Scenarios study on post-consumer plastic packaging waste recycling

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Abstract

We all use plastics on a daily basis. Plastics come in many shapes, sizes and compositions and are used in a wide variety of products. Almost all of the currently used plastic packaging are made from fossil resources, which are finite. The production of plastic packages causes environmental impacts, whereas the correct use of these packages will reduce product losses and hence reduce the much more negative environmental impacts associated with product losses. Wrongly discarded plastic objects have a negative impact on the environment, as these materials degrade only very slowly, creating problems such as the infamous 'plastic islands' in our oceans. Fortunately, recycling technologies are now emerging for plastic waste, enabling the reuse of these materials in a second life as a package or a utensil.

Plastic packaging waste (PPW) is complex in many ways. First of all, there are many different types of plastics, all with their own characteristics and compositions. To enable the re-use of PPW, it has to be sorted into separate fractions. Each type of plastic can then be dealt with in an appropriate way.
Second, the collection of PPW is also very complex. In the Netherlands there are many different PPW flows, from industry, offices and households for example. Each has its own collection system and household collection systems differ from one municipality to the next. To add to this complexity there is also the deposit refund system for large PET bottles, run by the soda producers via the supermarkets.

Everybody deals with PPW on a daily basis. Most of us think recycling is a good idea. But when we want to decide what the best and most efficient method of recycling is, we are all impaired by a lack of data. A clear view of our best options is inhibited by the existing infrastructure and 'the way it has always been done'. Also, the subject of recycling touches on our moral opinions about 'doing the right thing' and assumptions about the 'correct' way of dealing with our plastic waste. And politics also play a role.

To unravel the complexity of plastic packaging waste recycling and figure out the best way(s) to improve our recycling system we need science. We need technological, economical, logistical and environmental data to gain insight into recycling systems. By describing the system in detail we can learn how to optimise it. An improved recycling system will provide us with an easier and more efficient re-use of our plastic waste.

Background to this study

This study deals with the plastic waste from packaging materials generated in households. To illustrate the size of the issue, it was reported that in 2010 454 kton of plastic packaging was brought on the Dutch market, of which we estimate 280 kton was directly used at household level. The Stichting Nedvang was established to advocate the producers' responsibility, to create communication campaigns, monitor the performance of the system and organise the sorting and

reuse of collected fractions of PPW. Nedvang directs and pays for the Dutch recycling system of PPW, while the municipalities remain responsible for organizing the collection of all types of household waste. This division of responsibilities obviously leads to occasional differences of opinion. It adds to the complexity of the recycling system. They reported a response of 83 kton of PPW collected in 2010, which equalled about 60 kton net weight. Additionally, about 26 kton gross weight or 22 kton net weight of PET bottles from the deposit refund system was recycled in 2010.

The Dutch government aims to reduce the amount of waste produced and to enhance the reuse and recycling of waste materials. In 2006 a new packaging waste law introduced producer responsibility for all types of packaging waste. This means that producers have to organise and pay for the collection and recycling of their products. In the frame work treaty of 2007 between the Ministry, the Dutch association of municipalities VNG and the representatives of the producers of packed goods, the recycling targets for all types of PPW were defined as gradually increasing from 38% in 2009 to 42% in 2012.

Scope

This research project focuses on PPW from households. To gain more insight into the complexity of its recycling process, an objective and factual system performance analysis was called for. In-depth knowledge can then serve as evidence base for a factual appraisal of the system while providing starting points for optimising the system for recycling PPW. Especially since previous research suffered from data accessibility, transparency issues and lack of scientific basis.

With this study, we aim to close the knowledge gap by presenting a new approach to calculating the cost-efficiency and environmental impact of PPW recycling. We also present various scenarios based on alternative (combinations of) collection schemes, and variations in network logistics and response levels. Our choice of scenarios was based on reality; we compare situations that are actually achievable in the Netherlands rather than theoretical system outlines.

A number of scientific disciplines were integrated to tackle the complexity of the recycling process: technological mass balancing of recovery facilities and sorting facilities, collection and network logistics and environmental performance calculations.

By bridging the knowledge gap we hope to facilitate decision-makers. We want to present them with clear scientific data and choices. As you will see on the following pages, there are a number of possibilities to move forward with PPW recycling in the Netherlands. Those responsible can decide their next steps based on facts and with an overview of the complexity of the Dutch recycling situation.

Please note that this research focuses on the steps from collection of PPW at the household level to the production of milled goods. These are the steps that the producers of packaged goods are responsible for. The commercial resell of milled goods to secondary producers of products is not included in our calculations. The scope of this research project is depicted in figure 1.

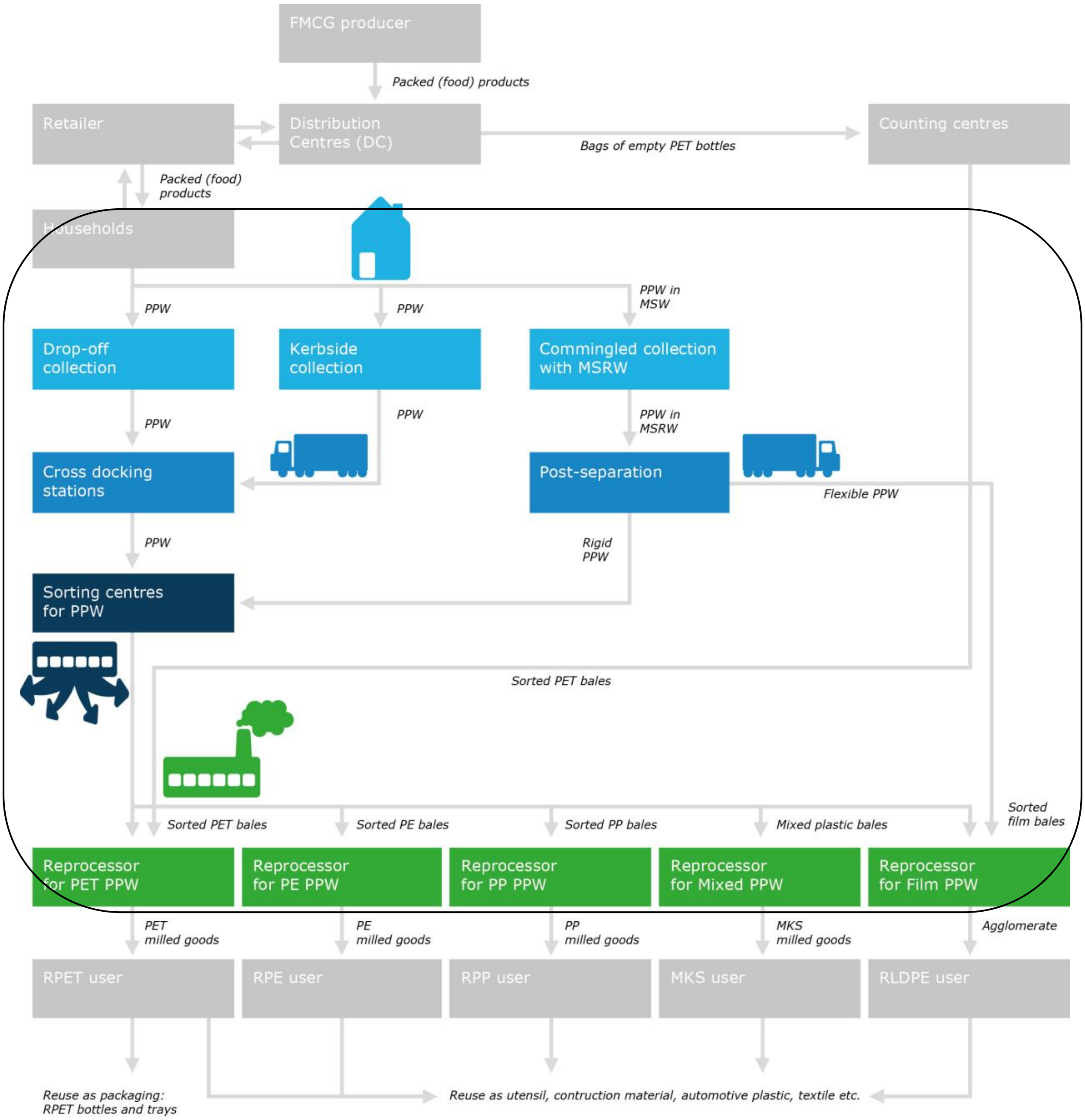


Figure 1: Schematic description of plastic packaging recycling

This study has scope boundaries from the point of collection (household level) up until the Reprocessors for the various plastics fractions (milled goods).

Research questions and the use of scenarios

To gain insight into the complex recycling system and to be able to compare different options, we addressed the following research questions:

- What is the correct technological description of the recycling chain in terms of a mass flow scheme? In other words: the amount of kilograms going in and coming out.
- What is the correct logistical description of the recycling network? Meaning: the precise truck movements required to execute the recycling network.
- What are the environmental consequences of the recycling chain?
- What are the economic costs associated with the recycling chain?

Recycling systems are complex - and they are also complex to calculate. There are many variables and data availability was problematic. In order to describe the composition of different waste flows and the yields of the recycling process, we performed many measurements. We also developed our own logistics models to calculate the data we needed.

After answering the first four questions, we came to the final research question:

- How do baseline and alternative scenarios on integrated recycling schemes compare on system costs and environmental impact?

We used scenarios because they help analyse different research outcomes and identify basic trends and uncertainties. They can funnel the avalanche of available data. Each scenario tells a story of how various elements might interact under certain conditions. This way we could capture the range of possibilities and challenge the prevailing mind-set by presenting alternative narratives. The scenarios helped us to investigate the possible future of PPW recycling.

Recycling systems in the Netherlands

The complexity of PPW recycling is partly due to the wide variety of recycling schemes that exist in the Netherlands. In essence, there are two major systems, source separation and post-separation. The complexity increases as these different systems are used within a given municipality in various combinations. To add to the complexity, there are different taxation schemes associated with household waste management, which influence the collection system and the waste collection responses.

For this study we discern the following types of systems, all of which are integrated in our calculations:

- Source separation: drop-off collection
- Source separation: kerbside collection
- Post-separation (or recovery)

Source separation means that plastics are kept separate from the other waste in the household and are subsequently collected separately. Post-separation means that plastic gets separated in recovery facilities, after the combined collection of plastic waste and other household waste (so-called municipal solid residual waste or MSRW).

There is also the distinction between Diftar (differentiated tariffs – tax scheme) versus non-Diftar recycling schemes. Diftar can be used in all three separation systems mentioned above. The presence of such a diftar system has a strong influence on the composition of the MSRW and the separately collected waste streams. This leads to six possible recycling systems.

Introducing the scenarios

Seven scenarios were used in this study. They are based on relatively incremental system changes and realistic estimations of future response levels, based on experiences in other European countries. They represent narratives of achievable, feasible and foreseeable futures in PPW recycling schemes. All scenarios were discussed with political and industrial stakeholders during the study.

1 – Reference scenario
PET deposit refund system for soda and water bottles > 1.0 litres only. No PPW recycling from households.

2 – Start-up scenario (2010 situation)
PET deposit refund system for soda and water bottles >1.0 litres and PPW recycling from households as in the 2010 situation (both source- and post-separation). This represents a young (start-up) system. For this scenario publicly available data was used.

3 – Baseline scenario (estimation of 2013 situation)
Estimation of 2013 situation with realistic combination of source and post-separation by municipalities, a small increase in response rates and the addition of a recovery site at the waste treatment centre near Rotterdam. Including PET deposit refund system for soda and water bottles > 1.0 litres. (In hindsight we can conclude that this recovery facility in Rotterdam has not been built yet, but at the time of this research 2011, this was foreseen)

4 – Baseline minus deposit refund scenario
Baseline scenario (scenario 3) without the PET deposit refund system for soda and water bottles > 1.0 litres.

5 – Post-separation Plus scenario
This scenario explores the situation in case of a significant rise in post-separation. New recovery facilities have been achieved in Rotterdam and Amsterdam and serve the four main cities (Amsterdam, Rotterdam, the Hague and Utrecht). Additionally the post-separation yields are realistically increased from the baseline scenario. Source separation and deposit-refund remain unchanged compared to baseline scenario 3.

6 – Source separation Plus scenario

This scenario explores the situation in case of a significant rise in source separation. The average municipal response levels for collection are increased to 55% (this percentage is based on evidence as maximally achievable increase in a voluntary source separation system in European countries such as Austria, Germany and France.). Post separation and deposit-refund remain unchanged compared to baseline scenario 3.

7 – 100% post-separation scenario
All PPW is separated and sorted via the post-separation system. The deposit-refund for PET bottles is abolished. In order to handle the increased volume of PPW, recovery facilities are added to all Dutch waste incinerators. There is one exception: the Drechtsteden (Dordrecht, Zwijndrecht & Papendrecht, combined in the old AVI installation of Gevuco) stick to source separation.

Filling in the data: results of the study

To calculate the environmental consequences and the costs of the Dutch PPW recycling scheme, we needed technological mass balance data: data on the composition of different waste flows and the volumes of MSRW and PPW in the current situation. We also needed to unravel the logistics of the current recycling systems.

Technological mass balance results

The mass balances of PPW-flows in the different scenarios were studied. This provided us with a technical description of the material flow going through the system, and the volumes, processing yields and composition information in the system for all scenarios.

The baseline responses were derived from Nedvang data, collected via reports filled out by the municipalities. Data were taken from these so-called municipal datasheets, which describe the response levels and systems of recycling in all Dutch municipalities. To create a mass balance of the various steps in the chain we used primary experimental data to calculate yields and composition. These data were coupled with a general technical datasheet based on primary experimental data.

All mass balance data were kept constant for all seven scenarios, except for the parameters of PPW recycling systems, which vary between the scenarios.

Table 1 shows the amounts of collected municipal solid refuse waste and various types of plastic packaging waste for all seven scenarios. The amount of MSRW was kept constant for all scenario's in 2013, to facilitate comparison and prevent circle calculations.

Table 1 : Overview of the total amounts collected per scenario

Scenario	Total MSRW [ton]	Total source separation [ton]	Total post separation [ton]	PET deposit refund system [ton]	PPW separated [ton]	PPW collected [kg/cap.]
Scenario 1	3,800,000	n.a.	n.a.	26,600	26,600	1.6
Scenario 2	3,860,000	83,086	9,514	26,600	119,201	7.2
Scenario 3	3,800,000	100,263	39,758	26,600	166,621	10.0
Scenario 4	3,800,000	114,649	44,581	n.a.	159,230	9.6
Scenario 5	3,800,000	94,651	105,618	26,600	226,869	13.6
Scenario 6	3,800,000	166,013	31,441	26,600	224,054	13.4
Scenario 7	3,800,000	1,038	325,585	n.a.	326,623	19.6

n.a. = not applicable

The data from this table is sourced from databases by CBS, Stichting Nedvang , and own experimental data and estimations by Wageningen UR FBR

The total amounts of PPW collected separately, recovered PPW and collected PET bottles from the deposit-refund system are shown per scenario. All PPW is also added together and presented in amounts collected per inhabitant per year. These amounts include the moisture and dirt attached to the PPW (moisture and dirt present in PPW accounts for 18.5 % in Diftar and 8.0 % in non-Diftar municipalities).

The sorting and reprocessing yields of the separately collected PPW and the recovered PPW differ slightly, due to the differences in composition. Although post separation recovery schemes can collect more material, due to the slightly lower reprocessing yields the differences between separate collection and post separation are smaller when comparing the amounts of produced milled goods and agglomerates that each system yields.

As there are losses in each step of the recycling process, yields are never 100%.

Table 2: Overview of the collected amounts of PPW per scenario and system

Scenario	System	Collected amounts, [kton]	Sorted recyclable fractions, [kton]	Produced milled goods and agglomerates, [kton]	
1	dr	26.6	26.6	22.8	22.8
	sc	0	0	0	
	re	0	0	0	
2	dr	26.6	26.6	22.8	79.5
	sc	85	65	51	
	re	9.5	8.7	5.7	
3	dr	26.6	26.6	22.8	111.4
	sc	100	81	64	
	re	39.7	37	24.6	
4	dr	0	0	0	100.9
	sc	114	93	73	
	re	44.6	42	27.9	
5	dr	26.6	26.6	22.8	151.7
	sc	95	76	61	
	re	105.6	101.5	67.9	
6	dr	26.6	26.6	22.8	149.7
	sc	167	135	107	
	re	31.7	25.2	19.9	
7	dr	0	0	0	213
	sc	1.0	0.8	0.67	
	re	325.6	318	212	

Including the amounts of sorted recyclable fractions and produced milled goods and agglomerates.
Dr = deposit refund
Sc = separate collection
Re = recovery or post-separation

Technological mass balances: comparing the scenarios

A comparison between the reference and start-up scenarios (1 and 2) shows that the plastic collection scheme introduced in the Netherlands in 2010 resulted in four times more collected plastic packaging waste than the PET bottle deposit refund system alone.

The base scenario for 2013 (scenario 3) includes only a moderate maturation of the separate source separation collection and post separation systems. Response increases from 5.8 to 6.7 kg/cap.a (per person per year) on average compared to scenario 2. Additionally, the system is expanded with one recovery line at MSWI Attero Wijster and one at AVR Rotterdam, which results in 39.7 kton of PPW recovered material instead of 9.5 kton for scenario 2.

This means that the total PPW system can be optimised with relatively little effort, when moving from the start-up phase to a more mature system.

The abolishment of the PET bottle deposit refund system in scenario 4 results in a partial shift of the PET bottles to the system of source separation and post separation. As is visible in table 2, this hardly results in a loss of total PPW collected.

In case the post separation system is expanded further, by adding three large cities and keeping the deposit refund system (scenario 5), the total amount of collected PPW rises by over a third compared to the 2013 scenario (3).

Should the current separate collection system be matured to its expected maximum (scenario 6), the total amount of collected PPW is almost equal to what can be expected of the expanded post separation system (scenario 5).

Scenario 7 describes what would happen should we make maximum use of post-separation and abolish the separate collection and deposit refund systems. In this case the total yield can grow to a maximum of about 20 kg PPW recovered per inhabitant each year.

The three collection systems (deposit refund, separate collection and post separation) cannibalise each other; expanding one of the three systems will automatically result in lower collection results for the other systems. This means that efficiency in PPW collection can be achieved by lowering the number of collection systems within the overall recycling scheme. At the same time, recovery can also be improved by introducing better technologies in post-separation. This could render much higher yields than are presently achieved. If no system changes or technological improvements are implemented, raising response levels by motivating civilians is the only option to improve yields.

The scenario comparison shows that maturation and expansion of the separate collection scheme and the post separation scheme can help to raise the amounts of PPW collected. Maximum post-separation – without a collection or deposit refund system - would result in the highest amounts of PPW collected.

Logistics results

The two Dutch collection systems – source separation and post-separation - differ in channel choice and facility requirements. Post-separation requires less infrastructure (bins, trucks, etc.), as all waste is combined in the same bin. The main problem with collecting plastic waste is that you basically spend a lot of time and money transporting voluminous but lightweight waste. In other words: you are shifting air. The efficiency of recycling logistics is mainly dependent on whether you are able to make efficient use of the loading capacity of the trucks and bins.

We compared source- and post-separation in terms of transport-efficiency and air emissions. Two different models were used to calculate the logistics of the different scenarios. We needed two different models as the characteristics of the two parts of the logistical chain are very different. The kilometres driven were essential to calculate the costs per ton of PPW collected.

- a collection model was used to calculate the logistical parameters of the collection of plastic at household level within municipalities;
- a network model was used to model plastic flows from municipalities to re-processors of the separated plastic fragments. Different size trucks are used for this part of the recycling chain.

The input for both models is based on the results of the technological mass balances. The values of other variables and parameters are derived from literature and/or collected during interviews and conversations with industry, municipalities and researchers. We used ten types of municipalities as proxies to calculate the logistical data (5 levels of urbanization and the presence of a Diftar system or not).

Collection and network logistics

As it is impossible to collect data for each collection route in the Netherlands, a comprehensive cost model was created. The collection-cost model is based on fixed and variable costs per vehicle, personnel costs, container or bag costs as well as emission costs. Each element is divided into parameters which include kilometres, fuel usage, time and quantities in such a way that cost factors can be allocated.

On average, the total collection cost per ton of plastic waste collected for source-separation municipalities is more than two times that of post-separation municipalities. This is because plastic is a lightweight material with a large volume. When plastic is collected separately in source-separation municipalities, the collection efficiency is much lower and air emissions are much higher than in post-separation municipalities.

Personnel costs are another important factor in the total costs for both collection methods. It is relatively higher in kerbside collection as three people man these trucks, whereas in drop-off collection trucks you only need a driver.

The collection trucks should be at least about half full in order for the collection to be eco-efficient. Collecting more plastic by kerbside collection can decrease the total costs, thanks to the economics of scale that can be achieved. The current collection trucks have enough capacity to collect more plastics. Higher response-rates can improve the eco-efficiency of collection trucks. For urban municipalities, more households aggregating their plastic bags for kerbside collection can help reduce the collection cost.

In case of drop-off collection: the better a drop-off container is filled, the lower the total costs are. If the utility rate falls below 50%, the collection can become very inefficient.

Table 3: Total kilometres driven in each scenario (collection + network logistics)

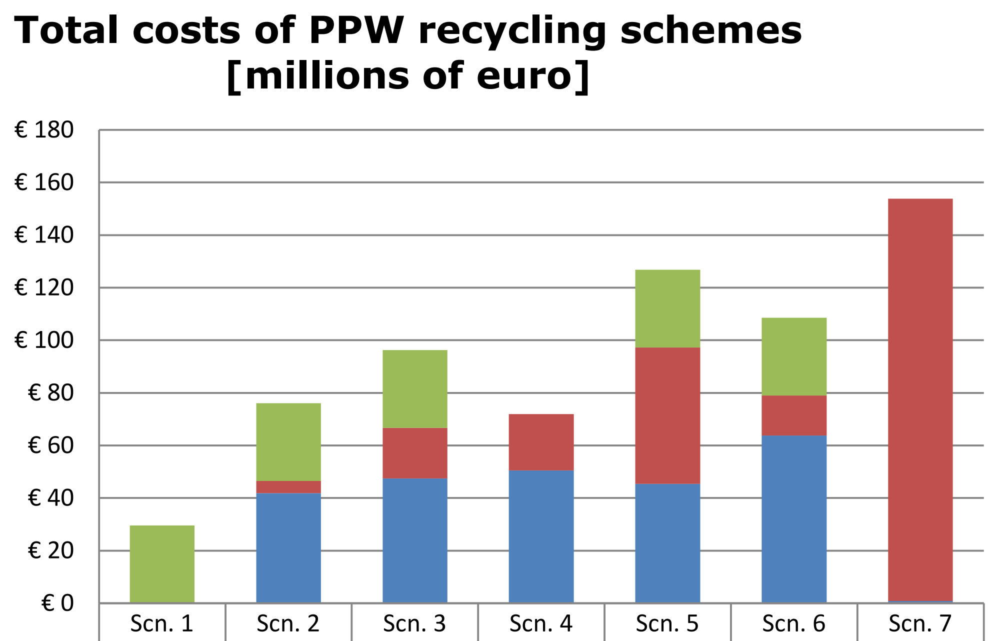
Scenario	Source separation	Post separation	Deposit refund	Total
1	0	0	3,911,499	3,911,499
2	1,723,350	238,781	3,911,499	5,873,630
3	2,013,694	1,130,689	3,911,499	7,055,882
4	2,326,988	1,333,956	0	3,660,944
5	1,862,692	3,206,886	3,911,499	8,981,077
6	2,520,084	1,045,860	3,911,499	7,477,443
7	25,267	10,846,560	0	10,871,827

Most differences between scenarios in terms of kilometres driven are due to different amounts of plastic in each scenario and per collection scheme. The abolishment of the PET refund system in scenario 4 results in the lowest number of kilometres driven. Scenario 7 is the scenario with the largest amount of kilometres driven. The potential cost savings on the whole PPW recycling system by optimising the collection logistics are estimated to be high.

Economic results

The technological mass balances and the logistics results combined, provided us with an insight into the economic consequences of each scenario. Economic modelling was carried out to calculate the results for each of the seven scenarios. At points in the supply chain where one type of product is transformed into several other products and waste flows, mass balances were used to determine the amounts. These mass balances were based on our own tests and calculations.

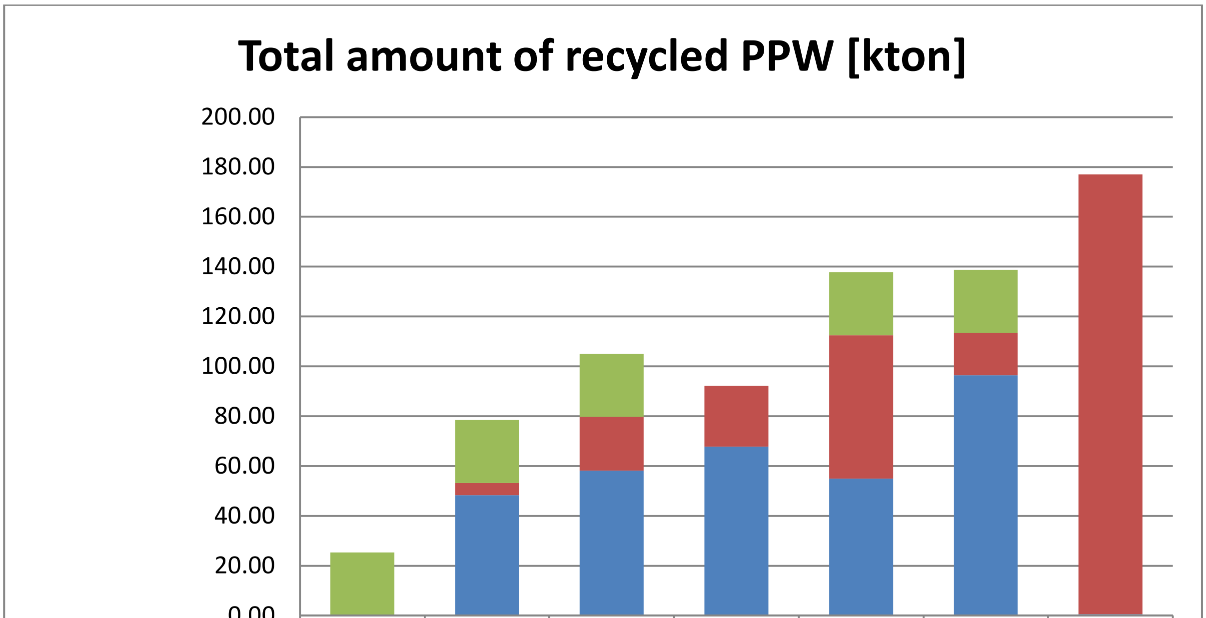
As we saw before, scenario 1 (without any PPW separation other than the PET deposit refund system) has the lowest performance in terms of PPW recycling. Scenario 7 (full post separation) has the highest performance. The figure below presents the total costs of the PPW recycling schemes for each scenario. Simply put: the more PPW is recovered, the higher the costs.



	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
PET Deposit Refund	€ 30	€ 30	€ 30	€ 0	€ 30	€ 30	€ 0
Post separation	€ 0	€ 5	€ 19	€ 21	€ 52	€ 15	€ 153
Source separation	€ 0	€ 42	€ 47	€ 50	€ 45	€ 64	€ 1

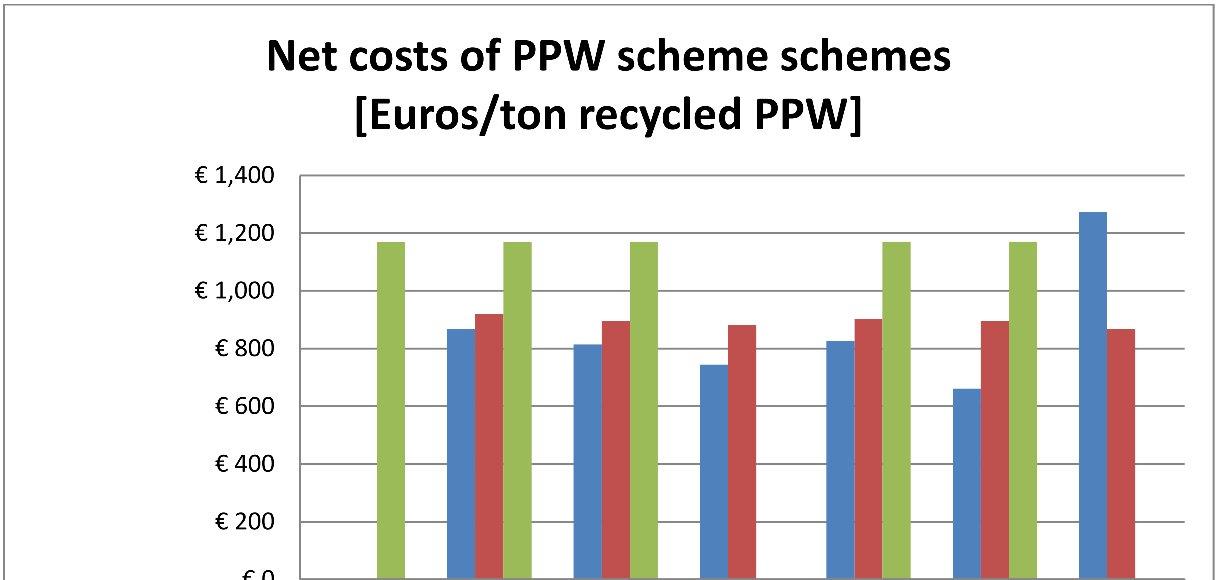
Figure 2: Total costs of PPW recycling scheme, in million Euros

When we look at the specific costs (expressed in Euros per ton of PPW collected), the results between the scenarios are quite constant for post separation and vary strongly for source separation. Note that in source separation lower costs per tonne are made when more plastic is collected. The PET deposit refund system has a higher cost per tonne compared to the other systems.



	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
PET Deposit Refund	25.27	25.27	25.27	0	25.27	25.27	0
Post separation	0.00	4.93	21.48	24.32	57.54	17.03	176.38
Source separation	0.00	48.24	58.22	67.80	54.96	96.40	0.61

Figure 3: Total amount of recycled PPW in ktons



	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
Source separation	€ 0	€ 869	€ 814	€ 745	€ 825	€ 661	€ 1,273
Post separation	€ 0	€ 920	€ 895	€ 882	€ 902	€ 896	€ 868
PET Deposit Refund	€ 1,169	€ 1,170	€ 1,170	€ 0	€ 1,171	€ 1,170	€ 0

Figure 4: Net costs of PPW recycling schemes in Euros per ton recycled PPW

The costs of recycling PPW differ somewhat per scenario, because of different costs of collection and hauling in the various municipalities. The costs are lowest in case of a source-separation system with hotspots (drop-off points) as this type of collection is most cost-efficient. The costs of incinerating MSRW are not included in the chain costs analysis and our model.

The costs for the post separation of PPW from MSRW depend strongly on the recovery rate, several cost allocation choices, personnel cost and investment cost. As the recovery rate has increased from 2% of the MSRW in 2009 to about 6% of the MSRW in 2012, the specific recovery costs have been reduced significantly. Based on estimations of the costs that contribute to the recovery process, we established that the minimal specific costs would amount up to 200 €/ton. To be able to achieve this, it is necessary to recover several value fractions of PPW simultaneously.

Environmental impact

The environmental impact of various PPW recycling schemes can be calculated by the process impacts of the system and the avoided impacts of primary production. Process impacts are the environmental impacts from collection, separation, sorting, recycling and incineration. Avoided impacts are derived by replacing the need to produce from primary materials. Environmental performance was then calculated by deducting the avoided impacts from the process impacts. In short: Environmental impacts = process impacts – avoided impacts of primary production.

The important environmental impact categories that should be looked into when developing and testing new recycling schemes and waste management techniques are:

- Climate change
- Fossil depletion
- Toxicity (human- and eco-toxicity)
- Particular matter

The environmental data have been collected by Blonk Environmental Consultants or pulled from the Eco-Invent database (version 2.2). These include data on electricity production, recovery of heat and electricity at incineration, energy use of trucks, emissions and recovery of secondary materials.

A model was built to analyze the 7 scenarios which consist of a mix of collection systems and waste treatment options. Simapro software was used to calculate results on climate change, fossil depletion and human toxicity of incineration including recovery of energy. Also environmental results of processes like transport, production of plastics and energy use were calculated using Simapro and the EcoInvent database. Due to the system boundaries, this calculation cannot be considered as a complete Life Cycle Analysis, instead, focusing on the environmental impact of the PPW recycling itself from collection to milled goods.

The efficiency of separation or sorting can vary depending on the type of plastic. And in source separation, the consumer is also inefficient to a certain degree. The model takes these differences in efficiency into account. The model also accounts for varying amounts of wet and dirt, which are inherent to used plastic packages. The avoided emissions due to use of re-granulates and recovery of energy are also included.

The input data come from the technological mass balance research (see table 2). The amount of plastic for the total of the Netherlands was converted to the functional unit of 1000 kg of plastic packaging waste in municipal solid rest waste, including the wet and dirt fraction it contains when collected. The model calculated the impacts of climate change (in kg CO2 eq/ton), fossil depletion (in MJ/ton), human toxicity (in kg 1.4-DBeq/ton) and particular matter (in kg PM10eq) of each scenario. The results are expressed as ReCiPe-scores, using equivalence factors and weighing factors to calculate the environmental impact.

The results are found in Figure 5, which has a negative scale. This means the least amount of points on the scale represents the lowest environmental pressure (e.g. -20 being higher than -40). Please take into account that only part of the life cycle of the PPW has been used to calculate the environmental impact here.

