-product heavy	13.2	52.03%	6.8
Process water + fibre	427000	0.515%	2198.1
Sum products			2965.8
Difference Input/output			16%
Fibre via tumble screen (overflow)	26740	9.150%	2446.7
Water from tumble screen (underflow)	400260	0.090%	360.2
Sum products tumble screen			3574.7
Difference Input/output			-1%

Table 37: Quality of the fibre product derived from recycled beverage cartons from Omrin.

By-product light	Fibre	Soluble substances and fibre losses
1.9%	87.2%	10.9%

Table 38: Quality of the input material to the recycling process generated at Omrin

	Share	Dry matter
Milk cartons	30,9%	79,6%
Juice/water/ice tea	32,3%	83,1%
Yogurt & dessert cartons	15,8%	69,5%
Cartons with fresh mixes of juice & dairy	11,1%	78,5%
Residual cartons	7,8%	52,7%
Paper and board	0,7%	84,2%
Plastics	0,6%	94,6%
Metals	0,4%	90,6%
Residue	0,3%	74,7%
Sum	100,0%	

Table 39: Calculation of the share of fibre from BC in the fibre fraction and of the amount of by-product from BC and lost by-product for the calculation of the yield of fibre/by-product (values are derived from Table 36, Table 37 and Table 38)

		Mass [kg]		Comment
Fibre product	Fibre from BC	2423	52,2%	After removal of soluble substances/fibre losses
	Fibre from paper	25	0,5%	Fibre from paper (estimated on input analysis)
	By-product loss	54	1,2%	By-product light in fibre product
	Soluble substances and fibre losses	305	6,6%	Losses of fibre/dissolved impurities
By-product	By-products	713	15,4%	Aluminium and plastics from BC
	Plastics, metals residue in by-product	54	1,2%	Other fractions (estimated on input analysis)
Moisture	Moisture in input	1064	22,9%	Measured (DM input)
Sum		4639	100,0%	

$$R_{w,by-product} = \frac{713\ kg}{713\ kg + 54\ kg} = \mathbf{93.0}\ \%$$

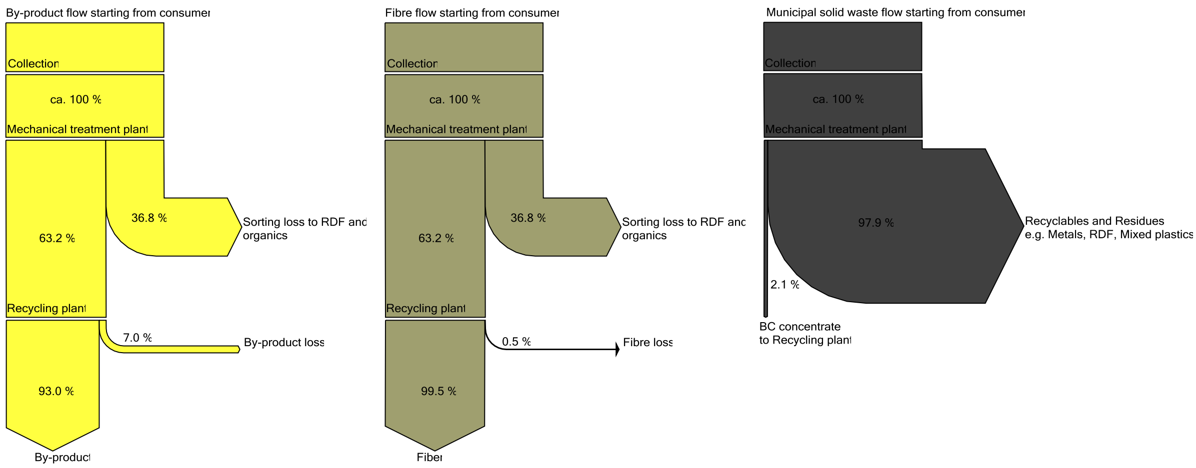

Figure 58: Material flow sheet for the fibre and by-product originating from MSW at Omrin (left and middle) and for the total MSW originating from Omrin (right)

The mass balancing results for the Omrin recycling chain are summarised in Figure 58. The data is from this study.

3.10.3 Results recycling chain co-collection with plastics via Sita Rotterdam

For one of the two recycling chains that starts with the co-collection of plastic packages and beverage cartons the collected material is sorted at Sita Rotterdam. The mass balance of this sorting facility is given in Table 40. The mass balance was recorded on the 1st of July and only 2% of beverage cartons were found in the input mixture, which can be attributed to the early stage in the pilot at which this measurement was conducted.

This sorting facility was not designed to sort out beverage cartons and hence the sorting was performed in a double run modus. In the first run the plastics were sorted conventionally and the beverage cartons were intended for mixed plastic fraction, although some already ended-up in the sorting rest and were lost. The last NIR sorter in the process chain was reprogrammed to sort out BC and mixed plastics simultaneously. BC found during quality control of the polymer fractions were also added to the mixed plastics fraction. In the second run the beverage cartons were recovered by manual sorting from the mixed plastics soft and hard and during quality control of the polymer products.

Table 40: Mass balance of the sorting plant Sita Rotterdam.

		BC	Residue	PP	PE	Mixed plastics 1	Mixed plastics 2	PET	Fe	Film	Residue fine	Input	
Sorted fractions	**BC**	98.6%	4.6%	0.6%	0.7%	9.2%	8.5%	0.2%	*0.0%*	0.0%	*0.0%*	5.8%	Quality [%]
	Paper and Board	0.2%	2.2%	0.0%	0.2%	4.2%	0.3%	0.0%	*0.0%*	0.0%	*0.0%*	1.2%	
	Plastics	1.2%	87.0%	99.4%	99.1%	80.1%	90.8%	99.5%	*0.0%*	100.0%	*100.0%*	89.3%	
	Metal	0.0%	1.3%	0.0%	0.0%	0.2%	0.1%	0.3%	*100.0%*	0.0%	*0.0%*	1.7%	
	Residue	0.0%	4.9%	0.0%	0.0%	6.4%	0.2%	0.0%	*0.0%*	0.0%	*0.0%*	2.0%	
	Sum	100%	100%	100%	100%	100%	100%	100%	*100%*	100%	*100%*	100.0%	
	BC	1121	335	27	28	876	465	6	0	0	0	2860	Quality [kg]
	Paper and Board	2	163	0	7	399	16	0	0	0	0	587	
	Plastics	13	6397	4493	3844	7638	4954	3865	0	8692	4250	44146	
	Metal	0	96	0	0	15	6	12	707	0	0	836	
	Residue	0	363	0	0	611	14	0	0	0	0	987	
	Sum	1137	7354	4520	3879	9539	5455	3883	707	8692	4250	49416	Mass balance
	BC	39.2%	11.7%	1.0%	1.0%	30.6%	16.3%	0.2%	0.0%	0.0%	0.0%	100.0%	Rw
	Paper and Board	0.3%	27.8%	0.0%	1.1%	68.0%	2.7%	0.0%	0.0%	0.0%	0.0%	100.0%	
	Plastics	0.0%	14.5%	10.2%	8.7%	17.3%	11.2%	8.8%	0.0%	19.7%	9.6%	100.0%	
	Metal	0.0%	11.5%	0.0%	0.0%	1.8%	0.7%	1.4%	84.6%	0.0%	0.0%	100.0%	
	Residue	0.0%	36.7%	0.0%	0.0%	61.9%	1.4%	0.0%	0.0%	0.0%	0.0%	100.0%	
	Sum	2.3%	14.9%	9.1%	7.8%	19.3%	11.0%	7.9%	1.4%	17.6%	8.6%	100.0%	Rm

Table 41: Mass balance of the recycling plant Repa using beverage cartons generated at Sita Rotterdam

	Mass [kg]	DM [%]	DM [kg-DM]
Input	4590	75.53%	3466.7
Water	373000	0.08%	282.4
Sum Input			3749.1
By-product light	964	79.96%	770.8
By-product heavy	5.857	68.93%	4.0
Process water + fibre	373000	0.647%	2414.1
Sum products			3188.9
Difference Input/output			15%

Table 42: Quality of the fibre product (Sita Rotterdam)

By-product light	Fibre	Soluble substances and fibre losses
3.6%	83.7%	12.7%

Table 43 Quality of the input material to the recycling process generated at Sita

	Share	Dry matter
Milk cartons	31,7%	70,7%
Juice/water/ice tea	38,8%	71,5%
Yogurt & dessert cartons	12,4%	64,9%
Cartons with fresh mixes of juice & dairy	12,4%	72,4%
Residual cartons	1,7%	76,5%
Paper and board	0,7%	69,4%
Plastics	2,1%	90,0%
Metals	0,0%	100,0%
Residue	0,1%	96,7%
Sum	100%	

The crude mass balance of the Repa plant with the beverage cartons generated from Sita Rotterdam is given in Table 41. The composition of the obtained fibre product is described in Table 42. Based on this mass balance and the analysed quality a more detailed product division was calculated, see Table 44

Table 44: Calculation of the share of fibre from BC in the fibre fraction and of the amount of by-product from BC and lost by-product for the calculation of the yield of fibre/by-product (values are derived from Table 41, Table 42 and Table 43)

		Mass [kg]		Comment
Fibre product	Fibre from BC	1998	47,3%	after removal of soluble substances/fibre losses
	Fibre from paper	21	0,5%	By-product light and heavy
	By-product loss	87	2,1%	removed by-product light
	Soluble substances and fibre losses	308	7,3%	0,0%
By-product	By-products	684	16,2%	0,0%
	Plastics, metals residue in by-product	91	2,1%	0,0%
Moisture	Moisture in input	1033	24,5%	measured (DM input)
Sum		4222	100,0%	

$$R_{w,by-product} = \frac{684\ kg}{684\ kg + 87\ kg} = \mathbf{88.7}\%$$

The mass flow charts for the beverage cartons that have been co-collected with plastic packages and were sorted at Sita Rotterdam are shown in Figure 59Table 59.

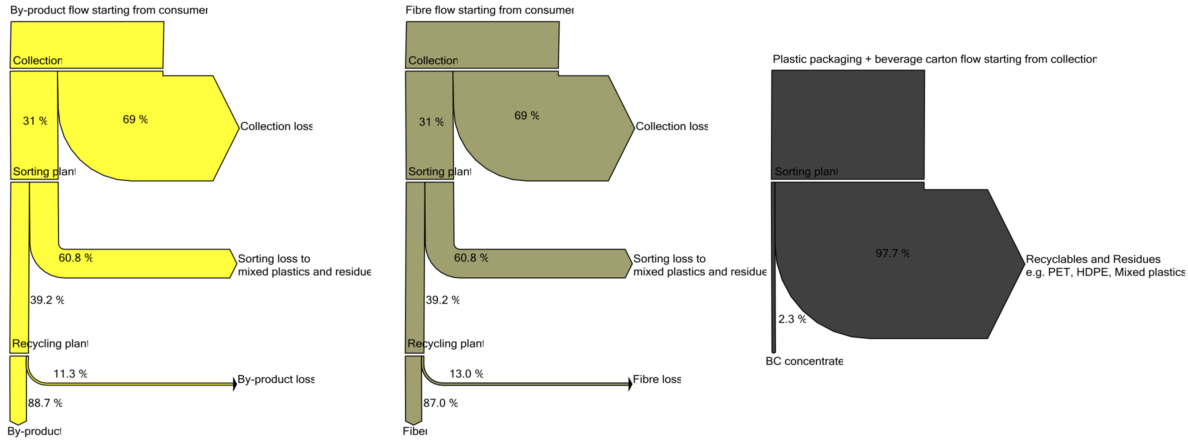

Figure 59: Material flow chart for the fibre and by-product originating from Sita Rotterdam (left and middle) and for the total mixture of co-collected plastic packages and beverage cartons being sorted at Sita Rotterdam (right) (the small amount of beverage cartons present in the mix of plastic packaging waste and beverage cartons is a result of the early stage of the collection system)

3.10.4 Results Schönmackers

The second recycling chain of beverage cartons that have been co-collected with plastic packages is the Milieuzakken chain. This material is cross-docked by Hummel and sorted by Schönmackers. This facility was previously used for sorting German LVP and is hence equipped with a dedicated NIR sorting machine for beverage cartons. The mass balance of this facility was determined accurately by measuring the production rate [kg/hr] of the various products. Since the input of the Milieuzakken-material had 20% of beverage cartons on the June 13th, 19% on July 15th and only 12% on the date of the mass balancing October 25th this balance shows relative smaller amounts of beverage cartons.

Table 45 Mass balance of the sorting plant Schönmackers (generation of BC for Brohl-Lützing, residue 2 and residue 2 coarse are no separate products, instead the mass is based on mass flow measurements)

Products

Sorted fractions

	BC	Residue BC	Residue 1	Residue 2	Residue 2 coarse	Residue fine	PE	PP	PET	Paper and Board	Film	Fe	Mixed plastics	Input	
BC	75.2%	34.3%	6.9%	*0.0%*	*0.0%*	2.7%	0.0%	2.1%	*0.0%*	1.8%	1.5%	2.2%	6.6%	12.1%	Quality [%]
Paper and Board	18.1%	27.4%	3.0%	*0.0%*	*0.0%*	0.0%	0.1%	0.0%	*0.0%*	72.8%	1.3%	3.4%	3.2%	10.1%	
Plastics	5.4%	28.1%	79.0%	*80.0%*	*80.0%*	0.0%	99.6%	97.8%	*100.0%*	21.5%	97.0%	14.7%	88.0%	65.4%	
Metal	0.1%	5.1%	0.4%	*0.0%*	*0.0%*	0.0%	0.0%	0.1%	*0.0%*	0.0%	0.1%	78.6%	0.3%	0.8%	
Residue	1.1%	5.0%	10.8%	*20.0%*	*20.0%*	97.3%	0.3%	0.1%	*0.0%*	3.9%	0.0%	1.1%	1.9%	11.6%	
Sum	100%	100%	100%	*100%*	*100%*	100%	100%	100%	*100%*	100%	100%	100%	100%	100.0%	
BC	1.41	0.23	0.22	0.00	0.00	0.05	0.00	0.02	0.00	0.03	0.01	0.00	0.57	2.55	Quality [kg]
Paper and Board	0.34	0.18	0.10	0.00	0.00	0.00	0.00	0.00	0.00	1.23	0.01	0.00	0.28	2.15	
Plastics	0.10	0.19	2.59	0.15	0.07	0.00	0.70	0.93	0.25	0.36	0.87	0.02	7.60	13.84	
Metal	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.03	0.17	
Residue	0.02	0.03	0.36	0.04	0.02	1.76	0.00	0.00	0.00	0.07	0.00	0.00	0.16	2.46	
Sum	**1.88**	**0.67**	**3.28**	**0.19**	**0.09**	**1.81**	**0.70**	**0.95**	**0.25**	**1.69**	**0.90**	**0.12**	**8.64**	**21.17**	Mass balance
BC	55.4%	9.0%	8.8%	0.0%	0.0%	1.9%	0.0%	0.8%	0.0%	1.2%	0.5%	0.1%	22.3%	100.0%	Rw
Paper and Board	15.9%	8.6%	4.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	57.3%	0.6%	0.2%	13.0%	100.0%	
Plastics	0.7%	1.4%	18.7%	1.1%	0.5%	0.0%	5.0%	6.7%	1.8%	2.6%	6.3%	0.1%	54.9%	100.0%	
Metal	1.2%	20.4%	6.8%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.2%	0.7%	53.4%	16.6%	100.0%	
Residue	0.8%	1.4%	14.5%	1.5%	0.8%	71.7%	0.1%	0.0%	0.0%	2.7%	0.0%	0.1%	6.6%	100.0%	
Sum	**8.9%**	**3.2%**	**15.5%**	**0.9%**	**0.4%**	**8.6%**	**3.3%**	**4.5%**	**1.2%**	**8.0%**	**4.3%**	**0.5%**	**40.8%**	**100.0%**	Rm

Table 46 Mass balance of the recycling plant using beverage cartons generated at Schönmackers

	Mass [kg]	DM [%]	DM [kg-DM]
Input	2955	74.89%	2213.1
Water	271603	0.03%	81.5
Sum Input			2294.6
Byproduct light	894	72.89%	651.6
Byproduct heavy	7.1	74.20%	5.3
Process water + fibre	271603	0.676%	1835.5
Sum products			2492.4
Difference Input/output			-9%
Fibre (Bypass)	271603	0.518%	1406.1
Sum Products Bypass			2063.1
Difference Input/output			10%

Table 47 Quality of the fibre product (Schönmackers)

By product light	**Fibre**	**Soluble substances and fibre losses**
1.5%	82.7%	15.8%

Table 48 Quality of the input material to the recycling process generated at Schönmackers

	Share	Dry matter
Milk cartons	23,3%	75,8%
Juice/water/ice tea	25,0%	78,4%
Yogurt & dessert cartons	15,8%	67,4%
Cartons with fresh mixes of juice & dairy	10,4%	71,6%
Residual cartons	4,1%	75,4%
Paper and board	12,9%	71,0%
Plastics	7,9%	86,1%
Metals	0,2%	93,2%
Residue	0,5%	79,7%
Sum	100,0%	

Table 49 Calculation of the share of fibre from BC in the fibre fraction and of the amount of by-product from BC and lost by-product for the calculation of the yield of fibre/by-product (values are derived from Table 46, Table 47 and Table 48)

		Mass [kg]		Comment
Fibre product	Fibre from BC	1070	35,2%	after removal of soluble substances/fibre losses
	Fibre from paper	271	8,9%	By-product light and heavy
	By-product loss	24	0,8%	removed by-product light
	Soluble substances and fibre losses	257	8,4%	0,0%
By-product	By-products	441	14,5%	0,0%
	Plastics, metals residue in by-product	216	7,1%	0,0%
Moisture	Moisture in input	764	25,1%	measured (DM input)
Sum		3041	100,0%	

$$R_{w,by-product} = \frac{441\ kg}{441\ kg + 24\ kg} = \mathbf{94.9}\ \%$$

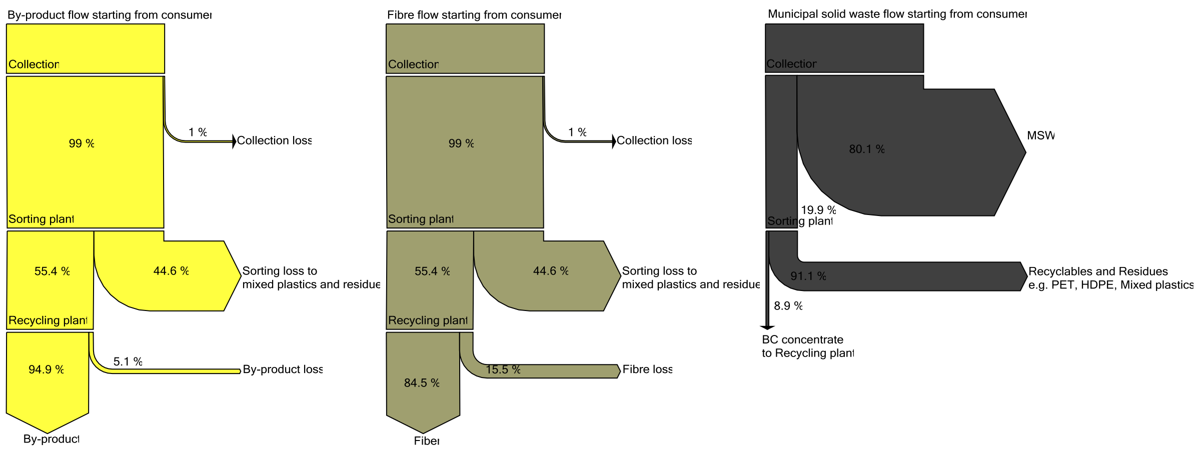

Figure 60 Material flow for the fibre and by-products originating from Schönmackers (left and middle) and for the total MSW originating from Schönmackers (right)

3.10.5 Results separate collection of beverage cartons

Separate collected beverage cartons recycled at Repa in May 2013. The crude mass balance is described in Table 50, the quality of the retrieved fibres is given in Table 51 and the final division of the products formed as compared to the input amount is given in Table 53

Table 50: Mass balance of the recycling plant using separate collected beverage cartons

	Mass [kg]	DM [%]	DM [kg-DM]
Input	4058	74,44%	3020,4
Water	445000	0,03%	133,5
Sum Input			3153,9
Byproduct light	1146,2	70,75%	811,0
Byproduct heavy	9,7	50,66%	4,9
Process water + fibre	445000	0,463%	2058,9
Sum products			2874,8
Difference Input/output			9%

Table 51: Quality of the fibre product (separate collection) (assumption mean from all trials)

By product light	Fibre	Soluble substances and fibre losses
2.2%	*83.2%*	*14.6%*

Table 52 Quality of the input material to the recycling process generated from the separate collection of BC

	Share	Dry matter
Milk cartons	33,5%	75,1%
Juice/water/ice tea	29,9%	78,1%
Yogurt & dessert cartons	13,1%	76,8%
Cartons with fresh mixes of juice & dairy	15,8%	65,7%
Residual cartons	3,2%	73,3%
Paper and board	2,9%	62,7%
Plastics	1,2%	86,1%
Metals	0,1%	100,0%
Residue	0,3%	72,2%
Sum	100,0%	

Table 53: Calculation of the share of fibre from BC in the fibre fraction and of the amount of by-product from BC and lost by-product for the calculation of the yield of fibre/by-product (values are derived from Table 50, Table 51 and Table 52)

		Mass [kg]		Comment
Fibre product	Fibre from BC	1639	42,4%	after removal of soluble substances/fibre losses
	Fibre from paper	74	1,9%	By-product light and heavy
	By-product loss	44	1,1%	removed by-product light
	Soluble substances and fibre losses	301	7,8%	0,0%
By-product	By-products	761	19,7%	0,0%
	Plastics, metals residue in by-product	55	1,4%	0,0%
Moisture	Moisture in input	987	25,6%	measured (DM input)
Sum		3862	100,0%	

$$R_{w,by-product} = \frac{761\,kg}{761\,kg + 44\,kg} = \mathbf{94.5}\,\%$$

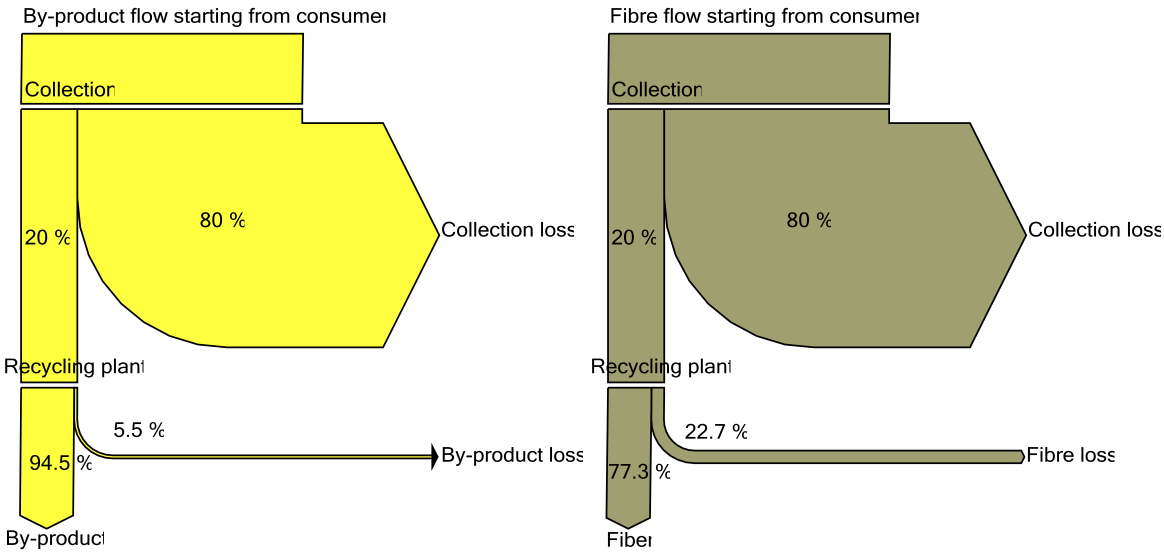

Figure 61 Material flow for the fibre and by-products originating from the separate collection of BC

The mass flow chart for the separate collected beverage cartons is given in Figure 61.

3.10.6 Results of Kempenaars

On 22nd of August two truckloads of co-collected paper & board and beverage cartons were delivered at the sorting facility Kempenaars. One load from in-hall collection containers in high rise buildings and one load from mini-containers from a low rise neighbourhood of Etten-Leur. From both 1 m^3 samples were taken of the input mixture and of the sorting rest. Furthermore, all separated beverage cartons were taken to Wageningen for weighing and analysis by sorting. The sorting results are listed in Table 54 and Table 55.

Table 54: Main sorting result from the manual sorting off the pile of co-collected paper & board and beverage cartons from in-hall collection containers in high rise buildings in Etten-Leur.

Weight	Input 1140 kg gross	Beverage cartons 13.7 kg gross	Sorting rest 1126 kg gross
Beverage cartons	4.1%	98.9%	0.9%
Paper & board	95.9%	1.1%	98.7%
Plastics	0.3%	0.0%	0.2%
Organic waste	0.0%	0.0%	0.1%
Textiles	0.0%	0.0%	0.0%
Metals	0.0%	0.0%	0.1%
Glass	0.0%	0.0%	0.0%

Table 55: Main sorting result from the manual sorting off the pile of co-collected paper & board and beverage cartons from mini-containers from low rise buildings in Etten-Leur.

Weight	Input 8040 kg gross	Beverage cartons 97.4 kg gross	Sorting rest 7943 kg gross
Beverage cartons	3.4%	97.9%	0.3%
Paper & board	95.6%	2.0%	99%
Plastics	0.3%	0.1%	0.4%
Organic waste	0.2%	0.0%	0.2%
Textiles	0.0%	0.0%	0.0%
Metals	0.0%	0.0%	0.1%
Glass	0.5%	0.0%	0.0%

Analysis of this data revealed inconsistencies in the sorting data, most probably originating from the uneven distribution of beverage cartons through the pile of co-collected paper & board. Nevertheless, this data suggests that the sorting efficiency of manual sorting of beverage cartons from a pile of paper & board is roughly 50%.

3.10.7 Results of Sita Soesterberg

On 31st August a truckload of co-collected paper & board and beverage cartons from Vianen was mechanically and manually sorted at Sita Soesterberg. The co-collected material mix was first sieved, yielding a corrugated board product. Subsequential a paper spike removed predominantly folding cartons and other large pieces of board, yielding the product “Folding carton 1”. Then the material was fed into a manual sorting cabinet, where the sorters removed first cardboard products and secondly beverage cartons. The main product continued to the paper product bunker. A visual inspection of the input material showed that the beverage cartons were spread uneven through the pile of co-collected material; in some locations pockets of beverage cartons were discovered, while in other locations none could be found. Visual inspection of the sieved corrugated board product and the manually sorted folding carton product showed no beverage cartons and hence these products were not analysed further. The sorting results are listed in Table 56.

Table 56: Main sorting result from the combined mechanical and manual sorting of co-collected paper & board and beverage cartons from Vianen.

	Input	Corrugat. board	Folding cartons 1	Folding cartons 2	Beverage cartons	Paper product
Weight, [kg gross]	8260	787	580	503	88	6360
Beverage cartons	2.3%	0%	5.1%	0%	95.7%	0.7%
Paper & board	97.5%	100%	93.6%	100%	4.2%	99.1%
Plastics	0.2%		1.3%		0.0%	0.2%
Organic waste	0.0%		0.0%		0.1%	0.0%
Textiles	0.0%		0.0%		0.0%	0.0%
Metals	0.0%		0.0%		0.0%	0.0%
Glass	0.0%		0.0%		0.0%	0.0%

Analysing of this sorting data yields a sorting efficiency of the beverage cartons of 50 ± 5%.

3.11 Recycling of by-products

Process technological analysis of the floating side products from the recycling of separately collected beverage cartons at Repa has shown that these by-products can be separated with relative ease in four product categories; a PO-mix of caps and closures, an aluminium-rich film fraction, a SRF of plastic film pieces and a paper fibre residue. This separation can be achieved by a wind sifter, an eddy current separator and a sieve. Roughly 40% of aluminium containing PE films were obtained, 38% SRF, 20% PO-mix and 2% fibre residues. The PO-mix can be sold to recyclers, the SRF can be sold as fuel and the aluminium containing PE film can either be added to the SRF, or potentially could be sold separately to a recycler.

The metal composition of four types of side products were determined for the four most important metals by XRF; PO-mix, Aluminium containing PE film, printed plastic flakes and unprinted plastic flakes. For cadmium, mercury and lead the content was below the detection limit of 1 ppm. For chromium a clear small signal was recorded for all side products, but it was too small for quantification. Therefore, much more side products need to be analysed. The chromium content is anyhow below 100 ppm for all studied side products. Chromium is likely to originate from the ink.

3.12 Cross-contamination

In this pilot three collection systems are studied with a carrier system; plastic packages, paper & board and municipal solid waste. For all these carrier streams the presence of the beverage cartons could potentially have negative effects on the recycling system of the carrier itself and the carrier system can potentially also negatively affect the quality of the beverage cartons. In the paragraph the cross-contamination effects are discussed.

3.12.1 Cross contamination between beverage cartons and plastic packages

Within the co-collection system of beverage cartons and plastic packaging waste two recycling chains were studied;

1. MZ, the so-called Milieuzakken-chain of the municipalities Grootegast, Leek and Marum which have Hummel recycling as cross-docking station and Schönmackers as sorting facility,
2. Sita, the Kunststof Hergebruik BV chain of the 8 other municipalities which have Sita Rotterdam as sorting facility.

Cross-contamination is studied for both chains at three levels:

1. The amount of attached moisture and dirt of the beverage cartons and the plastic packages in comparison to municipalities with separate collection systems,
2. Dispersion of beverage cartons over plastic packaging fractions, which would reduce the quality of the plastic products,
3. Reductions in sorting yields of valuable plastic products due to the presence of beverage cartons

<u>Ad 1. Cross contamination of moisture and dirt</u>

The amount of attached moisture and dirt on all the types of beverage cartons in the sorted products from the MZ and the Sita chain is listed in Table 57 and compared to the values of the separate collected beverage cartons (Table 12). The MZ chain has been studied twice, once with pressed material (13 June) and once with loose material (15 July). In general the amount of attached moisture and dirt to the beverage cartons was lower in the sorted products from the co-collection chains as compared to the separately collected beverage cartons. This difference can originate from two effects; cross-contamination and enrichment of lesser polluted beverage cartons due to sorting. Nevertheless, it is remarkable to see that the attached moisture and dirt level for the beverage cartons coming from the loose MZ material (15 July) is larger than that of the pressed MZ material (13 June), which indicates that pressing would release enclosed moisture and dirt from the beverage cartons towards plastic packages.

The amount of attached moisture and dirt on the five main categories of plastic packaging in the sorted products of the MZ and Sita chain is listed in Table 58 and compared to the values of the separate collected plastic packages[ii]. The moisture and dirt percentages of the plastic packages that have been co-collected with beverage cartons are similar to those from the separate collection system for plastic packaging. Hence, the attached moisture and dirt values do not indicate that cross-contamination occurred between beverage cartons and plastic packages.

Table 57: Attached moisture and dirt on beverage cartons from the MZ, KH chains in comparison to separately collected beverage cartons

Category	MZ 13 June	MZ 15 July	Sita 1 July	Sep. Coll.
Milk cartons ≥ 1 ltr	25%	28%	20%	24 ± 5%
Milk cartons < 1 ltr	20%	45%	17%	20 ±10%
UHT milk cartons ≥ 1 ltr	21%	25%	22%	27 ± 5%
UHT milk cartons < 1 ltr		27%	26%	28 ± 11%
Yoghurt & dessert cartons ≥ 1 ltr	30%	27%	29%	50 ± 10%
Yoghurt & desserts cartons < 1 ltr	48%	52%	32%	37 ± 18 %
Juice cartons ≥ 1 ltr	19%	23%	17%	24 ± 4%
Juice cartons < 1 ltr	22%	24%	16%	23 ± 7%
Cartons with fresh mixes of juice & dairy ≥ 1 ltr	28%	36%	25%	41 ± 8%
Cartons with fresh mixes of juice & dairy < 1 ltr	33%	35%	24%	39 ± 19%
Cartons with UHT mixes of juice & dairy ≥ 1 ltr	21%	35%	22%	34 ± 11%
Cartons with UHT mixes of juice & dairy < 1 ltr	25%		20%	26 ± 15%
Residual cartons ≥ 1 ltr	18%	22%	18%	24 ± 7%
Residual cartons < 1 ltr	19%	27%	19%	28 ± 7%
Weight averaged total	**23.5%**	**26.8%**	**20.4%**	**32 ± 5%**

Table 58: Attached moisture and dirt levels on plastic packages from the MZ and KH chains in comparison to previously obtained results for separate collected plastic packages.

Category	MZ 13 June	MZ 15 July	Sita 1 July	Sep. Coll.
PET bottles clear < 1 litre	19%	7%	10%	17 ± 12%
PE flasks	12%	16%	19%	18 ± 8%
PET rigids	6%	24%	12%	7 ± 4%
PP rigids	17%	6%	5%	11 ± 8%
PE film > A4	10%	5%	11%	10 ± 9%
Weight averaged total				**12 ± 5%**

Ad 2. Dispersion of beverage cartons over the plastic fractions

The two sorting facilities were sampled twice and the composition of the sorted products was determined by manual sorting. These sorting results with respect to the content of beverage cartons are listed in Table 59.

From the sorting test at Sita on 20th June with only plastic packages it is clear that there is already a small amount of beverage cartons present in Dutch separate collected plastic packaging waste and that it mostly contributes to the mixed plastic (MKS) product, but that it also occasionally occurs in the PE and PP fractions as a small level contaminant.

From the sorting test at Sita on 1st of July with a mixture of plastic packages and beverage cartons it is clear that some of the beverage cartons end up in the PP and MKS fractions. The levels of beverage cartons in these fractions are clearly raised as compared to the sorting run on 20th June with only plastic packages. This implies that the value of these products has been reduced for plastic recyclers. Additionally 2.3% of the sorting rest is composed of beverage cartons. This rest has to be incinerated and the additional contribution of the beverage cartons means that the economical balance for the sorting facility has worsened.

Table 59: Percentage of beverage cartons in the sorted fractions, [% gross weight]

Sorted fraction	Schönmackers, pressed MZ 13th June	Schönmackers, loose MZ 15th July	Sita, only PPW as input, 20th June	Sita, PPW + BC as input, 1st July
PET	0.0%	0.0%	0.0%	0.0%
PE	0.5%	0.0%	0.1%	0.0%
PP	2.4%	0.0%	0.0%	1.7%
FILM	1.9%	0.0%	0.0%	0.0%
MKS	2.6%	2.2%	0.2%	6.6%
FKN	72.6%	78.4%	na	98.5%
PK	1.7%	0.0%	na	na
Sorting rest	nd	nd	nd	2.3%

Nd = not determined, Na = not applicable.