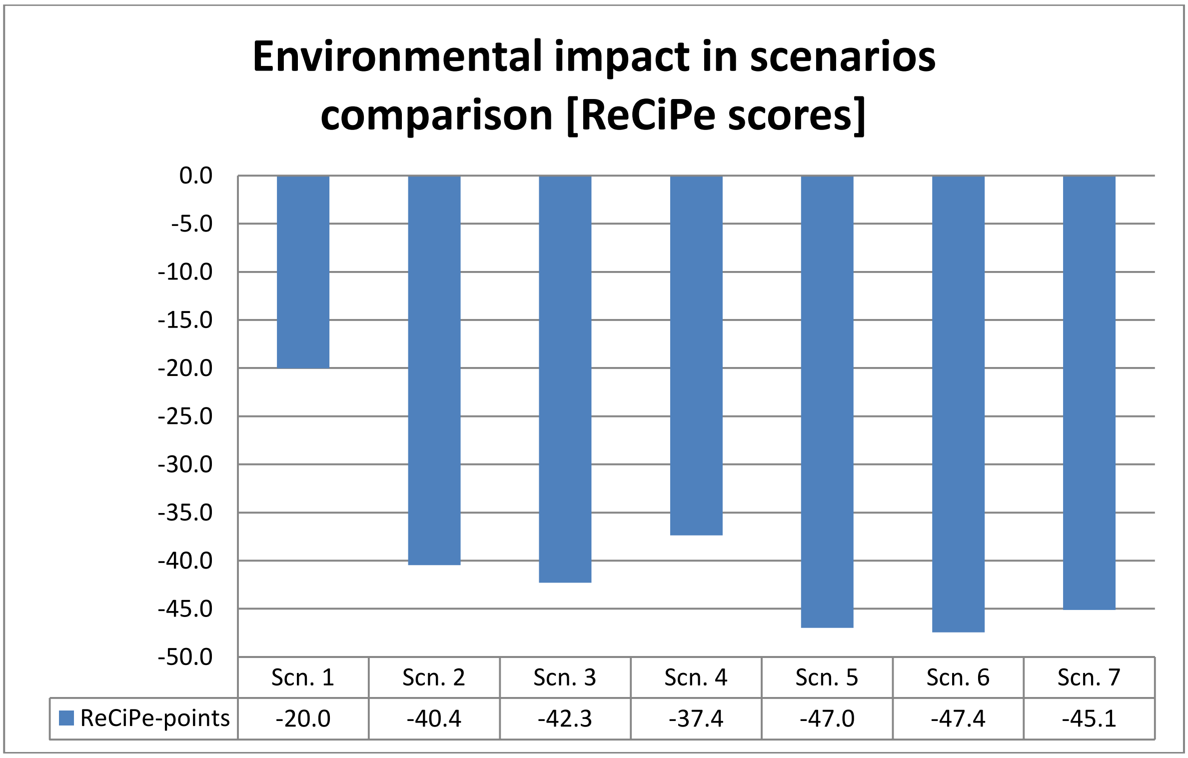
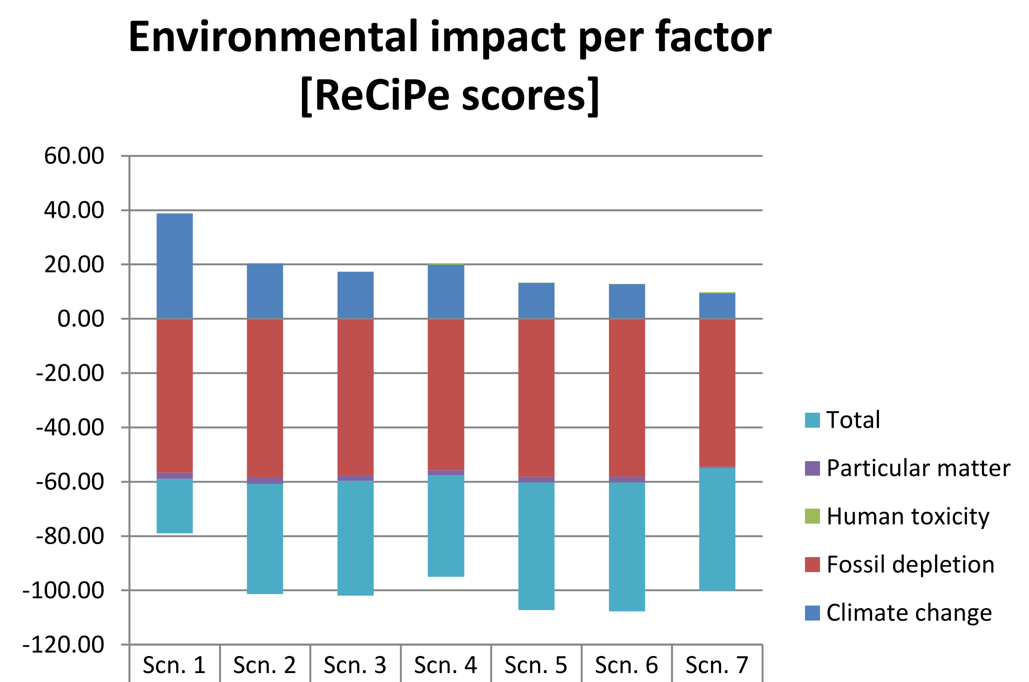


Figure 5: Scenario comparison expressed in ReCiPe Scores

In comparison, scenario 6 scores best according to the ReCiPe method, followed by 5, 7 and 3. More recycling of PPW generally leads to an improved environmental impact. It was found that

PET-recycling has the highest beneficial environmental impact, thus the scenarios including PET deposit refund are a bit more favorable from an environmental perspective. However, if the PET fractions can be sorted with higher yields within the source or post separation system, the environmental impact will also improve.

The ReCiPe scores were also calculated for each of the four impact factor categories, results are presented in Figure 6. Again, a negative score refers to a lower environmental impact. A positive score represents more environmental impact.



	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
Total	-20.01	-40.45	-42.30	-37.38	-46.97	-47.43	-45.12
Particular matter	-2.20	-2.39	-2.14	-1.86	-1.93	-2.12	-0.46
Human toxicity	0.29	-0.03	-0.01	0.30	0.09	0.07	0.38
Fossil depletion	-56.75	-58.45	-57.55	-55.75	-58.29	-58.12	-54.45
Climate change	38.64	20.42	17.40	19.93	13.17	12.73	9.41

Figure 6: Environmental impact per factor, expressed in ReCiPe scores

From figure 6 it becomes clear that the choice to implement a PPW recycling system has considerable environmental benefits. Scenario 1 is the least environmentally friendly, with a high climate change impact: all PPW is being incinerated. Overall, fossil depletion and climate change are the most important impact factors. Human toxicity and particular matter are only marginally contributing to environmental impact. Although there is very little difference between the fossil depletion score in the various scenarios, the climate change scores vary, because the reduced environmental pressure relates to higher yields of PET-recycling.

Integrated conclusion

- Of the total amount of 454 kton plastic packaging introduced on the Dutch market in 2010, about 48% was recycled (sum of post-industrial and post-consumer plastics). Separating PPW from household waste significantly reduces the environmental impact in terms of climate change, fossil depletion, human toxicity and the emission of particular matter.
- No matter which system of separation is used, the more PPW is recycled, the higher the costs. Economies of scale are hardly applicable because of the large share of fixed costs.
- The recycling results of both source separation and post-separation systems can still be improved in very significant ways.
- Source separated collection can be improved significantly and involves tailor-made solutions for each municipality. Kerbside collection can yield the highest response levels, but needs careful logistical planning to be cost-efficient. It is not feasible in traffic-congested areas and for high-rise buildings. Drop-off collection or post separation can be more efficient in the latter situations.

In short: costs can be reduced and PPW recycling can be almost doubled. As we are now gaining more and more insight into the recycling system, it is obvious that a lot still needs to be done. To improve recycling and reduce costs and emissions, all stakeholders need to cooperate and put in their best efforts. It is not sufficient that municipalities maximize their efforts; the packaging industry will also have to look at packaging designs and sorting facilities will have to produce more valuable fractions. When all stakeholders work together to take these steps, an almost cost-neutral plastic recycling system is within reach.

The way forward

Although the national debate has mainly focussed on the means of collection, the achieved recycling results in the past years have shown that not the system itself but the performance of the system is critical. Collection is critical and it really depends on local conditions whether or not a kerbside collection system, drop-off collection system or post-separation is practically feasible and economically executable. This insight has shaped the new framework treaty of June 2012 for the period 2013-2022 in which municipalities get freedom in their choice of system. From 2015 on the municipalities themselves become responsible for the sorting and the reprocessing and the recycling targets are gradually increased to 52%.

In general, the more recycling, the higher the total costs for PPW recycling. However, the costs per ton of PPW recycled (up to milled goods) can be significantly lowered. Abolishing the deposit refund system will lead to lower total costs of PPW recycling, but to a small decrease in

PET recycling. If the systems for source and post separation are extended and intensified, this loss will lessen and eventually turn around to result in a higher recycling percentage for PPW.

Notes on the data

The research described here, was performed with the data present at the time of research (mostly in 2010 and 2011). Some of the results are already obsolete due to for instance new and more accurate response data for 2011 and 2012 which are now available. Nevertheless, this analysis has increased the scientific understanding of the plastic packaging recycling network and yielded general insights which, although some underlying parameters have been changed, are still valid. It should be stressed that the conclusions of this research should be used inside the context of this research, meaning that we do not support generalisations or simplifications based on this research. This research programme has shown that the final results are determined by many individual parameters.

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List of Abbreviations

Diftar	GeDIFferentieerd TARief (differentiated tariff, pay as you throw scheme)
DIN	Deutsche Industrie Norm (german industrial standard)
DKR	Deutsche Gesellschaft für Kreislaufwirtschaf und Rohstoffe (German association for recycling and resources)
EPS	Expanded PolyStyrene
EVOH	Ethene Vinylalcohol
HHRA	HuisHoudelijk RestAfval (=MSRW, municipal solid refuge waste)
KVA	Kunststof VerpakkingsAfval
KWD	Kantoor, Winkel en Diensten (afval)
LAP-2	Landelijk AfvalbeheerPlan 2 (periode 2009 – 2021) (National waste management policy)
LOOPLA	Recycled PLA, trademarked by LOOPLA ®
MKS	MengKunststoffen (mixed plastics fraction)
MSRW	Municipal Solid Refuge Waste
NG	Niet Gezeefd (= ns, not sieved)
NIR	Near Infrared
NRK	Nederlandse Rubber- en Kunststofindustrie (Dutch rubber & plastics industry trade association)
nv	nat, vies (= wd, wet & dirty)
NVRD	Koninklijke Vereniging voor Afval- en Reinigingsmanagement (Royal Association for waste management)
PBT	Polybutyleneterephthalate
PC	PolyCarbonate
PCPR	Post-Consumer Packaging Recycling
PE	PolyEthylene
PET	PolyEthylene Terephthalate
PLA	PolyLacticAcid
PP	PolyPropylene
PPR	Plastic Packaging Recycling
PPW	Plastic Packaging Waste
PS	PolyStyrene
PVC	PolyVinylChloride
REPLA	Recycled PLA
SRN	Stichting Retourverpakking Nederland (Foundation Return packaging Netherlands)
UMP	Uitvoerings- en MonitoringsProtocol (Implementation & monitoring protocol)
VNG	Vereniging Nederlandse Gemeenten (Association of Dutch municipalities)

1- Introduction

1.1. Background of the study

1.1.1. Packaging, waste and sustainability

Over the past decades, the sustainable use of resources has become a major topic within policy, industry and society. Here, sustainability includes the efficient use of resources ('doing more with less') both from a material and economic point of view, and using them with as little negative environmental and social impact as possible. Although sustainability includes a long term and global perspective, it also has consequences on actions and decision made today.

One of the major uses for materials such as paper, cardboard, glass, sheet metal and plastics, is packaging: used as housing or wrapping for food or other products (serving as protection, containment, agglomeration, informing, marketing, preserving and transporting). Packaging can be described as a *coordinated system* of preparing goods for transport, warehousing, logistics, sale, and end use. An important sustainability issue with regards to packaging is the fact that most packaging are discarded after single use as packaging waste. It is no surprise that much household waste consists of packaging: it estimated that about 1430 kilo ton (kton) of packaging ends up in the waste bin every year (CBS, 2001, Ministry of Environment), which accounts for about 36% of all household waste. Since on average only 50% of this household packaging waste gets recycled, the relevance of the issue is clear.

Confronted with (long term) scarcity of resources (both economic as physical), including fossil based materials, various stakeholders have initiated measures for efficient use of resources and the prevention and reduction of packaging waste. There are various approaches for this, in which the Dutch government has embraced in its National Waste Policy Plan (2004) a 'Waste Hierarchy'. It is used to model ambitions, instruments and regulations, and is also supported by industrial and societal stakeholders as leading mechanism. The hierarchy is included in the principal Environmental Regulation ('Wet Milieubeheer', art. 10.4, 1993) and can described as follows:

1. Prevention: the generation of waste is prevented
2. Design for useful application: only materials that have no or as little as possible negative effects for the environment are used in the design and production of materials or products
3. Product reuse: materials and products are reused without remanufacturing
4. Material reuse: materials and products are remanufactured and then reused in new applications
5. Energy recovery: materials and products that are discarded are used as fuel for energy production.
6. Incineration: materials and products that are discarded are burned for disposal
7. Landfill: materials and products that are discarded are disposed via landfill

Within this research project, we focus on the end-of-life phase of plastic packaging, plastic packaging waste (PPW) from households. This material type has a relative short history of recycling (since 2008 for households) compared with other materials. Given the complexity of the issue, more insight in the post-consumer plastic packaging recycling is called for.

The TI Food & Nutrition project Post-consumer Plastic Packaging Recycling (SD001) focuses on developing an integrated scheme for analysis of the recycling of plastic packaging waste (PPW) from households in the Netherlands from a technological, logistical and environmental perspective. By analysing the existing scheme for recycling and by comparing it with various scenarios, the project team was able to create more insight on the system economic and environmental performance and improvement points for PPW recycling. The project aims to understand these chains of packaging waste processing scientifically and to evaluate them in terms of environmental benefits and societal costs.

Post-consumer packaging waste collection and recycling chains are complex and poorly understood on a scientific level. The main benefits of the project are:

- that more factual technical parameters will become available for scientists, giving the opportunity to other scientists to study and analyse plastic packaging recycling chains,
- developing models that can be used as decision support tools for the improvement of efficiency, profitability and sustainability of the packaging waste collection, sorting and reprocessing network,
- making reliable information on the costs and performance available on a system-level, rendering the possibility of minimising environmental impacts and costs. On a national level this can improve the competitiveness of the industry to some extent.

The objective of the scenarios study is to establish an integrated scheme on post-consumer plastic packaging recycling in the Netherlands and perform a scenarios analysis to study technical aspects, system costs and environmental impact in different settings (recycling scenarios for PPW). New options for improving the PPW recycling system will also be discussed in this report.

In 2011, a first short analysis and scenarios comparison was made by the project team, based on the available response data for municipal collection of PPW in 2009. This analysis served as try-out for developing the technological mass balance data and logistics collection and network model, and to address the parameters for the environmental performance analysis. As the response data of 2009 was heavily influenced by the start-up phase of the source separation system for municipal collection, these data were too full of omissions to base meaningfull conclusions on its analysis. Therefore, it was decided to do a second round of scenarios studies, based on response date of 2010/2011. This study is placed against the backdrop of the negotiations surrounding the Second Framework for Packaging for the period 2013-2022 (Ministry of Infrastructure & Environment).

1.1.2. Political context for PPW recycling

In the Netherlands, about 60 billion kilograms of waste are produced annually. The Dutch government strives to reduce the amount of waste produced and to enhance the reuse and recycling of waste materials. This is a matter of concern for all stakeholders involved: government, industry, and society. Since the mid-90s, a number of policy initiatives and instruments have been developed to stimulate the recycling of post-consumer plastic packaging waste. A timeline is included Figure 7.

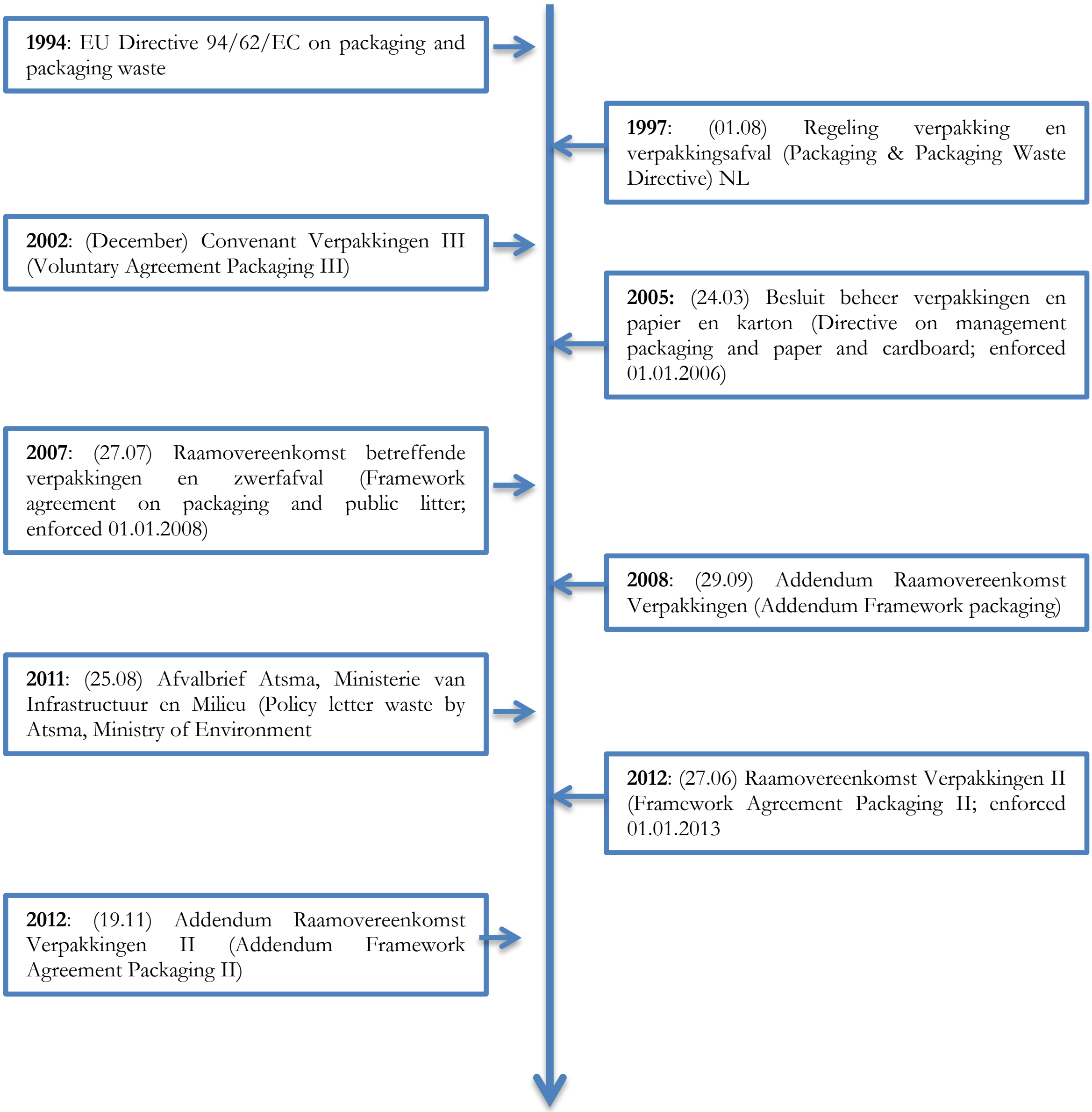

Figure 7: Timeline political context PPW recycling

Up to 2008 the Netherlands primarily recycled post-industrial plastic packaging waste (PPW) and had implemented a deposit refund system for the majority[1] of the large PET bottles from the households (which was mandatory by decree). The post-industrial PPW recycling scheme had grown autonomously; it was simply cost efficient for businesses to recycle their PPW. This is

[1] For PET bottles filled with water and soda drinks, but not those filled with juices, etc

organised by a multitude of collection services, sorting facilities and converting industries. According to the association of the involved companies (NRK) the amount of post-industrial PPW collected amounted 173 kton and the amount of produced recyclates amounted to 157 kton/year[2] The largest deposit refund system (SRN) collects roughly 25 kton of PET bottle waste annually and produces about 20 kton of RPET regranulate. Additionally two small independent deposit refund systems (Aldi and Lidl) do not publically report their results.

In 2006 a new packaging waste law[3] came into force in the Netherlands. This law introduced producer responsibility for all types of packaging waste in the Netherlands and set a number of recycling targets for packaging waste in the future. In the subsequent framework agreement of 2007 between the ministry, the association of municipalities and the representatives of the producers of packed goods the recycling targets for all the plastic packaging waste were redefined as gradually increasing from 38% in 2009 to 42% in 2012 (Raamovereenkomst betreffende verpakkingen en zwerfafval). Conflicts and issues arose when it was discovered that the newly introduced producer responsibility contradicted largely with the municipal caring duty for organising waste management. These conflicts have still not been resolved completely. The Stichting Nedvang was founded to advocate the producers' responsibility and to implement the arrangements stated in the Raamovereenkomst (communication campaigns to households, monitoring the performance of the system and to organise the sorting and reuse of collected fractions of PPW).

In 2008 the first pilots were performed with source separation municipal collection of PPW from households, resulting in 8 kton of collected PPW. In 2009 more municipalities started to contribute to this Nedvang system and the amount rose to 23 kton and in 2010 almost all municipalities contributed and 83 kton post-consumer PPW was collected. This fast rise of this separate collection system for PPW from households is a large success for the operational organisation Nedvang.

Another issue that impeded the implementation of the Nedvang separate collection system in 2007 to 2009 was the opinion of several municipalities that a comingled collection of MSRW together with PPW followed by the automatic separation of the PPW from the MSRW would be more efficient than separate collection. As political compromise two existing material recovery facilities in Friesland and Groningen were allowed to recover plastic packaging waste from MSRW and entitled to obtain a fee for the produced plastic concentrates. These recovered plastic concentrates were supplied to sorting companies. In January 2011 a newly build recovery facility in Wijster for PPW became available, but this facility was not granted a fee for the recovered PPW. Nevertheless, during 2008-2011 a very lively debate on source separation versus post-separation dominated the Dutch waste symposia and this slowed decision making process down within municipality on the introduction of PPW collection schemes.

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[2] Nedvang "Monitoring verpakkingen, resultaten 2010", Rotterdam, 7 september 2011.

[3] Besluit verpakkingen en papier en karton, of 25 March 2005.

From 2009 – 2012 a number of reports were published (commissioned by diverse stakeholders[4]) to evaluate the new arrangements for PPW recycling and the (cost)effectiveness of different collection systems. Although thorough, all reports wrought with data accessibility and transparency issues, resulting in results which should be carefully interpreted.

With high stakeholder interests at stake, an objective and factual approach on system performance analysis and comparison can clarify the difficulties in analysing the complex system of PPW and provide integrated technological, logistical and environmental insights.

In 2011 en 2012 the stakeholders to the first Framework Packaging (*Raamovereenkomst Verpakkingen en Zwerfafval 2008-2012*), including the Ministry of Environment, VNG (association of Dutch municipalities) and the packaging industry, are negotiating a new framework for the period 2013-2022. The results of the scenarios study will feed in the discussion on the rational-economic arguments concerning recycling-rates, technical, logistical and environmental performance of the recycling system and given alternatives.

1.1.3. Plastic packaging waste in NL

One of the complexity issues surrounding the recycling of post-consumer PPW, is the data availability on the amounts of plastic packaging on the market. In order to analyse the cost effectiveness and environmental impact of the PPW recycling system, basic data requirements on the origin and generation of plastic packaging waste are necessary. The most commonly reference on the presence of plastic packaging on the Dutch market is the Dutch Taxation Office (Belastingdienst, 2012) whose monitoring on the Packaging tax ("Verpakkingsbelasting") offers valuable insights. Their monitoring report on 2010 (issued in 2012) showed that 454 kton plastic packaging materials were brought on the market in 2010. However, some doubt surround these numbers. The Inspectie Leefomgeving Transport (Ministry of Environment, Department of Inspection of Environment & Transport) evaluated the Taxation Office data in 2012 and concluded that especially the data on post-industrial PPW are not accurate and therefore the data is not reliable enough to calculate exact recycling percentages on PPW in the Netherlands. They did conclude that the data on the collection of post-consumer PPW was reasonably accurate[5].

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[4] Including:

- HKT (2008). Kunststoffen verpakkingen van inzameling tot recycling – kosten en bate.
- KplusV (2008). Onderzoek gemeentelijke inzameling kunststof verpakkingen.
- KPMG (2010). Kostenonderzoek nascheiding kunststof verpakkingen uit huishoudelijk afval.
- CE Delft (2010). De milieueffecten van de verpakkingenbelasting.
- Bureau B&G / Recycling Netwerk (2010). De kunststofinzameling doorgelicht – opbrengst en perspectief in de steden.
- PWC (2011). Benchmark inzameling kunststof verpakkingsafval gemeenten.
- KplusV (2011). Evaluatie-onderzoek bron- en nascheiding verpakkingsafval.
- Agentschap NL (2011). Samenstelling van eht huishoudelijk restafval – resultaten sorteeranalyses 2010.
- NCDO (2012). Nederlanders & Afval

[5] Ministerie I&M - Inspectie Leefomgeving en Transport (2012). Hergebruik en monitoring verpakkingen nader bekeken.

Agentschap NL, as implementation agency for the Ministries of Economic Affairs and of the Environment monitors the national waste management data in cooperation with the Dutch national statistics agency (CBS). In various samples, they investigate the composition of household waste for data reference. In 2010 roughly 9.2 ± 1 % of the MSRW consisted of PPW[6]. This corresponds to 360 kton wet and dirty or roughly 275 kton PPW dry and clean[7] PPW. The amount of PPW generated by companies can then be calculated from the difference between the total amount and the amount in the MSRW, which would yield roughly 178 kton, including 28 kton PET bottles from the deposit refund system[8]. The amounts are visualised in Figure 8 below.

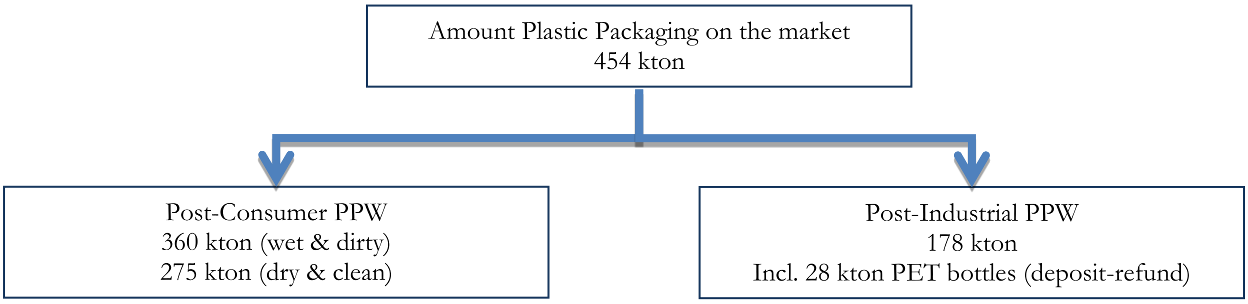

Figure 8: Amounts of Plastic Packaging (Waste) in the Netherlands

Currently, there do not exist publicly available data on the composition of Dutch PPW on the household level. The researcher performed a sorting analysis on the composition analysis of MSRW based on the city of Rotterdam in January 2011, in cooperation with Attero Wijster[9]. Up to date, Rotterdam has not implemented a source separation scheme for PPW, which provides insight on the situation prior to source separation. Although Rotterdam is not representative for the whole of the Netherlands, it is the only available detailed analysis of the composition of PPW at the households and is therefore used as reference point for this study.

[6] Agentschap NL (2011). Samenstelling van het huishoudelijk restafval, resultaten sorteeranalyses 2010.
[7] The amount of moist and dirt on PPW is estimated at 23.6%
[8] Reported by Stichting Retourverpakking Nederland; data from the deposit refund counting centers + estimation of the amounts in the privately organized deposit-refund system of Lidl and Aldi supermarkets.
[9] The results of this sorting analysis were published as "Thoden van Velzen, Jansen, M., 2011, Nascheiden van kunststof verpakkingsafval te Wijster: Massaalans van een nieuwe nascheidingsinstallatie". Wageningen UR, Food & Biobased Research (8 april 2011).

Table 4 shows a detailed insight on the composition of plastic content in Rotterdam's MSRW.

Table 4: Composition of plastic waste present in the MSRW of Rotterdam households in January 2011

Product type / material type	PET	PE	PP	PVC	PS	Total
Bottles	3.26%	1.29%	0.02%		0.02%	4.59%
Flasks	1.73%	3.65%	0.62%	0.09%		6.09%
Rigids	6.29%	0.86%	7.48%	0.38%	1.20%	16.21%
Flexibles	0.07%	36.01%	4.41%	0.11%	0.04%	40.64%
Laminated flexibles	0.26%	2.53%	1.21%	0.00%		4.00%
Non-packaging plastics	1.47%	5.29%	5.01%	1.84%	1.00%	14.61%
Undesired plastic packaging*		0.03%	0.01%	0.09%	0.60%	0.73%
Residual plastics**						13.14%
Total	13.08%	49.65%	18.75%	2.51%	2.87%	100.00%

The objects were first sorted by NIR and secondly manually. The percentages have been calculated from weights of the sorted fractions including attached moisture and dirt.

*** Residual plastics are mostly: black coloured packages and a small amount of PC, PLA objects.*

** Undesired plastics are: kit-tubes (PE), chewing gum and drug strips (PP, PVC) and expanded PS objects.*

The majority of plastic material in MSWR consists of flexible PE packaging, followed by PP and PET rigid packaging.

1.1.4. PPW recycling in the Netherlands

The complexity of PPW recycling is partly based on the wide variety of recycling schemes that exist in the Netherlands. In essence, there are two major systems, source separation and post-separation. Within the first system, households sort and store their PPW separately from other household waste (Municipal Solid Residual Waste – MSRW – in this study) and offer it separately to the waste collecting company. Within post-separation, PPW is collected together with MSRW (commingled collection) and separated at a waste treatment centre. For both systems, there can be drop-off or kerb side collection. Within drop-off collection, citizens bring their waste to a central location in their neighbourhood and drop it in a above or underground container. For kerb side collection, containers ("*kliko*"), bags or crates with the waste material considered are offered individually at street side.

The complexity increases as these major systems are combined within a given municipality in various combinations. To add to the complexity, there are different taxation schemes associated with household waste management, which influence the collection system and the waste collection responses. This taxation scheme, called Diftar (DIFferentiated TARiffs) has many faces itself: in principle, Diftar is based on the notion that households pay for the actual waste they discard, as opposed to a fixed tariff or municipal fee paid for waste collection. The calculation of the amount of actual waste can be done via e.g. volume (weighing) or number of actual collections. For this study we discern the following types of systems, which are integrated in our calculations:

- Source separation: drop-off collection
- Source separation: kerb side collection
- Post separation
- Diftar / non-Diftar

Figure 9 gives a schematic overview of PPW recycling in the Netherlands, starting from the packaging industry (producer of Fast Mover Consumer Goods, which packages [non-]food products) via retail, households, collection, separation, sorting and reprocessing towards the re-use of the recycled plastic content into new products, incl. bottles, trays, automotive plastics, textile, fibres, etc.

Glossary of terms:

SOURCE SEPARATION
Recyclable materials are stored, proffered and collected separately from households, through a:

(1) KERB SIDE COLLECTION
System in which recyclable materials, such as source separated plastic packaging waste, stored in separate bags, containers or wheeled bins, are collected per address.

or

(2) DROP-OFF COLLECTION
Source separated plastics are taken to a recycling center by the consumer himself. These recycling centers can include above ground as well as underground collection containers and can be located at central points in neighborhoods as well as near shopping centers/super markets.

POST SEPARATION / RECOVERY
at waste treatment stations (WTS)
is the (mechanical) removal of materials from household waste at a waste treatment station, in order to recycle these materials.

RECYCLING
Process through which materials previously used and discarded as waste are collected, processed, remanufactured and reused.

SEPARATION
Separating materials from household waste.

PROCESSING
Necessary processes to process materials from sorted material flows to a reusable secondary resource. Different types of technologies are available and usually include: milling, washing, heating, palletisation

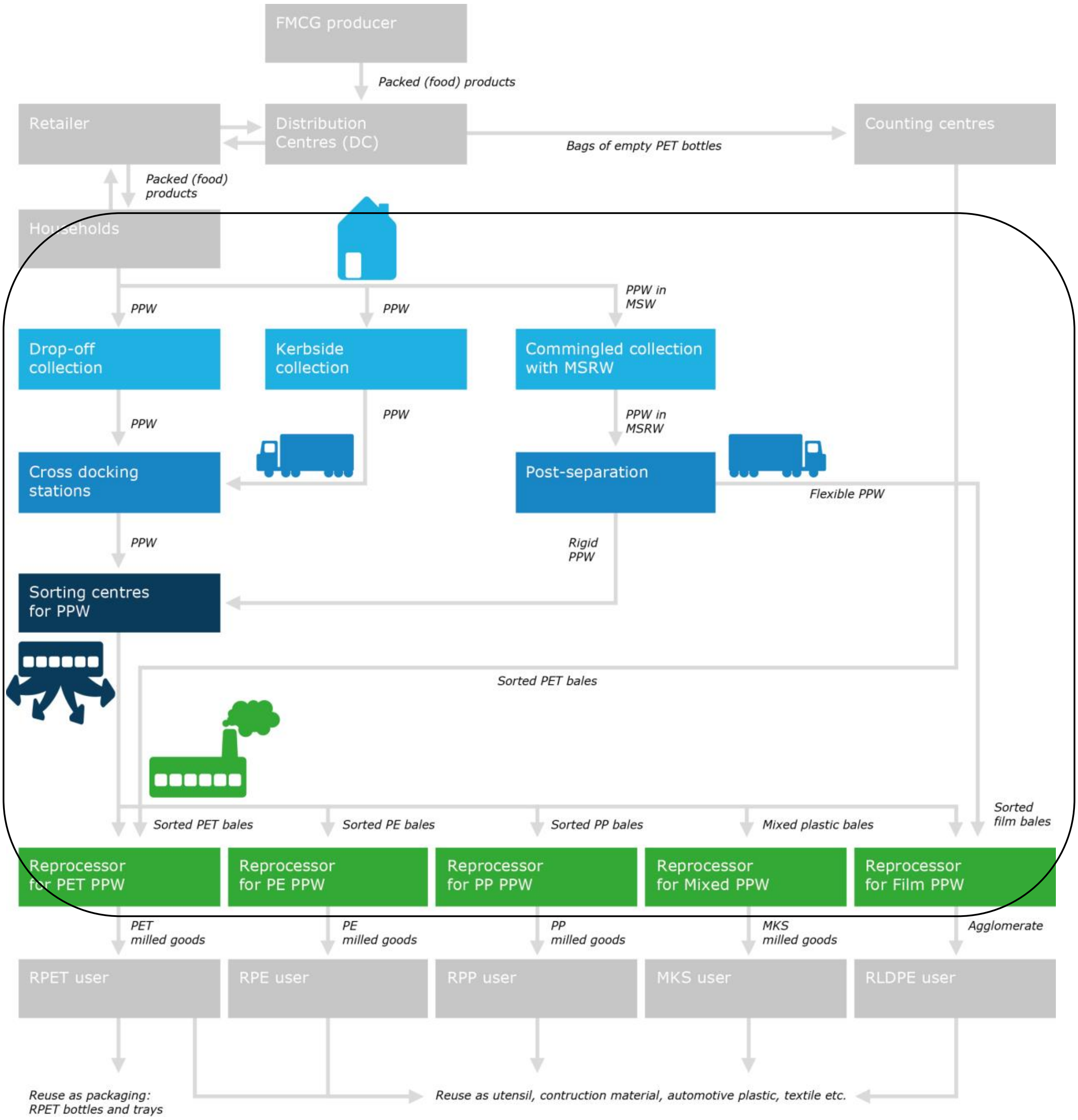

Figure 9: Schematic overview PPW recycling in the Netherlands

It is important to notice that, although the complete chain for plastic packaging and PPW recycling is larger, we focus our study on the steps in the chain, as indicated in Figure 3. The research scope is therefore from the collection of PPW at household level up to the production of milled goods. The commercial resell of milled goods to secondary producers of products is not included in our calculations.