Two sorting runs with Milieuzakken-material were studied at Schönmackers. One run had pressed material as input and one run had loose material as input. Baling of the co-collected material at the cross docking station Hummel clearly causes an increase in faulty sorted beverage cartons. In case of the loose material only some beverage cartons end up in the mixed plastics fraction, whereas in case of the baled material, much more of the beverage cartons end up in the PE, PP, Film and Paper & Board fractions. These sorting runs prove that the presence of beverage cartons in the input mixture does result in contamination of the plastic products and that technical aspects like baling and sorting modalities have a large influence on the magnitude of this negative impact.

Ad 3. Sorting efficiency for the plastic products

The four sorting divisions of the two sorting plants are listed in Table 60. The sum of the plastic value fractions (PET, PE, PP) is relative constant (within 1%) for both facilities.
This suggests that the impact of 2.3% beverage cartons in the input mixture for Sita on the 1st of July was minimal as compared to the run on 20th July without beverage cartons in the input mixture.
For Schönmackers it suggests that on the level of about 20% beverage cartons in the input level the effect of baling or keeping the material loose is limited on the total sum of plastic value fractions.
A much deeper analyses and much more thorough sorting analysis of all the product streams will be necessary to determine the sorting division of the most valuable plastic packages over the various product fractions in an accurate manner. Nevertheless, the first crude calculations based on the sorting data from this pilot study suggest that the sorting division of PET bottles, PE flasks and PP rigids has not diminished when comparing the results for Sita with and without beverage cartons in the input mixture. This indicative calculation is shown in Table 61 and shows the percentage of which an important valuable plastic package ends up in the correctly sorted fraction. Moreover, this indicative calculation shows that the sorting efficiencies are in general

lower for Schönmackers as compared to Sita, what is likely to be attributed to higher levels of beverage cartons in the input mixture.

Table 60: Sorting distribution for Schönmackers with pressed and loose Milieuzakken and for Sita Rotterdam with two different inputs: 1 plastic packaging and 2 plastic packaging and beverage cartons.

Sorted fraction	Schönmackers pressed MZ 13th June	Schönmackers loose MZ 15th July	Sita, only PPW as input 20th June	Sita, PPW + BC as input 1st July
PET	0.47%	1.62%	8.20%	6.70%
PE	2.24%	2.30%	6.80%	6.66%
PP	1.90%	1.35%	6.90%	7.31%
FILM	2.53%	3.53%	14.50%	16.78%
MKS	39.24%	38.45%	37.10%	36.59%
FKN	11.82%	12.57%	na	2.19%
PK	9.38%	3.22%	na	na
Metals			0.04%	1.40%
Sorting rests	32.43%	36.97%	26.50%	22.40%

Na = not applicable

Table 61: Indicatively calculated sorting efficiencies of three main types of plastic packages.

Sorted fraction	Schönmackers pressed MZ 13th June	Schönmackers loose MZ 15th July	Sita, only PPW as input 20th June	Sita, PPW + BC as input 1st July
PET bottles clear	20%	80%	70%	90%
PE flasks	80%	60%	90%	90%
PP rigids	20%	20%	40%	50%

In short, beverage cartons do not noticeably increase the levels of attached moisture and dirt levels of plastic packages, they do disperse for a small part into the plastic fractions and they are likely to lower the sorting efficiencies of valuable plastic packages, in case there are present in relative high percentages (about 20%) as would be expected for a fully matured co-collection system. Hence, there is a realistic risk that the presence of beverage cartons will negatively affect the recycling of plastic packages. But this risk can be mitigated for a large extent by the proper counter-actions (controlling the baling pressure at the cross docking stations, optimising the sorting process for the new input mixture, etc.).

3.12.2 Cross contamination between the beverage cartons and paper & board

In this pilot the combined collection of beverage cartons and paper & board was studied. This mixture is sorted to yield paper & board products and a beverage carton product. The sorting process of beverage cartons from paper & board was found to be rather in-efficient, about half of the beverage cartons could be removed. This low sorting yield can mostly be attributed to similarity of the materials and to a lesser extent to conglomerate formation. Although a few conglomerates have been found and they do attract attention, the reality is that most beverage cartons were found as loose objects in the paper & board. Conglomerates are likely to origin from product residues that flow from the beverage cartons to other paper and board objects and dry out to form glued bonds.

Figure 62: Two photos of conglomerates of beverage cartons and paper & board.

The beverage cartons that have been co-collected with paper & board contain less product residues than those from a separate collection system and those from the combined collection of beverage cartons and plastic packages (compare Table 12 with Table 21). Two factors might have contributed; washing behaviour by civilians prior to collection and the flow of residues from the beverage cartons to the paper & board. Visual inspection of the beverage cartons yields evidence for both. We have found beverage cartons that have been clearly cut open with a pair of scissors and were spotless clean and we also found conglomerates of beverage cartons that have been glued to paper, most likely because residues have flowed from the cartons to neighbouring pieces of paper, dried and formed a bond (Figure 62).

The poor sorting efficiency implies that also about half of the beverage cartons will end up in one of the sorted paper & board products. This can have several impacts on the further recycling of the sorted paper & board products, depending on the recycling technique applied:

- Conventional pulping will not be able to pulp the beverage cartons and hence the overall yield will lower and the amount of by products will rise,
- Advanced pulping will be able to pulp this mixture without any problems, but is only available at one proximate paper mill (Delkeskamp).

Several incumbents (W. van Oosterum, PRN, A. Westenbroek, KCPK) named the increased microbial risks of pulping mixtures of paper & board and beverage cartons. In the product residues that are contained within beverage cartons high levels of spoilage organisms are present (our exploratory analysis showed values of $>10^7$ CFU/cm^2) and possibly also food-borne pathogens. This would result in the use of more biocides to control the microbial growth in the pulping water and would make the paper & board industry in general more susceptible for pathogen outbreaks in the future. This opinion was contradicted by another incumbent (E. Bruns, Delkeskamp). Mr. Bruns claims to operate a pulping process with a mixture of paper &

board and beverage cartons as input for multiple years, without using biocides, but at well-controlled temperature and resident-time process settings. His products are regularly tested for microflora and the results are comparable to products from competitors that use plain paper & board as input. Possible reasons for this difference in opinion could lie in difference in used technology and different beverage carton materials.

To evaluate this microbial risk in more detail, standard paper products were produced from paper & board that has been in contact with beverage cartons during co-collection and these papers were analysed for micro-organisms, see Table 62.
Four test hand-sheets were produced, two from paper & board from Vianen and two from Etten-Leur and these results were compared with a reference (graphical white printing paper). The latter should have a minimal microbial load. The results of the microbial analysis for papers made from recycled paper & board that has been in contact with beverage cartons is fairly similar. The microbial load is –as expected – higher than for paper made from virgin fibres. In comparison to historic data on the microbial quality of paper & board these results fall within the large spread in values that have been observed for recycled paper & board in the past (^{10}Log CFU/g of 3.5 - 5.5), but these values are on the relative high side of the naturally occurring variance.

Table 62: Results of the microbiological analysis of papers that were produced from paper & board that has been co-collected with beverage cartons, [^{10}Log CFU/g].

Code	Total aerobic count	Total aerobic spore formers	Total anaerobic count	Total anaerobic spore formers	Yeasts and fungi
V1	5.3	5.1	3.8	4.0	2.0
V2	5.6	5.3	4.7	4.4	2.1
E1	5.3	4.8	4.1	4.2	2.2
E2	5.0	4.3	4.4	3.8	2.4
Ref	3.8	2.9	3.6	2.3	< 1.0

Hence, these results can neither confirm nor refute that co-collection of paper & board with beverage cartons will increase the microbial load of recycled paper & board directly. However, the microbial load of board products made from recycled beverage cartons is higher than of plain recycled paper & board (see Table 67). When corrugated board boxes made from recycled beverage cartons are discarded, they are most likely collected as paper & board and will be recycled as paper & board, implying that it is likely that they will raise the microbial load of recycled paper & board indirectly and gradually.

3.12.3 Cross contamination between the beverage cartons and MSW

The net material content of recovered beverage cartons from MSW that has been sorted to a product that meets the DKR 510 specification (61% for Attero and 60% for Omrin) is comparable to the net material content of separately collected beverage cartons (57 ± 13%, see Table 13). There is, however, a subtle difference in the type of impurities present on separate collected beverage cartons and on recovered beverage cartons. In the separately collected group there are mostly product residues (organic waste) inside the beverage cartons and some foreign materials on the exterior of the beverage cartons. Whereas on the recovered beverage cartons there is also attached organic waste, sand, etc. on the exterior of the beverage cartons.

There is, however, a legal difference between both types of beverage carton material. Since, recovered beverage cartons have had contact with MSW, the recycled paper fibre cannot be used for packages that have direct contact with food products. Since, most recycled fibres are used to make corrugated board, this does not have to be an issue.

3.13 Pulp analysis

Impurities and chemical properties of the pulp

Visual inspection of the pulps reveals that they contain not only fibre, but also small pieces of plastic and aluminium. To establish the amount of impurities in the pulp several measurements were performed. Ash content and the amount of large particles was measured on the pulp. Chemical oxygen demand was determined based on the water after hand-sheet production. Microbiological contamination was determined on the hand-sheets produced from the pulps.

Large size impurities

Large size impurities in pulps are normally removed from the pulp in the cleaning section of the paper & board producing company. These large size impurities consist of plastics, metal parts and larger bundles of fibres. The amount of large size impurities was established with a Sommerville fractionator. A slit width of 0.15 mm was used. The dry weight fraction of the pulp that is too large to pass these slits is shown in Figure 63.

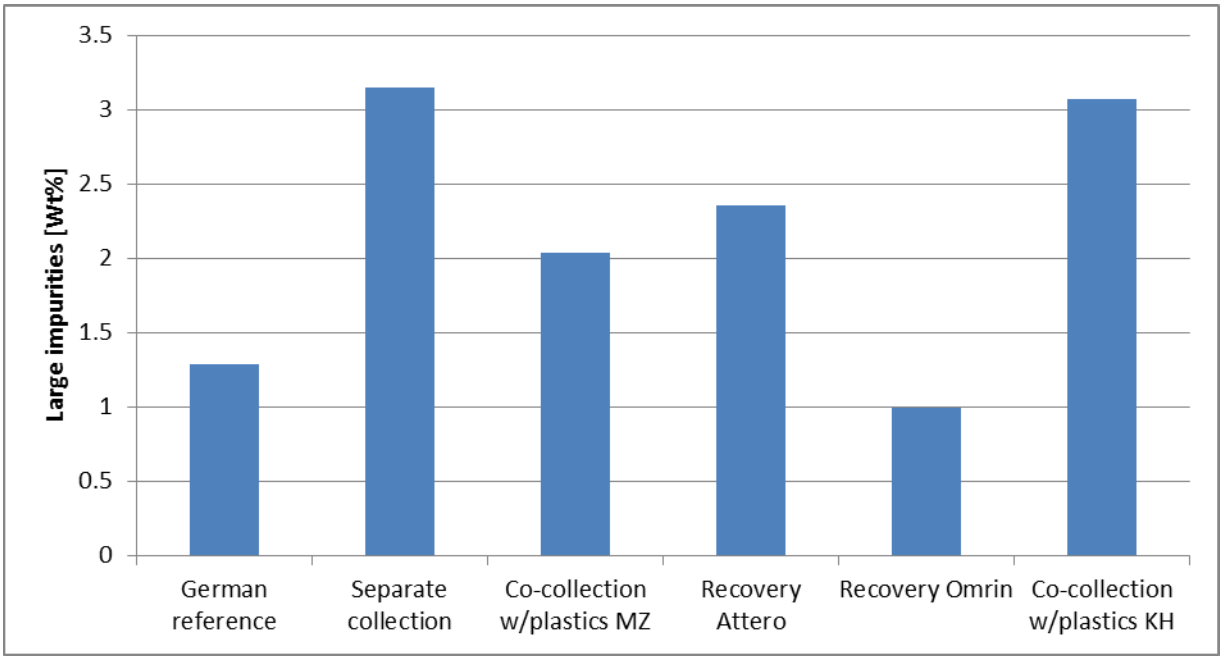

Figure 63: The amount of impurities in the pulp.

Except for the Omrin pulp, all pulps contain more large impurities than the German reference. These impurities will need to be removed in the cleaning section of the paper/board production company.

In Table 63 the ash content and the water retention value of the pulps are given. The ash content was determined at 575 °C (4 hours). The ash content of all pulps is very low. The low ash content is a result of the large amount of water that is used in the production of these pulps. Water retention value is shown as total amount of water per dry pulp. Water retention value for all pulps is within normal range.

Table 63: Water retention value (WRV) and ash content of the pulps.

	WRV [gr/gr]	Ash content [wt%]
German reference	1.46	3.2
Separate collection	1.47	6.3
Co-collection w/plastics MZ	1.47	4.3
Co-collection w/plastics KH	1.69	4.7
Recovery Attero	1.42	2.4
Recovery Omrin	1.49	4.2

Size distribution of the pulps

The different pulps have been fractionated into size classes using a Bauer-McNett classifier. The largest size fraction contains the large impurities and fibres longer than >1.4 mm. Part of this fraction consists of valuable long fibres, however the large impurities and thick fibre bundles will have to be removed in the cleaning section of the paper/board production company. The smallest size fraction contains the fines < 74 µm. This fraction has a limited value for the mechanical strength of the paper. The size distribution of the different pulps is shown in Figure 64.

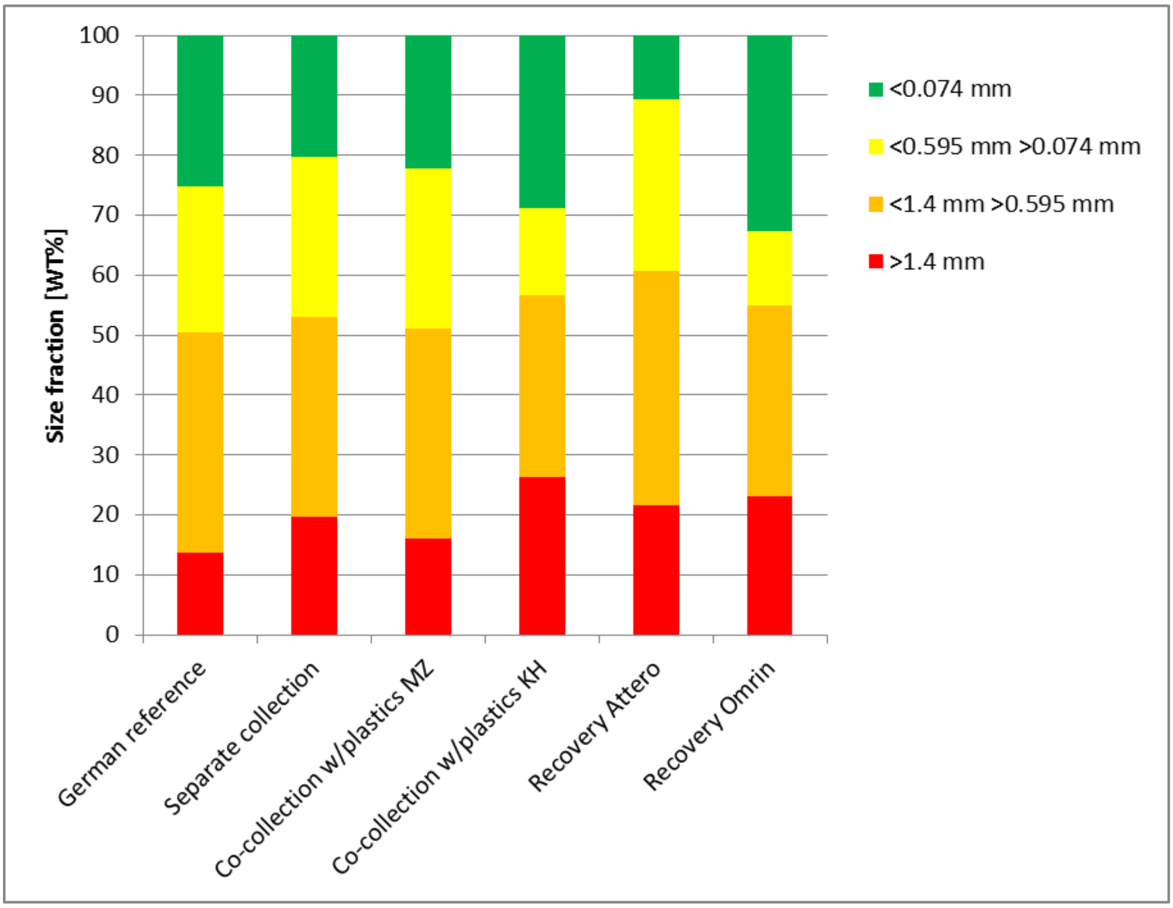

Figure 64: Size distribution of the pulps.

Large differences between the different pulps in sizes of the fibres can be observed. The German reference contains the lowest amount of large size fraction. Together with the low amount of large impurities in this pulp this indicates that large fraction were best removed or refined from the German reference. The large difference in the amount of the smallest fraction indicates that more or less washing of the pulps might have occurred. Normally the amount of the smallest fraction decreases when more water is used to produce a pulp.

Mechanical properties of the obtained pulps

Hand-sheets were produced from the wet pulps as obtained. These hand-sheets include the larger impurities that will need to be removed by the paper/board producing company. These larger impurities in general reduce the mechanical properties of the hand-sheets. Besides decreasing the mechanical properties they also increase the inhomogeneity of the hand-sheets and thereby the standard deviation of the measurements. Test results that are very clearly a result of impurities in the hand-sheets have been omitted from the results. An overview of the important mechanical properties is presented in Table 64. All measured data is given in the appendix E.

Table 64: Mechanical properties of the pulps.

	recycled	German reference	Separate collected	Co-coll. /pl. MZ	Co-coll. /pl. KH	Recovery Attero	Recovery Omrin	
Drainability	43	21	22	23	24	20	23	SR
Grammage	81.8	86.2	84.8	82.6	89.8	81.3	84.6	g/m^2
Apparent density	568	514	511	517	612	517	527	kg/m^3
Tensile index	23.2	30.7	28.0	28.7	32.0	27.7	33.8	Nm/g
Tearing resistance index	6.5	10.1	7.6	7.8	9.7	8.8	11.0	mNm^2/g
SCT index	14.4	17.5	16.9	17.8	19.4	15.4	19.7	Nm/g
Internal Bond	107	116	120	105	152	103	124	kJ/m^2

The drainability of the pulps produced from beverage cartons is significantly lower than the drainability of standard recycled paper pulp. Most likely this is a result of the experimental pulp production on pilot scale. In an industrial scale pulping process, a more intensive recycle of water will be needed. This recycled water contains a large amount of fines. These fines increase the dewatering rate and drainability. Although a low drainability is beneficial in the quality assessment of a pulp, in the evaluation of the pulps from the pilot process it is disregarded, because this phenomenon most likely will not occur on industrial scale.

In general it can be concluded that the mechanical properties of the pulps from beverage cartons are slightly superior to the standard recycled paper pulp. The pulps originating from the German collection system, from the Omrin recovery system and from the KH co-collection system are the highest in quality based on Tensile, Tear, SCT and internal bond strength.

Mechanical properties of the pulps mixed with recycled paper

Hand-sheets were produced from the wet pulps as obtained mixed with the standard recycled paper. These hand-sheets include the larger impurities from the wet pulps, that will need to be removed by the paper & board producing company. The hand-sheets contain 20 wt% of the pulps from the beverage cartons and 80 wt% of the recycled standard paper. An overview of the important mechanical properties is presented in Table 65. All measured data is given in the appendix E.

Table 65: Mechanical properties of the pulps mixed with standard recycled paper (20/80).

	100% recycled	German reference	Separate collected	Co-coll. /pl. MZ	Co-coll. /pl. KH	Recovery Attero	Recovery Omrin	
Drainability	43	36	37	37	35	37	39	SR
Grammage	81.8	81.9	84.3	82.9	88.9	85.2	92.3	g/m^2
Apparent density	569	551	571	551	563	569	573	kg/m^3
Tensile index	23.2	26.1	25.9	25.2	26.2	24.7	28.5	Nm/g
Tearing resistance index	6.5	8.3	7.2	6.7	7.4	7.2	8.1	mNm^2/g
SCT index	14.4	15.6	15.7	15.0	16.2	14.8	16.4	Nm/g
Internal Bond	107	112	110	108	122	106	123	kJ/m^2

The influence of the large size impurities in the pulps from beverage cartons on the mechanical properties is diminished. In general it can be concluded that the mechanical properties of the mixes with beverage carton are slightly superior to the standard recycled paper pulp. Also mixed, the pulps originating from the German collection system, the Omrin recovery system and the KH co-collection system are the highest in quality based on Tensile, Tear, SCT and internal bond strength.

Mechanical properties of the pulps after additional cleaning and refining

The mechanical properties of the pulps were also tested after additional cleaning and refining. This provides a better indication of the properties of the pulps as used in the paper/board production company. The additional cleaning is necessary to remove the larger impurities. Additional refining is normally not applied in the Dutch paper & board industry, when working with recycled pulps. However additional refining shows the potential of the pulps. The pulps were cleaned by first removing larger size impurities using the Sommerville fractionator and then thickening the pulp using a Bauer-McNett classifier. Thickening is necessary because the Sommerville fractionator dilutes the pulp. In Table 66 the amount of larger particles removed during this cleaning stage is listed.

Table 66: Amount of large particles removed during cleaning.

	Large particles removal [wt%]
German reference	2.2
Separate collected	5.0
Co-collection w/plastics MZ	2.3
Co-collection w/plastics KH	4.6
Recovery, Attero	3.0
Recovery, Omrin	2.8

The mechanical properties of hand-sheets produced from the pulps were tested directly after this cleaning procedure and after additional refining. Refining was done using a PFI-Mill. The intensity of the refining stage was adjusted by changing the amount of rotations from this milling procedure. Test sheets were made from 100% pulp of beverage cartons. In appendix E all measured data is given. In Figure 65 and Figure 66the tensile index and the SCT-index as function of the beating degree of the six pulps is given.

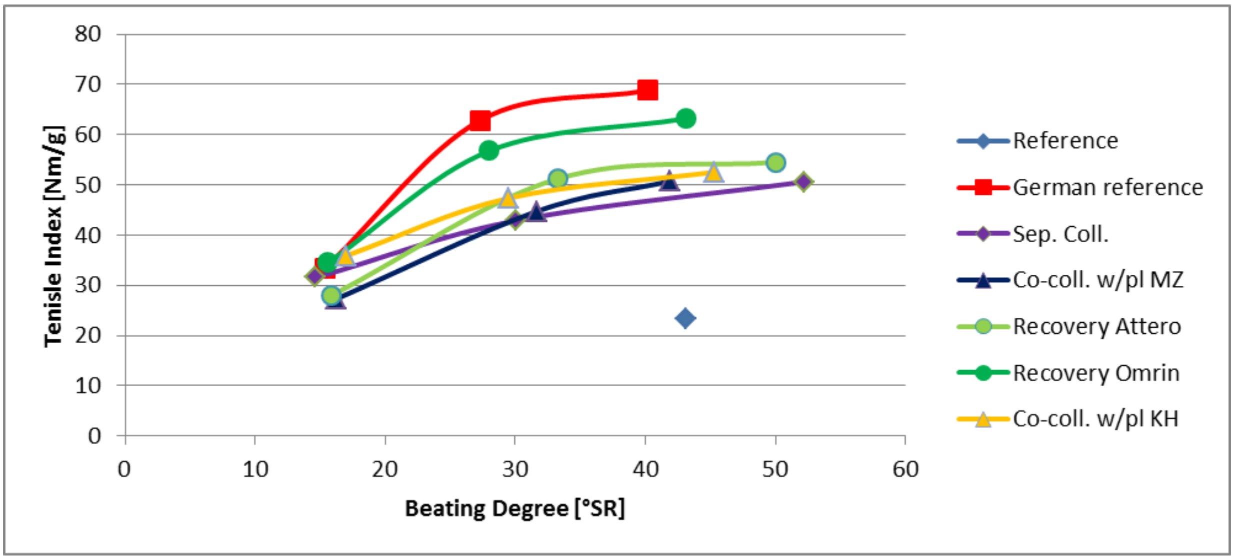

Figure 65: Tensile index of the pulps after cleaning and refining.

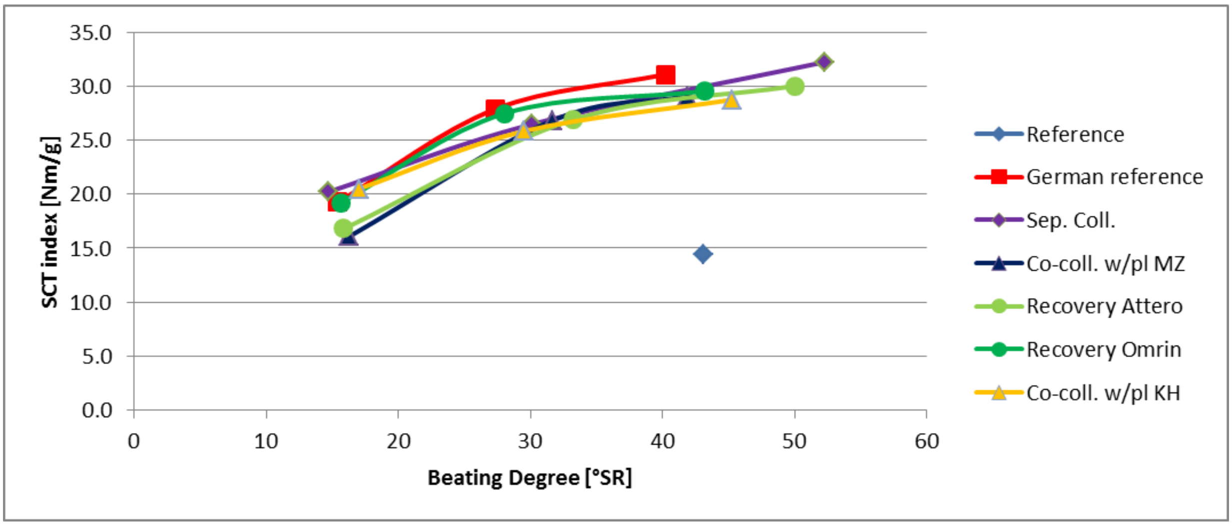

Figure 66: SCT index of the pulps after cleaning and refining.

These figures show that after the properties of the pulps improve after refining, as is expected. The properties of the German reference pulp, and the Omrin pulp are superior to the other pulps. The pulp originating from the KH co-collection system is only superior to the other pulps at low beating degree. The comparison with the reference (recycled pulp) is not valid, the cleaning and thickening stages have removed almost all fines and ashes, thereby increasing the amount of strong fibres.

Microbiological analysis of the pulps

The results of the microbiological analysis of the papers produced from the various pulps made from recycled beverage cartons are listed in Table 67. The graphic white paper made from virgin fibres served as low-end reference (Ref).

Table 67: Microbiological counts of hand-sheets produced from the recycled pulps, [^{10}Log CFU/g].

Code	Total aerobic count	Total aerobic spore formers	Total anaerobic count	Total anaerobic spore formers	Yeasts and fungi
German ref.	5.7	5.3	5.0	4.6	3.0
Separate collection	6.1	5.7	5.0	5.6	4.3
Co-coll. w/pl. MZ	6.1	5.5	5.1	4.7	4.3
Co-coll. w/pl. KH	6.6	5.2	5.1	4.6	5.1
Recovery Attero	5.9	5.7	5.2	4.6	4.3
Recovery Omrin	6.7	5.7	5.7	4.9	4.0
Production ref.	6.7	6.6	6.3	6.3	3.3
White paper ref.	3.8	2.9	3.6	2.3	< 1.0

Furthermore a sample of industrially produced brown paper produced from a mixture of recycled paper & board and beverage cartons served as the second reference at the high side (Production

ref). No reference of recycled paper & board was added, since it is known from previous work that the total aerobic count varies widely between 3.5 and 5.5 and it would imply that we would need to analyse many samples to get a reasonable picture.
In general the microbial load of all hand-sheets made from beverage carton pulp is fairly similar. The observed small differences are unlikely to be significant when repeated many times in case the variance is equal the one found for conventional paper & board. The general microbial load of papers produced from recycled beverage cartons is higher than for conventional recycled paper & board and comparable to the industrial reference that is partially made from beverage cartons.
Noteworthy, the microbial load of hand-sheets made from recovered beverage cartons is similar to hand-sheets made from separate collected beverage cartons.
The leading organisms are spore-formers, whereas the counts for yeasts and fungi are relatively low. This is reminiscent of the paper forming process which involves elevated temperatures during pulping and drying.

Possible Applications of the pulps

The tested pulps are unbleached and contain ink particles. Obviously these pulps cannot be used in white paper products. Additionally, their microbiological load is relatively high, excluding direct food contact applications. Their main quality attribute is the superior mechanical properties, therefore these pulps will be valuable in paperboard products were tensile and compression strength is crucial e.g. corrugated board, cardboard tubes and cores.

Conclusions on pulp quality

The pulp quality of the beverage cartons is slightly superior to a standard recycled pulp. It should be noted that some large size impurities are still present in the pulps, they will have to be removed at the paper & board producing companies. This superior quality can be observed in all three tests, before additional cleaning, in mixtures with recycled pulp and after cleaning and additional refining.
The large amounts of water that were currently used in the production of the tested pulps influence the properties of these pulps. On industrial scale water will be recycled which will have an effect on the pulp properties. Pulps produced on industrial scale will have a higher fines fraction, thereby increasing the beating degree of the pulps. The low drainability (beating degree) of the pulps compared to standard recycled pulps could be considered as a benefit, however it is envisaged that this is a results of the pulp production on pilot scale. Pulps produced on industrial scale will also have a higher ash fraction, decreasing the mechanical properties of the pulps.
The difference between the mechanical properties of the different pulps is small, they may be caused by differences during the pilot scale production of these pulps. Large differences between the size distributions of the pulps indicate that different amounts of water or different severity in washing stages have been used during the production of these pulps. Comparing the pulps as received the German reference pulp, the Omrin pulp and the pulp originating from the KH co-collection system are superior to the other three pulps.

4 Mass flow diagrams

All four mass flow diagrams are presented graphically and subsequently the composition of the material is described per chain element of the recycling chain in separate tables. All mass flow diagrams have the same system boundaries. They all start at the potential of beverage cartons present at the civilians and end at the production of recycled products: paper fibre pulp and side products. All mass flow diagrams are describes per extrapolated year.
In the mass flow diagrams abbreviations are used which are common in the trade, such as FKN for the beverage carton product and MKS for mixed plastics.

4.1 Mass flow diagram: separate collected beverage cartons

The mass flow diagram of the separate collected beverage cartons per extrapolated year is graphically shown in

Figure 67. The corresponding detailed description per chain element is given in the subsequent tables.

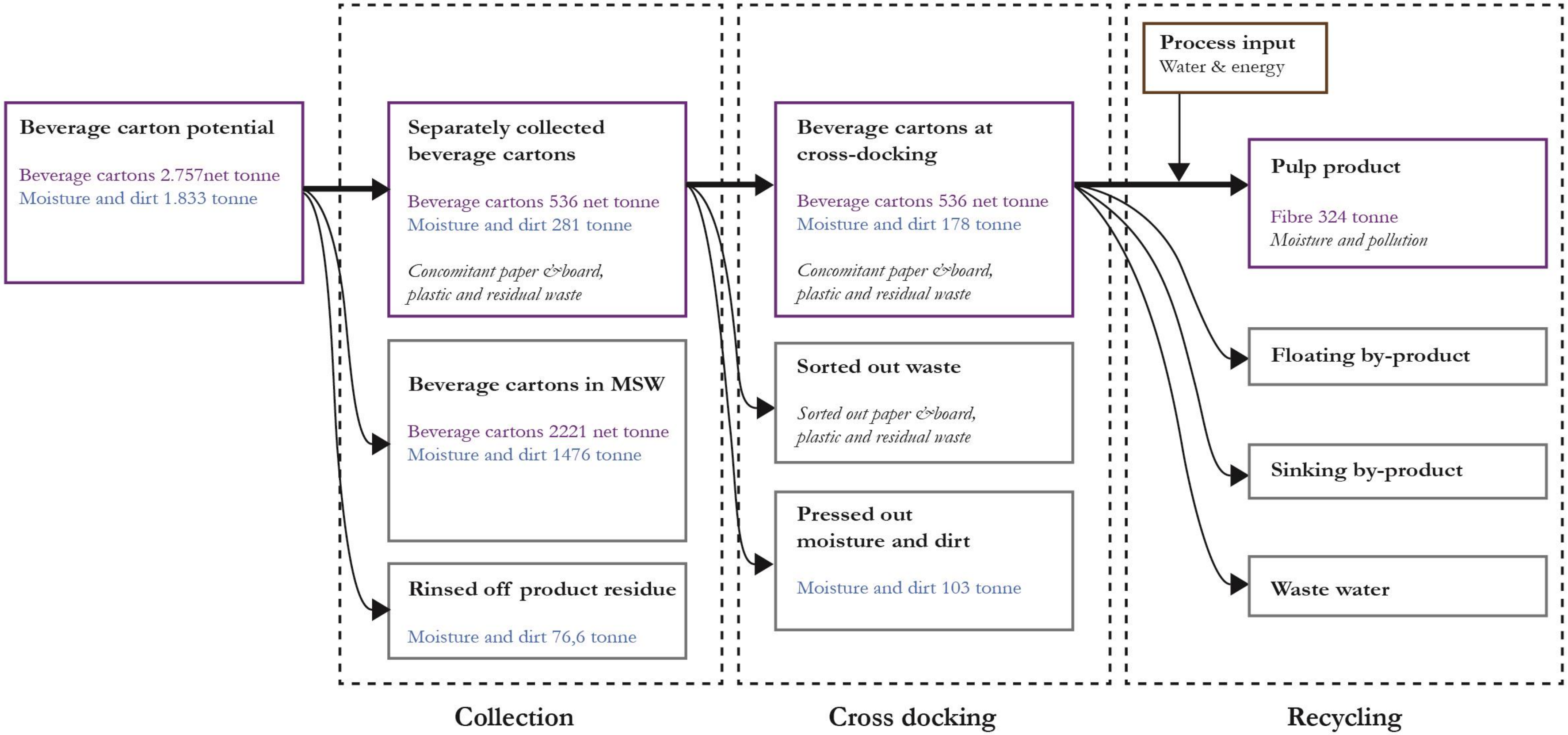

Figure 67: Overview of mass flow diagram for separate collection of beverage cartons

The potential of beverage cartons present at the civilians in the participating collection areas is given in Table 68.