1.2. Research approach

As stated in the introduction to this chapter, this research study aims to establish an integrated scheme on post-consumer plastic packaging waste recycling in the Netherlands and perform a scenarios analysis to study technical aspects, system costs and environmental impact in different settings.

The research underlying this report started in 2010 with describing the first contours of the Dutch recycling scheme and some preliminary calculations on various collection systems and costs mechanisms. At that point in time, very little research was done and/or available on PPW recycling and its system costs or technical merits. Since then, a number of studies have been published in the consultancy field, although lacking a sound scientific basis or the availability of primary experimental data.
With this scientific report, we aim to close this knowledge gap by presenting a new approach to calculate the cost-efficiency and environmental impact of PPW recycling. Taking it one step further, we also used the model of the integrated PPW recycling scheme to show various scenarios results, based on e.g. alternative (combinations of) collection schemes, variations in network logistics and using estimated response levels. Iterating on this early work, we integrated various disciplines to tackle the complexity of the recycling process: technological mass balancing, collection and network logistics and environmental performance calculations (limited LCA approach).

The results of this study should be placed against the backdrop of the political and societal developments surrounding the first framework for packaging (2007) and the consultation round on the second framework for packaging (by the Ministry of Environment) for the period 2013-2022.

Our research focuses on the following research questions:

- What are the technological mass balance properties of the recycling chain?
- What are the collection and network logistics properties of the recycling chain?
- What are the environmental impacts of the recycling chain?
- What are the economic costs associated with the recycling chain?
- How do baseline and alternative scenarios on integrated schemes compare on system costs and environmental impact?

The research was carried out following a scenarios study methodology integrating technological, logistics, economic and environmental disciplines (see Figure 10). The baseline scenario of the integrated model was established using our own primary experimental data, and the database of Stichting Nedvang on the response results of the Dutch municipalities, as was available on the year 2010 and 2011. Other variables were estimated based on publicly available information on costs and logistics.

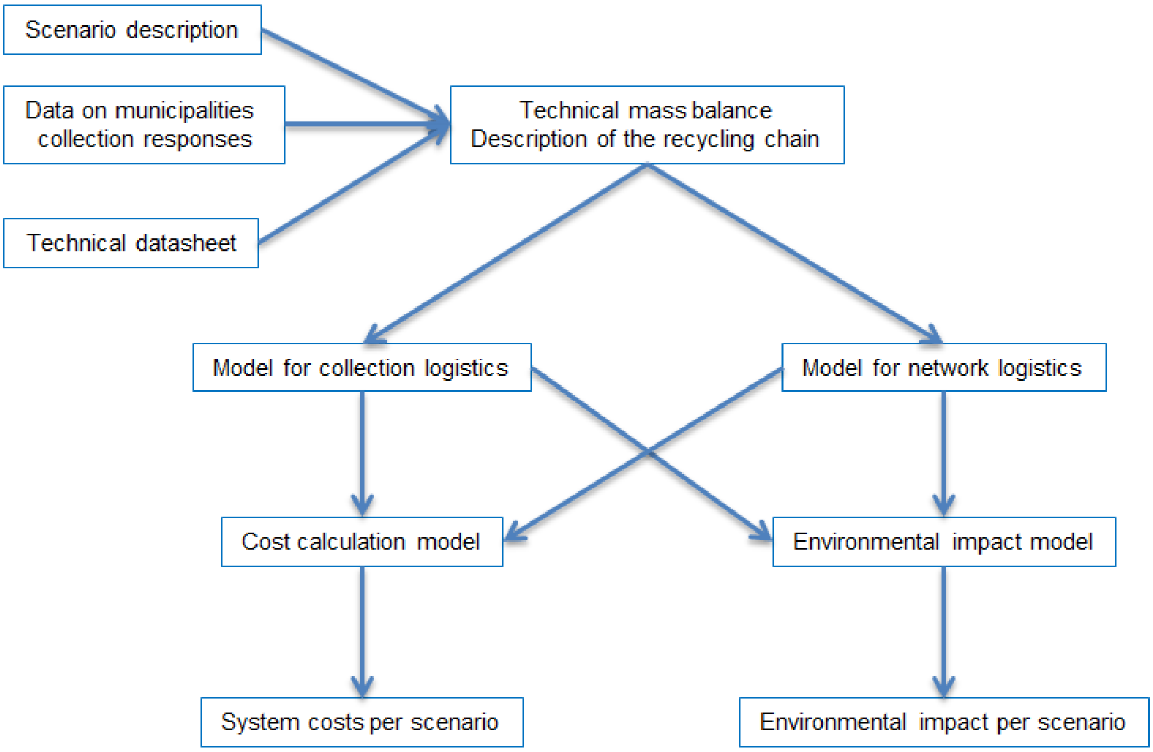

Figure 10: Schematic description of the followed methodology

1.3. Outline of the report

The remainder of this report is organised as follows: Chapter 2 describes the outline of the scenarios used in this study. Chapter 3 provides details the scenarios study methodology. The assumptions made on the technical mass balance data, logistics, economic and environmental modelling and calculation are presented in chapter 4. In Chapter 5 the results of the scenarios study are discussed, where chapter 6 ends with the conclusions based on this discussion. Chapter 7 closes with suggestions for improved recycling schemes for PPW in the Netherlands.

2- Scenarios for PPW recycling in the Netherlands: Methodology

2.1 Background

This research focuses on the description of the Dutch post-consumer PPW recycling scheme from the collection at household level up to the production of milled goods as boundary scope. The purpose is to describe an integrated scheme, to create a model in which different scenarios for recycling are compared on technical mass balance, logistics properties (both collection and network logistics), economic costs and environmental impact. The use of scenarios analysis serves multiple purposes:

- Identifying basic trends and uncertainties
- Challenging the prevailing mind set by presenting alternative narratives
- Investigating possible futures of issues, here: PPW recycling

Among the many tools stakeholders can use for strategic planning, scenario planning or studies stand out for their ability to capture a whole range of possibilities in rich detail. It simplifies the avalanche of available data into a limited number of possible states. Each scenario tells a story of how various elements might interact under certain conditions. When relationships between elements can be formalized, one can develop quantitative models. It should evaluate each scenario for internal consistency and plausibility. Although a scenario's boundary might at times be fuzzy, a detailed and realistic narrative can direct your attentions to aspects you would otherwise overlook. Scenarios attempt to interpret outputs of complex simulation models by identifying patterns and clusters among the millions of possible outcomes a simulation might generate. Hence, scenarios go beyond objective analyses to include subjective interpretations. In short, scenario planning attempts to capture the richness and range of possibilities, stimulating decision makers to consider changes they would otherwise ignore. It organizes such possibilities into narratives that are easier to grasp and use than great volumes of data[10].

Although scenarios studies can be used for alternative futures based on radical system or institutional changes, the researchers introduce here scenarios that are based on relatively incremental system changes and realistic estimations on future response levels, based on experiences in other European countries. These scenarios therefore represent narratives of achievable, feasible and foreseeable futures in PPW recycling schemes, and were discussed with political and industrial stakeholders during the study.

[10] Schoemaker, P.J.H., 1995. Scenario planning: a tool for strategic thinking. Sloan Management Review. Winter, pp. 25-40.

Table 5: Scenarios description

No.	Name	Description
1	**Reference scenario (<2008)**	No PPW recycling from households, only deposit-refund for PET bottles for water and sodas > 1.0 litres in place.
2	**Scenario 2010**	Based on the 2010 situation, using publicly available data on the presence of source and post-separation systems, including deposit-refund for PET-bottles for water and sodas > 10.5 litres.
3	**Baseline scenario**	2013 estimation, starting with the new Framework Agreement (2013-2022) situation), using a realistic combination of source and post-separation municipalities, with a small increase in response rates and the addition of a recovery site at the waste treatment centre near Rotterdam (planning installed by Attero).
4	**Baseline minus deposit refund**	Baseline scenario without deposit-refund for PET-bottles for water and sodas > 0.5 litres.
5	**Post-separation Plus-scenario**	The post-separation yields are realistically increased from the baseline scenario (% yield), as well as an inclusion of more participating municipalities (the big 4: next to Rotterdam also Amsterdam, Utrecht and The Hague). Source separation and deposit-refund remain unchanged from the baseline scenario.
6	**Source separation Plus-scenario**	The average municipal response levels for collection are increased to 55% (based on COUNTRY evidence as maxim achievable increase in a voluntary source separation system. Post separation and deposit-refund remain unchanged from the baseline scenario.
7	**100% Post-separation**	All PPW is separated and sorted via the post-separation system. In order to handle the increased volume of PPW to be separated, recovery treatment facilities are added to other Dutch AVIs (energy recovery/incineration facilities at Wijster, Moerdijk, Rotterdam, Amsterdam, Duiven, Alkmaar, Nijmegen, Hengelo and Emlicheim (D)). One exception: the Drechtsteden (Dordrecht, Zwijndrecht & Papendracht, combined in the old AVI installation of Gevuco) stick to source separation. Deposit-refund is abolished.

The scenarios are described in more details in the following paragraphs.

2.1 Technical data descriptions for the scenarios

This paragraph presents the work on the generation, composition and analysis of the technical data underlying the scenarios study. What type of data is generated, how did we do it, what is the usefulness of mass balancing for the project, how is it used, and how its outcomes should be interpreted

2.1.1. Data generation & analysis

An important aspect in this research is establishing a technical description of the PPW recycling schemes which are included in the scenarios. This technical description includes the material flow going through the system, and presents the volumes, processing yields and composition information in the system and its scenarios thereof.

To create these technical mass balances for each scenario, the researchers used three datasets: the description of the scenarios, a municipal datasheet and a general technical datasheet based on primary experimental data, see Figure 11.

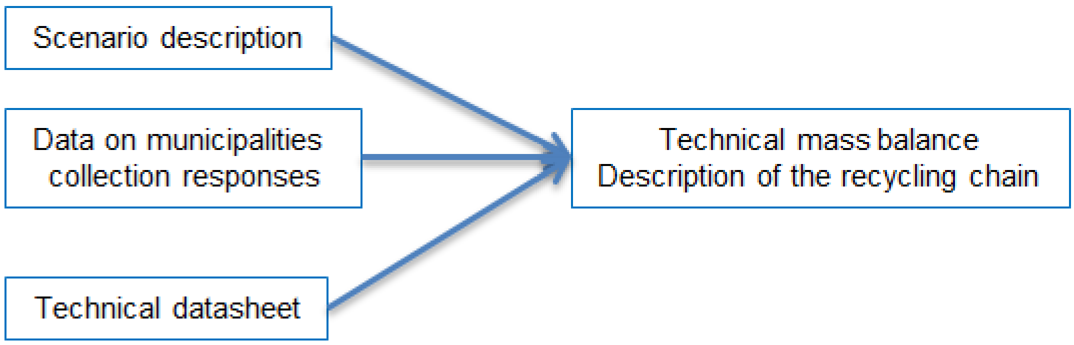

Figure 11: Data sources for the technical mass balance

<u>I: Detailed description for each scenario</u>

For all scenarios, a number of data variables need to be described, in terms of response levels, total amount of PPW present at the households, location of municipalities and recycling facilities (e.g. cross docking stations, waste treatment plants, AVIs, sorting companies, etc.), and types of primary and secondary PPW collection systems.

The two reference scenarios (1 and 2) were fairly straight-forward, since they are based on real life situations. The other scenarios needed additional information in terms of:

- The total amount of PPW present at the households. First of all, the available data was from and 2010 and needed extrapolation to 2013. Secondly, in a few scenarios (4, 7) the deposit-refund system is abolished and the amount of PPW had to be increased accordingly.
- The location of post-separation centres and their production
- The types of primary and secondary PPW collection systems for each municipality

II: Municipal data sheet

The municipal datasheet summarises the characteristics of all 418[11] Dutch municipalities using parameters relevant to recycling. They include the name of the municipality, the amount of inhabitants, the amount of connections (independent households), the type of primary PPW recycling system (source separation kerb side or drop-off, or post-separation) and wherever relevant, which type of secondary PPW recycling system (source separation drop-off or post-separation[12]), the type of municipal taxation scheme for MSRW collection system (Diftar or non-Diftar), the cross-docking station at which this municipality supplies its source separated PPW and the AVI (energy recovery plant/waste incinerator) to which the municipality supplies its MSRW. The sources of this information are shown below in Table 6.

Table 6: Municipal data sheet; its contents and sources

Parameter	Unit	Source
Municipality name	Text	CBS, Wikipedia
Geographical centre	Postal code	Wikipedia
Amount of inhabitants	Number	CBS, Wikipedia
Amount of connections	Number	Stichting Nedvang
Type of primary PPW system	[kerb side, drop-off, post-separation]	Stichting Nedvang
Type of secondary PPW system	[None, drop-off, post separation]	Stichting Nedvang
Connected cross docking station	Postal code	Research estimation using logistics software (proximity based)
Type of MSRW system	[Diftar, non-Diftar]	Stichting Nedvang
Connected incineration plant	Name facility	Waste companies

Due to the constant merging of municipalities much attention was paid to verifying the data for municipalities which merged in the period falling within the scope of the study. The list of AVIs was drawn with the help of various representatives from the waste management industry.

All data (with the exception of the PPW recycling systems) is kept constant for all the scenarios, except for the parameters on PPW recycling systems, which vary between the scenarios.

III: General technical datasheet based on primary experimental data

The general technical datasheet contains detailed data on the amount of PPW in the Netherlands, and volume responses, sorting yields and re-processing yields from the deposit-refund system, as well as of source separation and post-separation. source separation, post-separation and deposit

[11] Reference is 2010: due to municipal reorganisation, the number of municipalities in the Netherlands tends to decrease. This reorganisation is a political process and is difficult to predict. Therefore, this study freezes the number of municipalities at 418. Since the number of municipalities is not associated with the number of households or the collection yields within recycling, we assume that the influence of number of municipalities on the results of the scenarios is limited.

[12] Here, it is assumed that source separation kerb side collection of PPW only functions as primary system.

refund systems regarding responses, sorting yields and re-processing yields. These data are partially based on publicly available data (with regards to the PPW amounts and responses) and on data resulting from primary experimental data from studies performed by the researchers. They describe the situation in 2010 and therefore used as direct input for the technical mass balance results for Scenario 2 (Scenario 2010).

Amount of PPW in the Netherlands

According to the Dutch Taxation Office 454 kton plastic packaging materials were brought on the market in 2010.[13] For this study, the available data for the 2010 baseline scenario (no. 2) was based on the year 2009, which was set at 422 kton. This number was at the moment of the development of the model the most accurate, publicly available number. Since then, it has been corrected to 454 kton. The division between post-consumer and post-industrial PPW was estimated at 65 : 35%, which fitted best to the available sorting analysis information on MSRW composition in the Netherlands published by Agentschap NL. In 2010 roughly 9.2 ± 1 % of the Dutch MSRW was PPW[14], this corresponds to 360 kton with attached moisture and dirt (wd) or roughly 274.3 kton PPW dry and clean. Therefore, the average amount of PPW available per person in the Netherlands was 16.47 kg/cap.a. When attached moisture and dirt is included, the volume of PPW amounts to 20.67 kg/cap.a.

Yield of RPET and PO-mix from deposit-refund system

The Dutch deposit-refund system for large PET bottles (>0.5 litres) for sodas and water encompasses about 650 million bottles annually with an average weight of 44.6 gram/bottle. The researchers estimated that annually 26.6 kton of PET, 1.7 kton PO for caps and closures and 0.44 kton PO film for labels, are used for these bottles (total = 28.74 kton PPW). In general, the Stichting Retourverpakkingen Nederland (responsible for the majority of the deposit-refund system implementation) estimates the return percentage of these deposit-refund bottles by households to the retail collection points, at 95%. The re-processing yield is about 78%. Hence this system yields about 20.9 kton RPET milled goods and 2.3 kton PO-mix annually.

Source separation responses

The theoretical maximum for the collection response of PPW is 18.3 kg/cap.a for Diftar and 15.5 kg/cap.a for non-Diftar municipalities, respectively[15]. This is calculated from the total amount of PPW available at households level (= 274.3 kton, average of 18,6 kg/cap.a). It is also corrected for the amount of attached moisture and dirt, which accounts for 18.5 % in Diftar and 8.0 % for non-Diftar municipalities, as shown in Table 7.

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13 Stichting Nedvang "Monitoring verpakkingen, resultaten 2010", Rotterdam, 7 september 2011.

14 Agentschap NL, "Samenstelling van het huishoudelijk restafval, resultaten sorteeranalyses 2010", Utrecht, februari 2011.

15 The theoretical maximum response was calculated for Diftar and non-Diftar municipalities from the amount of PPW present at the household level and was corrected for the amount of moisture and dirt. Since PPW collected in Diftar municipalities contains more moisture and dirt, their theoretical maximum is higher.

Table 7: The average measured attached moisture and dirt contents of PPW originating from various sources

Type of PPW	Attached moisture, [%]	Attached dirt, [%]
Source-separated, diftar	12,5	6,0
Source-separated, non-diftar	5,0	3,0
Recovered rigids	20	6
Recovered flexibles	15	10
Deposit refund PET bottles	10	4

The responses of PPW collection at household level as provided on the Nedvang database, were then categorised and averaged per urbanisation degree (from 1 urban to 5 rural areas), type of MSRW collection system (Diftar or non-Diftar) and the type of primary PPW collection system (kerb side or drop-off). These data do not include post separation as primary systems in municipalities. The data is summarised in Table 8 below.

Table 8: Data on collection responses of PPW and amount of inhabitants for various types of municipalities in 2010

Urbanisation degree	Type of PPW collection system	Diftar		Non-Diftar	
		Response (kg/cap.a)	Inhabitants (number)	Response (kg/cap.a)	Inhabitants (number)
1	Kerb side	0.0	0	0	0
1	Drop-off	0.0	0	1.9	2,220,107
2	Kerb side	9.4	282,214	4.6	1,605,122
2	Drop-off	9.7	302,120	3.4	2,496,010
3	Kerb side	10.7	618,432	5.8	1,483,160
3	Drop-off	3.0	143,374	4.2	808,220
4	Kerb side	11.7	1,399,668	6.4	1,069,145
4	Drop-off	7.3	345,776	4.2	486,568
5	Kerb side	11.3	601,864	6.8	521,173
5	Drop-off	7.3	195,905	4.2	175,707
Theoretical maximum response		*18.3*		*15.5*	
Total			3,889,353		10,865,212

Only being in effect for a short two years at the reference year 2010, the collection responses from the various municipality types are promising. These averages show that the highest responses in collection are mainly found at (semi-)rural Diftar municipalities, using a kerb side collection system. Compared to their theoretical maximum, urban and Diftar municipalities face a larger challenge to raise their responses.

Up until now, the composition of collected PPW was largely unknown and not described in scientific literature. The researchers made a primary experimental sorting analysis based on samples from 4 different municipalities (Nijmegen, Grootegast, Zwolle and Harfsen-Lochem) in de period 2010-2011. The municipalities were selected to represent a mix of urban/Diftar, urban/non-Diftar, rural/Diftar and rural/non-Diftar type of municipalities, which can be generalised in an average overview of the composition of PPW in the Netherlands. It should be noted that there can be seasonal differences within the composition of PPW, and therefore, these results are a first indication available.

Diftar municipalities were found to have more residual waste (non-PPW) in their PPW (13 [urban] and 30%) than non-Diftar municipalities (2 and 7%). These compositions have been summarised in condensed form in Table 9 below. The original data is given in **Annex 1**. The aggregated numbers per polymer type were used to calculate the amount of PET, PE, PP, FILM, MKS and REST present within the source separated PPW and the amount of attached water and dirt for PET, PE, FILM and MKS. This division is also important for the calculation of the environmental impact of PPW recycling.

Table 9:: Average composition of source separated PPW in the Netherlands

Polymer types / Products	PET	PE	PP	PVC	PS	Other/non-polymers	Total
Bottles	6.00%	2.60%	0.05%		0.05%		8.70%
Flasks	3.28%	7.93%	2.25%				13.45%
Rigids	9.08%	1.20%	8.85%	1.58%	2.60%		23.30%
Flexibles	0.08%	20.78%	4.43%	0.58%			25.85%
Laminated flexibles	0.20%	1.72%	0.38%				2.30%
Non-packaging plastics	0.22%	1.02%	1.49%	0.97%	1.18%		4.88%
Undesired plastic packaging					0.68%		0.68%
Residual plastics						7.93%	7.93%
Residual waste						12.92%	12.93%
Total	18.84%	35.24%	17.44%	3.12%	4.51%	20.85%	100.00%

The percentages have been calculated from weights of the sorted fractions including moisture and attached dirt.
Undesired plastic packaging are: silicon kit tubes (PE) chewing gum and drug strips (PP, PVC) and expanded PS objects

The amounts of attached moisture and dirt to various types of PPW have been measured in detail for all different types of packaging, originating from the four studies municipalities and from the recovery facilities. In general bottles and flasks tend to contain the most product residues and flexible packaging can have larger levels of attached moisture and dirt due to their larger surface to volume ratio. These numbers have been weight-averaged for all types of plastic packaging and those values are listed in Table 10. These numbers tend to vary strongly with the origin.

Table 10: The weight-average attached moisture and attached dirt levels for various types of PPW.

Type of PPW	Weight-averaged moisture level, [%]	Weight-averaged attached dirt level, [%]
Source separated PPW, Urban, diftar, Nijmegen-city	11%	11%
Source separated PPW, Urban, diftar, Nijmegen-Lent	16%	5%
Source separated PPW, Rural, diftar, Grootegast	21%	8%
Source separated PPW, Urban, non-diftar, Zwolle	4%	2%
Source separated PPW, Rural, non-diftar, Harfsen	6%	4%
Source separated PPW, Urban, diftar, Apeldoorn 2012	10%	17%
Recovered rigids, 3 samples of different dates in 2010	9%, 20%, 17%	7%, 6%, 11%
Recovered flexibles	15%	10%
Deposit refund PET bottles	10%	4%

These numbers were generalised in 2011 to be used in the scenario study model as average moisture and dirt parameters in the scenario modelling.

In 2010, the source separated PPW from Dutch households in the Nedvang system was transported to four different German sorting facilities, located in Porta Westphalica, Sinn, Kempen and Borken. The PPW was then sorted into the following fractions: PET, PE, PP, Film and Mixed plastics. Nedvang[16] has reported the averaged sorting results of the four sorting facilities for 2010, see Table 11.

Table 11: Sorting results with source separated PPW

	Nedvang 2009	**Nedvang 2010**	**SITA R'dam 2011**	**Ideally sorted**
PET bottle	6%	5.6%	8%	10%
PE	5%	4.7%	10%	11%
PP	4%	3.3%	7%	11%
Film	19%	17.4%	17%	36%
MKS	49%	45.4%	46%	19%
Rest	17%	23.6%	12%	13%

Sources: Stichting Nedvang 2009: Presentation at VMK: Stichting Nedvang 2010; KplusV, evaluatierapport bronscheiding en nascheiding; and own estimations based on experiments

The sorting protocol followed the guidelines according to the German DKR[17] standards for PET: 328-1 (90% bottles), PP: 324, PE: 329, Film: 310 and MKS: 350. These standards are very relevant for the Dutch PPW recycling scheme, since the fees municipalities receive for their

[16] Nedvang 2009: Presentation at VMK, Nedvang 2010: KplusV evaluatierapport bronscheiding en nascheiding

[17] Deutsche Gesellschaft für Kreislaufwirtschaft und Rohstoffe mbH (DKR)

collection efforts and the sorting companies for their processing results are based on these quality standards. Therefore, it is in the interest of the cost-efficiency of the system, that these standards are met. The issue here is that the composition of Dutch PPW, as displayed in table 5 and in further detail in table 6, does not naturally match these standards. For instance, in the case of PET packaging waste, the PET:328-1 standard demands that the sorted PET should contain a minimum of 90% bottles and flasks, whereas the input material consists of roughly 50% bottles and flasks and 50% of trays (other rigids). To meet the quality criterion of PET:328-1, the majority of PET-trays should be removed from the sorted fraction and added to the MKS fraction (mixed PPW). Up to date, there is not yet a technological facility that does this automatically, which means that a manual sorting step is necessary in this process, adding to the costs. From a policy and environmental perspective it can be questioned whether it is desirable to include a mono-sorted PET flow (PET-trays) into a mixed plastics fraction, which can only be used for low-value secondary products.

For the calculation of the amount of milled goods and agglomerate products produced from the sorted fractions the researchers have used yields that were determined by empirical measurements at the Wageningen UR Food & Biobased research and RWTH Aachen facilities,(these extended results have been submitted for publication in 2012)[18]. The main reason for these experiments was that these data are not publicly available from the waste processing industry. These measurements yielded detailed results on reprocessing yields of various sorted fractions, as summarised in Table 12. They also gave more insight in environmentally relevant parameters, such as solid waste production, waste sludge production, waste water quantity and quality and energy use.

Table 12: Reprocessing yields of various sorted fractions

Sorted fractions	Source separated PPW fractions	Post-separation PPW fractions
PET	73 – 77%	70 - 75%
PE	82 – 92%	75 - 86%
PP	79 - 88%	70 - 77%
FILM	55% (95% ns)	50 - 55%
MKS	70 - 80%	68 - 74%

Yield in terms of recovered mass [kg dry and clean output / kg wet and dirty input]

Ns: not-sieved; most film fractions were sieved prior to washing, some of the source separated film fractions were relatively clean and did not need to be sieved.

Post-separation

In 2010 55 of the 418 municipalities supplied their MSRW to two waste treatment centres fitted with plastic recovery facilities (Omrin in Oude Haske and Attero-Vagron in Groningen). In 2010,

[18] The sorting companies Sita and Nehlsen generously provided samples of various sorted derived from Dutch source separated PPW. Tönsmeier and DELA provided the samples from post-separated PPW sorted fractions.

Omrin produced roughly 5 kton of separated PPW and Vagron produced 2.6 kton rigid PPW and 1.6 kton of flexible PPW. In total this amounted to 9.2 kton of PPW or 6.6 kg/connection.year. From these facilities 7 samples were brought to Wageningen for composition analysis, following the same sorting protocol as for the source separated samples in the previous section. It should be noted that there can be seasonal differences within the composition of PPW, and therefore, these results are a first indication available. The results are summarised in Table 13.

Table 13: Average composition of recovered PPW products from Vagron and Omrin

Vagron rigids 2010	**PET**	**PE**	**PP**	**PVC**	**PS**	**Total**
Bottles	8.0%	2.3%	0.06%		0.01%	10.4%
Flasks	5.2%	12.3%	2.4%			19.9%
Rigids	18.5%	1.5%	17.1%	0.1%	0.5%	37.7%
Flexibles	0.0%	4.0%	1.8%	0.1%		5.9%
Laminated flexibles	0.1%	1.1%	0.6%	0.01%		1.7%
Non-packaging plastics	1.7%	2.1%	3.6%	0.1%	0.03%	7.5%
Undesired plastic packaging		0.25%	0.03%	0.01%	0.13%	0.4%
Residual plastics						0.6%
Residual waste						15.7%
Total	33.6%	23.5%	25.6%	0.3%	0.6%	100.0%
Vagron flexibles 2010	**PET**	**PE**	**PP**	**PVC**	**PS**	**Total**
Bottles						0.0%
Flasks						0.0%
Rigids	0.2%		0.1%	0.003%	0.1%	0.3%
Flexibles	0.03%	54.4%	9.7%	0.1%	0.08%	64.3%
Laminated flexibles	0.04%		1.1%			1.2%
Non-packaging plastics		2.0%	0.8%			2.8%
Undesired plastic packaging				0.06%	0.08%	0.1%
Residual plastics						13.0%
Residual waste						18.1%
Total	0.2%	56.5%	11.7%	0.2%	0.2%	100.0%
Omrin rigids 2010	**PET**	**PE**	**PP**	**PVC**	**PS**	**Total**
Bottles	10.9%	1.1%	0.17%		0.00%	12.2%
Flasks	4.9%	7.9%	0.3%			13.1%
Rigids	16.1%	1.3%	11.6%	0.2%	0.3%	29.4%
Flexibles	1.0%	27.0%	0.9%			28.9%
Laminated flexibles	0.2%	1.4%	0.9%			2.5%
Non-packaging plastics	0.6%	1.1%	3.4%	0.1%	0.11%	5.3%
Undesired plastic packaging				0.01%	0.10%	0.1%
Residual plastics						1.0%
Residual waste						7.4%
Total	33.7%	39.7%	17.3%	0.4%	0.5%	100.0%

The given percentages include attached water and dirt.

On average, the post-separated PPW contains more residual waste (non PPW) than the source separated PPW (see tables 5 and 8, 12.9% vs. 13.7%). In general, the presence of residual waste influences the sorting results in a slightly negative manner. For example, organic waste can cause PPW objects to stick together and newspapers can cover PPW objects.

The sorting results of the post-separated PPW rigids from Vagron and Omrin, as presented in Table 13, differ slightly. This is mainly caused by differences in the input stream (only rigids or a mixture of rigids and flexibles) and differences in the destination of the residual waste fraction. At Tönsmeier the residual waste is concentrated in the fraction Rest, whereas at DELA, it is more dispersed over all the polymer fractions. The underlying rationale is that Tönsmeier only produces according to the DKR standards and specification, whereas DELA also produces under-specified fractions for specific customers/markets.[19] All fractions are sellable and can be recycled. For obvious reasons, the fractions that are below DKR specifications are sold for lower prices and sometimes more time is required to find a potential buyer for these fractions. The flexible PPW products of Vagron and Wijster are not send to sorting companies, but directly send to a re-processor of film waste.

Table 14: Sorting results with recovered PPW products

Company	**Tönsmeier**	**DELA**	**DELA**
Input	**Omrin, mix of rigid and flexible**	**Attero-Vagron, only rigids**	**Attero-Wijster, only rigids**
PET	5%	8%	2.6%
PE	8%	15%	6.6%
PP	5%	25%	12.3%
FILM	26%	2%	37.0%
MKS2	42%	48%	38.0%
Rest	14%	2%	3.5%

These sorting yields were used as facility-specific parameters in the scenario modelling.

The re-processing yields of the sorted fractions have been determined in detail with various sorted fractions originating from various recovering and sorting facilities with a laboratory set-up. These measurements will be published in a separate publication, which is in press. These yields are –not surprisingly- slightly lower than for fractions made from source separated PPW., see Table 12.

[19] *This is no longer the case in 2013; now all sorted fractions originating from recovery facilities should attain the DKR specifications, but in 2010-2012 this was a serious discussion issue. Hence, the sorting percentages in 2013 are modified.*

2.2.2 Detailed description of scenario 1

Scenario 1 is a theoretical point of reference and should not be regarded as realistic scenario. It describes a situation in 2013 where we would have a deposit refund system for PET bottles and no source separation or recovery system in place.
Hence, the basic parameters for the PET deposit refund system remained unchanged as compared to the parameters in the technical datasheet, yielding 22.8 kton (1.38 kg/cap.a) RPET.

2.2.3 Detailed description of scenario 2

This reference scenario for 2010 consists of 3 system element (deposit-refund, source separation and post-separation), which are described in more detail below.

Scenario 2: Deposit refund system
The basic parameters for the PET deposit refund system remained unchanged as compared to the parameters in the technical datasheet.

Scenario 2: Source separation
The 360 municipalities that contributed to the source separation system in 2010 were categorised according to their urbanisation degree[20], the type of taxation scheme (or lack thereof) for waste collection and the type of PPW collection system. The total amount collected per category of municipalities was calculated by multiplying the amount of inhabitants in this category with the average annual response per category and applying a correction for those municipalities were a secondary system was in place. Secondary systems in source separation mean that besides a primary kerb side collection system there is also a drop-off system in place. Only four municipalities had such double collection systems. We studied the responses of these municipalities and compared them to similar municipalities with only a primary kerbside collection system and concluded that a secondary drop-off system will lower the yield of the primary system with 10%, whereas the additional yield of the secondary drop-off system is only 30% of what was expected in case it was a primary system. Hence, these correction factors were used to model the response of secondary systems. All results are summarised in Table 15.

[20] *Urbanisation degree based on information from the CBS database on municipalities*

Table 15: Modelled responses of the 20 different types of municipalities in 2010

Code	Primary inhabitants. [#]	Secondary. inhabitants [#]	Response [kg/cap.a]	Total collected amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
1DK	0	0	0	0	0	0	0	0
1DDr	0	0	0	0	0	0	0	0
1NK	0	0	0	0	0	0	0	0
1NDr	2,220,107	0	1.9	4,218,203	3,725,517	168,728	202,474	121,484
2DK	282,214	0	9.4	2,652,812	1,686,392	583,619	258,649	124,152
2DDr	302,120	0	9.7	2,930,564	1,862,960	644,724	285,730	137,150
2NK	1,605,122	66,105	4.6	7,353,153	6,494,305	294,126	352,951	211,771
2NDr	2,496,010	0	3.4	8,553,861	7,554,770	342,154	410,585	246,351
3DK	618,432	0	10.7	6,617,222	4,206,568	1,455,789	645,179	309,686
3DDr	143,374	0	3	430,122	273,429	94,627	41,937	20,130
3NK	1,483,160	0	5.8	8,602,328	7,597,576	344,093	412,912	247,747
3NDr	808,220	0	4.2	3,394,524	2,998,044	135,781	162,937	97,762
4DK	1,399,668	16,548	11.7	16,356,754	10,397,989	3,598,486	1,594,784	765,496
4DDr	345,776	33,079	7.3	2,632,848	1,673,701	579,227	256,703	123,217
4NK	1,069,145	54,177	6.4	6,807,855	6,012,697	272,314	326,777	196,066
4NDr	486,568	0	4.2	2,111,849	1,865,185	84,474	101,369	60,821
5DK	601,864	0	11.3	6,801,063	4,323,436	1,496,234	663,104	318,290
5DDr	195,905	0	7.3	1,430,107	909,119	314,623	139,435	66,929
5NK	521,173	0	6.8	3,543,976	3,130,040	141,759	170,111	102,067
5NDr	175,707	0	4.2	737,969	651,775	29,519	35,423	21,254
Total	**14,754,565**	**169,909**		**85,175,211**	**65,363,502**	**10,580,277**	**6,061,059**	**3,170,373**
Average			*5,77*	*5,77*	*4,43*	*0,72*	*0,41*	*0,21*

D= Diftar, N= non-Diftar

H= kerb side collection, B= drop-off collection

The applied methodology of modelling the collected amounts per category of municipality caused the total collected amount to be 85 kton, 2 kton higher than the 83 kton that was really collected in 2010, creating a collection response error of 2 kton (= 2.4 %). Since the modelling of the municipality responses is necessary to build a system model to calculate the technical, logistical and environmental impacts on PPW recycling, the researchers decided not to correct the responses. It is a generic error in all scenarios.

The total amount of collected plastic packaging waste per category was further split up in plastics, residual waste, attached moisture and attached dirt with the parameters from Table 9 and the averaged percentage of residual waste for diftar and non-diftar municipalities from Table 10.

The amount of sorted fractions were calculated from the total collected amount and the sorting division that Nedvang published for 2010. Subsequent multiplication with the re-processing yields, yielded the produced amounts of milled goods and agglomerates, see Table 16 below).

Table 16: Overview of the produced sorted fractions and final products from the source separated PPW in scenario 2

Fraction	**Sorting division, [%]**	**Amount of sorted fraction, [kg/a]**	**Re-processing yield, [%]**	**Amount of produced milled goods and agglomerates, [kg/a]**
PET	6%	4,769,812	80.7%	3,849,238
PE	5%	4,003,235	89.1%	3,566,882
PP	3%	2,810,782	81.9%	2,302,030
FILM	17%	14,820,487	66.6%	9,870,444
MKS	45%	38,669,546	81.8%	31,631,688
REST	24%	20,101,350		
TOTAL		85,175,211		51,220,283
Average, [kg/cap.a]		*4.41*		*3.47*

The collected technical data of the has been used to calculate the overall recycling chain yield (from collection to milled goods and agglomerates). From the 85 kton (5.77 kg/cap.a) of collected source separated PPW in the Netherlands 65 kton (4.41 kg/cap.a) was sorted into recyclable fractions, which resulted in the production of 51 kton (3.47 kg/cap.a) milled goods and agglomerates, a graphical description of the recycling chain is presented in Figure 12 below.

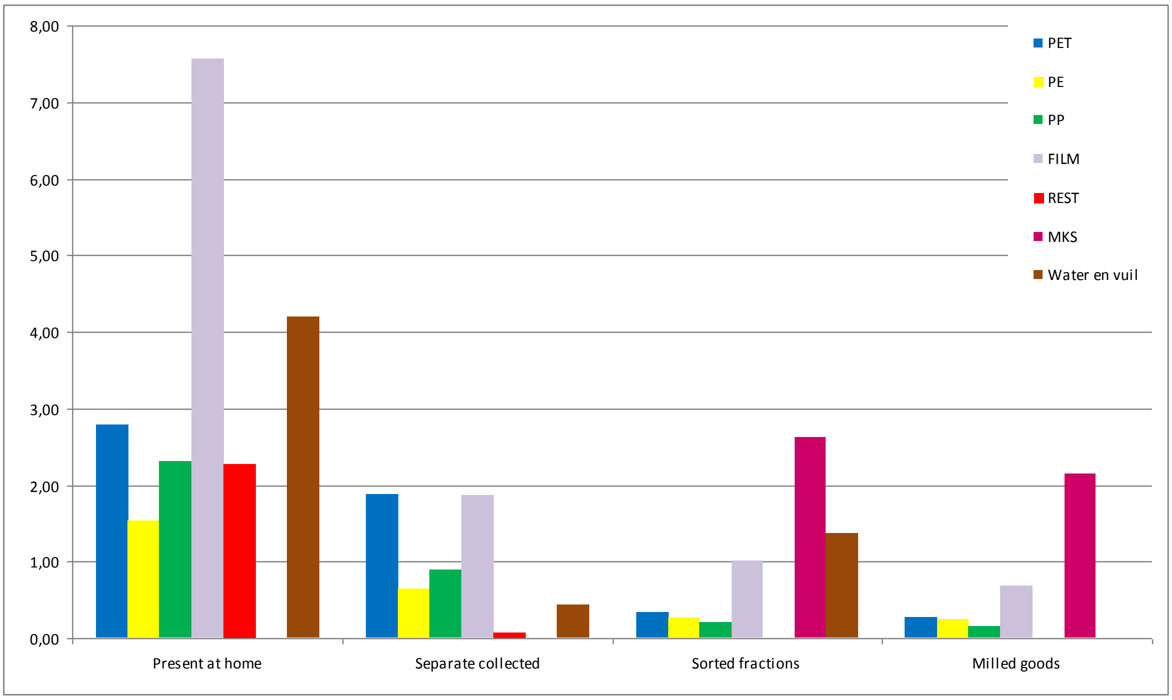

Figure 12: Schematic description of the PPW recycling chain for source separated PPW from the households up to milled goods and agglomerates, [kg/cap.a]

Scenario 2: post-separation

The amount of PPW that has been recovered by the Dutch MRF's in 2010 was calculated by multiplying the amount of inhabitants that supply their MSRW to that facility times the production parameter of that facility. These production parameters [kg PPW/cap.a] was retrieved from the annual production data of the MRF and the amount of inhabitants it serves.
A minority of the municipalities that contributed to the recovery system also had a source separation system in place, mostly drop-off containers. In order to estimate the recovered amounts of these municipalities, first the correction factor for that municipality was calculated by calculating the percentage of PPW potential as the amount of PPW still available after the source separated amount has been subtracted from the originally available amount. These correction factors were averaged for each MRF facility with weight factors based on the inhabitants of the secondary municipalities. In 2010 the correction factor for the Omrin facility was 71% and for the Vagron facility 48%.
The total amount of PPW recovered was further divided into the amount of plastic packaging, residual waste, attached moisture and attached dirt, with the compositional data from Table 13 and Table 12.

Table 17: Modelled amounts of recovered PPW in scenario 2 in 2010

MRF	Primary inhabitants [#]	Secundary inhabitants [#]	Production parameter [kg/cap.a]	Total recovered amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
Omrin mix	734,520	55,425	6.81	5,271,425	2,847,624	1,423,285	769,628	230,888
Vagron rigids	474,002	59,568	5.27	2,651,234	1,432,196	715,833	387,080	116,124
Vagron flexibles	474,002	59,568	3.16	1,590,740	867,351	434,272	173,470	115,647
Total	1,208,522	114,993		**9,513,398**	**5,147,171**	**2,573,390**	**1,330,178**	**462,659**
Average			*7.19*	*7.19*	*3.89*	*1.94*	*1.01*	*0.35*

The sorting re-processing of the recovered PPW is performed differently for the materials that originate from the two different MRF's. The PPW mix of Omrin is send to the sorting company Tönsmeier and the sorting division and re-processing yields are listed below.

Table 18: Modelled amounts of sorted fraction and products made from the recovered PPW from Omrin in scenario 2 in 2010

Fractions of Omrin mix	Sorting division, [%]	Amount of sorted fraction, [kg/a]	Re-processing yield, [%]	Amount of produced milled goods and agglomerates, [kg/a]
PET	5%	263,571	74.8%	197,151
PE	8%	421,714	85.6%	360,987
PP	5%	263,571	76.3%	201,105
FILM	26%	1,370,570	52.8%	723,661
MKS	42%	2,213,998	68.3%	1,512,161
REST	14%	737,999		
TOTAL		**5,271,425**		**2,995,065**
Average, [kg/cap.a]		*6.67*		*3.79*

The rigid material of Vagron is send to sorting company DELA and the flexible material is send to directly to a re-processor. The sorting division and yields are listed below.

Table 19: Modelled amounts of sorted fraction and products made from the recovered PPW of Vagron in scenario 2 in 2010

Fractions of Vagron rigid	Sorting division, [%]	Amount of sorted fraction, [kg/a]	Re-processing yield, [%]	Amount of produced milled goods and agglomerates, [kg/a]
PET	8%	212,099	71.3%	151,226
PE	15%	397,685	75.6%	300,650
PP	25%	662,808	69.9%	463,303
FILM	2%	53,025	52.8%	27,997
MKS	48%	1,272,592	73.9%	940,446
REST	2%	53,025		
Subtotal		**2,651,234**		**1,883,622**
Vagron film		1,590,740	52.8%	839,911
TOTAL		**4,241,974**		**2,723,533**
Average, [kg/cap.a]		*7.95*		*5,10*

This means that in total 9.5 ktons of PPW (7.19 kg/cap.a) has been recovered from MSRW in the Netherlands in 2010 and this resulted in the production of 8.7 ktons of saleable products (sorted fractions and film) (6.59 kg/cap.a), which were re-processed into 5.7 ktons of milled goods and agglomerates (4.32 kg/cap.a).

In total 3.96 kg/cap.a of milled goods and agglomerates were produced in 2010 from Dutch recovered PPW. These products were traded with industries in Europe and were used for making new utensils. The industries which bought and recycled milled goods and agglomerates from source-separation and recovery are for a large extent the same.

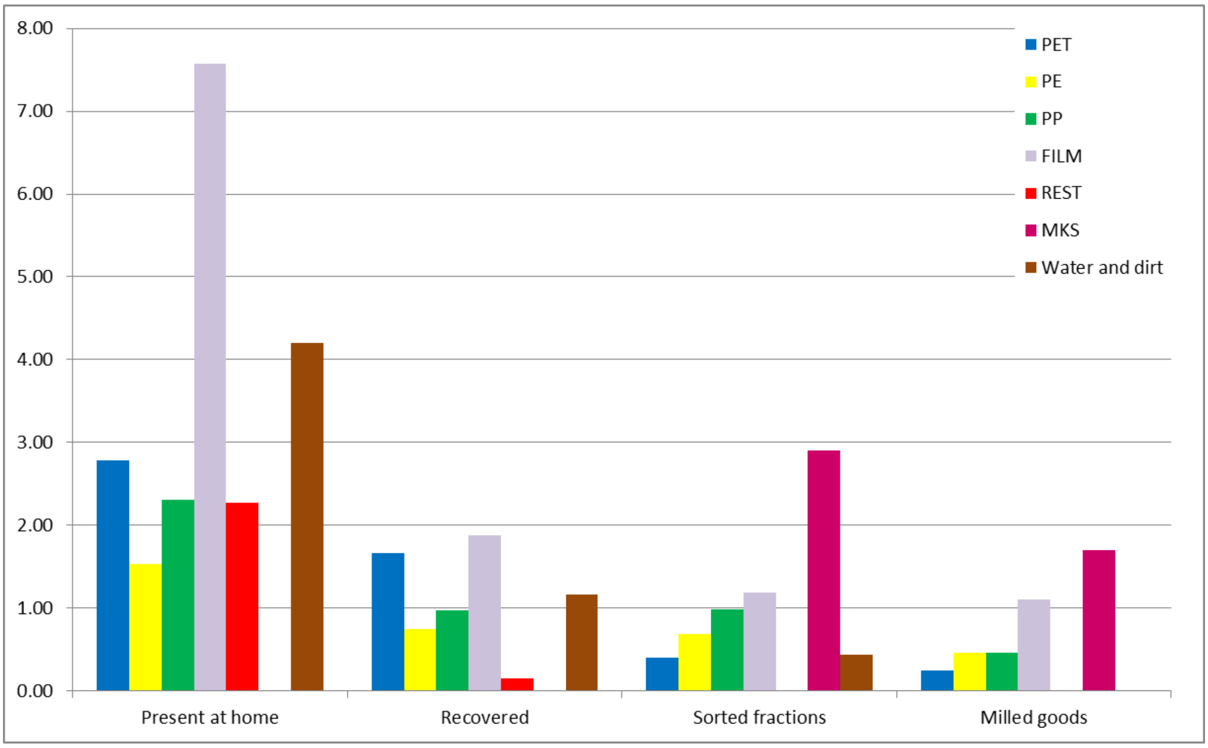

Figure 13: Schematic description of the PPW recycling chain for recovered PPW; from the household level up to the milled goods and agglomerates, [kg/cap.a]

In summary, the three different recycling schemes for post-consumer PPW in the Netherlands have yielded in 2010 the following amounts of milled goods and agglomerates; deposit refund 22.8 kton (1.38 kg/cap.a), source separation 51 kton (3.47 kg/cap.a) and recovery 5.7 kton (4.32 kg/cap.a). The deposit refund system was mature. The source separation system benefited from existing infrastructure in Germany to sort and reprocess PPW and was established fast. The recovery system was new and suffered in 2010 from several quality related issues. The recovered PPW quality did not always match the expectations of existing German sorting companies that had to adjust their facilities to produce sorted fractions that either complied with DKR specifications or almost complied with these specifications. The latter fractions had to be sold as a lower quality grade sorted fractions which resulted in slightly lower prices.

The net yield of the recovery chain was 5.7 kton and was higher than the 5.1 kton plastics to be present in the recovered PPW (Table 17**Fout! Verwijzingsbron niet gevonden.**). This is obviously impossible and is caused by the relative large errors in the parameters used. These parameters are determined with much effort from samples of recovered PPW, sorted fractions and milled goods and apparently, the sample sizes (50-250 kg/sample) are insufficient to obtain reliable parameters. It is a consequence of our intention to model attached dirt and moisture as well, while these amounts are known to vary largely. Hence, the results of this modelling should preferably be used comparatively between the scenarios.

2.2.4 Detailed description of scenario 3

Scenario 3 is the base scenario; the expected continuation of the current policy in 2013. This means that we will have three PPW systems operating simultaneously; deposit refund, source separation and recovery. The deposit refund system will remain unchanged as compared to scenario 1 and 2. The source separation system is expected to have matured further and it was expected that an additional recovery facility for PPW is operational in Rotterdam. Hence, the basic parameters for the PET deposit refund system remained unchanged as compared to the parameters in the technical datasheet, yielding 22.8 kton (1.38 kg/cap.a) RPET.

For the source separation system in 2013, the total amount collected per category of municipalities was calculated by multiplying the amount of inhabitants in this category with the average annual response per category and applying a correction in case there was a secondary system in place. The amount of inhabitants per type of municipality was kept constant but the response per category was raised with on average 17% to round estimated figures for 2013.

Table 20: Modelled responses of the 20 different types of municipalities in 2013

Code	Primary inhabitants [#]	Secundary inhabitants [#]	Response [kg/cap.a]	Total collected amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
1DK	0	0	0	0	0	0	0	0
1DDr	0	0	0	0	0	0	0	0
1NK	0	0	0	0	0	0	0	0
1NDr	2,220,107	0	3	6,660,321	5,882,396	266,413	319,695	191,817
2DK	282,214	0	10	2,822,140	1,794,034	620,871	275,159	132,076
2DDr	302,120	0	10	3,021,200	1,920,577	664,664	294,567	141,392
2NK	1,605,122	66,105	5	7,992,558	7,059,027	319,702	383,643	230,186
2NDr	2,496,010	0	5	12,975,148	11,459,650	519,006	622,807	373,684
3DK	618,432	0	12	7,421,184	4,717,647	1,632,660	723,565	347,311
3DDr	143,374	0	8	1,146,992	729,143	252,338	111,832	53,679
3NK	1,483,160	0	6	8,898,960	7,859,561	355,958	427,150	256,290
3NDr	808,220	0	6	4,849,320	4,282,919	193,973	232,767	139,660
4DK	1,399,668	16,548	12	16,776,158	10,664,604	3,690,755	1,635,675	785,124
4DDr	345,776	33,079	8	2,885,313	1,834,193	634,769	281,318	135,033
4NK	1,069,145	54,177	8	8,509,818	7,515,872	340,393	408,471	245,083
4NDr	486,568	0	5	2,514,106	2,220,458	100,564	120,677	72,406
5DK	601,864	0	12	7,222,368	4,591,259	1,588,921	704,181	338,007
5DDr	195,905	0	8	1,567,240	996,294	344,793	152,806	73,347
5NK	521,173	0	8	4,169,384	3,682,400	166,775	200,130	120,078
5NDr	175,707	0	5	910,380	804,048	36,415	43,698	26,219
Total	**14,754,565**	**169,909**		**100,342,589**	**78,014,082**	**11,728,971**	**6,938,143**	**3,661,393**
Average			*6.76*	*6.76*	*5.26*	*0.79*	*0.47*	*0.25*

The sorting division is slightly improved as compared to 2010; not completely to the best possible division, but already a good step in that direction. The re-processing yields were kept constant.

Table 21: Overview of the produced sorted fractions and final products from the source separated PPW in scenario 3

Fraction	**Sorting division, [%]**	**Amount of sorted fraction, [kg/a]**	**Re-processing yield, [%]**	**Amount of produced milled goods and agglomerates, [kg/a]**
PET	7%	7,023,981	80.7%	5,668,353
PE	6%	6,020,555	89.1%	5,364,315
PP	5%	5,017,129	81.9%	4,109,029
FILM	18%	18,061,666	66.6%	12,029,070
MKS	45%	45,154,165	81.8%	36,936,107
REST	19%	19,065,092		
TOTAL		100,342,589		64,106,873
Average, [kg/cap.a]		*6.76*		*4.32*

Hence, for source separation in scenario 3 about 100 kton (6.76 kg/.cap.a) was collected, which was sorted into 81 kton (5.48 kg/cap.a) recyclable fractions, which resulted in the production of 64 kton (4.32 kg/cap.a) milled goods and agglomerates

The production parameters for the recovery facilities Omrin and Vagron were deduced from the annually produced amounts in 2010 and 2011 of recovered plastics and the expected growth potential for the coming years. The parameter for Wijster was deduced from own measurements in 2011 and a correction of 33% for the fact that plastic is only recovered on 1 of the 3 waste pre-treatment lines. The number for Rotterdam has been estimated based on the Wijster measurements and was rounded off towards a realistic and feasible number with a new facility. The correction parameters for the contributions of municipalities that contributed to the yield of recovery as a secondary system, were: Omrin 70.8%, Vagron 43.4%, Wijster 59.6% and Rotterdam 0%.

Table 22: Modelled amounts of recovered PPW in scenario 3 in 2013

MRF	Primary inhabitants [#]	Secundary inhabitants. [#]	Production parameter [kg/cap.a]	Total recovered amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
Omrin mix	734520	55425	13.61	10,534,505	5,690,740	2,844,316	1,538,038	461,411
Vagron rigids	474002	104859	6.33	3,288,105	1,776,234	887,788	480,063	144,019
Vagron flexibles	474002	104859	4.22	2,192,070	1,195,226	598,435	239,045	159,363
Wijster rigids	0	2718612	5.67	9,184,659	4,961,553	2,479,858	1,340,960	402,288
Wijster flexibles	0	2718612	3.33	5,402,741	2,945,844	1,474,948	589,169	392,779
Rotterdam	610395	0	15.00	9,155,925	4,946,031	2,472,100	1,336,765	401,030
Total	**1818917**	**2878896**		**39,758,005**	**21,515,628**	**10,757,446**	**5,524,040**	**1,960,891**
Average			*8.46*	*8.46*	*4.58*	*2.29*	*1.18*	*0.42*

For the recovered plastics that were sorted, the modelled sorting results are listed below. For Omrin mix we used the sorting division achieved at Tönsmeier, for Vagron rigid and Rotterdam rigid the sorting division at Dela, for Wijster rigids the separate sorting division obtained at Dela.

Table 23: Modelled amounts of sorted fractions from the recovered PPW in scenario 3 in 2013

Fractions	Omrin mix, [kg/a]	Vagron rigid, [kg/a]	Wijster rigid, [kg/a]	Rotterdam, [kg/a]	Total, [kg/a]
PET	526,725	263,048	238,801	732,474	**1,761,049**
PE	842,760	493,216	606,188	1,373,389	**3,315,552**
PP	526,725	822,026	1,129,713	2,288,981	**4,767,446**
FILM	2,738,971	65,762	3,398,324	183,119	**6,386,176**
MKS	4,424,492	1,578,290	3,490,170	4,394,844	**13,887,797**
REST	1,474831	65,762	321,463	183,119	**2,045,174**
TOTAL	**10,534,505**	**3,288,105**	**9,184,659**	**9,155,925**	**32,163,194**
Average, [kg/cap.a]					

The amount of produced milled goods and agglomerates made from these recovered sorted fractions in scenario 3 in 2013 are listed in Table 24. In short, 39.7 kton recovered PPW was sorted to 30 kton (6.41 kg/cap.a) of saleable fractions and 7 kton of separate film product, which were converted into 24.6 kton (5.24 kg/cap.a) of milled goods and agglomerates.

Table 24: Modelled amounts of produced milled goods and agglomerates made from the recovered PPW in scenario 3 in 2013

Fractions	Omrin, [kg/a]	Vagron, [kg/a]	Wijster, [kg/a]	Rotterdam, [kg/a]	Total, [kg/a]
PET	393,990	187,554	170,265	522,254	1,274,063
PE	721,403	372,871	458,278	1,038,282	2,590,834
PP	401,891	574,596	789,669	1,599,998	3,366,155
FILM	1,446,177	34,722	1,794,315	96,687	3,371,901
MKS	3,021,928	1,166,357	2,579,236	3,247,790	10,015,310
Subtotal	**5,985,390**	**2,336,100**	**5,791,763**	**6,505,010**	**20,618,263**
Additional film		1,157,413	2,852,647		4,010,060
TOTAL	**5,985,390**	**3,493,513**	**8,644,410**	**6,505,010**	**24,628,323**
Average, [kg/cap.a]					*5.24*

2.2.5 Detailed description of scenario 4

Scenario 4 is a continuation of the current policy in 2013 with one major exception; the abolishment of separate deposit refund system for large PET bottles and the addition of these PET bottles to the source separation and recovery systems.
The most relevant parameter for this scenario is the expected response of PET bottles in the new system; how much PET bottles will return via the source separation and recovery systems? Mature foreign separate collection systems for PPW show a general threshold value of 55-60% for all types of PPW. However, large PET bottles are better recognised as a plastic package than for instance PE bags, therefore, the threshold value for PET bottles is likely to be much higher. Switzerland has abolished the deposit refund system for large PET bottles and replaced it with a voluntary separate collection system (Redilo) and after some years achieves a response of 83%. Therefore, we choose a response of 70% for the large PET bottles via source separation and recovery. This is the most important parameter for this scenario and arbitrary. The precise final value will strongly depend on how the new collection system is build; how many additional collection bins will be placed, how often those bins will be emptied, etc. Since, that is not exactly known, a more precise estimation is impossible.
The addition of the PET bottles deposit refund system will increase the amount of PPW that is potentially available per civilian from 20.58 to 22.69 kg/cap.a. Furthermore, the composition of the available PPW at the households changes to slightly more PET and somewhat less PE, PP etc, which will influence the sorting divisions etc.

For the source separation system in 2013, the most important change will be the increased responses due to the added PET bottles. This was calculated by taking 70% of 28 kton of PET bottles and correcting it for the division of PPW between source separation and recovery in scenario 3, which was 70:30%, which amounts to average rise of 14% of all the responses as compared to scenario 3. The calculation per category is shown in Table 25.

Table 25: Modelled responses of the 20 different types of municipalities in 2013 for scenario 4

Code	Prim. inh. [#]	Sec. inh. [#]	Response [kg/cap.a]	Total collected amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
1DK	0	0	0.00	0	0	0	0	0
1DDr	0	0	0.00	0	0	0	0	0
1NK	0	0	0.00	0	0	0	0	0
1NDr	2,220,107	0	3.43	7,615,978	6,726,432	304,639	365,567	219,340
2DK	282,214	0	11.43	3,227,075	2,051,452	709,957	314,640	151,027
2DDr	302,120	0	11.43	3,454,697	2,196,151	760,033	336,833	161,680
2NK	1,605,122	66,105	5.72	9,139,371	8,071,892	365,575	438,690	263,214
2NDr	2,496,010	0	5.72	14,836,888	13,103,940	593,476	712,171	427,302
3DK	618,432	0	13.72	8,486,014	5,394,559	1,866,923	827,386	397,145
3DDr	143,374	0	9.15	1,311,568	833,764	288,545	127,878	61,381
3NK	1,483,160	0	6.86	10,175,828	8,987,292	407,033	488,440	293,064
3NDr	808,220	0	6.86	5,545,125	4,897,455	221,805	266,166	159,700
4DK	1,399,668	16,548	13.72	19,183,288	12,194,816	4,220,323	1,870,371	897,778
4DDr	345,776	33,079	9.15	3,299,312	2,097,373	725,849	321,683	154,408
4NK	1,069,145	54,177	9.15	9,730,851	8,594,287	389,234	467,081	280,249
4NDr	486,568	0	5.72	2,874,842	2,539,061	114,994	137,992	82,795
5DK	601,864	0	13.72	8,258,670	5,250,037	1,816,907	805,220	386,506
5DDr	195,905	0	9.15	1,792,116	1,139,248	394,265	174,731	83,871
5NK	521,173	0	9.15	4,767,629	4,210,770	190,705	228,846	137,308
5NDr	175,707	0	5.72	1,041,006	919,416	41,640	49,968	29,981
Total	**14,754,565**	**169,909**		**114,740,259**	**89,207,944**	**13,411,904**	**7,933,663**	**4,186,749**
Average			*7.73*	*7.73*	*6.01*	*0.90*	*0.53*	*0.28*

The sorting division will change due to the relative increase in relative good sortable large PET bottles. The re-processing yields were kept constant.

Table 26: Overview of the produced sorted fractions and final products from the source separated PPW in scenario 4

Fraction	**Sorting division, [%]**	**Amount of sorted fraction, [kg/a]**	**Re-processing yield, [%]**	**Amount of produced milled goods and agglomerates, [kg/a]**
PET	9%	10.502.989	80.7%	8.475.912
PE	6%	6.454.140	89.1%	5.750.638
PP	5%	5.378.450	81.9%	4.404.950
FILM	17%	19.362.419	66.6%	12.895.371
MKS	45%	51.633.117	81.8%	42.235.889
REST	19%	21.409.145		
TOTAL		**114.740.259**		**73.762.761**
Average, [kg/cap.a]		*7.73*		*4.97*

Hence, for source separation in scenario 3 about 114 kton (7.73 kg/.cap.a) was collected, which was sorted into 93 kton (6.29 kg/cap.a) recyclable fractions, which resulted in the production of 73 kton (4.97 kg/cap.a) milled goods and agglomerates

The production parameters for the recovery facilities were corrected for the expected gain with 14% due to the rise in the amount of PET bottles present in the household waste.

Omrin and Vagron were deduced from the annually produced amounts in 2010 and 2011 of recovered plastics and the expected growth potential for the coming years. The parameter for Wijster was deduced from own measurements in 2011 [[21]] and a correction of 33% for the fact that plastic is only recovered on 1 of the 3 waste pre-treatment lines. The number for Rotterdam has been estimated based on the Wijster measurements and was rounded off towards a realistic and feasible number with a new facility. The correction parameters for the contributions of municipalities that contributed to the yield of recovery as a secondary system, were: Omrin 70.8%, Vagron 43.4%, Wijster 59.6% and Rotterdam 0%.

[21] *Thoden van Velzen EU, Jansen M "Nascheiden van kunststofverpakkingsafval te Wijster" Wageningen –UR, FBR report 1296, April 8th 2012.*

Table 27: Modelled amounts of recovered PPW in scenario 4 in 2013

MRF	Prim. inh. [#]	Sec. inh. [#]	Production parameter [kg/cap.a]	Total recovered amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
Omrin mix	734520	55425	15.71	12,143,246	6,559,781	3,278,676	1,772,914	531,874
Vagron rigids	474002	104859	8.27	4,280,108	2,312,115	1,155,629	624,896	187,469
Vagron flexibles	474002	104859	4.22	2,182,837	1,190,192	595,915	238,038	158,692
Wijster rigids	0	2718612	6.48	10,238,800	5,531,000	2,764,476	1,494,865	448,459
Wijster flexibles	0	2718612	3.33	5,267,797	2,872,266	1,438,109	574,453	382,969
Rotterdam	610395	0	17.15	10,468,232	5,654,939	2,826,423	1,528,362	458,509
Total	**1818917**	**2878896**		**44,581,020**	**24,120,293**	**12,059,227**	**6,233,528**	**2,167,972**
Average			*9.49*	*9.49*	*5.13*	*2.57*	*1.33*	*0.46*

For the recovered plastics that were sorted, the modelled sorting results are listed below. The soting division were altered to reflect the changed composition of the recovered PPW.

Table 28: Modelled amounts of sorted fractions from the recovered PPW in scenario 3 in 2013

Fractions	Omrin mix, [kg/a]	Vagron rigid, [kg/a]	Wijster rigid, [kg/a]	Rotterdam, [kg/a]	Total, [kg/a]
PET	793,970	447,758	348,114	1,095,122	**2,684,964**
PE	910,743	601,890	633,526	1,472,095	**3,618,255**
PP	569,215	1,003,150	1,180,662	2,453,492	**5,206,519**
FILM	2,959,916	80,252	3,551,584	196,279	**6,788,031**
MKS	5,315,601	2,066,805	4,188,954	5,054,964	**16,626,325**
REST	1,593,801	80,252	335,961	196,279	**2,206,293**
TOTAL					**37,130,386**
Average, [kg/cap.a]					*7,43*

The amount of produced milled goods and agglomerates made from these recovered sorted fractions in scenario 4 in 2013 are listed in Table 23. In short, 44.6 kton recovered PPW was sorted to 35 kton (7.43 kg/cap.a) of saleable fractions and 7 kton of separate film product, which were converted into 27.9 kton (5.95 kg/cap.a) of milled goods and agglomerates.

Table 29: Modelled amounts of produced milled goods and agglomerates made from the recovered PPW in scenario 4 in 2013

Fractions	Omrin, [kg/a]	Vagron, [kg/a]	Wijster, [kg/a]	Rotterdam, [kg/a]	Total, [kg/a]
PET	593,889	319,252	248,205	780,822	1,942,168
PE	779,596	455,029	478,945	1,112,904	2,826,475
PP	434,311	701,202	825,282	1,714,991	3,675,786
FILM	1,562,836	42,373	1,875,236	103,635	3,584,081
MKS	3,630,556	1,527,369	3,095,637	3,735,619	11,989,181
Subtotal					
Additional film		1,152,538	2,781,397		3,933,935
TOTAL					**27,951,625**
Average, [kg/cap.a]					*5,95*

2.2.6. Detailed description of scenario 5

Scenario 5 is a realistically extended post-separation scenario. It implies that also the MSRW of the cities of The Hague, Amsterdam and Utrecht is post-separated and source separation is no longer taking place within these municipalities. Furthermore, the MRF in Wijster is extended to treat all the MSRW for post-separation and not just one third. Besides the cities of the Hague, Amsterdam and Utrecht, the source separation system remains as it is and the deposit refund system is also present.

Hence, the basic parameters for the PET deposit refund system remained unchanged as compared to the parameters in the technical datasheet, yielding 22.8 kton (1.38 kg/cap.a) RPET.

For the source separation system within scenario 5 most remained the same as in scenario3. However, a little bit less PPW was collected due to the fact that the source separation systems were abolished for three large cities. So the total collected amount drops with about 6 kton but the average response rises to 7.27 kg/cap.a.

Table 30: Modelled responses of the 20 different types of municipalities in 2013 within scenario 5

Code	Prim. inh. [#]	Sec. inh. [#]	Response [kg/cap.a]	Total collected amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
1DK	0	0	0	0	0	0	0	0
1DDr	0	0	0	0	0	0	0	0
1NK	0	0	0	0	0	0	0	0
1NDr	481,290	0	3	1,443,870	1,275,226	57,755	69,306	41,583
2DK	282,214	0	10	2,822,140	1,794,034	620,871	275,159	132,076
2DDr	302,120	0	10	3,021,200	1,920,577	664,664	294,567	141,392
2NK	1,605,122	66,105	5	7,992,558	7,059,027	319,702	383,643	230,186
2NDr	2,496,010	0	5	12,579,208	11,109,956	503,168	603,802	362,281
3DK	618,432	0	12	7,421,184	4,717,647	1,632,660	723,565	347,311
3DDr	143,374	0	8	1,146,992	729,143	252,338	111,832	53,679
3NK	1,483,160	0	6	8,898,960	7,859,561	355,958	427,150	256,290
3NDr	808,220	0	6	4,849,320	4,282,919	193,973	232,767	139,660
4DK	1,399,668	16,548	12	16,776,158	10,664,604	3,690,755	1,635,675	785,124
4DDr	345,776	33,079	8	2,885,313	1,834,193	634,769	281,318	135,033
4NK	1,069,145	54,177	8	8,509,818	7,515,872	340,393	408,471	245,083
4NDr	486,568	0	5	2,514,106	2,220,458	100,564	120,677	72,406
5DK	601,864	0	12	7,222,368	4,591,259	1,588,921	704,181	338,007
5DDr	195,905	0	8	1,567,240	996,294	344,793	152,806	73,347
5NK	521,173	0	8	4,169,384	3,682,400	166,775	200,130	120,078
5NDr	182,076	0	5	910,380	804,048	36,415	43,698	26,219
Total	13,022,117	169,909		**94,730,198**	**73,057,219**	**11,504,475**	**6,668,748**	**3,499,756**
Average			*7.27*	*7.27*	*5.61*	*0.88*	*0.51*	*0.27*

The sorting division and reprocessing yields were kept the same as in scenario 3. The amounts of sorted goods and milled goods under scenario 5 are listed in Table 31.

Table 31: **Overview of the produced sorted fractions and final products from the source separated PPW in scenario 5**

Fraction	**Sorting division, [%]**	**Amount of sorted fraction, [kg/a]**	**Re-processing yield, [%]**	**Amount of produced milled goods and agglomerates, [kg/a]**
PET	7%	6,631,114	80.7%	5,351,309
PE	6%	5,683,812	89.1%	5,064,276
PP	5%	4,736,510	81.9%	3,879,202
FILM	18%	17,051,436	66.6%	11,356,256
MKS	45%	42,628,589	81.8%	34,870,186
REST	19%	17,998,738		
TOTAL		94,730,198		60,521,229
Average, [kg/cap.a]		*5.89*		*4.65*

Hence, for source separation in scenario 5 about 95 kton (7.27 kg/.cap.a) was collected, which was sorted into 76 kton (5.89 kg/cap.a) recyclable fractions, which resulted in the production of 61 kton (4.65 kg/cap.a) milled goods and agglomerates

The production parameters for the recovery facilities Omrin, Vagron and Rotterdam were kept the same as compared to scenario 3. The factors of Wijster were tripled (reflecting the extension of one to three lines). The factor for Amsterdam was chosen to be equal to the Rotterdam factor. The correction parameters for the contributions of municipalities that contributed to the yield of recovery as a secondary system, were: Omrin 70.8%, Vagron 43.4%, Wijster 59.5%, Rotterdam 0% and Amsterdam 69%.