Table 68: Beverage carton potential for the separate collection scheme.

Beverage cartons potential	**2.757**	**[net tonne]**
Carton fibre	2039	[net tonne]
Aluminium	67	[net tonne]
PE rigid	168	[net tonne]
PE film	444	[net tonne]
PP rigid	36	[net tonne]
PP film	2	[net tonne]
Attached moisture and dirt	*1.833*	[tonne]

The overall composition of the separately collected beverage cartons is described in Table 69.

Table 69: Separate collected beverage cartons

Separately collected beverage cartons	**536**	**[net tonne]**
Carton fibre	400	[net tonne]
Aluminium	11	[net tonne]
PE rigid	35	[net tonne]
PE film	84	[net tonne]
PP rigid	6	[net tonne]
PP film	0,08	[net tonne]
Attached moisture and dirt	*281*	[tonne]
Concomitant paper & board	*77*	[tonne]
Concomitant plastic	*21*	[tonne]
Concomitant residual waste	*24*	[tonne]

The composition of the beverage cartons that not have been separated by the civilians is specified in Table 73. In total 76.6 ton of residues is rinsed off by the civilians.

Table 70: beverage cartons in MSW

Beverage cartons in MSW	**2.221**	**[net tonne]**
Carton fibre	1639	[net tonne]
Aluminium	57	[net tonne]
PE rigid	133	[net tonne]
PE film	360	[net tonne]
PP rigid	29	[net tonne]
PP film	2	[net tonne]
Attached moisture and dirt	*1476*	[tonne]

The composition of the cross-docked beverage cartons is described in Table 71. At the cross-docking stations the beverage cartons are pressed and baled. In total 101 tonnes of moisture and dirt is released from the cartons at the cross docking stations and leaves the recycling chain.
A part of the beverage cartons had to be manually sorted at the cross docking station, these residues that leave the recycling chain are listed in Table 72. In total 103 tonnes of moisture and dirt

Table 71: Cross docked beverage cartons from the separate collection system

Beverage cartons at cross-docking	**536**	**[net tonne]**
Carton fibre	400	[net tonne]
Aluminium	11	[net tonne]
PE rigid	35	[net tonne]
PE film	84	[net tonne]
PP rigid	6	[net tonne]
PP film	0,08	[net tonne]
Attached moisture and dirt	*178*	[tonne]
Concomitant paper & board	*23*	[tonne]
Concomitant plastic	*14*	[tonne]
Concomitant residual waste	*13*	[tonne]

Table 72: Residual waste manually sorted out of the collected beverage cartons

Waste sorted out		
Concomitant paper & board	*54*	[tonne]
Concomitant plastic	*8*	[tonne]
Concomitant residual waste	*11*	[tonne]

The cross-docked and baled beverage cartons continue to the recycling facility. In this pilot study the measured process parameters of Repa are used. The water and energy usage in shown in Table 73. No chemicals or heating is applied at Repa.

Table 73: Process input REPA

Input REPA		
Water	3.816	[m^3/jr]
Energy	66661	[kWh/jr]

Table 74: Pulp product of the separate collection system

Pulp product		
Fibre	324	[tonne]
Attached moisture	1390	[tonne]
Pollution	23	[tonne]

The composition of the pulp product is shown in Table 74. The composition of the by-products is shown in Table 75 and Table 76. Finally the waste water parameters are shown in Table 77.

Table 75: Floating by-product of the separate collection system

Floating by-product		
Carton fibre	0	[tonne]
Aluminium	12	[tonne]
PE rigid	93	[tonne]
PE film	38	[tonne]
PP rigid	7	[tonne]
PP film	0,089	[tonne]
Attached moisture	*46*	[tonne]
Concomitant paper & board	*0*	[tonne]
Concomitant plastic	*5,5*	[tonne]
Concomitant residual waste	*2,2*	[tonne]

Table 76: Sinking by-product of the separate collection system

Sinking by-product		
Residual waste	3,1	[tonne]
Attached moisture	1,5	[tonne]

Table 77: Waste water parameters of the separate collection system

Waste water		
TKN	11	[mg/kg]
COD	520	[mg/kg]
Fibre and solute	60	[tonne]

4.2 Mass flow diagram for the combined collection of beverage cartons and plastics

The mass flow diagram for the combined collection of beverage cartons and plastic packages is graphically displayed in

Figure 68.

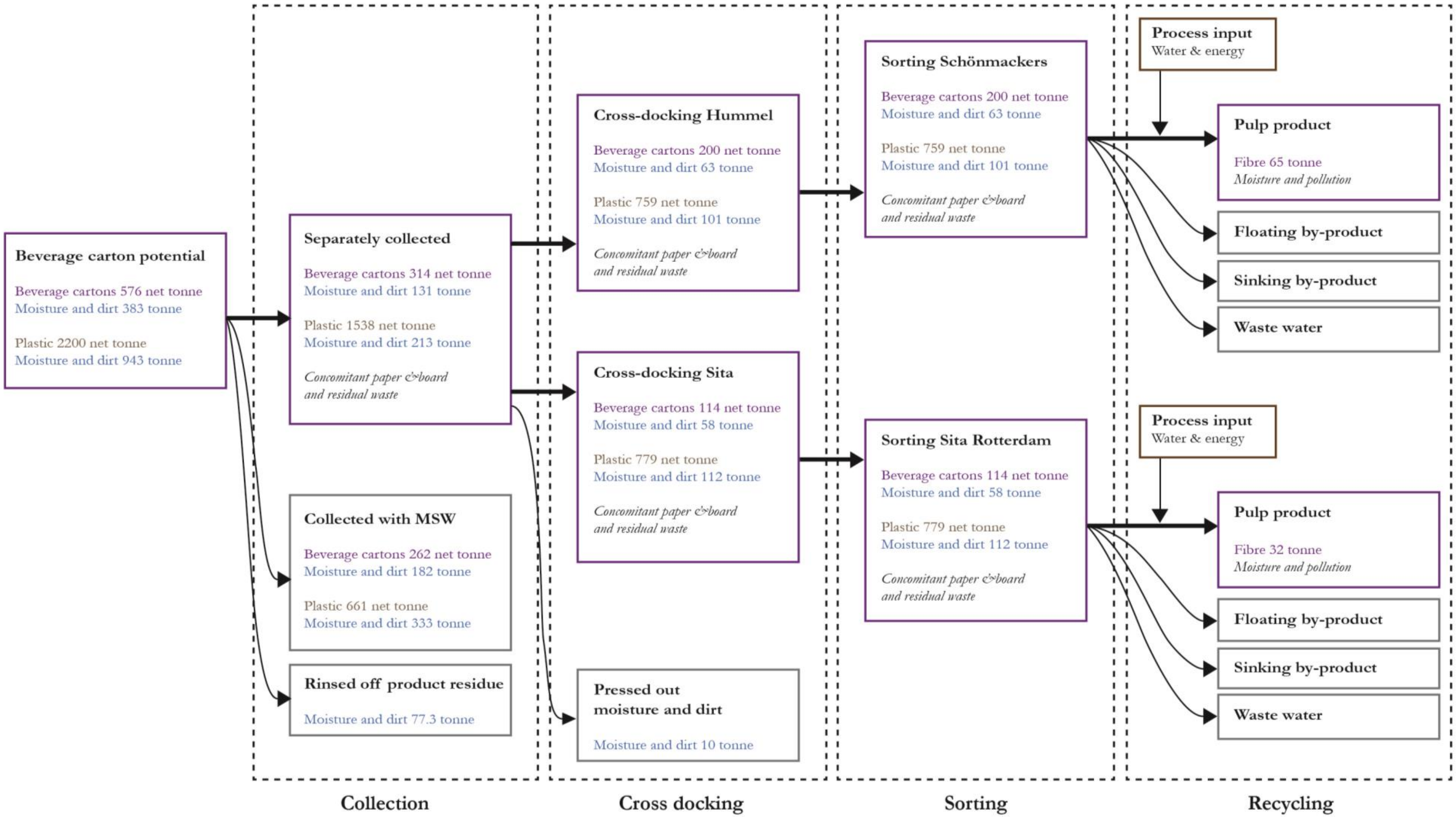

Figure 68: Overview of mass flow diagram for separate collection of beverage cartons

The potential of beverage cartons and plastic packages present at the civilians in the participating municipalities is displayed in Table 78.

Table 78: potential of beverage cartons and plastic packages available at the civilians in the participating municipalities.

Beverage cartons potential	**576**	**[net tonne]**
Carton fibre	426	[net tonne]
Aluminium	14	[net tonne]
PE rigid	35	[net tonne]
PE film	93	[net tonne]
PP rigid	7	[net tonne]
PP film	0	[net tonne]
Attached moisture and dirt	*383*	[tonne]
Plastic potential	**2200**	**[net tonne]**
Attached moisture and dirt	*943*	[tonne]

The collected amounts of beverage cartons and plastic packages are shown in Table 79. From the beverage cartons 77.3 tonne of residues has been rinsed off by the civilians.

Table 79: collected beverage cartons and plastic

Beverage cartons collected	**314**	**[net tonne]**
Carton fibre	233	[net tonne]
Aluminium	7	[net tonne]
PE rigid	20	[net tonne]
PE film	50	[net tonne]
PP rigid	4	[net tonne]
PP film	0,1	[net tonne]
Attached moisture and dirt	*131*	[tonne]
Plastic collected	**1538**	**[net tonne]**
Attached moisture and dirt	*213*	[tonne]
Concomitant residual waste		
Paper & board	*212*	[tonne]
Organic waste	*83*	[tonne]
Textile	*31*	[tonne]
Metal	*32*	[tonne]
Glass	*3*	[tonne]

The beverage cartons and plastic packages that not collected separately and remain in the MSW are shown in Table 80.

Table 80: Beverage cartons and plastics in MSW

Beverage cartons in MSW	**262**	**[net tonne]**
Carton fibre	193	[net tonne]
Aluminium	7	[net tonne]
PE rigid	16	[net tonne]
PE film	43	[net tonne]
PP rigid	4	[net tonne]
PP film	0,3	[net tonne]
Attached moisture and dirt	*182*	[tonne]
Plastic in MSW	**661**	**[gross tonne]**
Attached moisture and dirt	*333*	[tonne]

The amounts of collected materials that have been cross docked at Hummel are shown in Table 81. In total 10 tonnes of residues are pressed out of the beverage cartons. The collected materials that are cross docked prior to sorting at Sita are shown in
Table 82.

Table 81: cross-docking at Hummel

Cross-docking Hummel		
Beverage cartons	**200**	**[net tonne]**
Carton fibre	148	[net tonne]
Aluminium	5	[net tonne]
PE rigid	12	[net tonne]
PE film	32	[net tonne]
PP rigid	3	[net tonne]
PP film	0,05	[net tonne]
Attached moisture and dirt	*63*	[tonne]
Plastic	**759**	**[net tonne]**
Attached moisture and dirt	*101*	[tonne]
Concomitant residual waste		
Paper & board	*166*	[tonne]
Organic waste	*38*	[tonne]
Textile	*23*	[tonne]
Metal	*19*	[tonne]

Glass	*1*	[tonne]

Table 82: Cross-docking of collected materials prior to sorting at Sita

Cross-docking prior to Sita		
Beverage cartons	**114**	**[net tonne]**
Carton fibre	85	[net tonne]
Aluminium	2	[net tonne]
PE rigid	7	[net tonne]
PE film	18	[net tonne]
PP rigid	1	[net tonne]
PP film	0,05	[net tonne]
Attached moisture and dirt	*58*	[tonne]
Plastic	**779**	**[net tonne]**
Attached moisture and dirt	*112*	[tonne]
Concomitant residual waste		
Paper & board	*47*	[tonne]
Organic waste	*45*	[tonne]
Textile	*8*	[tonne]
Metal	*14*	[tonne]
Glass	*2*	[tonne]

The Milieuzakken-material that was cross-docked at Hummel is sorted at Schönmackers, see Table 83. And the collected materials that was sorted at Sita Rotterdam is shown in Table 84.

Table 83: Sorting at Schönmackers

	FKN	FKN-rest	PET	PE	PP	Film	MKS	REST	PB	
Beverage cartons	**115,6**	**19,7**	**0,0**	**0,0**	**1,7**	**1,2**	**48,2**	**10,9**	**2,6**	**[net tonne]**
Carton fibre	85,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	[net tonne]
Aluminium	3,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	[net tonne]
PE rigid	6,9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	[net tonne]
PE film	18,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	[net tonne]
PP rigid	1,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	[net tonne]
PP film	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	[net tonne]
Attached moisture and dirt	*35,5*	*5,1*	*0,0*	*0,0*	*0,4*	*0,3*	*12,5*	*2,8*	*0,7*	[net tonne]
Plastic	**5,7**	**10,6**	**14,2**	**39,4**	**53,8**	**50,5**	**387,4**	**177,8**	**20,2**	**[net tonne]**
Attached moisture and dirt	*0,7*	*1,3*	*1,6*	*3,9*	*4,0*	*4,4*	*85,0*	*21,8*	*2,5*	[net tonne]
Concomitant residual waste										
Paper & board	*26,5*	*14,4*	*0,0*	*0,1*	*0,0*	*0,9*	*21,4*	*3,1*	*95,5*	[net tonne]
Organic waste	*0,2*	*0,3*	*0,0*	*0,1*	*0,0*	*0,0*	*4,1*	*50,0*	*0,1*	[net tonne]
Textile	*0,3*	*0,5*	*0,0*	*0,0*	*0,0*	*0,0*	*0,0*	*0,0*	*1,6*	[net tonne]
Metal	*0,2*	*3,8*	*0,0*	*0,0*	*0,1*	*0,1*	*2,8*	*0,6*	*0,0*	[net tonne]
Glass	*0,0*	*0,0*	*0,0*	*0,0*	*0,0*	*0,0*	*0,0*	*0,0*	*0,0*	[net tonne]

Table 84: Sorting at Sita Rotterdam

	FKN	PET	PE	PP	Film	MKS	REST	
Beverage cartons	**53,6**	**0,0**	**0,0**	**1,0**	**0,0**	**47,3**	**12,0**	**[net tonne]**
Carton fibre	39,807							[net tonne]
Aluminium	1,209							[net tonne]
PE rigid	3,077							[net tonne]
PE film	8,781							[net tonne]
PP rigid	0,773							[net tonne]
PP film	0,001							[net tonne]
Attached moisture and dirt	*13,5*							[net tonne]
Plastic	**0,2**	**70,6**	**62,5**	**85,7**	**156,6**	**226,3**	**177,0**	**[net tonne]**
Attached moisture and dirt	*0,0*	*7,8*	*14,7*	*4,5*	*19,4*	*28,0*	*38,3*	[net tonne]
Concomitant residual waste								
Paper & board	*0,18*							[net tonne]
Organic waste	*0*							[net tonne]
Textile	*0*							[net tonne]
Metal	*0*							[net tonne]
Glass	*0*							[net tonne]

The beverage carton material that was sorted at Schönmackers was recycled at Repa. The process parameters are shown in Table 85 and the products in the subsequent tables.

Table 85: process input recycling sorted material from Schönmackers

Input REPA		
Water	923	[m3/jr]
Energy	25611	[kWh/jr]

Table 86: Pulp product

Pulp product		
Fibre	64,9	[tonne]
Attached moisture and dirt	331,2	[tonne]
Pollution	1,4	[tonne]

Table 87: Floating by-product

Floating by-product		
Carton fibre	0,0	[tonne]
Aluminium	2,7	[tonne]
PE rigid	16,6	[tonne]
PE film	6,1	[tonne]
PP rigid	1,4	[tonne]
PP film	0,0	[tonne]
Attached moisture and dirt	*10,1*	[tonne]
Concomitant paper & board	*0,0*	[tonne]
Concomitant plastic	*9,4*	[tonne]
Concomitant residual waste	*1,0*	[tonne]

Table 88: Sinking by-product

Sinking by-product		
Residual waste	2,73	[tonne]
Attached moisture and dirt	0,71	[tonne]

Table 89: Waste water

Waste water		
TKN	8,2	[mg/kg]
COD	597	[mg/kg]
Fibre and solute	15,6	[tonne]

The beverage carton material that was sorted at Sita Rotterdam was also recycled at Repa. The process parameters are shown in Table 90 and the products in the subsequent tables.