Table 32: Modelled amounts of recovered PPW in scenario 5 in 2013

MRF	Prim. inh. [#]	Sec. inh. [#]	Production parameter [kg/cap.a]	Total recovered amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
Omrin mix	734,520	55,425	13.61	10,534,505	5,690,740	2,844,316	1,538,038	461,411
Vagron rigids	474,002	104,859	6.33	3,288,105	1,776,234	887,788	480,063	144,019
Vagron flexibles	474,002	104,859	4.22	2,192,070	1,195,226	598,435	239,045	159,363
Wijster rigids	0	2,747,933	17.00	27,810,146	15,023,041	7,508,739	4,060,281	1,218,084
Wijster flexibles	0	2,747,933	10.00	16,358,909	8,919,695	4,465,982	1,783,939	1,189,293
Rotterdam	1,417,254	0	15.00	21,258,810	11,484,009	5,739,879	3,103,786	931,136
Amsterdam	1,011,146	876,016	15.00	24,175,171	13,012,183	6,527,296	3,529,575	1,106,118
Total	**3,636,922**	**3,784,233**		**105,617,716**	**57,101,128**	**28,572,436**	**14,734,728**	**5,209,424**
Average			*14.23*	*14.23*	*7.69*	*3.85*	*1.99*	*0.70*

For the recovered plastics that were sorted, the modelled sorting results are listed below. For Omrin mix we used the sorting division achieved at Tönsmeier, for Vagron rigid, Rotterdam rigid and Amsterdam rigids the sorting division at Dela, for Wijster rigids the separate sorting division obtained at Dela.

Table 33: Modelled amounts of sorted fractions from the recovered PPW in scenario 5 in 2013

Fractions	Omrin mix, [kg/a]	Vagron rigid, [kg/a]	Wijster rigid, [kg/a]	Rotterdam, [kg/a]	Amsterdam, [kg/a]	Total, [kg/a]
PET	526,725	263,048	723,064	1,700,705	1,934,014	**5,147,556**
PE	842,760	493,216	1,835,470	3,188,822	3,626,276	**9,986,543**
PP	526,725	822,026	3,420,648	5,314,703	6,043,793	**16,127,895**
FILM	2,738,971	65,762	10,289,754	425,176	483,503	**14,003,167**
MKS	4,424,492	1,578,290	10,567,855	10,204,229	11,604,082	**38,378,949**
REST	1,474831	65,762	973,355	425,176	483,503	**3,422,628**
TOTAL	**10,534,505**	**3,288,105**	**27,810,146**	**21,258,810**	**24,175,171**	**87,066,737**
Average, [kg/cap.a]						*11,27*

The amount of produced milled goods and agglomerates made from these recovered sorted fractions in scenario 5 in 2013 are listed in Table 34.

In short, 105.6 kton (14.23 kg/cap.a) recovered PPW was sorted to 83 kton (11.27 kg/cap.a) of saleable fractions and 18.5 kton of separate film product, which were converted into 67.9 kton (9.15 kg/cap.a) of milled goods and agglomerates. In short the moderate extension of the post-separation system for the four largest cities and Wijster generates a small loss for the source separation system which is more than compensated by a large gain in the post separation system.

Table 34: Modelled amounts of produced milled goods and agglomerates made from the recovered PPW in scenario 5 in 2013

Fractions	Omrin, [kg/a]	Vagron, [kg/a]	Wijster, [kg/a]	Rotterdam, [kg/a]	Amsterdam, [kg/a]	Total, [kg/a]
PET	393,990	187,554	515,544	1,212,603	1,378,952	3,688,643
PE	721,403	372,871	1,378,615	2,410,749	2,741,464	7,634,103
PP	401,891	574,596	2,391,033	3,714,977	4,224,611	11,307,109
FILM	1,446,177	34,722	5,432,990	224,493	255,290	7,393,672
MKS	3,021,928	1,166,357	7,809,645	7,540,925	8,575,417	28,114,272
Subtotal	**5,985,390**	**2,336,100**	**17,536,828**	**15,103,747**	**17,175,734**	**58,137,798**
Additional film		1,157,413	8,637,504			**9,794,917**
TOTAL	**5,985,390**	**3,493,513**	**26,174,332**	**15,103,747**	**17,175,734**	**67,932,715**
Average, [kg/cap.a]						*9,15*

2.2.7. Detailed description of scenario 6

In scenario 6 the responses of the source separation system are increased until 55% of the overall response for post-consumer PPW is attained, which is believed to be the threshold value. The deposit-refund system and the post-separation systems are kept the same as in scenario 3. Hence, the basic parameters for the PET deposit refund system remained unchanged as compared to the parameters in the technical datasheet, yielding 22.8 kton (1.38 kg/cap.a) RPET.

The maximum amount of post-consumer PPW is estimated to be 167 kton (55% * 14.8 mln inhabitants connected* 20.57 kg/cap.a). The responses in scenario 2 were multiplied with 2.034 to approach an overall collected amount of 167 kton. We are fully aware that this is an approximation of what the responses will look like in a mature system.

Table 35: Modelled responses of the 20 different types of municipalities in 2013 in scenario 6

Code	Prim. inh. [#]	Sec. inh. [#]	Response [kg/cap.a]	Total collected amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
1DK	0	0	0	0	0	0	0	0
1DDr	0	0	0	0	0	0	0	0
1NK	0	0	0	0	0	0	0	0
1NDr	2,220,107	0	3.864	8,579,761	7,577,645	343,190	411,829	247,097
2DK	282,214	0	19.119	5,395,778	3,430,096	1,187,071	526,088	252,522
2DDr	302,120	0	19.729	5,960,723	3,789,231	1,311,359	581,170	278,962
2NK	1,605,122	66,105	9.356	14,956,201	13,209,317	598,248	717,898	430,739
2NDr	2,496,010	0	6.915	17,946,052	15,849,953	717,842	861,410	516,846
3DK	618,432	0	20.573	12,722,902	8,087,949	2,799,038	1,240,483	595,432
3DDr	143,374	0	6.102	874,862	556,150	192,470	85,299	40,944
3NK	1,483,160	0	11.797	17,497,004	15,453,354	699,880	839,856	503,914
3NDr	808,220	0	8.543	6,904,410	6,097,975	276,176	331,412	198,847
4DK	1,399,668	16,548	20.573	28,761,100	18,283,431	6,327,442	2,804,207	1,346,019
4DDr	345,776	33,079	14.848	5,355,173	3,404,283	1,178,138	522,129	250,622
4NK	1,069,145	54,177	13.018	13,847,073	12,229,735	553,883	664,659	398,796
4NDr	486,568	0	8.543	4,295,468	3,793,757	171,819	206,182	123,709
5DK	601,864	0	20.573	12,382,051	7,871,270	2,724,051	1,207,250	579,480
5DDr	195,905	0	14.848	2,908,815	1,849,134	639,939	283,609	136,133
5NK	521,173	0	13.8311	7,208,394	6,366,454	288,336	346,003	207,602
5NDr	175,707	0	8.543	1,555,427	1,373,753	62,217	74,661	44,796
Total	**14,754,565**	**169,909**		167,151,192	129,223,486	20,071,100	11,704,147	6,152,460
Average			*11.26*	*11.26*	*8.71*	*1.35*	*0.79*	*0.41*

D= DifTar, N= non-DifTar, K= kerb side, Dr = drop off

The sorting division and re-processing yields were kept the same as in scenario 3. The resulting products are shown in Table 36.

Table 36: Overview of the produced sorted fractions and final products from the source separated PPW in scenario 6

Fraction	Sorting division, [%]	Amount of sorted fraction, [kg/a]	Re-processing yield, [%]	Amount of produced milled goods and agglomerates, [kg/a]
PET	7%	11,700,583	80.7%	9,442,371
PE	6%	10,029,072	89.1%	8,935,903
PP	5%	8,357,560	81.9%	6,844,841
FILM	18%	30,087,215	66.6%	20,038,085
MKS	45%	75,218,036	81.8%	61,528,354
REST	19%	31,758,727		
TOTAL		**167,151,192**		**106,789,554**
Average, [kg/cap.a]		*9.12*		*7.20*

Hence, for source separation in scenario 6 about 167 kton (11.26 kg/.cap.a) was collected, which was sorted into 135 kton (9.12 kg/cap.a) recyclable fractions, which resulted in the production of 107 kton (7.20 kg/cap.a) milled goods and agglomerates

The production parameters for the recovery facilities Omrin, Vagron, Wijster and Rotterdam were precisely the same as in scenario 3. However, due to the raised responses for source separation the contribution of municipalities with post-separation as secondary system dropped slightly, as can be seen from the correction parameters for the contributions of municipalities that contributed to the yield of recovery as a secondary system; Omrin 42.7%, Vagron 2.9%, Wijster 29.7% and Rotterdam 0%.

Table 37: Modelled amounts of recovered PPW in scenario 6 in 2013

MRF	Prim. inh. [#]	Sec. inh. [#]	Production parameter [kg/cap.a]	Total recovered amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
Omrin mix	734520	55425	13.61	10,321,878	5,575,878	2,786,907	1,506,994	452,098
Vagron rigids	474002	104859	6.33	3,019,471	1,631,118	815,257	440,843	132,253
Vagron flexibles	474002	104859	4.22	2,012,981	1,097,578	549,544	219,516	146,344
Wijster rigids	0	2718612	5.67	4,572,289	2,469,951	1,234,518	667,554	200,266
Wijster flexibles	0	2718612	3.33	2,689,582	1,466,495	734,256	293,299	195,533
Rotterdam	610395	0	15.00	9,155,925	4,946,031	2,472,100	1,336,765	401,030
Total	**1818917**	**2878896**		**31,772,126**	**17,187,050**	**8,592,582**	**4,464,971**	**1,527,523**
Average			*6.76*	*6.76*	*3.66*	*1.83*	*0.95*	*0.33*

For the recovered plastics that were sorted, the modelled sorting results are listed below. The same sorting divisions were used as in scenario 3.

Table 38: Modelled amounts of sorted fractions from the recovered PPW in scenario 6 in 2013

Fractions	Omrin mix, [kg/a]	Vagron rigid, [kg/a]	Wijster rigid, [kg/a]	Rotterdam, [kg/a]	Total, [kg/a]
PET	516,094	241,558	118,880	732,474	**1,609,005**
PE	825,750	452,921	301,771	1,373,389	**2,953,831**
PP	516,094	754,868	562,392	2,288,981	**4,122,335**
FILM	2,683,688	60,389	1,691,747	183,199	**4,618,943**
MKS	4,335,189	1,449,346	1,737,470	4,394,844	**11,916,849**
REST	1,445,063	60,389	160,030	183,199	**1,848,601**
TOTAL	**10,321,878**	**3,019,471**	**4,572,289**	**9,155,925**	**27,069,563**
Average, [kg/cap.a]					*5.37*

The amount of produced milled goods and agglomerates made from these recovered sorted fractions in scenario 6 in 2013 are listed in Table 34. In short, 31.7 kton recovered PPW was sorted to 25.2 kton (5.37 kg/cap.a) of saleable fractions and 4.7 kton of separate film product, which were converted into 19.9 kton (4.23 kg/cap.a) of milled goods and agglomerates.

Table 39: Modelled amounts of produced milled goods and agglomerates made from the recovered PPW in scenario 6 in 2013

Fractions	Omrin, [kg/a]	Vagron, [kg/a]	Wijster, [kg/a]	Rotterdam, [kg/a]	Total, [kg/a]
PET	386,038	172,231	84,761	522,254	**1,165,284**
PE	706,842	342,408	228,139	1,038,282	**2,315,671**
PP	393,780	527,653	393,112	1,599,998	**2,914,542**
FILM	1,416,987	31,886	893,242	96,687	**2,438,802**
MKS	2,960,934	1,071,067	1,283,990	3,247,790	**8,563,781**
Subtotal	**5,864,581**	**2,145,244**	**2,883,244**	**6,505,010**	**17.398.079**
Additional film		1,062,854	1,420,099		**2,482,953**
TOTAL	**5,864,581**	**3,208,098**	**4,303,344**	**6,505,010**	**19,881,033**
Average, [kg/cap.a]					*4.23*

2.2.8. Detailed description of scenario 7

Scenario 7 is a full post-separation scenario; the source separation and deposit refund systems are abolished and all MSRW-incinerators are equipped with post-separation equipment; Wijster, Moerdijk, Rotterdam, Amsterdam, Duiven, Alkmaar, Nijmegen, Hengelo and Emlichheim (D.). Only the old Gevuco incinerator in Dordrecht is left unchanged; for the municipalities that bring their waste to this facility a source separation system is maintained. Although this scenario is politically unlikely (various rural municipalities will not give their source separation system up) and technically unlikely (not all incinerators are suitable to add a pre-treatment and post-separation line), it offers a theoretical insight in what a maximum post-separation system could offer.

There is no contribution from a deposit refund system and the contribution of the source separation system is limited to those municipalities that supply their MSRW to Gevuco. Like in scenario 4, the amount of PPW present at the households and that is potentially available for source separation has increased due to the abolishment of the deposit refund system.

Table 40: Modelled responses of the 20 different types of municipalities in 2013 within scenario 7

Code	Prim. inh. [#]	Sec. inh. [#]	Response [kg/cap.a]	Total collected amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
1DH	0	0	0	0	0	0	0	0
1DB	0	0	0	0	0	0	0	0
1NH	0	0	0	0	0	0	0	0
1NB				0	0	0	0	0
2DH				0	0	0	0	0
2DB				0	0	0	0	0
2NH	195,195	0	5.315	1,037,572	916,384	41,503	49,803	29,882
2NB				0	0	0	0	0
3DH				0	0	0	0	0
3DB				0	0	0	0	0
3NH				0	0	0	0	0
3NB				0	0	0	0	0
4DH				0	0	0	0	0
4DB				0	0	0	0	0
4NH				0	0	0	0	0
4NB				0	0	0	0	0
5DH				0	0	0	0	0
5DB				0	0	0	0	0
5NH				0	0	0	0	0
5NB				0	0	0	0	0
Total				**1,037,572**	**916,384**	**41,503**	**49,803**	**29,882**
Average					*4.69*	*0.21*	*0.26*	*0.15*

The sorting division and reprocessing yields were kept the same as in scenario 4. The amounts of sorted goods and milled goods under scenario 7 are listed in Table 41.

Table 41: Overview of the produced sorted fractions and final products from the source separated PPW in scenario 7

Fraction	Sorting division, [%]	Amount of sorted fraction, [kg/a]	Re-processing yield, [%]	Amount of produced milled goods and agglomerates, [kg/a]
PET	9%	94.976	80.7%	76.646
PE	6%	58.363	89.1%	52.002
PP	5%	48.636	81.9%	39.833
FILM	17%	175.090	66.6%	116.610
MKS	45%	466.908	81.8%	381.930
REST	18%	184.818		
TOTAL		1.028.791		667.021
Average, [kg/cap.a]		*4.32*		*3.42*

The production parameters for the recovery facilities Omrin, Vagron, Wijster and Rotterdam were precisely the same as in scenario 3. For the new post-separation facility in Moerdijk the same parameters are used as for the Wijster facility, because it is owned by the same company. For the other new facilities the parameters for Rotterdam are used. Since there is no source separation with post-separation as secondary system, the correction parameters for all facilities equalled 0%.

Table 42: Modelled amounts of recovered PPW in scenario 6 in 2013

MRF	Primary inhabitants. [#]	Sec. inh. [#]	Production parameter [kg/cap.a]	Total recovered amount	Plastics	Residual waste	Moisture	Dirt
				[kg /year]				
Omrin mix	789,945	0	14.05	11,098,572	6,799,085	1,910,619	1,837,591	551,277
Vagron rigids	578,861	0	6.73	3,895,450	2,386,388	670,602	644,970	193,491
Vagron flexibles	578,861	0	4.22	2,442,793	1,462,103	493,322	292,421	194,947
Wijster rigids	2,764,481	0	18.07	49,962,276	30,607,340	8,601,006	8,272,254	2,481,676
Wijster flexibles	2,764,481	0	10.00	27,644,810	16,546,455	5,582,869	3,309,291	2,206,194
Rotterdam	3,472,222	0	15.95	55,370,498	33,920,465	9,532,031	9,167,693	2,750,308
Amsterdam	1,898,705	0	15.95	30,278,088	18,548,629	5,212,373	5,013,143	1,503,943
Moerdijk rigids	2,796,387	0	18.07	50,538,911	30,960,592	8,700,274	8,367,728	2,510,318
Moerdijk flexibles	2,796,387	0	10.00	27,963,870	16,801,081	5,647,304	3,309,291	2,206,194
Duiven	867,962	0	15.95	13,841,134	8,479,203	2,382,751	2,291,676	687,503
Twence	1,222,192	0	15.95	19,489,935	11,939,709	3,355,192	3,226,948	968,085
HVC	1,091,746	0	15.95	17,409,751	10,665,370	2,997,089	2,882,532	864,760
Emlich	479,222	0	15.95	7,642,012	4,681,565	1,315,572	1,265,288	379,586
ARN	502,121	0	15.95	8,007,175	4,905,268	1,378,435	1,325,748	397,724
Total	**16,463,844**	**0**		**325,585,275**	**198,703,255**	**57,779,439**	**51,206,574**	**17,896,007**
Average				*19.78*	*12.07*	*3.51*	*3.11*	*1.09*

For the recovered plastics that were sorted. the modelled sorting results are listed below. The same sorting divisions were used as in scenario 3.

Table 43: Modelled amounts of sorted fractions from the recovered PPW in scenario 7 in 2013

Fractions	**Omrin mix. [kg/a]**	**Vagron rigid. [kg/a]**	**Wijster. Moerdijk rigid. [kg/a]**	**All new other facilities. [kg/a]**	**Total. [kg/a]**
PET	725,665	407,518	3,416,989	15,905,337	20,455,509
PE	832,393	547,798	6,218,511	21,380,427	28,979,129
PP	520,246	912,996	11,589,043	35,634,045	48,656,330
FILM	2,705,277	73,040	34,861,350	2,850,724	40,490,390
MKS	4,858,304	1,881,059	41,117,600	73,417,336	121,274,299
REST	1,456,688	73,040	3,297,695	2,850,724	7,678,146
TOTAL	**11,098,572**	**3,895,450**	**100,501,188**	**152,038,591**	**267,533,802**
Average. [kg/cap.a]					*15.78*

The amount of produced milled goods and agglomerates made from these recovered sorted fractions in scenario 7 in 2013 are listed in Table 44. In short. 325.6 kton recovered PPW was sorted to 260 kton (15.78 kg/cap.a) of saleable fractions and 58 kton of separate film product. which were converted into 212 kton (12.88 kg/cap.a) of milled goods and agglomerates.

Table 44: Modelled amounts of produced milled goods and agglomerates made from the recovered PPW in scenario 7 in 2013

Fractions	**Omrin. [kg/a]**	**Vagron. [kg/a]**	**Wijster. [kg/a]**	**Rotterdam. [kg/a]**	**Total. [kg/a]**
PET	542,797	290,560	2,436,313	11,340,505	14,610,176
PE	712,528	414,135	4,701,194	16,163,603	21,991,460
PP	396,947	638,184	8,100,741	24,908,197	34,044,070
FILM	1,428,386	38,565	18,406,793	1,505,182	21,378,926
MKS	3,318,222	1,390,103	30,385,906	54,255,411	89,349,642
Subtotal	6,398,881	2,771,547	64,030,948	108,172,898	181,374,274
Additional film		1,289,795	29,361,383		30,651,178
TOTAL	6,398,881	4,061,342	93,392,331	108,172,898	212,025,452
Average. [kg/cap.a]					*12.88*

This data is not perfect; 212 kton of recycled milled goods and agglomerates is produced from 325.6 kton recovered PPW, which is estimated to contain 199 kton plastics net. The percentages of attached moisture and dirt (table 4) are relatively too large and would yield an underestimation of the recycled materials in comparison to the sorting and reprocessing yields. Although this data is not flawless, it still allows us to estimate the impacts of a maximal recovery scenario.

3- Logistics

The result of the logistics calculations are contributing to the economic and environmental models. Typical results used in the next steps are logistical parameters such as kilometres and logistical costs for each chain step throughout each scenario.

The logistical calculations are split into 2 different models, a collection model for the calculation of logistical parameters of the collection of plastic at household level within municipalities and a network model for the modelling of the plastic flows from municipalities until reprocessors of the separated plastic fragments.

The input for both models are based on the results from the mass balances described in the technical mass balance tables from the previous chapter .The values of other variables and parameters used are derived from literature and/or collected by interviews and conversations with industry, municipalities and researchers by the researchers.

3.1 Collection logistics

For the collection of municipality waste quite some calculations are made in the past by various authors around the world. For a general approach of calculating the costs, total km and CO_2-eq emissions of collecting plastic waste within municipalities in The Netherlands we make use of a basis of 3 articles (Rhoma et al., 2010), (Sonesson, 2000), adapted when necessary) and various assumptions based on literature or expert knowledge. Formulas 1 to xx are derived from literature.

Until this research no attempt has been made to describe the Dutch system of collection of post-consumer plastic packaging waste in detail. This chapter uses an approach to build up cost factors bottom up, for example costs made picking up bags and emptying containers, driving between stops and driving to the site where a truck is emptied. The three systems of collection (kerb side and drop-off for source separation and post separation) have different collection methods and or parameter values. As it is not possible to collect data for each collection route in The Netherlands a comprehensive cost model is created.

The model is used to compare costs of municipal collection systems, based on a case study of the Netherlands. The results support decision making process by stakeholders in the PPW recycling scheme (governments, consumers, packaging and recycling industry) can be supported with in-depth insights in the variables that influence the costs of such systems. The collection cost model is based on fixed and variable costs per vehicle, personnel cost, container or bag costs as well as on emission costs. Each element is divided into parameters which include kilometres, fuel uses, time and quantities in such a way cost factors can be allocated.

Activity based costing is used to be able to calculate energy use and time needed for the determination of variable vehicle cost and personnel cost respectively. Different trucks are used for each collection system with their corresponding capacity and investment cost.

The collection costs consist of vehicle cost, labour cost, container cost and emission cost. Vehicle cost is split into fixed and variable cost. This calculation is based on one municipality for the period of a year and per ton of plastic waste collected. Costs are calculated per municipality. At the system of source-separation results are aggregated into the 10 different municipality categories as described in Table 8, making use of 5 different urbanization levels and a tax system for residual waste or not. Those 10 different types are split into kerb side and drop-off collection.

In this research the cost breakdown is made for all 418 municipalities in the Netherlands for the year 2011. Data from municipalities (number of inhabitants and number of households are extracted from Statistics Netherlands (CBS)). Plastic separated per municipality is calculated with this information combined with the following tables. Municipalities are categorized by urbanization level with a scale from 1 to 5. Level 1 represents the most urban municipalities and level 5 is the least urban municipalities. The estimated response rates of municipalities in 2013 are shown below for each scenario separately. The response rates are an extrapolation of the measured situation in 2011 (KplusV, 2011).

Input parameters for all scenario's for the collection model can be found in Table 45. The full model description can be found in the article 'A comprehensive cost model for sustainable post-consumer plastic packaging waste collection' by Groot et al. (2012, *in press*). Scenario specific parameters are described in the following paragraphs.

Table 45: Input parameters of the collection model within municipalities

Input parameters	Kerb side	Drop-off	Post separation	Unit
Insurance cost / year [1]	2500	2500	2500	euro
Tax cost / year [1]	1000	1000	1000	euro
Depreciation period of a vehicle [1]	5	5	5	yr
Interest rate of the investment [1]	0.05	0.05	0.05	%
% of use of a vehicle per year [2]	0.8	0.8	0.8	%
Time one vehicle can be used per year [3]	3000	3000	3000	hr
The average hauling speed [4]	60	60	60	km/hr
The average hauling distance [5]	18	18	18	km
Fuel price / litre [6]	1.4	1.4	1.4	euro/ltr
The average speed while collecting between stops [4]	25	40	15	km/hr
The number of households per kerb side point [7]	10	0	10	-
The average time per stop [8]	0.014	0.5	0.069	hr
The investment cost of a vehicle [1]	206000	250000	206000	euro
The salvage cost of a vehicle [1]	30900	37500	30900	euro
The average truck load per collection round [8]	1800	750	7200	kg
The total maintenance cost of the vehicle / year [1]	3000	4000	3000	euro
Fuel consumption for vehicle / km while driving [1]	0.33	0.25	0.4	l/km
Fuel consumption for vehicle / hr while idling [1]	4	4	4	l/hr
Fuel consumption for vehicle / km while hauling [1]	0.25	0.25	0.33	l/km
The driver wage per year [8]	30000	30000	30000	euro
The loader wage per year [8]	25000	25000	25000	euro
The regular working hours of driver/year [8]	1650	1650	1650	hr
The regular working hours of loader/year [8]	1650	1650	1650	hr
The number of driver per vehicle [8]	1	1	1	-
The number of loader per vehicle [8]	2	0	2	-
The total cost of container maintenance per year [8]	0	2000	0	euro
The investment cost of the aboveground container [8]	0	30000	0	euro
Depreciation Period of container [8]	0	10	10	yr
Capacity Container [8]	0	750	0	ton
The investment cost of the container 240l [8]	0	0	58	euro
Cost of a bag [8]	0.055	0	0	euro

1 *Derived from literature, backed up by experts and contractor*
2 *Difficult to obtain, based on own judgement, backed up by expert*
3 *Every day, eight hours a day*
4 *Difficult to access but good rules of thumb exist*
5 *Derived from a network optimization model described by Bing et al. (2012b)*
6 *Well known figure*
7 *Difficult to access, counted within own neighbourhood, backed up by experts*
8 *Derived from experts and contractor*

Table 46: The average distance (km) between stops per urbanization level

Urbanization level	Kerb side	Drop off
1	0.15	3
2	0.16	3
3	0.175	3
4	0.19	3
5	0.2	3

An increase of the urbanization level means a lower density of inhabitants. Therefore an estimation is made for the increase of distance between stops.

Hauling with truckloads to cross docking sites (source separation) or separation centres is calculated as well within the collection model. The average differences are extracted from the network model and represented in the next table.

Table 47: Average hauling distances (in km) of truckloads of plastic

Collection scheme	Location	Average hauling distance [km]
Source separation		18
Post separation	Vagron	25
	Omrin	43
	Rotterdam	10
	Wijster	136
	Duiven	90
	Moerdijk	90
	AEB	90
	Twence	90
	HVC	90
	Emlich	90
	ARN	90

The next paragraphs describe the differences between the scenario's. The biggest differences are found in the collected and separated amounts of plastics described in the technical mass balances in summarized the previous Chapter.

3.1.1. Scenario parameter settings and input for the Collection Model

Not all the collection costs of municipal solid waste can be allocated to the post separation system of municipal plastic packaging waste. Assumed is the percentage of plastic weight separated within the municipal solid waste is used to allocate cost of collection to the post separation system. This is done with a differentiation at each separation center. The next 3 tables indicate the percentage used for scenario 1-7. These separation figures are extracted from the data collection of Chapter 4.2. Furthermore the same Municipal data sheets are used. Other input are the collection responses of PPW as described in Chapter 4.2.

Table 48: Total Municipal Residual Waste per inhabitant per scenario [kg]

Scenario	Total MSW [kg]
2	231.71
3-7	228.10

Table 49: Amount of wet and dirty plastic packaging waste separated per separation centre per scenario

	Amounts of PPW separated [kg]					
Scenario	**2**	**3**	**4**	**5**	**6**	**7**
Vagron	8.44	10.55	12.49	10.55	10.55	10.95
Omrin	6.81	13.61	15.71	13.61	13.61	14.05
Rotterdam	15.00	15.00	17.15	15.00	15.00	15.95
Wijster	9.00	9.00	9.81	27.00	9.00	28.07
Duiven	-	-	-	15.00	-	15.95
Moerdijk	-	-	-	-	-	28.07
Others	-	-	-	-	-	15.95

Table 50: Percentage of collection cost of MSW allocated to the post separation system per scenario

	Percentage of MSW					
Scenario	**2**	**3**	**4**	**5**	**6**	**7**
Vagron	3.60%	4.60%	5.50%	4.60%	4.60%	4.80%
Omrin	2.90%	6.00%	6.90%	6.00%	6.00%	6.20%
Rotterdam	6.50%	6.60%	7.50%	6.60%	6.60%	7.00%
Wijster	3.90%	3.90%	4.30%	11.80%	3.90%	12.30%
Duiven	-	-	-	6.60%	-	7.00%
Moerdijk	-	-	-	-	-	12.30%
Others	-	-	-	-	-	7.00%

3.2 Network logistics

This research studies the Dutch household waste collection network. Two separation methods exist in the Netherlands: source-separation and post-separation (see Figure 9). With source-separation, separating plastics from other waste occurs in the household, while with post-separation this occurs later in separation centres, after the combined collection of plastic waste and other household waste. The two collection systems differ in channel choice and facility requirements. Currently, both source-separation and post-separation systems exist in the Netherlands with source-separation dominating (88% of municipalities) as this is preferred by regulation (Bing *et al.*, 2012). There is a trade-off between source-separation and post-separation. In general, source-separation prevents contamination of plastic waste by separating it from other waste at the source. Less non-plastic is found in the plastic waste from source-separation than in the plastic waste from post-separation. This reduces the need for cleaning and drying plastic waste before further treatments. Post-separation normally has a higher separation rate than source-separation, as the efficiency of separating plastic from other waste is decided by machines instead of householders. Furthermore, post-separation requires fewer infrastructures (bins, trucks, etc.) for collection in the municipalities, as all the waste is combined in the same bin. From a reverse network design angle, we compare these two options to show their differences in transportation efficiency and air emissions when adopting multi-modality, using the estimated quantity inputs for 2013.

The system boundary of the reverse network is from the municipalities in the Netherlands to the re-processors of recycled plastic materials within Europe. Household plastic packaging waste does not include plastics from industry or PET bottles, which go through a different recycling channel by recycling machines in supermarkets. Plastic waste can influence the density and quantity of the remaining waste[22]. In post-separation, plastic waste is mixed with other waste during transport for some parts of the network. Therefore, besides plastic waste, we also include the transportation of other waste in this research. The parties in this reverse chain are:

Municipalities: Waste is collected from households within municipalities, so all municipalities in the Netherlands (418) are included as the source of the waste in the reverse chain, or in other words, the suppliers in the network. In this study, collection rounds conducted within municipalities are not modelled, but costs for the collection are provided by experts of industry and we use those as input for our model. Each municipality constitutes a source node in the network, which generates waste that goes through the system.

Cross-docking centres/separation centres: Depending on which separation method is chosen, waste collected from municipalities goes to different centres. For source-separation, plastic waste goes to cross-docking centres where it is baled up and transferred for further transportation. Other waste goes directly from municipalities to incineration centres. For post-separation, waste goes to separation centres where plastic waste is separated from other waste, before further transport.

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[22] *Other waste, excluding separated collected waste such as paper, glass, textile, organic waste*

Sorting centres: After cross-docking centres and separation centres, plastic waste goes to sorting centres to be sorted for each plastic type. After the plastics are sorted, contamination and plastics falsely sorted (due to inefficiencies of sorting machines) are dealt with through special facilities

Incineration centres: Other waste from source-separation municipalities and separation centres (remaining waste after plastic waste is separated) goes to incineration centres for energy recovery. The remaining waste goes to incineration centres. This includes plastic which is not separated due to an inefficiency of the separation process.

Re-processors: After sorting, plastic types are transported to various re-processors for processing. These re-processors are usually specialized in processing one or several types of plastic.

The waste flows through the network are categorized as follows:

- PET (Polyethylene terephthalate)
- PP (Polypropylene)
- PE (Polyethylene)
- Film
- Mix of hard plastic (MKS2)
- Other waste (remaining waste after separated collected waste is taken out)
- Non-plastic (impurities and contamination of plastic waste, falsely sorted plastic waste due to inefficiency of sorting machines)

The first 5 categories are the sorted plastic types to be used in further re-processing. "Other waste" is the remaining waste that cannot be separately collected for recycling; this waste will be incinerated. The quantity of this waste category depends on the collection method. Less plastic waste is separated from source-separation than post-separation; so, the amount of other waste from post-separation municipalities is lower than that from source-separation municipalities. "Non-plastic" is mingled with plastic waste even after separation. In the sorting procedure, plastics will be cut in flakes and washed. "Non-plastic" will be transferred to and disposed of in special treatment facilities.

In post-separation municipalities, plastic waste is collected mixed with other waste. This mix is called municipal solid residue waste (MSRW). MSRW goes to separation centres, where plastic waste is separated from other waste. Other waste is then sent to incineration centres, while plastic waste goes on to sorting centres. In separation centres, part of the film fraction of plastic waste is sorted out and sent to processors. Afterwards, plastic waste is sorted into the 5 types as mentioned earlier. Non-plastic is sorted out and disposed through specialized facilities. Each of the plastic types is then transferred to its specialized processors. Plastic waste from source-separation municipalities is not mixed with other waste. Therefore, after collection, plastic waste is transferred to cross-docking centres and other waste goes directly to incineration. Plastic waste, after cross-docking, is further transported to sorting centres where sorting procedures happen. Afterwards, all the plastics are sent to their specialized processors, as well as the non-plastic. Currently, trucks are the major transportation mode utilized throughout the network. However, MSRW from a few post-separation municipalities in Gelderland (east province) and from all the post-separation municipalities in Limburg (south province) are gathered at Apeldoorn and

Maastricht and sent by train to a separation centre in Wijster. Trucks are used to transport MRSW from the municipalities to Apeldoorn and Maastricht. From these two locations to Wijster, the train is used. There is no current existing barge transport in the network. Figure 14 describes this situation.

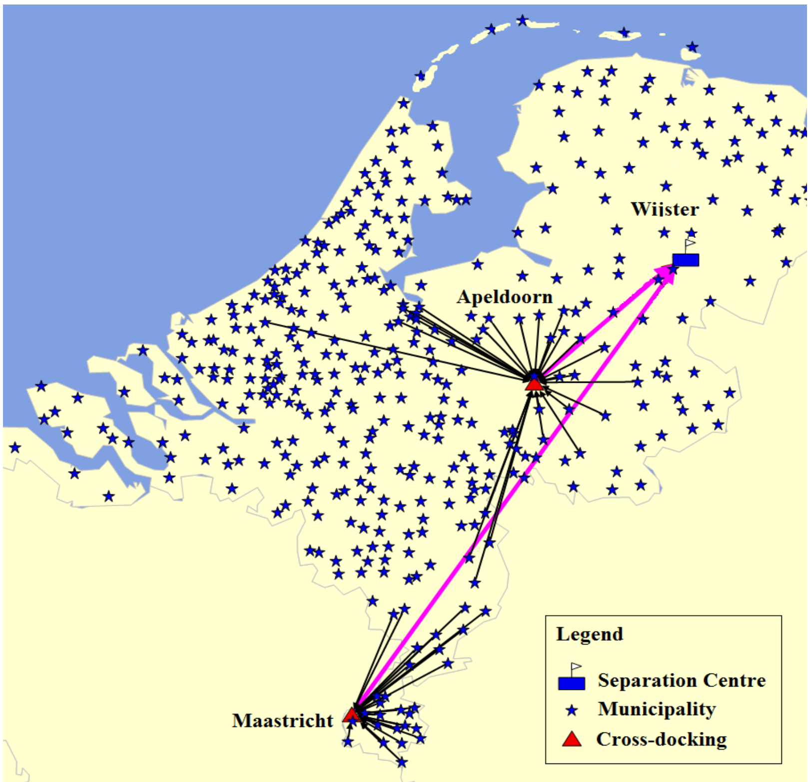


Figure 14: Existing train connections in the network

Municipalities (population, quantity of plastic waste, location): Statistics are collected from the Central Bureau of Statistics in the Netherlands. There were 418 municipalities in 2011, varying a lot in population (CBS, 2011). Quantity of PPW recycled is estimated for the year 2013. This estimation is based on the current collection data combined with the future trend. Estimation is conducted and experimental results of this study were used (Thoden van Velzen *et al.*, 2012). This collection cost estimation is based on Groot et al (2012 *in press*)

Processing facilities (function, location, availability, costs): Nedvang provided data on the locations, functions and costs of processing facilities. We have a cost input for each of cross-docking, separation, incineration, sorting, non-plastic disposal and re-processing. These are 25 €/ton, 350 €/ton, 88 €/ton, 135 €/ton, 88 €/ton, and 280 €/ton respectively (Thoden van Velzen *et al.*, 2012). The cost for non-plastic disposal is the same as the incineration cost because the handling of other waste is usually through incineration in some special facilities.

Current connections in scenario 2: The flow of plastic waste through the network is defined by the actual situation (contracts made between parties) in the baseline scenario. The information on the flow details is provided by KCN. An exception is the connections to Cross Docking sites. The current locations are known but it is not completely clear to us what the current connections are for the routes municipalities -> cross docking site ->

sorting centre. The connections are defined by the optimization model and therefore can be more efficient then the real situation

3.2.1. Scenario parameter settings and input for the Network Model

Assumptions used in the baseline scenario of the network model are as follows:

- Network flows are defined as described in the case description section.
- There is no mechanical efficiency or cost difference between the same facilities in different scenario's.
- Cost input of the "nodes" in the network include (1) collection costs in municipalities (2) processing costs in separation centres, cross-docking centres, sorting centres (3) incineration costs, non-plastic disposal costs and re-processing costs. Emission costs of these "nodes" are not included in the model, as multi-modality does not influence the emission of these facilities.
- Truck is the major modality used in this scenario (see Figure 3). Four truck types are used. Capacity and cost details can be found in Table 1.
- The exception of train connections in the current network will not be included in the benchmarking and baseline scenario, to better compare of the results between scenarios with and without multi-modality options.
- Model optimizes costs in the model only, not yields, as yields depend on the market of recycled materials which is not within our research scope.

Table 51: **Cost details for all modalities used in the modelling**

Modality	Capacity	Transportation cost	Emission	Emission cost	Total cost
	[ton]	[EUR/km/vehicle]	[g CO_2 / ton/km]	[€/km/vehicle]	[€/km/vehicle]
Truck type 1	13,5	1,3	295	0,08	1,38
Truck type 2	18,0	1,3	295	0,11	1,41
Truck type 3	1,8	1,43	480	0,02	1,46
Truck type 4	7,2	1,43	480	0,07	1,50
Train	1350	33,75	22	0,6	34,3

Assumptions for network logistics model:

- Highly differentiated cost model
- A combination of Swedish, English and Dutch collection models
- Network flows are defined as described in the case description section
- There is no mechanical efficiency or cost difference between the same types of facilities.
- Cost input of the "nodes" in the network include (1) collection costs in municipalities (2) processing costs in separation centres, cross-docking centres, sorting centres (3) incineration costs, non-plastic disposal costs and re-processing costs. Emission costs of

these "nodes" are not included in the model, as multi-modality does not influence the emission of these facilities.

- Four truck types are used.
- Model optimizes costs in the model only, not yields, as yields depend on the market of recycled materials which is not within our research scope.

4- Economics

4.1 Economic modelling

Input from the technical mass balances and logistics are used. Table 52 and Table 53 describe the assumptions underlying the model. In Table 52 the baseline number of households and the amounts of municipal small refuse waste (MSRW), and PET via the pet refund system is given. Dutch inhabitants produce about 228 kg of MSRW Table 53 gives the amounts of MSRW and PPW collected for the different scenarios. The amounts of MSRW produced differ slightly. These amounts are calculated by FBR and part of the input data of the model.

Table 52: Total amounts collected per scenario, in tons

Scenario	Total MSRW [ton]	Total source separation [ton]	Total post separation [ton]	PET deposit refund system [ton]	PPW separated [ton]	PPW collected [kg/cap.]
Scenario 1	3,800,000	n.a.	n.a.	26,600	26,600	1.6
Scenario 2	3,860,000	83,086	9,514	26,600	119,201	7.2
Scenario 3	3,800,000	100,263	39,758	26,600	166,621	10.0
Scenario 4	3,800,000	114,649	44,581	n.a.	159,230	9.6
Scenario 5	3,800,000	94,651	105,618	26,600	226,869	13.6
Scenario 6	3,800,000	166,013	31,441	26,600	224,054	13.4
Scenario 7	3,800,000	1,038	325,585	n.a.	326,623	19.6

n.a. = not applicable

The data from this table is sourced from databases by CBS, Stichting Nedvang , and own experimental data and estimations by Wageningen UR FBR

Table 53: Costs parameters, in Euro per ton of input at respective activity

	Kerb side MSRW	**Source separation kerb side**	**Source separation hotspot**	**Post separation**
Collection[a]	72	181 - 580	184 - 185	56 - 82
Haulage[b]	n.a.	7.0	4.4	4.6 - 11.6
Pre-separation	n.a.	n.a.	n.a.	19
AVI tariff	88	88	88	88
Separation	n.a.	n.a.	n.a.	200
Cross-docking	n.a.	25	25	n.a.
Transport to sorting[b]	n.a.	10.9 - 17.2	10.9 - 17.2	41.3 - 46.9
Sorting	n.a.	125	125	145
Transport to recycling[b]	n.a.	17.9 - 19.0	17.9 - 19.0	10.3 - 11.5
Recycling	n.a.	90 - 230	90 - 230	100 - 250

n.a.: not applicable.

a. Range depending on scenario because of collection logistics

b) Range depending on scenario because of network logistics and volume differences.

Sources: estimations by Wageningen UR FBR, databases from Stichting Nedvang, KPMG 2010, PWC 2011

At points in the supply chain where one type of product is transformed into several other products and waste flows, mass balances are used to determine the amounts. The mass balances used are based on the tests and calculations done by FBR. Column 3 and 4 give the mass balances after separation for source separation and plastic recovery respectively. The given parameters are those for scenario 2. They may differ per scenario. On the whole the source separated material is cleaner (has less moist and dirt attached to the plastic) and the separation efficiency for source separation is higher, with the notable exception of the rigid PE fraction. In columns 5 and 6 the mass balances are given after sorting of the separated material. The processing yields refer to the amount of plastic granulates produced from a kg of sorted plastic input.

5- Environmental impacts

The objective of the modeling of environmental impacts for the different scenarios of plastic packaging waste recycling is to predict the environmental impact of varying technical and logistical parameters as a consequence of the different scenarios. These calculations are based on the functional unit. The system which is being analyzed is the recycling system of household waste. The boundaries are the same as in the models of the other disciplines (technological, logistics, economics). This includes plastic packaging waste from the collection phase through to the incineration phase and the processing/recycling phase. It does not include the production of new products with the re-granulates produced in recycling, but the avoided emissions due to production of re-granulates (milled goods) are taken into account (see also chapter 1). Also, the avoided emissions due to recovery of energy at incineration are taken into account.
The environmental impact of various PPW recycling schemes can be calculated by the process impacts of the system and the avoided impacts of primary production. Process impacts are the environmental impacts from collection, separation, sorting, recycling and incineration. Avoided impacts are derived by replacing the need to produce from primary materials. In recovery of energy at incineration primary production of electricity and heat is replaced and in recycling to produce re-granulates primary production of granulates is replaced.

The environmental impact performance of the different scenarios was then calculated by deducting the avoided impacts from the process impacts. In short: Environmental impacts = process impacts – avoided impacts of primary production.

The environmental data have been collected by Blonk Environmental Consultants or pulled from the Eco-Invent database (version 2.2). These include data on electricity production, recovery of heat and electricity at incineration, energy use of trucks, emissions and recovery of secondary materials. The functional unit is 1000 kg of plastic packaging waste in municipal solid rest waste, including the wet and dirt fraction (20% - 23%) it contains when collected.

The important environmental impact categories that should be looked into when developing and testing new recycling schemes and waste management techniques are:

- Climate change
- Fossil depletion
- Toxicity (human- and eco-toxicity)
- Particular matter

A model was built to analyze the 7 scenarios which consist of a mix of collection systems and waste treatment options. Simapro software was used to calculate results on climate change, fossil depletion and human toxicity of incineration including recovery of energy. Also environmental results of processes like transport, production of plastics and energy use were calculated using Simapro and the EcoInvent database. Due to the system boundaries, this calculation cannot be considered as a complete Life Cycle Analysis. Instead, it focuses on the environmental impact of the PPW recycling itself from collection to milled goods.

The efficiency of separation or sorting can vary depending on the type of plastic. And in source separation, the consumer is also inefficient to a certain degree. The model takes these differences in efficiency into account. The model also accounts for varying amounts of wet and dirt, which are inherent to used plastic packages. The avoided emissions due to use of re-granulates and recovery of energy are also included.

The input data were based on the technological mass balance research (see chapter 2). The first step was to aggregate the data according to urbanization level and waste treatment system. Since this data include separated amounts of plastic instead of total amounts of plastic in municipal solid rest waste, the second step was to derive the amount of plastic in municipal solid rest waste according to urbanization level and waste treatment system. The amount of plastic for the total of the Netherlands was converted to the functional unit of 1000 kg of plastic packaging waste in municipal solid rest waste. The third step was to divide the total amounts of plastic into separate plastic fractions (PET, HDPE (PE), LDPE (PE foil), PP, MIX). For plastic recovery and the PET system (refund and Swiss) this is the data needed as input for the model. For source separation one more step is needed for generating the input data. This step includes the separation of plastic fractions by the consumer. The plastic fractions which are not separated by the consumer are incinerated.

Some stages have a certain amount of inefficiency, leading to plastics being incinerated. The wet and dirt of the plastic packages is also separated, either at separation or at recycling, and incinerated. Energy is recovered at incineration (electricity and heat). The outputs of the succeeding processes are re-granulates of the various plastic types.

The model calculates climate change (in kg CO2eq/ton), fossil depletion (in MJ/ton), human toxicity (in kg 1,4-DBeq/ton) and particular matter (in kg PM10eq.) of each scenario. Climate change is an indicator for emission of greenhouse gasses like carbon dioxide, methane and nitrous oxide. Greenhouse gasses are emitted for instance during the production and use of energy like electricity and natural gas or by incineration of waste materials. Fossil depletion is an indicator for the amount of energy which is used. Various types of energy use are included in this indicator like use of diesel, electricity and natural gas. Human toxicity is an indicator for the amount of toxic substances affecting human health emitted.

The amount of plastic packaging for the total of the Netherlands was converted to the functional unit of 1000 kg of plastic packaging waste in municipal solid rest waste, including the wet and dirt fraction it contains when collected. The model calculated the impacts of climate change (in kg CO2 eq/ton), fossil depletion (in MJ/ton), human toxicity (in kg 1,4-DBeq/ton) and particular matter (in kg PM10eq) of each scenario. The results are expressed as ReCiPe-scores, using equivalence factors and weighing factors to calculate the environmental impact.

The most important data for calculating environmental impacts are recovery rates. The recovery rates for plastic recovery and source separation vary and this variation is determining for the environmental results and in choosing the best scenario based on these results. The most important data for calculating environmental impacts are recovery rates. The recovery rates for

plastic recovery and source separation vary and this variation is determining for the environmental results and in choosing the best scenario based on these results.
There is uncertainty in the recovery rates which have been used for the calculations. There are literature reports (Shonfield, 2008) stating the recovery rate for plastic recovery should be higher than the recovery rate which has been decided to use for this analysis, so for further research recovery rates for plastic recovery should be looked into deeper.

Other important data for environmental results are recovery rates for energy recovery at incineration. Recovery rates vary between countries, and between incinerators within countries.

These rates have not been reported into detail and the currently used rates have been based on assumptions based on data from a confederation of European waste-to-energy plants (BRBS, 2008). Recovery rates for energy recovery are expected to increase over time due to modernization of the incinerators.

Also replacement percentages and replaced materials are important in calculating environmental impact. In order to be able to calculate avoided emissions due to the use of re-granulates it is necessary to know what material is being replaced and how much of this material is being replaced. If re-granulates of LDPE do not have a good enough quality to replace primary LDPE granulates but can only replace materials like wood, the avoided greenhouse gas emissions and fossil energy will be very different. It might turn out not to be an avoidance of greenhouse gas emission but an added greenhouse gas emission. For this analysis the re-granulates have been assumed to be able to replace their counterpart primary granulates, but LDPE has been assumed to be able to replace a smaller percentage of primary granulates. The percentage of replacement is also a determining factor for calculating the environmental results of recycling.

Recovery rates of plastic recovery and source separation, energy recovery rates at incineration, replacement percentages and replaced materials of re-granulates are determining factors for the results on environmental impacts. This analysis has been based on assumptions on these factors based on estimations and expert insights as there are no public references available with sufficient detailed information.

In terms of fossil resource depletion both incineration and avoided emissions thanks to secondary materials were important. For particular matter network transport is also significant.

PET contribution is important to fossil depletion because of the high levels of avoided energy use associated with PET recycling. PET has a low energy content at incineration. PET recycling is also important to human toxicity; primary PET production has a high human toxicity impact.

6- Results

6.1 Technical mass balance results

The amounts of collected municipal solid refuse waste and various types of plastic packaging waste for all seven scenarios have been gathered in Table 54.
The amount of MSRW was kept constant for all scenario's in 2013, while a small reduction of less than 8% is expected, due to the rise in separately collected PPW. However, at the time of the calculations it was impossible to model these reductions in MSRW per municipality accurately, without introducing erroneous circle-calculations. Therefore, was a first estimation, the amount of MSRW per municipality was kept constant.

Table 54: Overview of the total amounts collected per scenario

Scenario	Total MSRW [ton]	Total source separation [ton]	Total post separation [ton]	PET deposit refund system [ton]	PPW separated [ton]	PPW collected [kg/cap.]
Scenario 1	3,800,000	n.a.	n.a.	26,600	26,600	1.6
Scenario 2	3,860,000	83,086	9,514	26,600	119,201	7.2
Scenario 3	3,800,000	100,263	39,758	26,600	166,621	10.0
Scenario 4	3,800,000	114,649	44,581	n.a.	159,230	9.6
Scenario 5	3,800,000	94,651	105,618	26,600	226,869	13.6
Scenario 6	3,800,000	166,013	31,441	26,600	224,054	13.4
Scenario 7	3,800,000	1,038	325,585	n.a.	326,623	19.6

n.a. = not applicable
The data from this table is sourced from databases by CBS, Stichting Nedvang , and own experimental data and estimations by Wageningen UR FBR

The total amounts of separately collected PPW, recovered PPW and collected PET bottles from the deposit-refund system are shown in the table above per category. These contributions to the collection of post-consumer PPW are added together and also presented in amounts collected per inhabitant per year. These amounts are obviously gross amounts, including the contained moisture and attached dirt.

A comparison between the points of reference (scenario 1 and 2) shows that the plastic collection scheme in the Netherlands in 2010 resulted in four times more plastic packaging waste than with only the PET bottle deposit refund system. The base scenario for 2013 (no 3) with only a moderate maturation of the separate collection system and the recovery system yields already 35% more collected PPW; hence the total PPW collection scheme can be optimised with relatively little effort. The growth originates from the Nedvang part of the system, not from the deposit refund system, which remains stable. The abolishment of the PET bottle deposit refund system (scenario 4) results in a partial shift of the PET bottles to the Nedvang schemes of source separation and recovery. With the assumptions we have used, this hardly resulted in a loss of PPW. In case the recovery system is expanded further (scenario 5) and even maximally without separate collection or deposit refund system (scenario 7) the total scheme can grown to a maximum amount of about 20 kg recovered per inhabitant and year. In case the separate collection system is matured to what is expected to be maximal (scenario 6) the total amount of collected PPW is almost equal to what can be expected for the expanded recovery system (scenario 5).

In conclusion, maturation and expansion of the separate collection scheme for PPW and the recovery scheme for PPW can help to raise the amounts of collected PPW. The three collection systems (deposit refund, separate collection and recovery) cannibalise each other, in the sense that an expansion of one of the three systems will automatically result in a lowering of the collection yields of the other systems. Hence, efficiency in PPW collection can best be achieved by lowering the amount of collection systems within the overall scheme.

Collection yields of the separate collection system

Nedvang shared with us detailed response information of each municipality that contributed to the separate collection system, this data is categorised for the urbanisation degree [1-5] and the type of MSRW collection system (with or without a differentiated rate) and for the type of PPW collection system (drop-off versus kerbside). This data clearly shows that in general non-urban communities with a diftar system for the MSRW collection and kerbside collection system will yield the largest responses, see Figure 15.

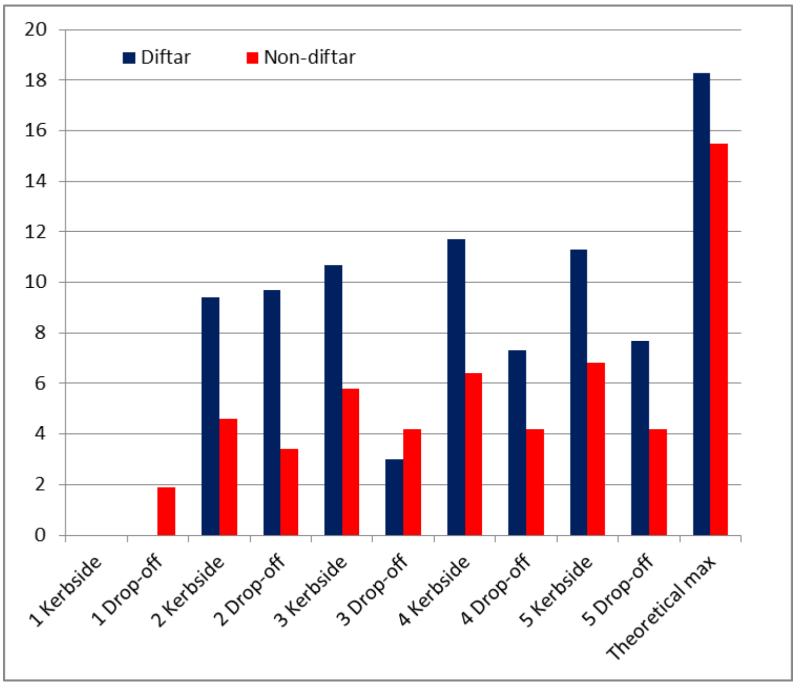


Figure 15: Responses for the collection of PPW in 2010 in the Netherlands categorised for the type of municipality

The amount of recovered PPW at post-separation centres has gradually increased in time. Initially in 2009 both Omrin and Vagron reported separation yields for the recovery of PPW from MSRW of 2%, whereas the PPW content of the MSRW was roughly 12-15%. Vagron reported separation yields of 4% in 2011 and of 6% in 2012. Omrin reported similar gains in recovery rates. Simultaneous with the improvement in quantity, the quality improved as well, with roughly 70% PPW in the recovered concentrates in 2009 and more than 85% in 2012. The time scales required to optimise the recovery process (machine settings, maintenance, etc.) are apparently several years. Hence, the response of a PPW recovery operation is mostly dependant on the chosen technologies, maintenance and operational execution.

The sorting and reprocessing yields of the separately collected PPW and the recovered PPW differ slightly, due to the differences in composition. Hence, although recovery schemes can collect more material, due to the slightly lower overall sorting and reprocessing yields the differences between separate collection and recovery are smaller when comparing the amounts of produced milled goods and agglomerates, see Table 55.

Table 55: Overview of the collected amounts of PPW per scenario and system, the amounts of sorted recyclable fractions and produced milled goods and agglomerates

Scenario	System	Collected amounts, [kton]	Sorted recyclable fractions, [kton]	Produced milled goods and agglomerates, [kton]	
1	dr	26.6	26.6	22.8	22.8
	sc	0	0	0	
	re	0	0	0	
2	dr	26.6	26.6	22.8	79.5
	sc	85	65	51	
	re	9.5	8.7	5.7	
3	dr	26.6	26.6	22.8	111.4
	sc	100	81	64	
	re	39.7	37	24.6	
4	dr	0	0	0	100.9
	sc	114	93	73	
	re	44.6	42	27.9	
5	dr	26.6	26.6	22.8	151.7
	sc	95	76	61	
	re	105.6	101.5	67.9	
6	dr	26.6	26.6	22.8	149.7
	sc	167	135	107	
	re	31.7	25.2	19.9	
7	dr	0	0	0	213
	sc	1.0	0.8	0.67	
	re	325.6	318	212	

Including the amounts of sorted recyclable fractions and produced milled goods and agglomerates.
Dr = deposit refund
Sc = separate collection
Re = recovery or post-separation

With the maturation and or expansion of both the source separation or recovery system large increases in the output of recycled milled goods and agglomerates can be achieved. The abolishment of the deposit refund for PET bottles results in higher amounts of material in the separate collection and recovery systems, but the final output of milled goods and agglomerates is slightly lower. This reduction in the amount of produced milled goods and agglomerates is strongly dependant on estimated parameters such as the response rate for the PET bottles and could well turn out to be both higher or lower depending on the precise execution of the replacing system. In case simultaneous with the abolishment of PET bottle system the collection means for separate collection are extended, the loss of material will turn out to be lower.

The gains in material that can be reached by maturing the separate collection system and improving the recovery system are roughly ten times larger than the potential losses due to the abolishment of the deposit refund system for PET bottles.

6.2 Logistics results

First an overview will be given for the results of Scenario 3. This provides in-depth insights on the way different elements of cost and a variation in parameter values interact on collection cost of plastic packaging waste schemes.

After this specification of Scenario 3 the collection cost results are presented for each scenario.

6.2.1. Collection results of Scenario 3

We conducted the cost calculation for all the municipalities in the Netherlands (at that time 418). On average, the total collection cost per ton of plastic waste collected for source-separation municipalities is more than two times higher than that of post-separation municipalities. This is because plastic is a light weight material with a large volume. When plastic is collected separately in source-separation municipalities, the collection efficiency is much lower. For the same reason, the emission cost is also much higher than that in post separation municipalities

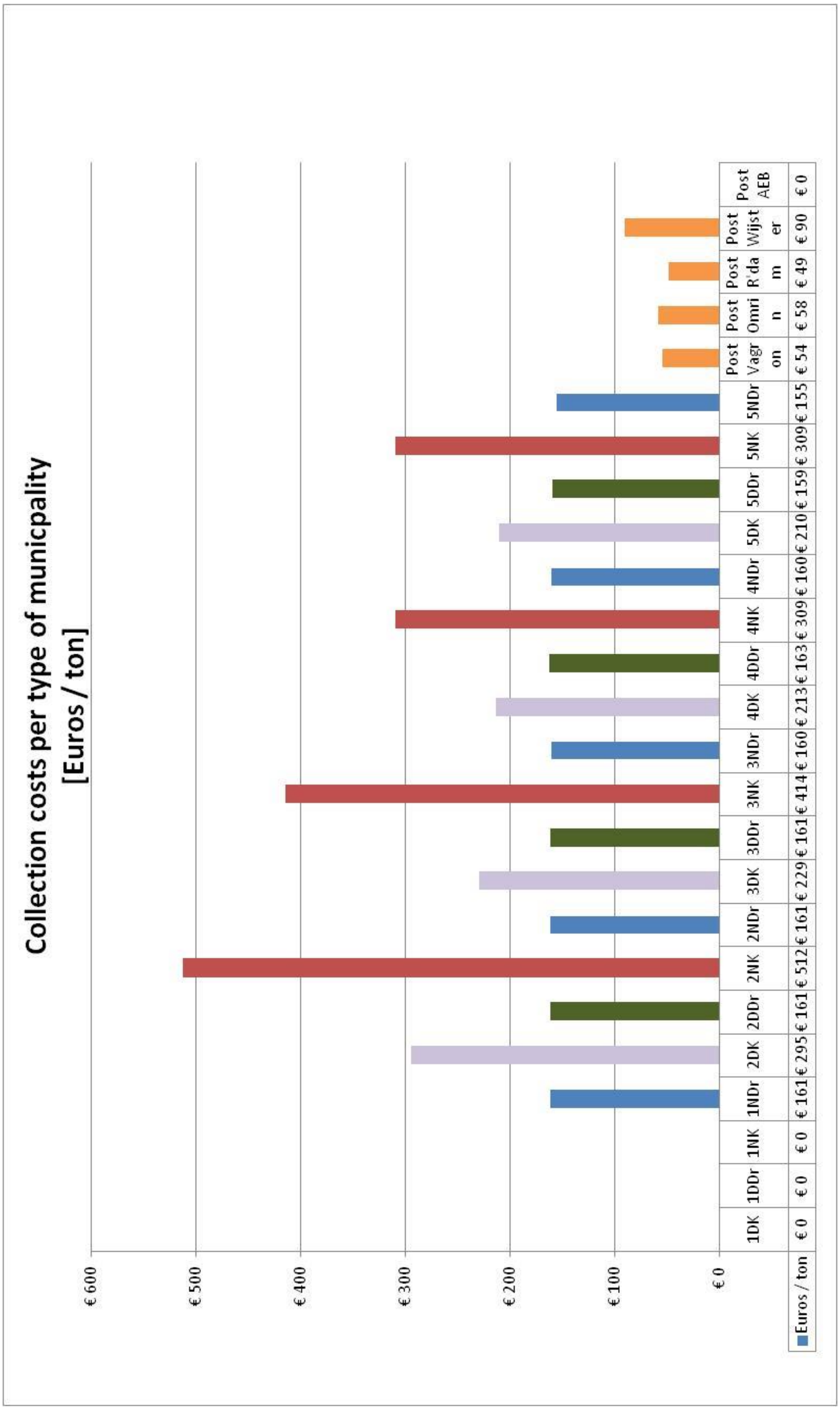


Figure 16: Collection cost per municipality type. *Municipality type is based on urbanisation degree (1 Urban, 5 Rural), taxation system (D= DifTar, N= Non-DifTar) and Collection method (K= Kerbside, DR = Drop off). Post = Post separation.*

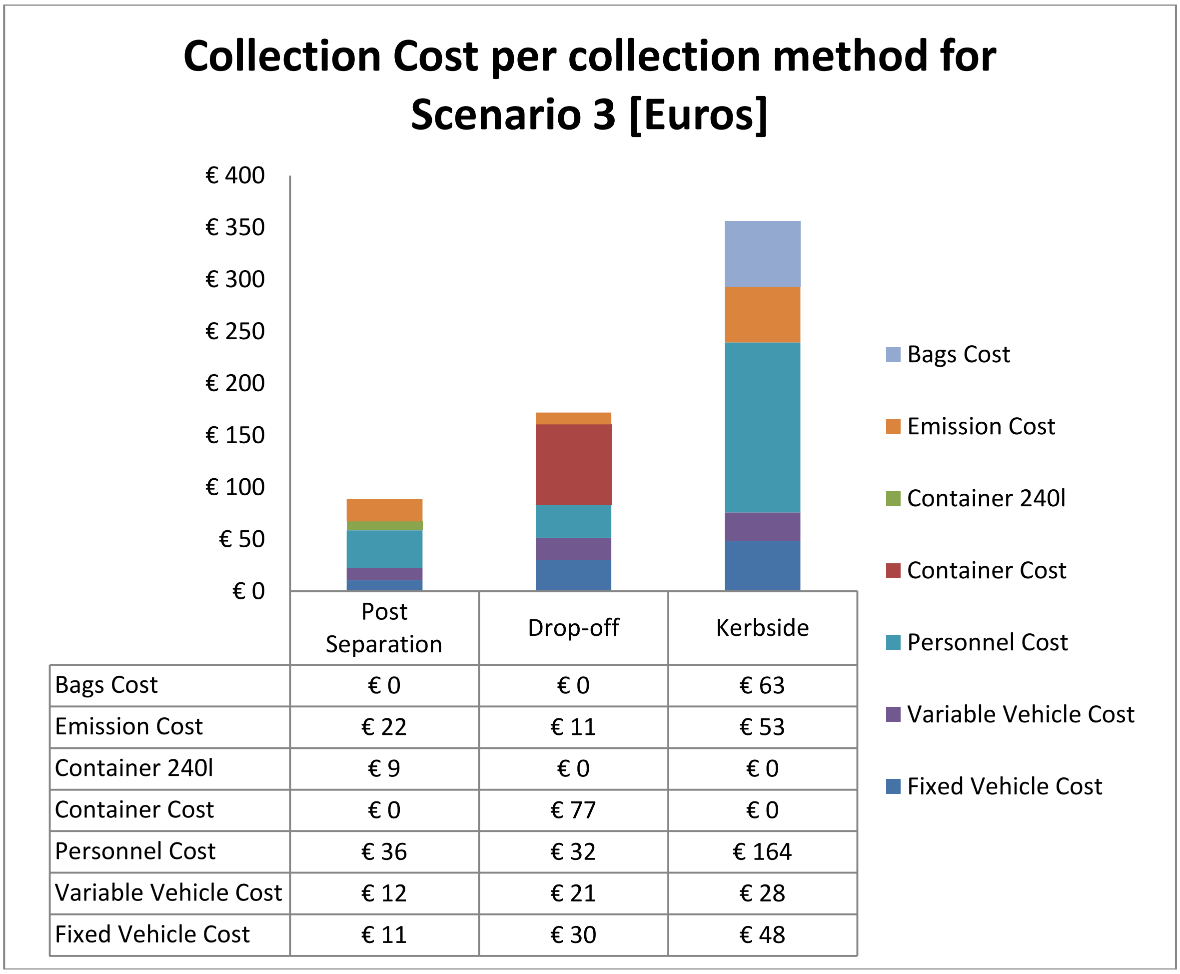
Comparing kerb side and drop-off collection, we can see that drop-off collection has a higher percentage of fixed cost which results from the heavy lifting trucks used in drop-off collection to empty big containers at collection sites. Personnel cost is a major part of the total cost for both collection methods. It is relatively higher in kerb side collection because in kerb side collection, besides one driver for each truck, there are also two loading persons assigned, whereas in drop-off collection trucks, there is only one driver per truck. Drop off collection has container cost which is not in the kerb side collection.

Driving in kerb side collection with frequent stops and short idling time consumes more fuel than driving to less spots with longer idling time. This difference is more obvious when the parameter of urban class of municipalities is added in the comparison. Urban municipalities have larger difference between the two collection methods as making frequent small stops for kerb side collection in high population density area costs more.

As we assume the same number of householders served by making each stop in kerb side collection for all municipalities, this result implies that for urban municipalities, more householders aggregating their plastic bags for kerb side collection can help reduce the collection cost. Kerb side collection costs vary a lot with different urbanization of municipalities, while drop-off collection has almost the same cost for all municipalities.

Labour cost is the biggest cost factor in both separation systems. Combined with the large difference in total collection cost between the systems (see figure below) the impact of labour cost in source separation is larger than with post-separation. Collecting waste that has a low weight density is cheaper when stopping less and idle more at one collection point.

With source separation the distribution of plastic transparent bags made of virgin plastic is a significant cost factor.

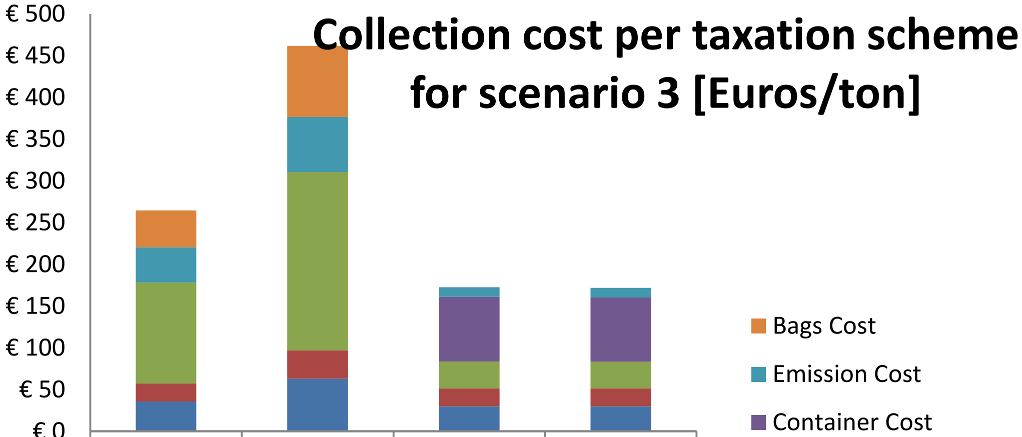


	Post Separation	Drop-off	Kerbside
Bags Cost	€ 0	€ 0	€ 63
Emission Cost	€ 22	€ 11	€ 53
Container 240l	€ 9	€ 0	€ 0
Container Cost	€ 0	€ 77	€ 0
Personnel Cost	€ 36	€ 32	€ 164
Variable Vehicle Cost	€ 12	€ 21	€ 28
Fixed Vehicle Cost	€ 11	€ 30	€ 48

Figure 17: Collection Cost per separation method for Scenario 3

Calculations include minimum and maximum municipality

Tax charges influence the total collection cost which can be seen in Figure 18. Diftar is in general the tax charges that differentiate the waste separated and not separated which will result in a higher separation rate. For kerb side collection, with a larger amount of plastic waste to be collected, the trucks have the same amount of stops but per stop trucks can load more plastics, therefore, the utility of trucks raised. The lower cost and less emission result from the higher truck utility. However in drop-off collection, the containers have to be emptied when they are full. This means that with more amounts of plastics into the containers, more driving rounds are needed in order to empty the containers even though the truck are not full after emptying containers. This compensates the economics of scale achieved by a raised plastic waste input.