Table 90: process input recycling sorted material from Sita Rotterdam

Input REPA		
Water	338	[m3/jr]
Energy	8839	[kWh/jr]

Table 91: Pulp product

Pulp product		
Fibre	32,0	[tonne]
Attached moisture and dirt	134,9	[tonne]
Pollution	1,7	[tonne]

Table 92: Floating by-product

Floating by-product		
Carton fibre	0,0	[tonne]
Aluminium	1,0	[tonne]
PE rigid	7,0	[tonne]
PE film	2,4	[tonne]
PP rigid	0,6	[tonne]
PP film	0,001	[tonne]
Attached moisture and dirt	*2,4*	[tonne]
Concomitant paper & board	*0,0*	[tonne]
Concomitant plastic	*1,2*	[tonne]
Concomitant residual waste	*0,0*	[tonne]

Table 93: Sinking by-product

Sinking by-product		
Residual waste	0,290	[tonne]
Attached moisture and dirt	0,090	[tonne]

Table 94: Waste water

Waste water		
TKN	8,2	[mg/kg]
COD	597	[mg/kg]
Fibre and solute	4,9	[tonne]

4.3 Mass flow diagram for the combined collection of beverage cartons and paper & board

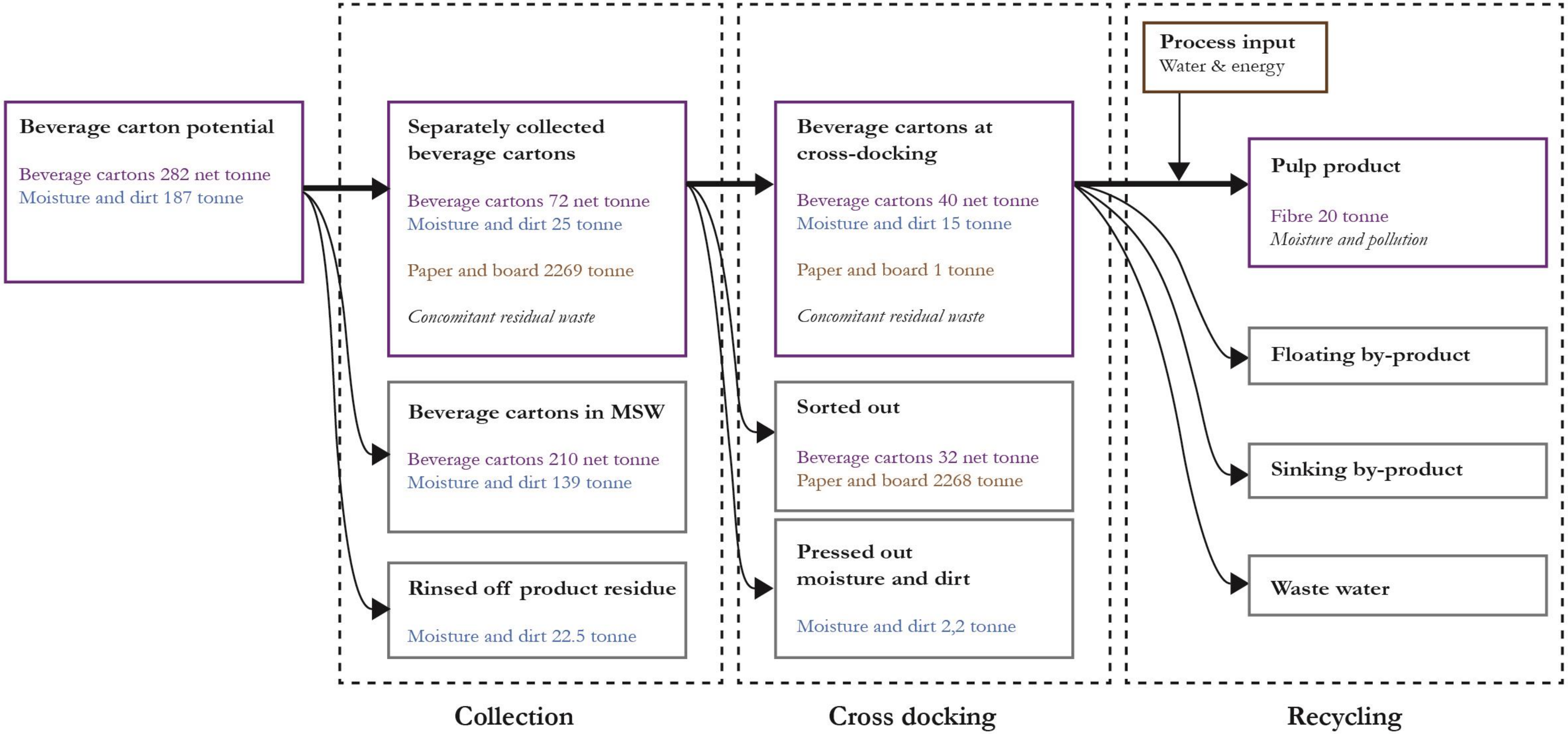

Figure 69: Mass flow diagram for the combined collection of beverage cartons and paper & board

Table 95: beverage carton potential

Beverage cartons potential	282	[net tonne]
Carton fibre	208	[net tonne]
Aluminium	7	[net tonne]
PE rigid	17	[net tonne]
PE film	45	[net tonne]
PP rigid	4	[net tonne]
PP film	0,2	[net tonne]
Attached moisture and dirt	*187*	[tonne]

Table 96: separately collection

Beverage cartons potential	72	[net tonne]
Carton fibre	53	[net tonne]
Aluminium	2	[net tonne]
PE rigid	4	[net tonne]
PE film	12	[net tonne]
PP rigid	1	[net tonne]
PP film	0,1	[net tonne]
Attached moisture and dirt	*25*	[tonne]
Concomitant paper & board	*2269*	[tonne]
Concomitant residual waste	*21*	[tonne]

Table 97: beverage cartons in MSW

Beverage cartons in MSW	210	[net tonne]
Carton fibre	155	[net tonne]
Aluminium	5	[net tonne]
PE rigid	13	[net tonne]
PE film	33	[net tonne]
PP rigid	3	[net tonne]
PP film	0	[net tonne]
Attached moisture and dirt	*139*	[tonne]

Rinsed off residues is 22,5 tonne. Shown in overview

Table 98: Beverage cartons at cross-docking

Beverage cartons potential	**40**	**[net tonne]**
Carton fibre	29	[net tonne]
Aluminium	1,1	[net tonne]
PE rigid	2,2	[net tonne]
PE film	6,5	[net tonne]
PP rigid	0,6	[net tonne]
PP film	0,01	[net tonne]
Attached moisture and dirt	*15*	[tonne]
Concomitant paper & board	*1,1*	[tonne]
Concomitant residual waste	*0,06*	[tonne]

Sorted out, shown in overview. Beverage cartons 32 tonne , paper and board 2268 tonne. With attached moisture and dirt of 8,4 tonne.
Pressed out moisture and dirt is 2,2 tonne. Shown in overview.

Table 99: Process input REPA

Input REPA		
Water	278	[m3/jr]
Energie	4854	[kWh/jr]

Table 100: Pulp product

Pulp product		
Fibre	19,5	[tonne]
Attached moisture	99,7	[tonne]
Pollution	5,4	[tonne]

Table 101: Floating by-product

Floating by-product		
Carton fibre	0,0	[tonne]
Aluminium	0,8	[tonne]
PE rigid	5,1	[tonne]
PE film	1,7	[tonne]
PP rigid	0,5	[tonne]
PP film	0,006	[tonne]
Attached moisture and dirt	3,3	[tonne]
Concomitant paper & board	0	[tonne]
Concomitant plastic		[tonne]
Concomitant residual waste	3,2	[tonne]

Table 102: Sinking by-product

Sinking by-product		
Residual waste	0,79	[tonne]
Attached moisture	0,39	[tonne]

Table 103: Waste water

Waste water		
TKN	11	[mg/kg]
COD	520	[mg/kg]
Fibre and solute	4,7	[tonne]

4.4 Mass flow diagram recovery at Omrin

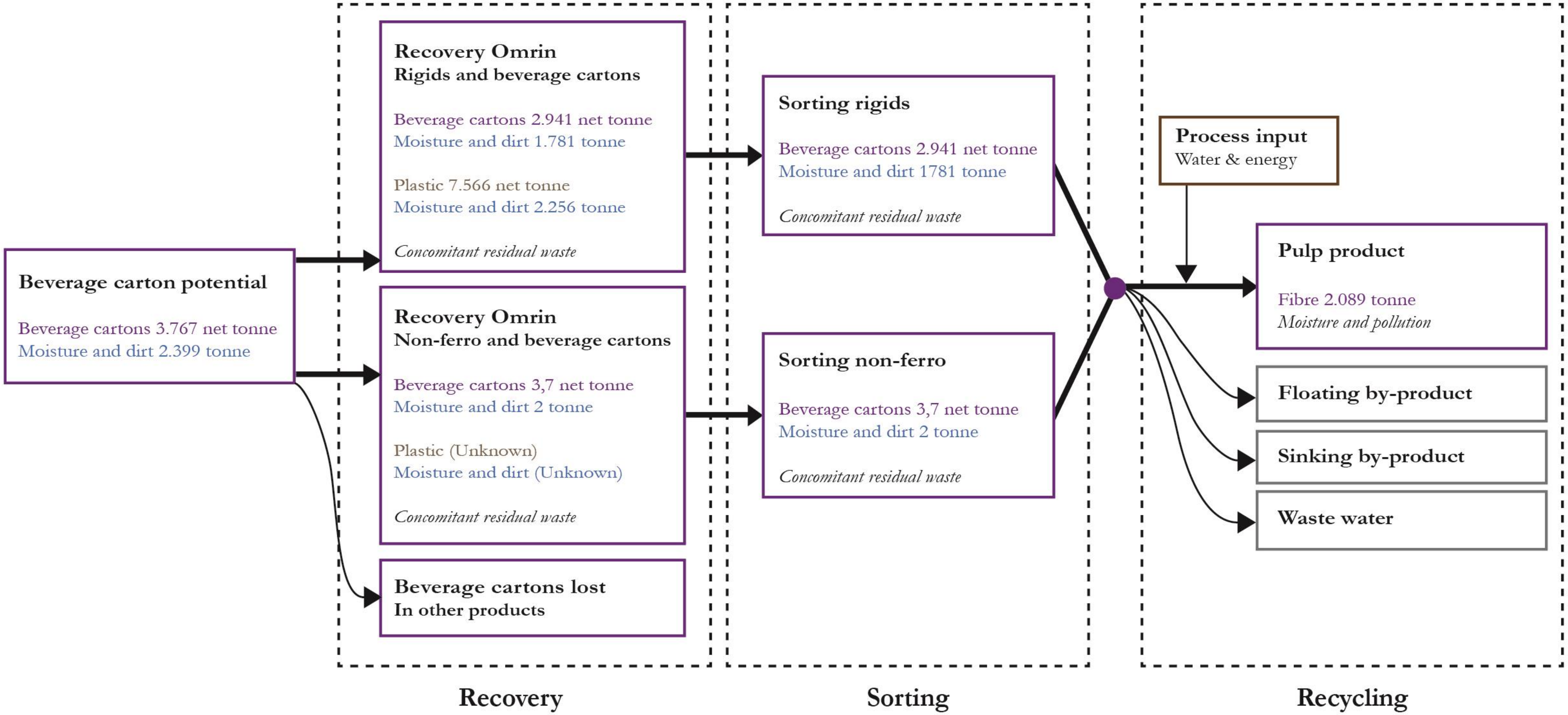

Figure 70: Mass flow diagram for the recovery of beverage cartons at Omrin

Table 104: beverage carton potential

Beverage cartons potential	**3.767**	**[net tonne]**
Carton fibre	2787	[net tonne]
Aluminium	92	[net tonne]
PE rigid	230	[net tonne]
PE film	607	[net tonne]
PP rigid	48,7	[net tonne]
PP film	2,7	[net tonne]
Attached moisture and dirt	*2.399*	[tonne]

Table 105: Recovery at Omrin, rigids and beverage carton

Omrin Rigids and Beverage Carton		
Beverage cartons	**2.941**	**[net tonne]**
Carton fibre	2.185	[net tonne]
Aluminium	67	[net tonne]
PE rigid	187	[net tonne]
PE film	465	[net tonne]
PP rigid	35	[net tonne]
PP film	1,4	[net tonne]
Attached moisture and dirt	*1.781*	[tonne]
Plastic	**7.566**	**[net tonne]**
Attached moisture and dirt	*2256*	[tonne]
Concomitant residual waste		
Paper & board	*1.992*	[tonne]
Organic waste	*2.073*	[tonne]
Textile	*1.131*	[tonne]
Metal	*214*	[tonne]
Glass	-	[tonne]

Table 106: Recovery at Omrin, non-ferro and beverage carton

Omrin Non-ferro and Beverage Carton		
Beverage cartons	**3,67**	**[net tonne]**
Carton fibre	2,58	[net tonne]
Aluminium	0,16	[net tonne]
PE rigid	0,12	[net tonne]
PE film	0,71	[net tonne]
PP rigid	0,09	[net tonne]
PP film	0,01	[net tonne]
Attached moisture and dirt	*2,03*	[tonne]

Plastic	-	**[net tonne]**
Attached moisture and dirt		[tonne]
Concomitant residual waste		
Paper & board	-	[tonne]
Organic waste	-	[tonne]
Textile	-	[tonne]
Metal	*570*	[tonne]
Glass	-	[tonne]

Table 107: beverage carton in other products (loss of beverage cartons)

Beverage carton in sorting products		
BC in RDF	992	[gross tonne]
BC in OWF	271	[gross tonne]
BC in Small films	20	[gross tonne]

Table 108: sorting of rigids and BC at Omrin

	FKN	Rigids	Flat sorting residue	OWF	
Beverage cartons	**2404**	**86**	**451**	**0**	**[net tonne]**
Carton fibre	1785	64	336	-	[net tonne]
Aluminium	57	1,5	9,4	-	[net tonne]
PE rigid	151	5,8	29,7	-	[net tonne]
PE film	382	13	70,2	-	[net tonne]
PP rigid	29	0,73	4,8	-	[net tonne]
PP film	1	0,06	0,4	-	[net tonne]
Attached moisture and dirt	*1382*	*55*	*344*	-	[net tonne]
Plastic	**108**	**6318**	**3396**	**0**	**[net tonne]**
Attached moisture and dirt		*1451*			[net tonne]
Concomitant residual waste					
Paper & board	*84*	*413*	*1496*	*0*	[net tonne]
Organic waste	*12*	*731*	*950*	*380*	[net tonne]
Textile	*0*	*64*	*1068*	*0*	[net tonne]
Metal	*4*	*125*	*0*	*0*	[net tonne]
Glass	*0*	*0*	*0*	*0*	[net tonne]

Table 109: sorting of non-ferro and BC at Omrin

	FKN	NF	
Beverage cartons	**3,67**	-	**[net tonne]**
Carton fibre	2,58	-	[net tonne]
Aluminium	0,16	-	[net tonne]
PE rigid	0,12	-	[net tonne]
PE film	0,71	-	[net tonne]
PP rigid	0,09	-	[net tonne]
PP film	0,01	-	[net tonne]
Attached moisture and dirt	*2,03*		[net tonne]
Plastic	**0,00**	**0,00**	**[net tonne]**
Attached moisture and dirt			[net tonne]
Concomitant residual waste			
Paper & board	*0,0*	*0,0*	[net tonne]
Organic waste	*0,0*	*0,0*	[net tonne]
Textile	*0,0*	*0,0*	[net tonne]
Metal	*0,0*	*570*	[net tonne]
Glass	*0,0*	*0,0*	[net tonne]

Table 110: Process input REPA

Input REPA		
Water	19998	[m3/jr]
Energie	370229	[kWh/jr]

Table 111: Pulp product

Pulp product		
Fibre	2089	[tonne]
Attached moisture	8629	[tonne]
Pollution	68	[tonne]

Table 112: Floating by-product

Floating by-product		
Carton fibre	0,00	[tonne]
Aluminium	56,2	[tonne]
PE rigid	378,8	[tonne]
PE film	150,0	[tonne]
PP rigid	29,0	[tonne]
PP film	0,890	[tonne]
Attached moisture and dirt	*122,6*	[tonne]
Concomitant plastic	*32,7*	[tonne]
Concomitant residual waste	*4542,4*	[tonne]

Table 113: Sinking by-product

Sinking by-product		
Residual waste	0,00	[tonne]
Attached moisture	4,65	[tonne]

Table 114: Waste water

Waste water		
TKN	9,9	[mg/kg]
COD	265	[mg/kg]
Fibre and solute	262,8	[tonne]

4.5 Mass flow diagram recovery at Attero Noord

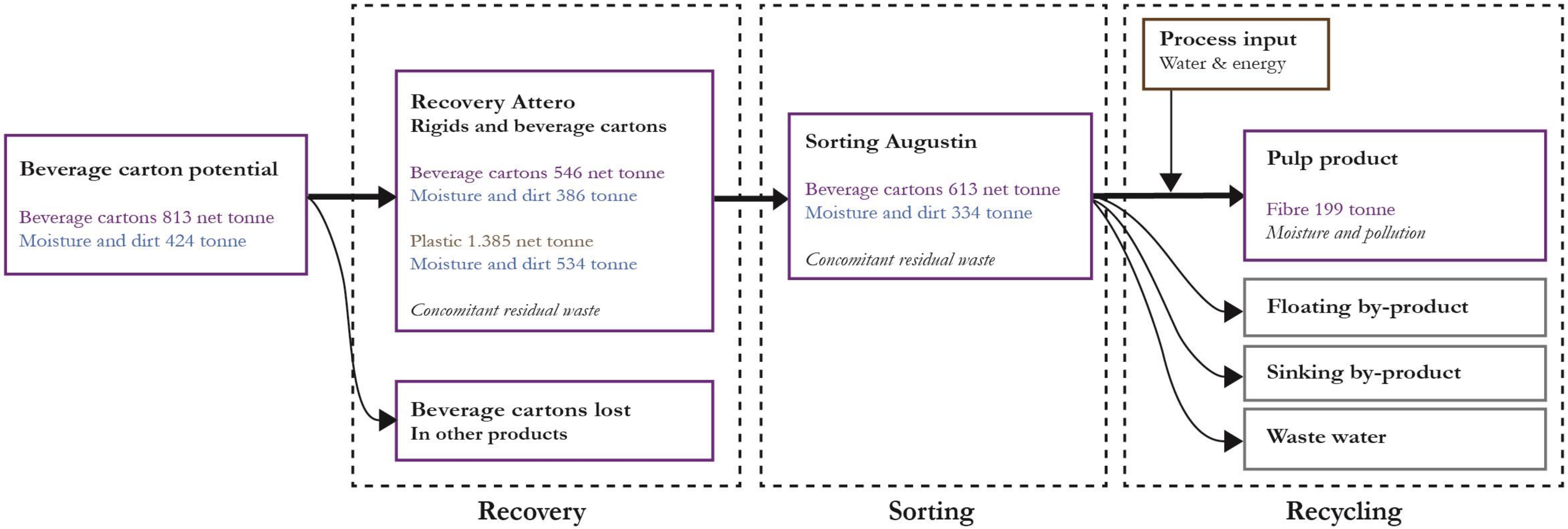

Figure 71: Mass flow diagram for the recovery of beverage cartons at Attero Noord