	Kerbside Diftar	Kerbside No Diftar	Drop-off Diftar	Drop-off No Diftar
Bags Cost	€ 44	€ 85	€ 0	€ 0
Emission Cost	€ 42	€ 66	€ 11	€ 11
Container Cost	€ 0	€ 0	€ 78	€ 77
Personnel Cost	€ 121	€ 213	€ 32	€ 32
Variable Vehicle Cost	€ 22	€ 34	€ 21	€ 21
Fixed Vehicle Cost	€ 36	€ 63	€ 30	€ 30

Figure 18: Collection cost per taxation scheme for Scenario 3

With some changes in the input parameters and assumptions, the calculation model proposed in this paper can further help to provide more insight into the collection system and provide decision support for making future changes in the collection. We further tested in our model with different values of a few input parameters that are utilities, fuel prices and carbon costs. In our case study, we made the assumption of a fixed truck utility and container utility, which is according to the data we collected from waste collection companies. We analysed with our model the impact of a different utility rate of the trucks and containers on the total cost, without investment cost change.

The collection truck has the same maximum capacity of 3000 kg for both drop-off collection and kerb side collection. For drop-off collection, as explained before in the result section, there is no difference in cost between Diftar and Non-Diftar. The average total collection cost per municipality of kerb side and drop-off collection with different capacities of a collection truck shows that with such a collection truck, to achieve a relatively low cost by each of the collection method, the utility of the truck should be around 1500 kg. In other words, the collection trucks should be at least about half full, so that the collection can be eco-efficient. For the utility rate of drop-off containers, we observe a sharp decrease of total cost when containers are filled from 0% to 50%. After 50%, the decrease of cost slowed down. The result indicates that, in general, the fuller a container is filled, the less total cost is. If the utility rate falls below 50%, the collection can be very in-efficient. Furthermore, the result of container utility rate above 100% indicates that over filling a container (sometimes containers are full and some plastic waste bags are placed around the container) brings a very limited cost reduction.

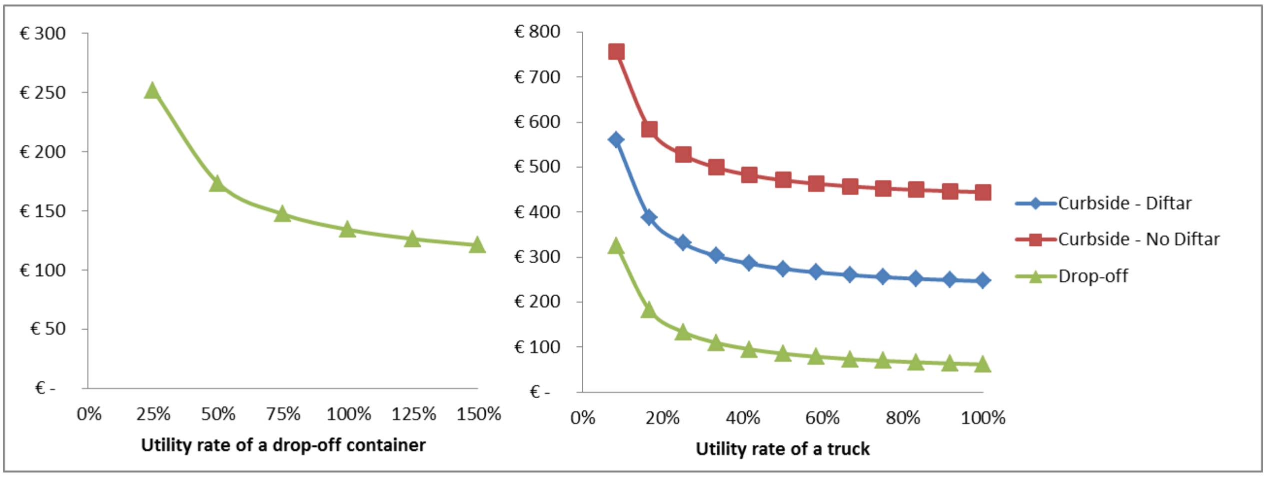


Figure 19: Average total collection cost per municipality of kerb side and drop-off collection with different utility rates of a container and collection truck (Euros/ton)

The proposed model can also help with providing decision support in analysing the future changes. With the pressure from the regulations as mentioned in the introduction section, a possible change in the future is the increase of plastic recycling and a better behaviour in separating plastics of householders. With this trend, there will be more plastics input in the source separated plastics. To investigate the impact of plastic waste input on the collection cost, we tested the collection cost changes with a decreased and raised amount of source separated plastic by kerb side collection. The result in Figure 7 shows that collecting more plastic by kerb side collection can decrease the total cost due to the economics of scale achieved. The current collection trucks (with pressing function) have enough capacity in collecting more plastics. Doubling the current amount of source separated plastics, the total cost can drop by about 100 €/ton. This result implies that a higher response rate can improve the eco-efficiency of collection trucks.

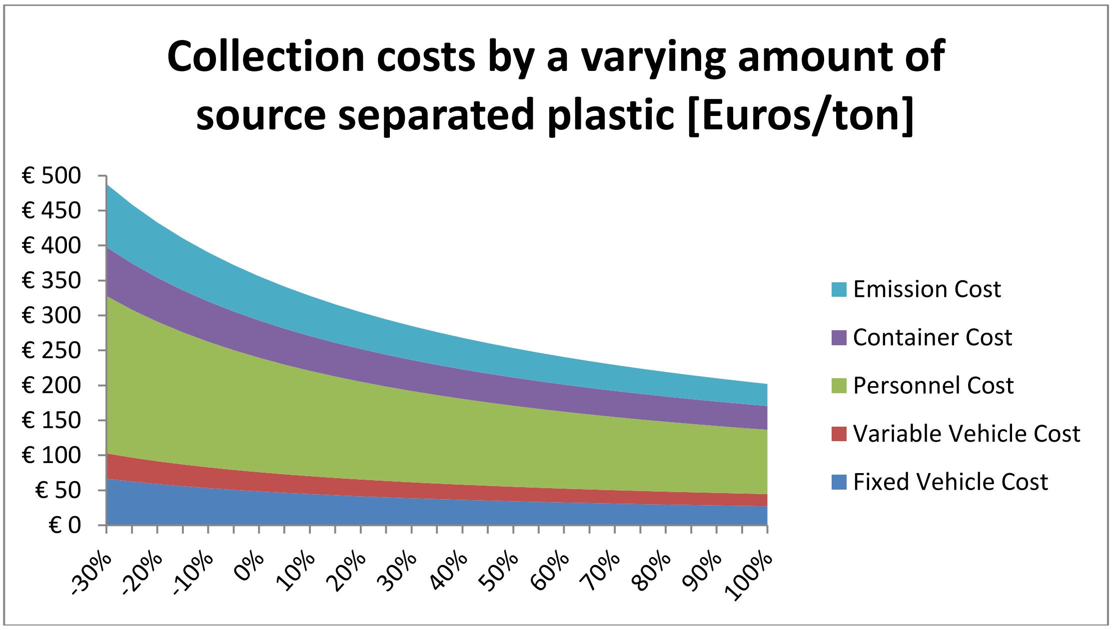


Figure 20: Collection costs by a varying amount of source separated plastic (Euros/ton)

6.2.2. Collection cost of all Scenario's

Table 56: Average total collection costs for all scenarios in Euros

Scenario	Source separation Kerb side	Source separation drop-off	Post separation
1	n.a.	n.a.	n.a.
2	383	185	56
3	354	185	67
4	314	185	67
5	354	185	82
6	213	186	68
7	570	n.a.	68

At the source separation collection cost results for kerb side collection a variation can be seen. This is due to different available amounts of plastic at the kerb side. In general can be said, the more plastic available at a collection point, the cheaper the collection costs. For post-separation also a variation can be observed. The increase of collection cost compared with the situation in 2010 (scenario 2) can be explained by the increased amount of plastic separated. Separation centres become more efficient and the percentage of cost separated is assumed to be the factor for the allocation of collection cost of MSW to the post-separation scheme. The higher collection cost of Scenario 5 are a result of a combination of a higher amount of separated plastic and due to the large distances waste from The Hague, Amsterdam and Utrecht have to be transported before separation. This last mentioned effect is not present in Scenario 7 where multiple separation centres are added at several locations of incineration centres.

6.2.3. Network results

The following table gives the total kilometres driven in the source separation scheme, the post-separation scheme and for the PET bottle collection scheme. This overview of total kilometres is represented in the model impression below as well. Kilometres driven inside municipalities are excluded from the network model and these results.

Table 57: Total kilometres driven in each scenario (collection + network logistics)

Scenario	Source separation	Post separation	Deposit refund	Total
1	0	0	3,911,499	3,911,499
2	1,723,350	238,781	3,911,499	5,873,630
3	2,013,694	1,130,689	3,911,499	7,055,882
4	2,326,988	1,333,956	0	3,660,944
5	1,862,692	3,206,886	3,911,499	8,981,077
6	2,520,084	1,045,860	3,911,499	7,477,443
7	25,267	10,846,560	0	10,871,827

As stated earlier with the results of the collection model, most differences between scenario's of driven kilometres are due to different amounts of plastic in each scenario and per collection scheme.

The abolishment of the PET refund system in scenario 4 is the scenario with the least amount of driven kilometres in the network this scenario decreases the total driven kilometres in the network with roughly 3.4 million kilometres compared with the baseline of scenario 3.

Scenario 7 is the scenario with the highest amount of kilometres drive. This scenario has an increase of the total kilometres of 3.8 million kilometres compared with the baseline.

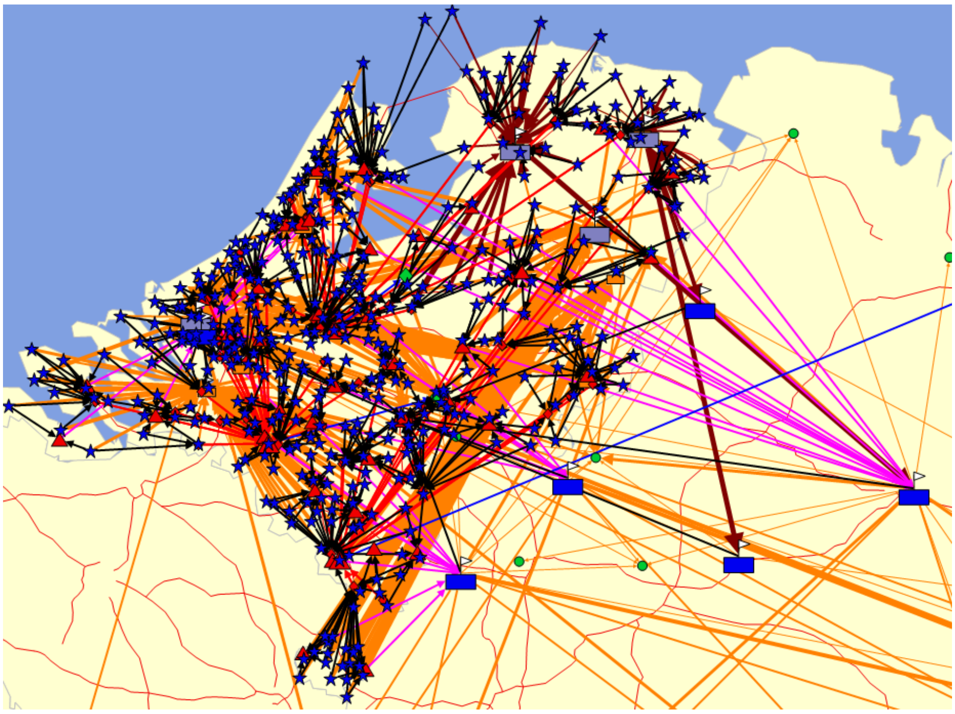


Figure 21: Impression of the network model

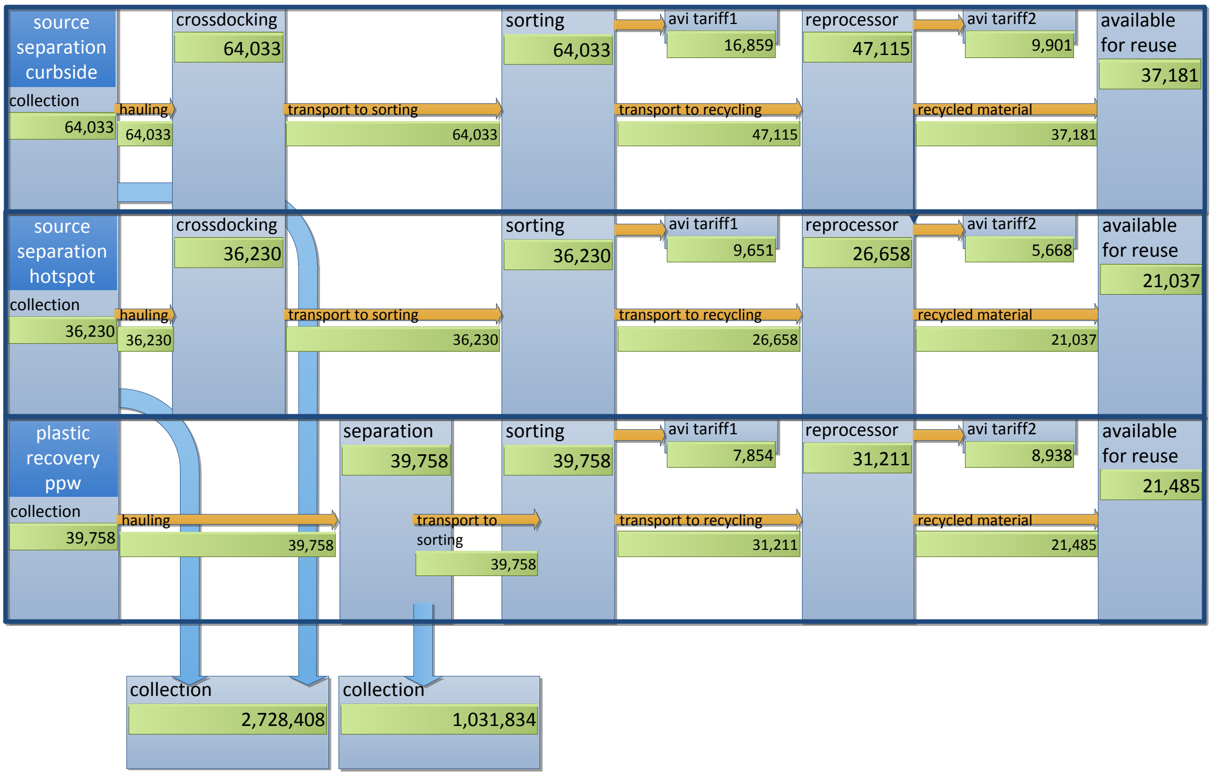


Figure 22: **Flow diagram of network logistics, based on Scenario 3 (in tons of plastic)**

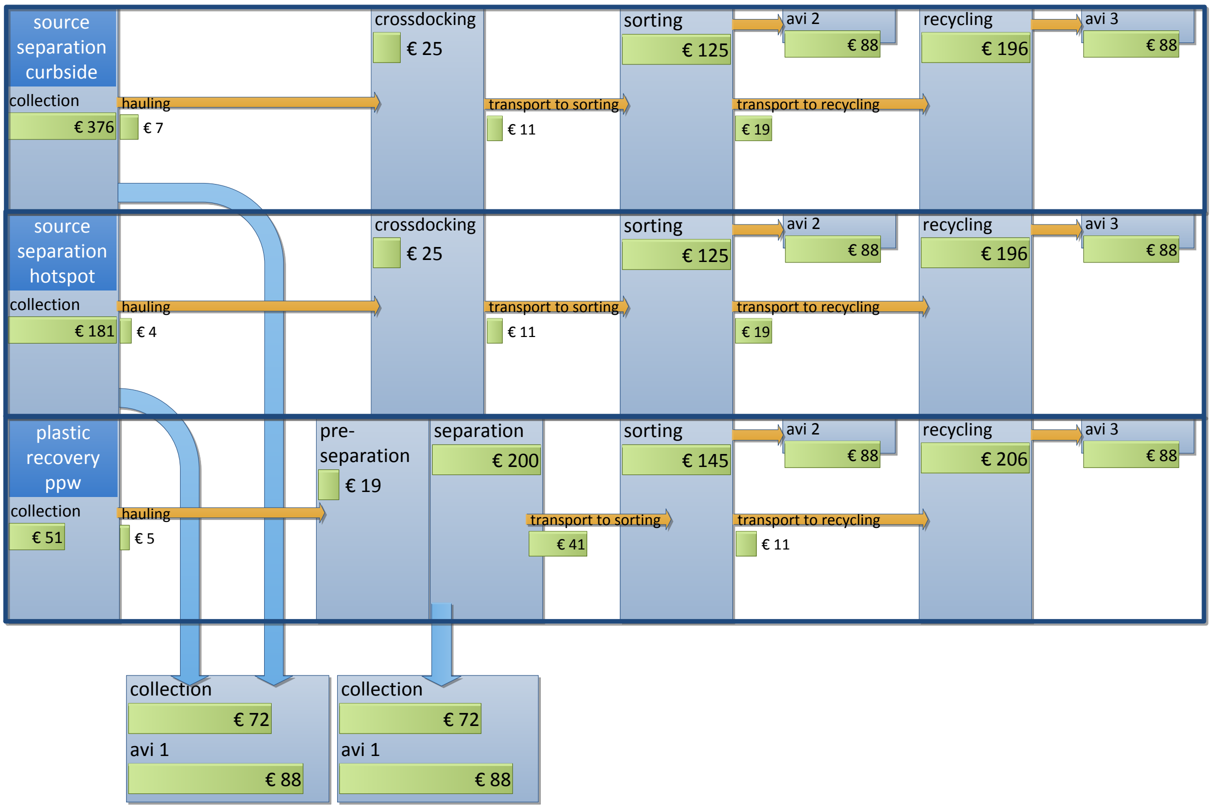


Figure 23: **Flow diagram of network logistics based on Scenario 3 (in Euro/ton per recycling step)**

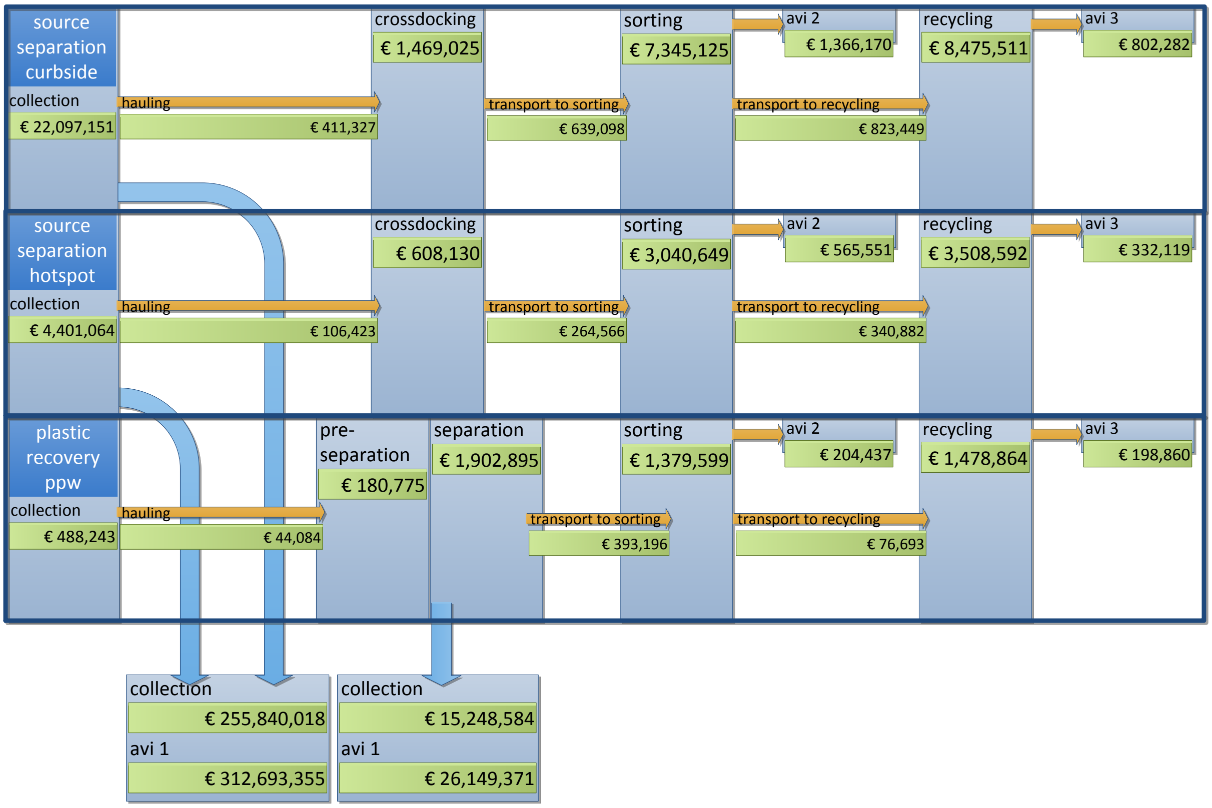
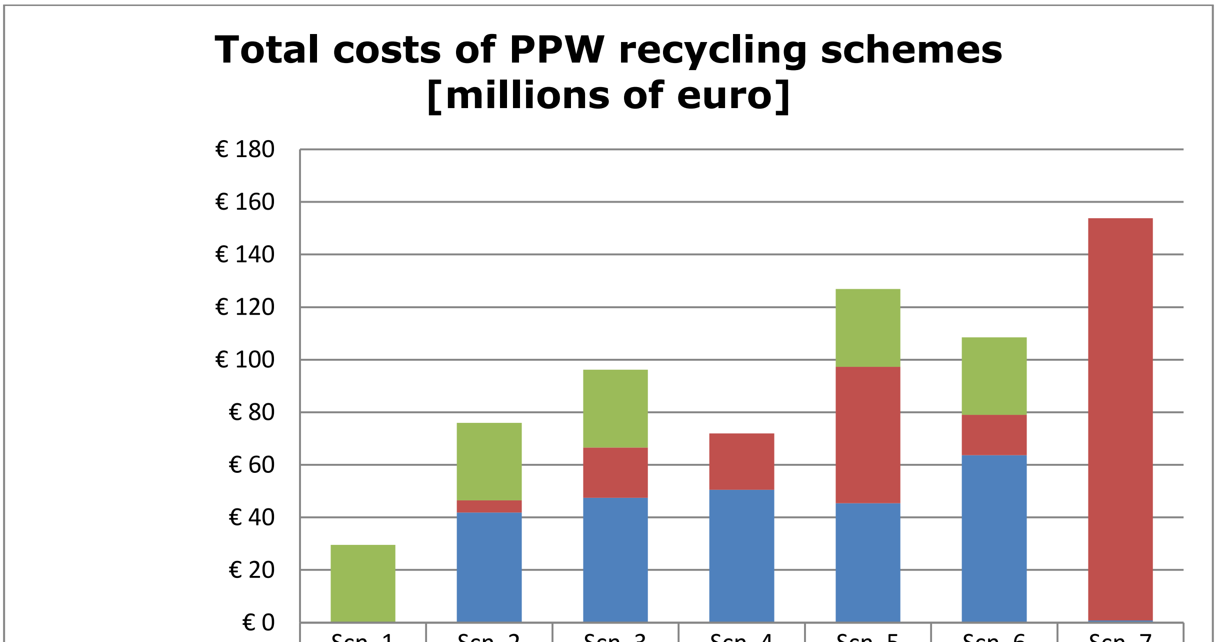


Figure 24: **Flow diagram of network cost of scenario 3 (in Euro per recycling step)**

6.3. Economic results

6.3.1. Economic cost results

The amounts of plastic packaging waste (PPW) separated are given in Figure 25. Clearly scenario 1 (without any PPW separation other than the PET deposit refund system) has the lowest performance in terms of PPW recycling and scenario 7 (full plastic separation) the highest. In scenario 6 (source separation) the total amounts are lower, because the 55% response rate assumed for source separation in this scenario is lower than what a plastic recovery system can realise. The pet refund system amounts to 26 kton of PET. That is about 10-22% of the total PPW recycled, depending on the scenario.

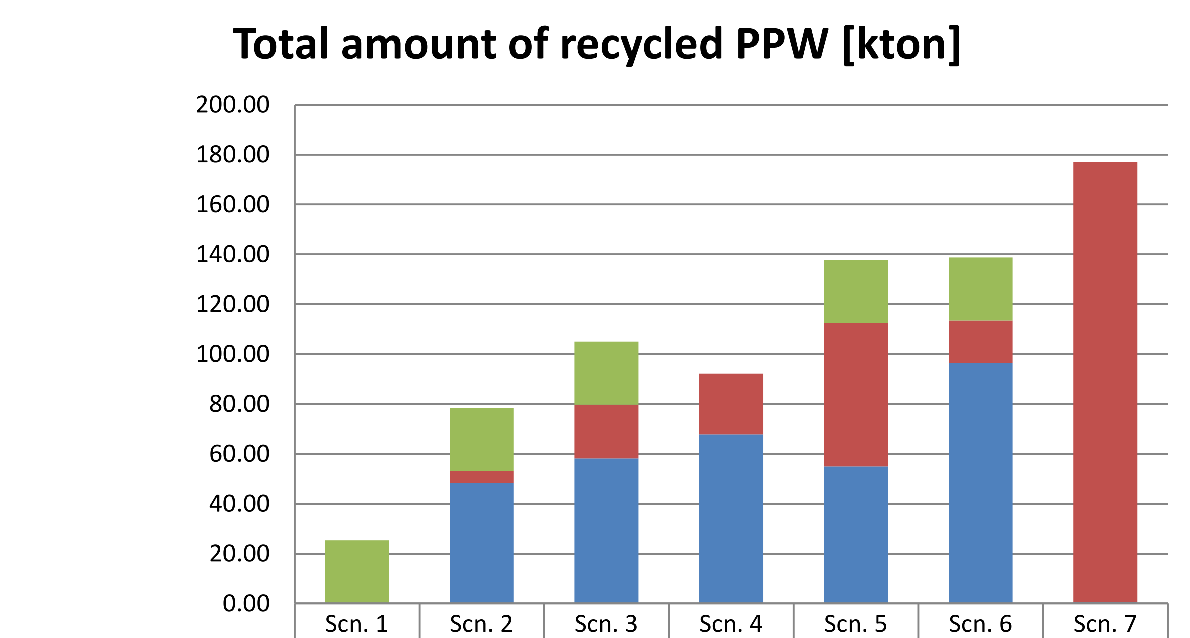


	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
PET Deposit Refund	€ 30	€ 30	€ 30	€ 0	€ 30	€ 30	€ 0
Post separation	€ 0	€ 5	€ 19	€ 21	€ 52	€ 15	€ 153
Source separation	€ 0	€ 42	€ 47	€ 50	€ 45	€ 64	€ 1

Figure 25: Total costs of PPW recycling schemes, in million Euros.

The total costs for the post-consumer plastic packaging waste scheme in 2013 (scenario 3) are estimated as 46.5 mln euro. Realising the full grown plastic recovery system in the Netherlands does increase the amounts of recycled PPW more than tenfold, compared with scenario 1. In comparison with the current situation (scenario 2) the amounts per inhabitant will increase by 170%.

The costs of recycling PPW - from the initial separation from the rest of the MSRW until reprocessing - are calculated. It differs somewhat per scenario, because of different costs of collection and hauling in different municipalities. The results in the graphs below depict averages for all municipalities. The total chain costs are lowest for source separation with hotspots. This is due to the fact that the collection costs are lower in the hotspot system. Part of the costs is borne by households. The collection costs of MSRW in the plastic recovery system are allocated to plastic recovery based on the volume shares of plastic in the total MSRW. The costs of incinerating MSRW are not included in the chain costs analysis.

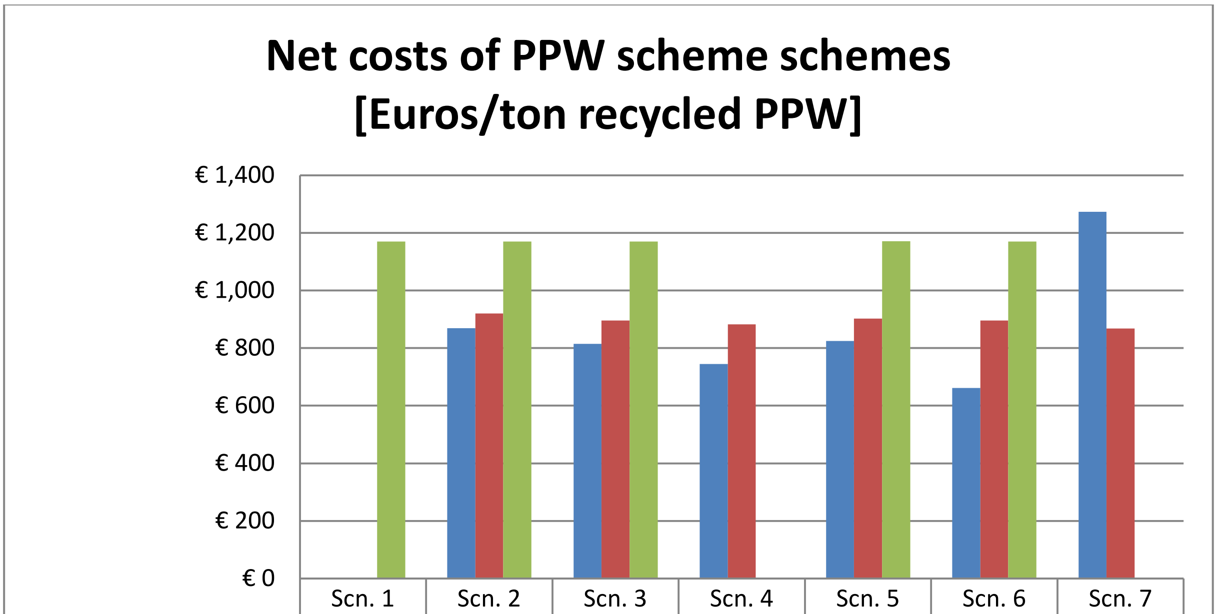


	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
PET Deposit Refund	25.27	25.27	25.27	0	25.27	25.27	0
Post separation	0.00	4.93	21.48	24.32	57.54	17.03	176.38
Source separation	0.00	48.24	58.22	67.80	54.96	96.40	0.61

Figure 26: Total amount of recycled PPW in ktons

As we saw before, scenario 1 (without any PPW separation other than the PET deposit refund system) has the lowest performance in terms of PPW recycling. Scenario 7 (full post separation) has the highest performance. The figure below presents the total costs of the PPW recycling schemes for each scenario. Simply put: the more PPW is recovered, the higher the costs.

When we look at the specific costs (expressed in Euros per ton of PPW collected), the results between the scenarios are quite constant for post separation and vary strongly for source separation. Note that in source separation lower costs per tonne are made when more plastic is collected. The PET deposit refund system has a higher cost per tonne compared to the other systems.



	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
Source separation	€ 0	€ 869	€ 814	€ 745	€ 825	€ 661	€ 1,273
Post separation	€ 0	€ 920	€ 895	€ 882	€ 902	€ 896	€ 868
PET Deposit Refund	€ 1,169	€ 1,170	€ 1,170	€ 0	€ 1,171	€ 1,170	€ 0

Figure 27: Net costs of PPW recycling schemes in Euros per ton recycled PPW

The costs of recycling PPW differ somewhat per scenario, because of different costs of collection and hauling in the various municipalities. The costs are lowest in case of a source-separation system with hotspots (drop-off points) as this type of collection is most cost-efficient. The costs of incinerating MSRW are not included in the chain costs analysis and results.

When we look at a cost breakdown of the chain costs we can differentiate various cost for each chain step. Collection costs within the municipalities are derived from the logistics collection model. Hauling costs and the transportation to sorting and recycling are derived from the logistics network model. Hauling cost include both transportation costs from municipality to cross docking centres for source separation and transportation cost from municipalities to separation centres. Costs for cross docking, separation, sorting and recycling are determined by experts from industry and research. AVI 2 are the cost for incineration of dirt and moist separated after sorting and AVI 3 are the cost for incineration of dirt and moist after the recycling of PPW. To illustrate those different chain costs the following figures are added for scenario 2 and 6.

The differences between the scenarios are mostly due to differences in collection cost. Lower collection costs for scenario 6 are the result of the different responses between the scenario's. Scenario 6 is a scenario with a higher amount of source separated plastic available at household level. More plastic, lower collection cost.