Table 115: beverage carton potential

Beverage cartons potential	**813**	**[net tonne]**
Carton fibre	602	[net tonne]
Aluminium	20	[net tonne]
PE rigid	50	[net tonne]
PE film	131	[net tonne]
PP rigid	10,5	[net tonne]
PP film	0,6	[net tonne]
Attached moisture and dirt	*424*	[tonne]

Table 116: Recovery at Attero Noord, rigids and beverage carton

Attero Noord Rigids and Beverage Carton		
Beverage cartons	546	**[net tonne]**
Carton fibre	403	[net tonne]
Aluminium	14	[net tonne]
PE rigid	32	[net tonne]
PE film	89	[net tonne]
PP rigid	7	[net tonne]
PP film	0,4	[net tonne]
Attached moisture and dirt	*386*	[tonne]
Plastic	**1.385**	**[net tonne]**
Attached moisture and dirt	*534*	[tonne]
Concomitant residual waste		
Paper & board	*497*	[tonne]
Organic waste	*650*	[tonne]
Textile	*233*	[tonne]
Metal	*88*	[tonne]
Glass	*6*	[tonne]

Table 117: beverage carton in other products (loss of beverage cartons)

Beverage carton in sorting products		
BC in RDF	110	[gross tonne]
BC in OWF	22	[gross tonne]
BC in Small films	-	[gross tonne]

Table 118: sorting of rigids and BC at Augustin

	FKN	MKS	Flat sorting residue	
Beverage cartons	**300,1**	**59,6**	**252,9**	**[net tonne]**
Carton fibre	220,0	43,7	185,5	[net tonne]
Aluminium	8,6	1,7	7,4	[net tonne]
PE rigid	16,9	10,1	42,8	[net tonne]
PE film	49,8	3,2	13,4	[net tonne]
PP rigid	4,6	0,9	3,6	[net tonne]
PP film	0,1	0,0	0,1	[net tonne]
Attached moisture and dirt	*186,8*	*28,1*	*119,1*	[net tonne]
Plastic	**3,5**	**1.027,3**	**432,1**	**[gross tonne]**
Concomitant residual waste				
Paper & board	6,0	33,6	238,6	[net tonne]
Organic waste	1,0	44,9	605,6	[net tonne]
Textile	0,7	5,5	-	[net tonne]
Metal	-	2,4	20,0	[net tonne]
Glass	0,3	-	-	[net tonne]

Table 119: Process input REPA

Input REPA		
Water	2492	[m3/jr]
Energy	38110	[kWh/jr]

Table 120: Pulp product

Pulp product		
Fibre	199	[tonne]
Attached moisture	842	[tonne]
Pollution	9	[tonne]

Table 121: Floating by-product

Floating by-product		
Carton fibre	0,00	[tonne]
Aluminium	8,7	[tonne]
PE rigid	50,5	[tonne]
PE film	17,2	[tonne]
PP rigid	4,7	[tonne]
PP film	0,057	[tonne]
Attached moisture and dirt	*26,3*	[tonne]
Concomitant plastic		[tonne]
Concomitant residual waste	*3,5*	[tonne]

Table 122: Sinking by-product

Sinking by-product		
Residual waste	0	[tonne]
Attached moisture	0,4	[tonne]

Table 123: Waste water

Waste water		
TKN	15,8	[mg/kg]
COD	568	[mg/kg]
Fibre and solute	49,5	[tonne]

The final products formed in each mass flow diagram have been listed in Table 124.

Table 124: Final products formed for each mass flow diagram.

Recycling chain	Fibre product, [kg net/cap.a]	By-products, [kg/cap.a]	Overall recycling percentage for fibres, [%]
Separate collected	0.50	0.24	16%
Co-collected with plastics	0.73	0.29	23%
Co-collected with paper & board	0.32	0.13	9%
Recovered from MSW	2.3	0.68	68%

5 Comparison of systems

The systems can be compared if the yield for fibre and by-products of the stages collection, sorting in recovery facility and/or sorting facility and recycling facility is cumulated. To be able to do so it is assumed that the measured yields for beverage carton in collection and sorting apply as well for fibre and by-product. However, it is expected that losses in sorting show higher levels of contamination and therefore less fibre and by-product is lost. Nevertheless, that had to be neglected in the study as it was too difficult to generate large enough samples of beverage cartons from streams which show low concentration of beverage carton but which hold a significant share of lost beverage cartons at the same time (e.g. RDF in the recovery facility).
Table 125 shows a comparison of the observed yields.

Table 125: Comparison of the Systems (Recovery and yield per stage (top) and cumulated yield (bottom))

	Recovery at Attero	Recovery at Omrin	Separate collection	Co-coll. w/pl. MZ	Co-coll. w/pl. KH	Co-coll. w/p&b	Comment
Collection							
Rm	100%[α]	100%[α]					
Rw	100%	100%	20%	99%	31%	28%	
Recovery facility							
Rm	9.4%	2.1%	na	na	na	na	
Rw	87.3%	63.2%					
Sorting facility							
Rm	10.3%	na	na	8.9%	2.3%		
Rw	50.7%			55.4%	39.2%	~50%	
Recycling facility							
Rw fibre	85.7%	99.5%	77.3%	*84.5%*	87.0%	~85%	
Rw by-product	89.6%	93.0%	94.5%	94.9%	88.7%	~95%	
Cumulated chain yield							
Collection	100%	100%	20%	99%	31%	28%	η_1
Recovery facility	87.3%	63.2%					$\eta_1*\eta_2$
Sorting facility	44.3%			54.8%	12.2%	~14%	$\eta_1*\eta_2*\eta_3$
Recycling plant (fibre)	38.0±27%	62.9±26%	15.5±23%	46.3±20%	10.6±55%	~11±29%	$\eta_1*\eta_2*\eta_3*\eta_{4(\text{fibre})}$
Recycling plant (byproducts)	39.7%	58.8%	18.9%	52.0%	10.8%	~13%	$\eta_1*\eta_2*\eta_3*\eta_{4(\text{by-product})}$

α: The net collection yield for the recovery chain is by definition 100% since all the beverage cartons that are present within the household will be discarded with the MSW. Some of the beverage cartons are discarded out-of-home, however, a good inside in these numbers is lacking and hence no correction for out-of-home discarding is made.
na: not applicable

It becomes clear that certain process chains seem to perform better than others. However, to be able to draw the complete picture the significance for the total system has to be taken into account. A well performing beverage carton recovery system that is only available in a certain region can hardly replace a bad performing system in another region. Collection yields or sorting yields were partly measured during unfavourable conditions (collection system still being built up; sorting plant not being equipped for recovery of beverage cartons) and will likely undergo changes if one system will be established permanently.

The in Table 125 presented numbers reflect the actual situation during the pilot in 2013 and are merely of predictive value for yields that could be attained in the future with similar schemes. The significance of the chain yields is limited due to the large errors which are common in collection and recycling schemes. The error in the collection yield is the standard deviation of the recorded collection yields. Since these numbers show a large variance, the standard deviation is also large. The variance in sorting yields is largely determined by the variance in composition of the sorted products and waste streams and these are substantial on an hour timescale. Hence errors in sorting yields are in the order of 10%.
The error in recycling is predominantly determined by the methology of measuring the amount of produced fibres and is substantial in two cases. The sum of these three types of error forms the error in the net chain yield and is hence also substantial. These large errors indicate that the net chain yields are indicative values and care should be taken not to use them boldly as a forecast for coming years.

Table 126: Comparison of the inputs to the recycling facilities.

Input recycling plant	Recovery, Attero	Recovery, Omrin	Separate Collected	Co-coll. w/pl. MZ	Co-coll. w/pl. KH	DKR 510 specification
BC	97.1%	97.9%	95.5%	78.6%	97.1%	90.0%
Paper and board	0.7%	0.7%	2.9%	12.9%	0.7%	<2.5%
Plastics	1.4%	0.6%	1.2%	7.9%	2.1%	<4%
Metal	0.0%	0.4%	0.1%	0.2%	0.0%	<0.5%
Residue	0.8%	0.3%	0.3%	0.5%	0.1%	<3%

Further comparison of the systems has to take into account if the quality of the beverage cartons fraction generated meets market specification and is therefore likely to be recycled. A relevant specification for beverage cartons is likely to follow the DKR specification 510, a well-established standard for beverage cartons based upon available process technology for beverage carton recycling. If the input quality to the recycling stage is compared in each case to the DKR 510 it becomes clear that in two cases the requirements defined in the specification were not met. The material originating from the separate collection shows a slightly too high share of paper and board. The material originating from the sorting of the Milieuzak shows significant dilution with paper and plastics. While it is not sure if a dilution with paper and board would cause the fraction to be rejected the amount of plastic could be problematic. However, in case of the Milieuzak adjusting of the sorting technology will most likely result in a beverage carton fraction meeting the requirements.

Table 127 Comparison of waste water quality (cursive: the sample was stored in an inappropriate way which might have influenced the water quality)

	Recovery, Attero	Recovery, Omrin	Separate Collected	Co-coll. w/pl. MZ	Co-coll. w/pl. KH
COD per kg-input [g/kg]	52.4	24.3	*56.5*	54.3	21.1
TKN per kg-input [g/kg]	1.4	0.9	*1.2*	0.7	0.6

It can be seen that two cases, the beverage cartons from Omrin and the beverage carton from KH show a lower concentration of COD in the input material. The result of the TKN analysis is similar with the exception to the Milieuzak.
It didn't become clear what the reasons for these results are. Several possibilities exist: the dirt adhering to the surface of the beverage carton is responsible for the difference, different compositions of the input (milk cartons, juice cartons, etc.) are responsible and/or the age of the beverage carton is responsible for the differences.
The dirt adhering to the surface wasn't measured at the input to the recycling plant but only after collection. Therefore it can't be proven nor can it be excluded that the level of adhered dirt is the reason for the differences.
The composition of the input is comparable in all cases. Smaller deviations can be spotted but would unlikely cause those big differences in the amount of COD and TKN in the input.
The age of the beverage cartons is dependent on the logistical chain behind the recycling chain. A longer chain containing more stages and longer collection frequencies would result in an aged input material. However, the logistical chain was not studied in detail. Therefore it not possible to conclude, that the reason for the different amount of COD and TKN are based on the age of the beverage carton.

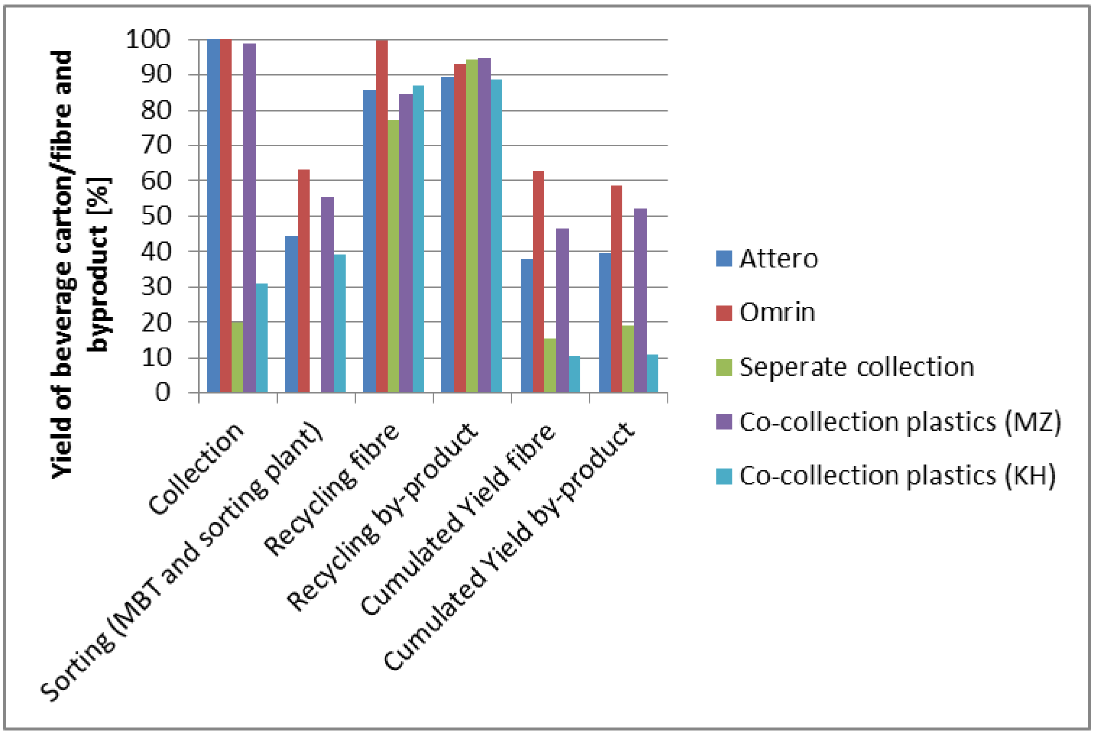

Figure 72 Yield per system per stage and cumulated yield of fibre/by-products.

Figure 72 shows the yield per system and per stage of the recycling chain. It becomes clear that the main influence factors on the efficiency of the chain are the collection and sorting (MBT and sorting plant). While the recycling stage has the same impact on the chain the recycling process is well-optimised to recover fibre and by-products. The sorting yield is mainly important for the separate and co-collection systems. The amount of collected material depends on urbanisation degree, information provided to the households in the collection areas, collection frequencies and so on. In case of the recovery schemes the collection yield is approximately 100%. Some losses occur due to citizens disposing of beverage cartons in public places or disposing of them in other separate collection systems. The sorting is equally important for all but the separate collection system. Co-collected and recovered beverage cartons have to be purified before recycling. These purification processes will cause losses. However, well-optimised sorting processes can yield a high share of the beverage cartons (app. 60%). Experiences with sorting of other packaging waste streams, e.g. plastic packaging waste, showed a constant improvement of sorting yields.[i] Further it could not be seen that the source of the beverage carton (recovered or co-collected) is important for the sorting yield but mainly the stage of development of the sorting plant. All systems with the exception to the Milieuzak delivered a quality fulfilling relevant quality criteria. The input qualities were not influenced in the view of the moisture content by the source of material. All cases showed approximately 25% moisture content with one exception being higher and one being lower (both recovery systems).

6 Discussion

6.1 Data quality

This pilot beverage cartons has been conducted in 2013 under the strict condition that the complete pilot should be performed and reported within 2013, as described in the framework treaty. This time constraint had strong implications on the pilot and the quality of the data gathered. Most new collection systems require a few years to mature and this pilot just had 6 months of collection time, including the summer season, which is not ideal. Hence, it is very likely that response levels would have continued to grow during the coming months, that several municipalities could address quality issues with the collected material and that sorting facilities could have implemented improvements. Although, the time constraint has clearly influenced the pilot execution, the produced data is of high quality and can be understood, analysed and it compares favourably with results from abroad. Since, the majority of municipalities have agreed with the pilot management to continue, it is likely that even better collection response data will become available in the coming months.

6.2 Factors determining collection yields

Collection and sorting yields are the prime parameters that limit the overall yields of the recycling chain. However, sorting yields for beverage cartons from mixed plastics can in most cases be optimised towards 80% by technical improvements. Hence most attention should be directed towards measures to enlarge the collection response.

The fact that 4 municipalities achieve an almost complete collection of the beverage cartons that are available within their collection areas is promising. Apparently, the ingredients rural regions with larger farm houses, a PAYT scheme for MSW and a fortnightly kerbside co-collection system for plastic packages and beverage cartons can render high net amounts of beverage cartons. For three of these four municipalities the co-collected material, however, also contains substantial amounts of residual waste, which hampers the subsequent sorting and recycling. So caution is needed to find the proper balance between high net collection yields, sortability and recyclability in the design of the collection scheme.
Two related municipalities did not achieve such high collection yields; Steenwijkerland and Vught. Steenwijkerland has a reverse collection scheme (drop-off for MSW and kerbside for recyclables) and the collection area (de Gagels) is residential area with mostly Dutch townhouses. Here the net collection yield is not about 100%, but close to 70%. An impressive result, but also less than the other four, which suggests that perhaps the spaciousness of the dwellings is an important factor that determines the collection yield. In Vught the net collection yield is only 18% for beverage cartons, whereas the factors are remarkably similar (PAYT, fortnightly co-collection with plastic packages). Vught could be considered as a relative rich suburb with amongst others Victorian-age houses. The net collection yield for plastic packages is in Vught one of the highest of the Netherlands, but the collection yield for beverage cartons lags behind.

The factors which contribute to this lower collection yield could be; insufficient information of the civilians to add beverage cartons to the plastic packaging waste, insufficient time for the collection system to mature and possibly insufficient space in the houses to store plastic packages and beverage cartons for a fortnight.

In general, the percentage of high rise buildings in the collection area is a strong indicator for the success of a separate collection system. This indicator is likely to be related to the available space in the houses for the storage of beverage carton material. The only clear exception was the co-collection with paper & board in the high rise area of Etten-Leur. This collection system yielded about 50% of the beverage cartons present, which is a relatively large amount for a collection area with high-rise buildings. Most likely, the inhabitants of these houses were already accustomed to the separate collection of paper & board, had already bins in their houses for paper & board and found the addition of beverage cartons relatively easy to accomplish.

Although the gathered data suggests that a low amount of high rise buildings, a PAYT scheme for MSW and co-collection kerbside collection system with plastics are all positive indicators for high net collection yields, several examples were observed of municipalities with limited facilities and / or poor communication to the civilians that performed below average. Hence, although factors and conditions can be deduced which improve the collection yield, other factors can be far more detrimental and result in very low collection yields; unclear communication, limited amount of drop-off containers, kerbside collection with more than 2 weeks between collection. For example:

- Tilburg started with placing drop-off containers and obtained mostly residual waste until a self-adhesive label was placed on the container "beverage cartons only". From that moment on the collection results improved.
- Hengelo is an urban centre with a PAYT scheme for MSW and offered their residents of three neighbourhoods the choice, throwing their MSW bags in the paid bin for MSW or in the free adjacent bin for beverage cartons. This resulted in the largest amount of residual waste in separately collected beverage carton material.
- Oosterhout and Bernheze are suburbs with an existing separate collection system; one drop-off container at the municipalities waste park. This resulted in a net collection yield of 8% and 4%, respectively, which is relatively low compared to municipalities like Apeldoorn (33%) that placed drop-off containers in the residential areas and near shopping centres.
- Voorst started with 2 drop-off containers for the whole municipality and achieved a net collection yield of 3%.

6.3 Regional variation

During this pilot evidence was gathered which suggests that there is a regional variation in the consumption of products in beverage cartons (see paragraph 3.8). Based on this indicative evidence an assumption was made that the consumption in the rural regions with <10% low-rise buildings was +15% from the average and that the consumption for the urban regions with

>50% high-rise buildings was -15% from the average. This assumption has a strong influence on the net collection yields of individual municipalities and indirectly on the overall chain yields of the systems. Therefore, it is recommended at KIDV to study the regional variation of packaging material consumption in greater depth in the future.

6.4 By-product recycling

In this pilot study fibre recycling was the prime target of beverage carton recycling. Up to a few years ago all by-products of the beverage carton recyclers went to the cement kilns to serve as fuel and reducing agent. However, many technical developments have occurred in the last few years, that will make it likely that the by-products will be recycled differently in the near future. Since, this is a domain with relatively much innovation, it is difficult to predict which direction will prevail in the future. Additionally, the precise future fate of these by-products will not only depend on technical aspects, but also on economic and political factors.
Here is a small list of developments:

- Alucha and Enval have developed a pyrolysis system to obtain thin aluminium flakes and PE-wax,
- APK in Merseburg have a running pilot factory to separate the polyolefines from the aluminium by solvolysis. According to Hedra the Niederauer Papiermühle currently sends its by-products to APK for recycling,

This pilot study does not consider the by-product recycling in detail, since it would involve a choice for a recycling scheme and the need to mass-balance such a recycling facility. The current pilot study had too much time constraint, to allow for this type of work. Nevertheless, it can imply that the results of a pilot study in about 5 years' time from now, will lead to different results for the approximately 26% of potential by-products.

This pilot study has shown that two types of by-products can easily be derived from the recycling of beverage cartons: a sinking by-product which contains metal impurities from the input and high density plastics (e.g. PET, PS) and a floating by-product which contains the plastics from the beverage cartons itself and other low density plastics (PE, PP). The recycling of the sinking by-product would follow state-of-the-art metal recycling schemes and will therefore not be elaborated. The floating by-product contains several materials which have to be separated for efficient recycling:

- Caps and closures made from PE and PP
- LDPE films
- LDPE films with an aluminium coating and
- Residual materials.

The separation difficulty is influenced by the moisture content of the material (wetter material is more difficult to treat) and the stress applied by the recycling process (higher stress comminutes the material and/or causes the material to coil itself up). A lower separation difficulty means more products can be generated from the same amount of input material.

While it is technical possible to recover a LDPE film fraction, caps and closures and aluminum coated films from the by-product the cost efficiency of the process decides if it is done. The cost efficiency is influenced by the value of the products, disposal costs of the residues, resource cost (price of the by-product), the separation difficulty and the treatment costs. Several factors are likely to see changes in the near future: the value of the products is increasing due to increasing demand for plastics of all kinds. The disposal costs are dependent on the incineration prices where no greater changes are expected. The separation difficulty is dependent on the prior recycling process. Once a recycling chain has been established it can be seen as constant. The treatment costs are dependent on land and labour costs and the complexity of the process (and are therefore dependent on the constant separation difficulty). The resource costs are directly related to the development status of the market for by-products. They will change once the recycling starts off but are constant in the near future.
The major driver for material recycling of by-products from the beverage carton recycling is therefore the price of the products. An increase in the near future is likely. However, it is not known where the breakeven point for such a recycling operation lies.

6.5 Future scenario's

The determined process yields per chain step in Table 125 are snap-shots of the technical situation in 2013. All mentioned yields can potentially be improved, which will result in more efficient collection and recycling chains. Some of these improvements can fairly easy be forecasted, such as the maximal sorting yield of beverage cartons from plastic packages (roughly 80% from German sorting facilities that sort co-collected LVP) and the maximal recovery yield, from our own pilot test. Other improvements, such as the future net collection yields are more difficult to forecast, therefore, two future scenarios are shown in Table 128 which show the chain efficiencies that might be achieved in the coming 5 years for the beverage carton collection and recycling chains, with two different levels of net collection yields.

Table 128: Yields of all involved facilities in the collection and recycling chains with regard to beverage cartons which are technologically likely to be achieved in the coming 5 years.

Scenario 1	Separate collection	Co-collection w/plastic	Co-collection w/P&B	Recovery	
Collecting*	40%	40%	40%	100%	$\eta_{c.}$
Recovering	na	na	na	88%	$\eta_{r.}$
Sorting	na	80%	na	80%	$\eta_{s.}$
Recycling fibres	81%	80%	76%	99%	η_f
Recycling by-products	95%	89%	94%	92%	η_b
TOTAL fibres	32%	26%	30%	69%	$\eta_c*\eta_r*\eta_s*\eta_f$
TOTAL by-products	38%	28%	38%	65%	$\eta_c*\eta_r*\eta_s*\eta_b$

Scenario 2	Separate collection	Co-collection w/plastic	Co-collection w/P&B	Recovery	
Collecting*	75%	75%	75%	100%	$\eta_{c.}$
Recovering	na	na	na	88%	$\eta_{r.}$
Sorting	na	80%	na	80%	$\eta_{s.}$
Recycling fibres	81%	80%	76%	99%	η_f
Recycling by-products	95%	89%	94%	92%	η_b
TOTAL fibres	61%	48%	57%	69%	$\eta_c*\eta_r*\eta_s*\eta_f$
TOTAL by-products	71%	53%	71%	65%	$\eta_c*\eta_r*\eta_s*\eta_b$

na: not applicable

For the co-collection chain with paper & board the sorting process is likely to be omitted in the near future, since it adds costs and it is technically proven that a mixture paper & board and beverage cartons can be recycled. This combined recycling is operational for several years in a paper mill in Nortrup, Germany.

6.6 Relationship between logistical lead-time and recycling results

Several incumbents have suggested that there should be a relation between the logistical lead time of the collection & recycling chain and the recycling results. The differences found in this study between the fibre recycling yields for the various systems could possibly be explained by this hypothesis. However, in this pilot study, not only the logistical-lead time varied between systems, also the composition of the beverage carton product that served as input for recycling varied between the systems. Therefore, this study cannot validate this hypothesis. Nevertheless, it remains likely. Therefore, it is recommended to study this hypothesis in the future and to deliver practical guidelines on the maximal logistical lead-time for collection services.

6.7 Expected infrastructure changes per system and interaction with renewable energy policies

This pilot study has shown that the collection and sorting yields are the main impact factors to optimise complete collection and recycling systems. In case of optimisation of the yields for each system individual requirements for the generation of new infrastructure can be identified:

Recovery schemes: MSW is collected extensively in the Netherlands. It is either brought to recovery or incineration facilities. If recovery schemes become a predominant form for the recycling of beverage cartons existing transport routes have to be adjusted away from incinerators to recovery facilities. This can be seen as a minor change. However, the recovery facilities themselves do not exist in certain parts of the Netherlands nor do the existing ones have sufficient capacity to treat major parts of the Dutch MSW. That means new facilities have to be constructed and operated for the next 20 to 30 years. Due to treatment costs such a facility is likely to generate not only beverage cartons but also plastics for material recycling, metals, an organic fraction for production of biogas and RDF. Due to the reduction of mass for incineration unused incineration capacity is generated. However, most likely waste from other countries will be used to increase the incinerators utilisation. Therefore the system will experience some net changes in the view of the energy output: the generation of biogas from organic waste is likely to increase and the energy recovery from RDF is likely to increase. Biogas can be used to compensate for fluctuating energy sources like solar and wind energy. RDF will most likely be incinerated in continuously operating incinerators. The net effect on the Dutch energy system depends on the heating value of the RDF: a lower heating value than MSW would mean a decreased continuously electricity production due to lower thermal efficiency in the incinerator; a higher heating value would cause the opposite case.

Co-collection with plastics: Plastic packaging waste is currently collected in most Dutch municipalities by the KH system. The collected plastic packaging waste is brought to sorting plants in the Netherlands and Germany. Adding a new component to the plastic packaging waste would therefore partly cause the need for new infrastructure: the Dutch sorting plants, e.g. the one of SITA in Rotterdam, have been planned and built for the sorting of plastic mixtures only. Sorting plants in neighbouring countries, e.g. in Germany or Belgium, are equipped to sort multi-material mixtures like the “yellow bag” or the “PMD bag”. The removal of beverage cartons from the MSW by co-collection would cause the remaining MSW to have a lower average heating value (beverage cartons have a higher heating value than MSW, the free capacity in the incinerators would be replaced with MSW or RDF from other countries). Therefore the thermal efficiency of the incinerators will be lower. That means the production of continuously available electricity would decrease.

Co-collection with paper and board: Paper and board is currently collected extensively in the Netherlands. Major changes to collection infrastructure are therefore not needed. The paper and board is always brought to sorting plants where the paper and the board get separated. Both fractions are recycled in separate facilities. Adding a new component to the paper and board would cause either of the fractions to change: one holds the major part of the beverage cartons, the other one the rest of the beverage cartons. However, in any case state-of-the-art technology is available to upgrade the recycling facility which receives the changed mixture. The effects on the Dutch energy systems are similar to the effects described under co-collection with plastics.

Separate collection of beverage cartons: a group of about 40 municipalities have already a separate collection system for beverage cartons currently in place in the Netherlands. Therefore new collection infrastructure has to be generated for municipalities that would start with this collection method. The removal of beverage cartons from MSW by separate collection has similar effects on the Dutch energy system as described under co-collection with plastics.

Depending on the final choices made by the decision makers, an amount of beverage cartons for recycling could be generated (with exception to the co-collection with paper and board) which is suitable for one or maximally two recycling facilities. Several recycling facilities which are able to treat beverage cartons already exist all over Europe. It is likely that the existing recycling infrastructure is able to absorb the amounts of beverage cartons that could potentially be collected or recovered in the Netherlands, in principle no new recycling infrastructure appears to be required.
The net effects on the Dutch energy system are difficult to quantify. A set of other effects exists, e.g. waste water treatment of the recycling process of beverage carton, which can counter or amplify the described effects. A more in depth analysis is needed. Decision makers are recommended to consider the impacts on the Dutch energy system.

7 Conclusions

It is technically possible to collect and recycle Dutch beverage cartons according to the four studied collection & recycling schemes (separate collection, co-collection with plastics, co-collection with paper & board and recovery from MSW). All these recycling schemes are comprised off multiple steps, which usually involve collection, sorting and recycling, only for the recovery scheme it is collection, recovery, sorting and recycling. The efficiency of the overall recycling yield of these schemes is governed by the collection yield and the sorting yield, the recycling yield is already near-optimal.

For separate collection systems the net collection yield determined the whole chain efficiency. This net collection yield varied from 3% to 57% and the weight-averaged net collection yield equalled 20%. The large variance in collection yields for similar municipalities, suggests that there is substantial room for improving these net collection yields, and that the following factors are relevant; service level of the collection system, clear communication to the civilians, space inside the houses to store and keep beverage cartons separate until collection.

For co-collection systems with plastic packages four rural collection areas (Deventer rural area, Grootegast, Leek, Marum) approached complete collection of the beverage cartons present in the collection area, while more urban municipalities achieved much lower net collection yields (Vught 18%, Nijmegen 16%, Binnenmaas 16%, Zeist 14%, Schiedam 5%). Here the details of the collection system and area determine the collection yields. The recorded sorting yields were 39% and 55%, which is relatively low for beverage cartons. In case of Sita Rotterdam this yield was relatively low, since the facility was not designed and equipped for the sorting of beverage cartons from mixed plastic waste. In case such a system would be chosen, it is likely that such a sorting center will be fitted with an additional NIR sorting machine devoted to beverage cartons and achieve much higher sorting yields of about 80%. In case of Schönmackers the input material (Milieuzakken) contained relatively large amounts of residual waste which hampered the sorting process and resulted in a poor sorting result. Here the remedy should be sought in changes to the collection system which would reduce the pollution level of the co-collected material. Cross-contamination between beverage cartons and plastic packages is likely and should be controlled by asking the civilians to rinse out the beverage cartons with cold water, flatten them and close the lid and to make adjustments to the sorting process.
For co-collection systems with paper & board the net collection yields were relatively low, only for an area with high-rise buildings 50% net collection yield was achieved. This collection and recycling scheme suffered from low collection yields and low sorting yields. However, in case this scheme would be chosen in the future, the sorting process will be omitted from the chain and the material will be recycled as mixture[iii] to corrugated boxes.

For the recovery scheme, high recovery yields were observed, medium and high sorting yields were found and high recycling yields were determined. The Omrin recovery chain was the most efficient collection and recycling scheme studied during this pilot. The Attero recovery chain suffered from a relative low sorting yield during this pilot, however this can relatively easily be improved and this chain still has one of the highest overall recycling yields.

All recycled pulps made from different types of beverage cartons could be converted in relatively strong paper materials from which corrugated boxes can be produced. The mechanical properties of paper hand-sheets made out of pulp from the four recycling schemes are relatively similar. The microbiological load of these materials is, however, relatively high for all of them, which limits the applicability to non-food packaging and secondary packaging. The final properties of the recycled products are hardly affected by type of collection & recycling scheme.

.

Acknowledgements

Many persons have contributed to this report and it is impossible to thank everybody individually. We would like to thank the following individuals for their contributions.

The three members of the review committee: Prof. B. Bilitewski, Prof. H. Wenzel and Dr. M. Gell.

All members of the societal advisory board.

The waste sorting team in Wageningen: Marcel Staal, Alexander Versteeg, Johan ten Besten, Joost Starmans, Eric Verhoeff and Arjen Gootzen

The researchers: Richard op den Kamp, Willem Spekking and Jacqueline Donkers. Alan Campbell for the metal analysis of the by-products and Frank de Bok of KBBL for the microbiological analysis.

The enthusiastic team of Repa Boltersdorf, especially Mr. Boltersdorf and Ms. Spill.

Gerard Nijkamp, Kees Bouter and Bernard Scholtens from Attero. Aucke Bergsma, Albert Buma and Frans Goerres from Omrin. Mr. Bruns of Delkeskamp. Mr Dammer from Schönmackers. Ms. Roelofsen of Augustin. Albertino Perreira, Daan de Rooij en Eric Scheggetman van Sita. Eric Kempenaars van Kempenaars. Carel Cornelisse van Virol.

Definition of terms

BC	Liquid food packaging board (Beverage carton)
c	Concentration
COD	Chemical oxygen demand
DM	Dry matter
Fe	Ferrous metals
FKN	Flüssigkeitskartonnage, German word for beverage carton used by the sorting industry to describe a sorted fraction that predominantly (>90%) consists from beverage cartons
(HD)PE	(High density) polyethylene
m	Mass
m`	Mass flow
MBT	Mechanical biological treatment plant, recovery facility (Nascheiding plant)
MKS	Mixed plastic in sorting facility (Mengkunststof)
MRF	Material recovery facility (nascheidingsinstallatie)
MSW	Municipal Solid Waste / gemengd huishoudelijk restafval
Mix	Mixed plastics
NF	Non-ferrous metals
NIR	Near infrared sorter
PAYT	Pay as you throw scheme for MSW, Dutch abbreviation is diftar
PET	Polyethyleneterephthalate
PO	Polyolefines
PP	Polypropylene
RDF	Refuse derived fuel
R_m	Recovery of mass
R_w	Yield of recyclable material
SEM	Scanning Electron Microscopy
t	Time
TKN	Total Kjeldahl Nitrogen
V	Volume

References and endnotes

[i] Scenarios study on post-consumer plastic packaging waste recycling, 2013, U. Thoden van Velzen, H. Bos-Brouwers, J. Groot, X. Bing, M. Jansen, B. Luijsterburg, Wageningen UR Food & Biobased Research.

[ii] Annex 1 van: Scenarios study on post-consumer plastic packaging waste recycling, 2013, U. Thoden van Velzen, H. Bos-Brouwers, J. Groot, X. Bing, M. Jansen, B. Luijsterburg, Wageningen UR Food & Biobased Research.

[iii] The company Delkeskamp recycles mixtures of paper & board and beverage cartons for approximately 5 years and due to its geographic location close to Drenthe, is keen on contracting Dutch municipalities for such a co-collected mixture.