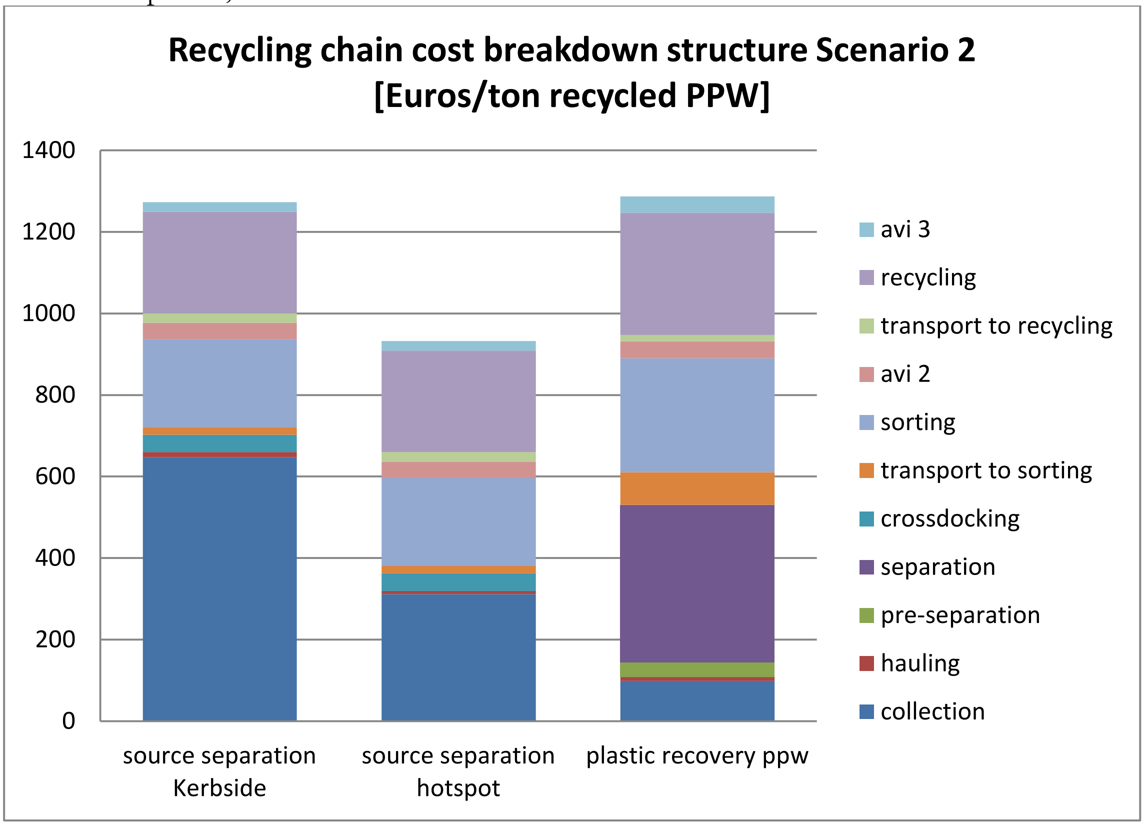


Figure 28: **Recycling chain cost breakdown structure for Scenario 2 in Euros per ton recycled PPW**

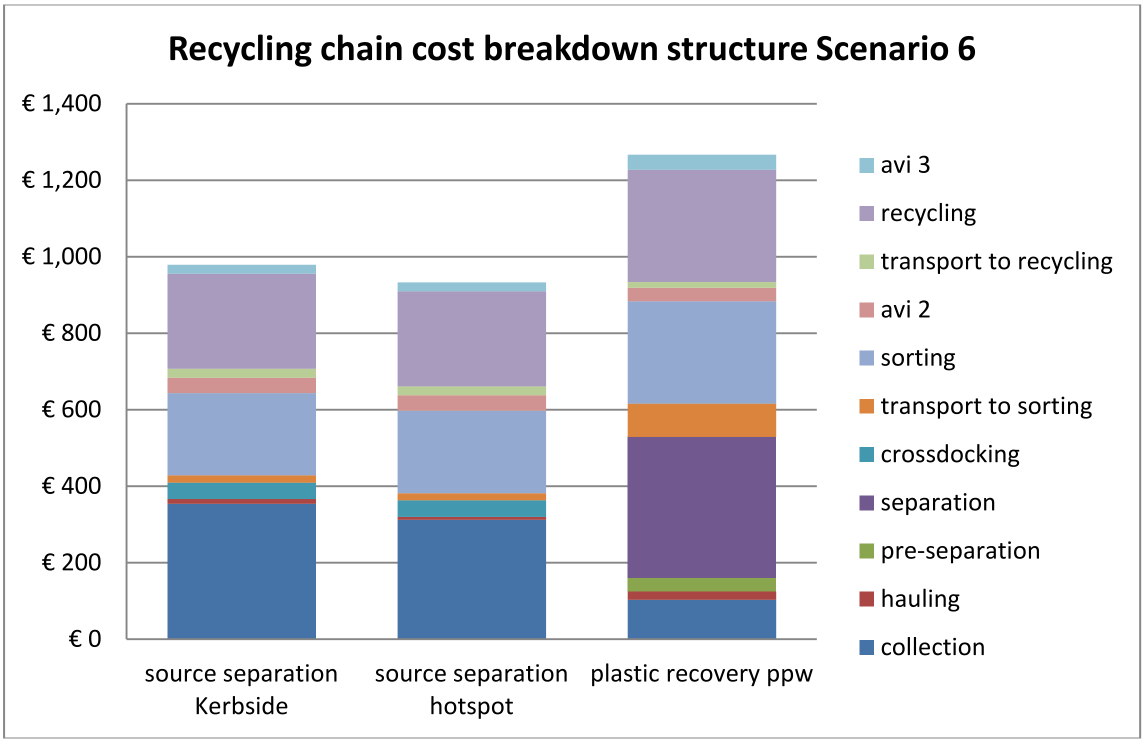


Figure 29: **Recycling chain cost breakdown structure for Scenario 6 (excluding PET deposit refund) in Euros per ton recycled PPW**

6.4. Environmental impact results

The environmental impact results were calculated using the ReCiPe methodology, and were provided by Blonk Environtal Consultancy. The basics behind the ReCiPe methodology are to transform a list of eighteen Life Cycle Inventory results, into an indicator score: ReCiPe score. For this study, a shortened version was used, based on 4 life cycle inventory results, because these were expected to contribute most to the environmental impact of PPW recycling schemes: climate change, fossil depletion, human toxicity and particular matter. The ReCiPe score uses equivalence factors and weighing factors to calculate the environmental impact of systems. To interpret the results, the least amount of points on the scale represent the least environmental pressure.

The overall results for the comparison of the scenarios can be found in figure 30 below. The results are found in figure 31, which has a negative scale. This means the least amount of points on the scale represents the lowest environmental pressure (e.g. -20 being higher than -40). Please take into account that only part of the life cycle of the PPW has been used to calculate the environmental impact here.

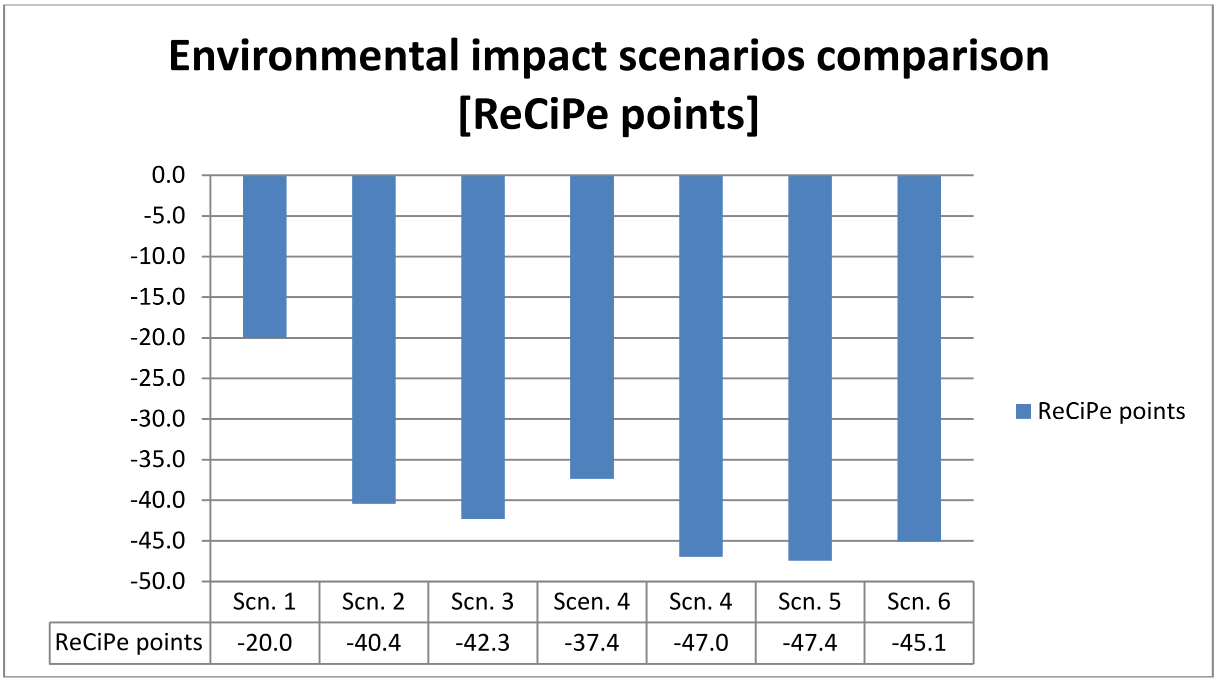
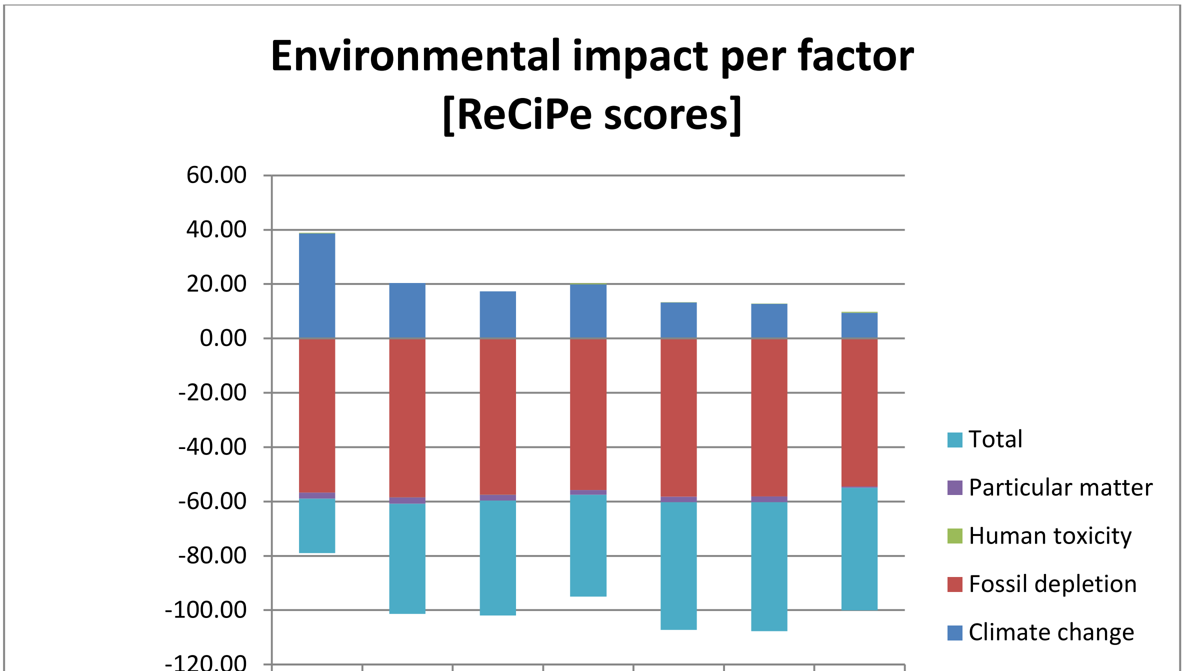


Figure 30: Environmental impact scenarios comparison expressed in ReCiPe Scores

In comparison, scenario 6 scores best according to the ReCiPe method, followed by 5, 7 and 3. More recycling of PPW generally leads to an improved environmental impact. It was found that PET-recycling has the highest beneficial environmental impact, thus the scenarios including PET deposit refund are a bit more favorable from an environmental perspective. However, if the PET fractions can be sorted with higher yields within the source or post separation system, the environmental impact will also improve.

The ReCiPe scores were also calculated for each of the four impact factor categories, the overall results are presented in Figure 31. Again, a negative score refers to a lower environmental impact. A positive score represents more environmental impact.



	Scn. 1	Scn. 2	Scn. 3	Scn. 4	Scn. 5	Scn. 6	Scn. 7
Total	-20.01	-40.45	-42.30	-37.38	-46.97	-47.43	-45.12
Particular matter	-2.20	-2.39	-2.14	-1.86	-1.93	-2.12	-0.46
Human toxicity	0.29	-0.03	-0.01	0.30	0.09	0.07	0.38
Fossil depletion	-56.75	-58.45	-57.55	-55.75	-58.29	-58.12	-54.45
Climate change	38.64	20.42	17.40	19.93	13.17	12.73	9.41

Figure 31: Environmental impact per factor, expressed in ReCiPe scores

From Figure 31 it becomes clear that the choice to implement a PPW recycling system has considerable environmental benefits. Scenario 1 is the least environmentally friendly, with a high climate change impact: all PPW is being incinerated. Overall, fossil depletion and climate change are the most important impact factors. Human toxicity and particular matter are only marginally contributing to environmental impact. Although there is very little difference between the fossil depletion score in the various scenarios, the climate change scores vary, because the reduced environmental pressure relates to higher yields of PET-recycling.
The results on the different environmental impact categories were studied in greater detail, looking at the contribution of each recycling step to the overall score per scenario. The results are given below per impact category:

1: Climate change

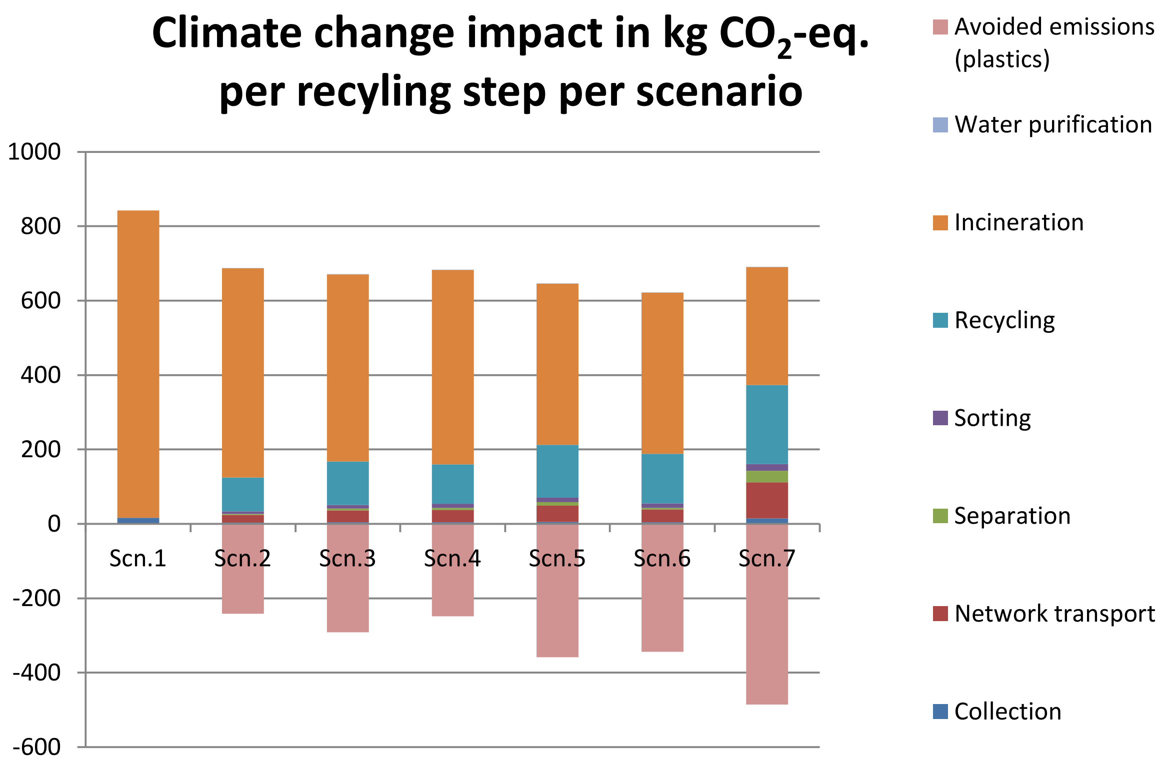


Figure 32: Climate change impact in kg CO_2-eq. per recycling step per scenario

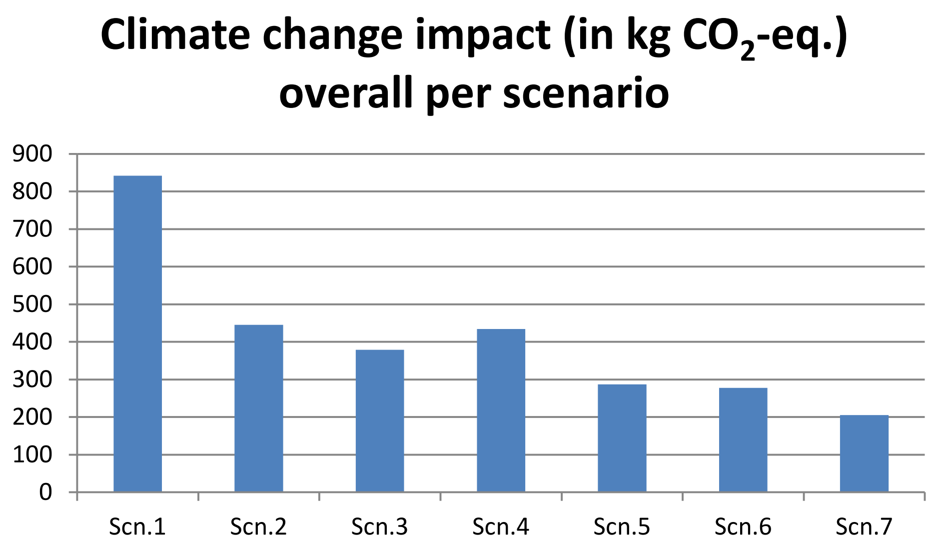


Figure 33: Climate change impact (in kg CO2-eq.) overall per scenario

From the Climate change impact performance per scenario we can see that the most significant effects can be found at incineration: scenarios including the relatively highest incineration levels (connected with recycling yields) have a higher environmental impact than others. The contribution on environmental impact by avoided emissions by use of secondary materials and the reduction of energy use in the primary production are important factors here. From this perspective, scenarios 7 and 5 are most environmentally friendly. Whereas no plastics recycling (i.e. scenario 1) proves to be the least environmentally friendly option. This scenario has almost a double impact compared with the recycling schemes avoiding incineration.

2: Fossil depletion

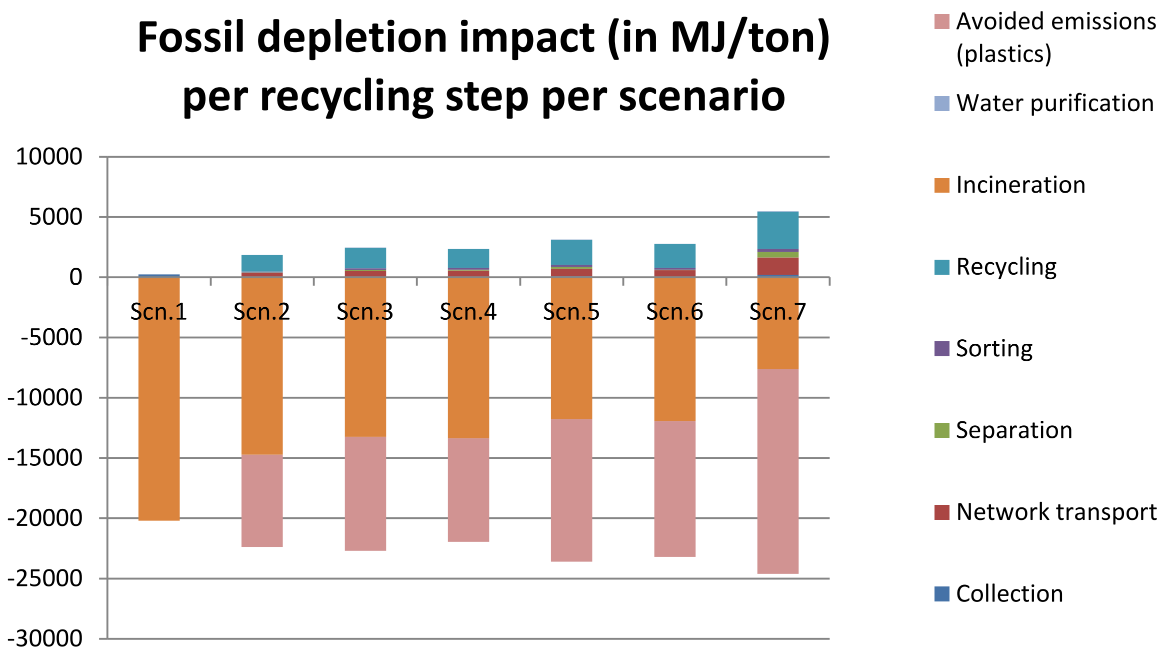


Figure 34: Fossil depletion impact (in MJ/ton) per recycling scheme per scenario

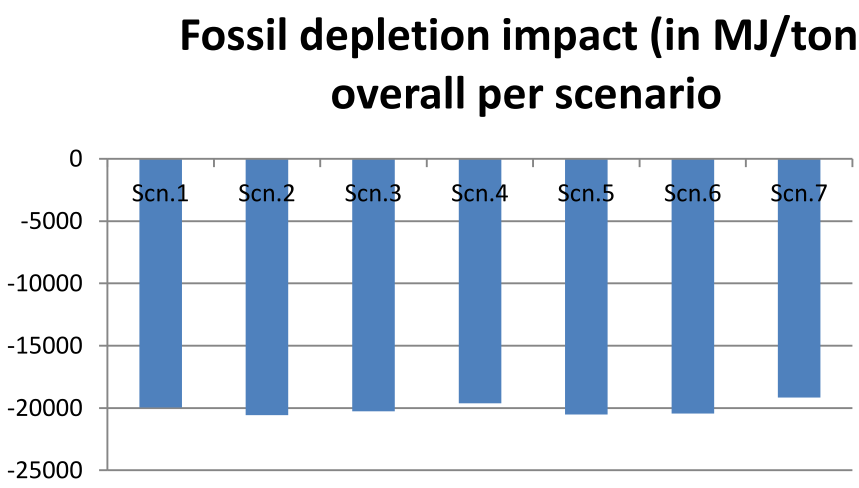


Figure 35: Fossil depletion impact (in MJ/ton) overall per scenario

From the fossil depletion impact calculation we can see that the scenarios do not show many differences between them, although the impact itself is relatively high. The most significant contributors to the impact are at the incineration level, and the avoided emissions by use of secondary materials. We can see here that avoiding the use of primary materials is slightly better from an environmental perspective than incineration. This is reflected most significantly in the PET contribution: here, high levels of avoided energy use in primary production counterfeit the low energy content when incinerated.

3: Human Toxicity

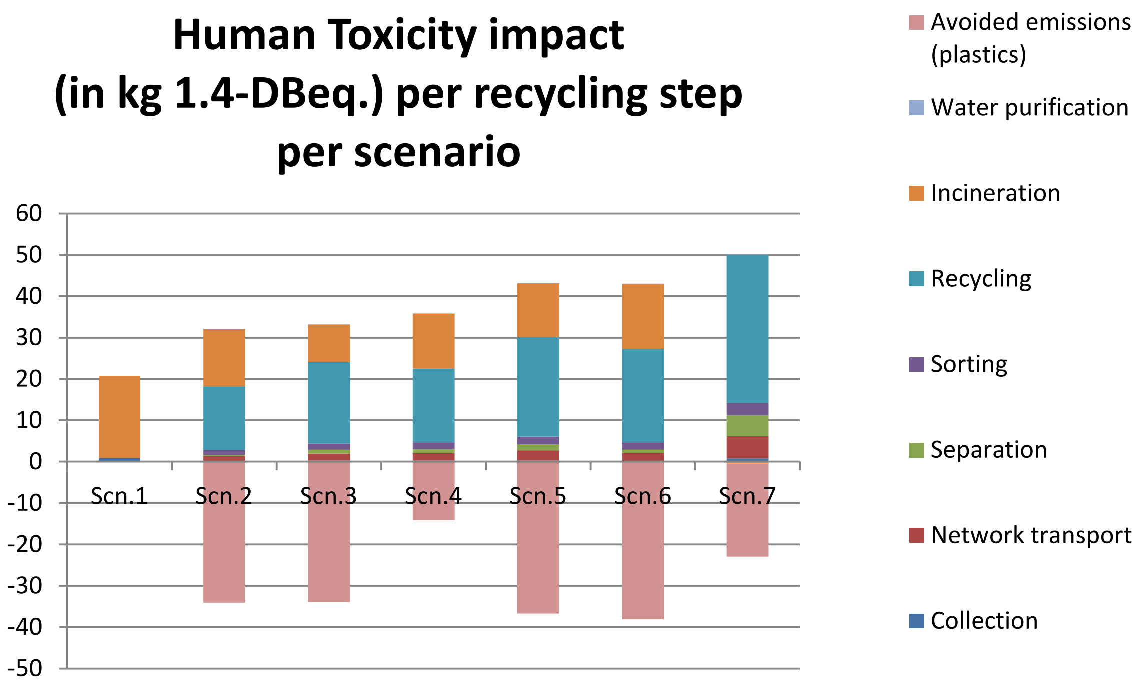


Figure 36: Human toxicity impact (in kg 1.4-DBeq.) per recycling step per scenario

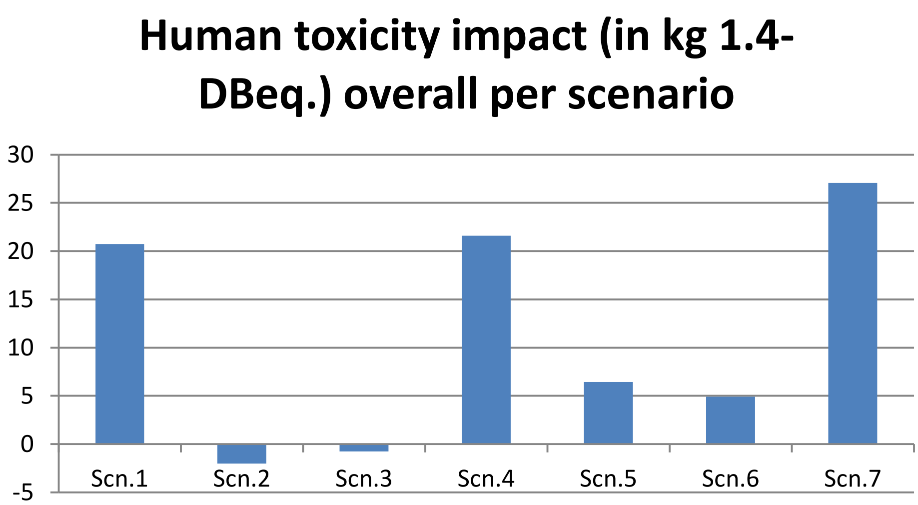


Figure 37: Human toxicity impact (in kg 1.4-DBeq.) overall per scenario

On the human toxicity impact we can see the most significant effects in the recycling steps of incineration, avoided emissions by use of secondary materials and the recycling process itself (energy use). Remarkable is the relatively high contribution from the primary PET production, which has a high human toxicity impact associated to its production. All scenarios which avoid this primary production are relatively more environmentally friendly than others. Especially within the recycling schemes including PET deposit refund, as this delivers the highest quality rPET that can replace virgin PET in many cases.

4: Particular matter

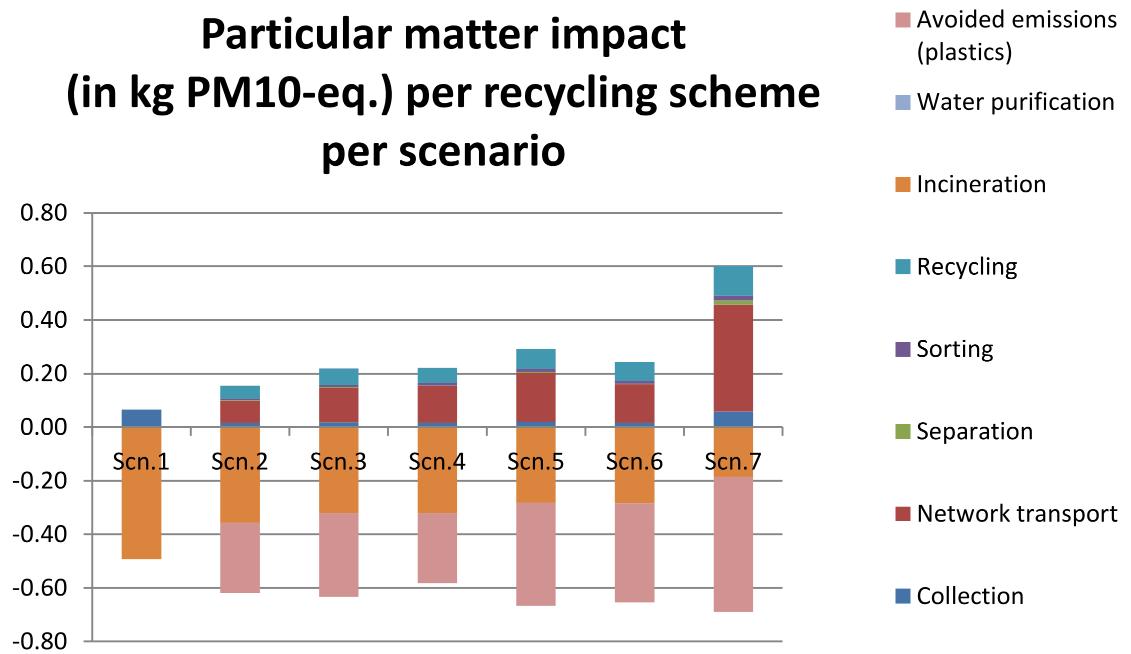


Figure 38: Particular matter impact (in kg PM10-eq.) per recycling scheme per scenario

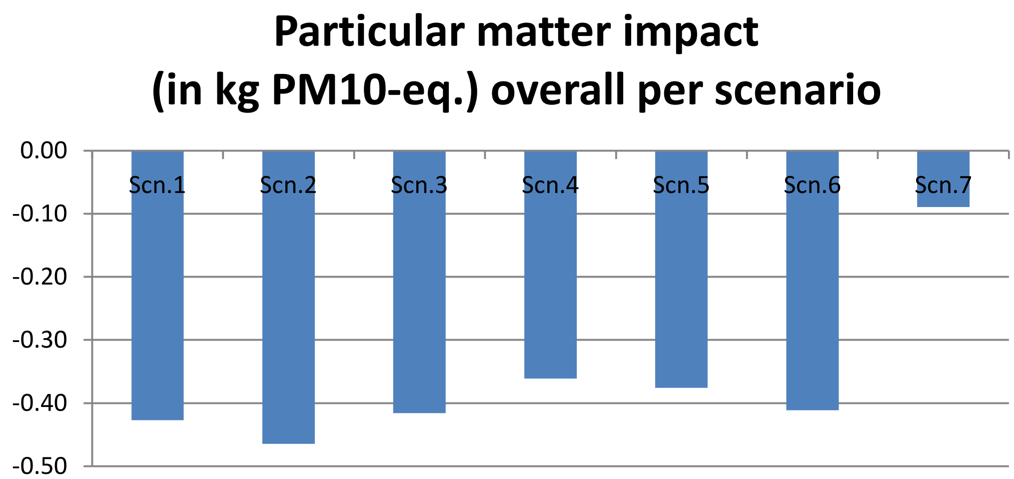


Figure 39: Particular matter impact (in kg PM10-eq.) overall per scenario

As we can see from the Particular matter impact results, the most significant effects can be found at incineration, avoided emissions by use of secondary materials, network transport (specifically to sorting centres and to recyclers) and the recycling process itself (energy use). As particular matter is largely associated with energy related combustion processes (both in transport as in the recycling process itself), the scenarios with the highest levels of these activities score relatively higher. Therefore, the more environmentally friendly scenarios from a particular matter perspective can be found at scenario 2, but also 1, 3 and 6. Reducing transport (or replace the transport mode with cleaner alternatives) and the reduction of energy use in the recycling processes are important in reducing particular matter impact.

7. Conclusions

The Dutch system of post-consumer plastic packaging waste recycling in 2010 has been thoroughly studied with respect to its technological performance, logistical consequences, environmental impacts and economic impact. The first objective of this study was describe the system of PPW recycling in 2010 as accurate as possible in technological and logistical terms and to use these descriptions to estimate the environmental impacts and economic impact. The second objective of this study was define several realistic scenarios for future PPW recycling schemes and to estimate the environmental and economic impacts of these scenarios.

The approach has been unorthodox in various ways. The time spend and effort made to describe these recycling schemes for the Netherlands per municipality, with a detailed description of the PPW in terms of composition and of the PPW in the MSRW and with the correct logistical chains for PPW and MSRW per municipality has not been achieved previously.
Most of the work for this study has been conducted in 2010 and 2011, with the data on responses for PPW and MSRW per municipality that was available at that time. Later in 2011 and 2012 more data became available, that we could, unfortunately, not process in our study, due to the sequential nature of the tasks in our approach. Therefore, although better data is now available for example on the amount of plastic packaging put on the market in 2010, this data was not used for this study. This will result in small errors in the absolute values of the environmental impact and the societal costs, but the differences between those parameters for various scenarios will hardly be affected by those primary data issues.

Our base scenario 2, the description of the PPW recycling chain in 2010, compares reasonably good with the officially published numbers; amounts collected (83 versus 85 kiloton) amounts recycled milled goods and agglomerates produced and societal costs of 76 mln Euro. Small differences arise from the recovered PPW chain, the use of average response data per municipality category instead of the actual response data per municipality, the use of modelled real costs of collection per municipality instead of collection fees, etc.. Additionally, 5.8 mln transport kilometres were required for the recycling of PPW in 2010. Furthermore, the calculated environmental impacts associated with the PPW recycling system in 2010 equalled to about: +450 kg CO_2 eqv/1000 kg PPW for the potential for climate change, 20000 MJ/1000 kg PPW for the fossil depletion, -2 kg 1.4-DBeqv./1000 kg PPW for human toxicity and -0.47 kg PM-10 eqv. /1000 kg PPW for particular matter.

Hence, the recycling of PPW by source separation and recovery as it occurred in 2010 raised the societal costs of waste management with roughly 46 mln Euro, caused 1.9 mln additional transport kilometres and resulted in environmental impact reductions in the categories of potential for climate change (-400 kg CO_2 eqv./1000 kg of PPW), fossil depletion (negligible) , human toxicity (-25 kg 1.4-DBeqv./1000 kg PPW) and the emission of particular matter (-0.05 kg

PM-10eqv./1000 kg PPW) (comparison of scenario 2 to 1).These environmental impacts were found to be especially sensitive for the amount of PPW that is not recycled and incinerated; the more PPW that is recycled (and not incinerated) the lower the impacts on especially the potential for climate change, human toxicity and particular matter.

From this scenario study it is clear that the Netherlands can collect and recycle more PPW in various manners in the near future. Roughly a doubling of the amount of collected PPW material and of the amount of recycled products is possible in the near future. In general, the more PPW is collected, the more transport kilometres will be driven, the more recycled products will be made, the higher the societal costs and the lower the overall environmental impacts. The economics of scale appear to be hardly applicable, because of the large share of fixed costs.

The scenario's that yield the most recycled materials are scenario 5, 6 and 7, which represent a moderately extended recovery scenario (5), a completely full grown separate collection scenario (6) and complete full grown recovery scenario with the simultaneous abolishment of the PET bottle deposit refund system and the separate collection system. The scenario with the most recycled products, the largest amount of required transport kilometres, the highest societal costs and the lowest potential for climate change is number 7. In case we would focus on other environmental impact categories like human toxicity and particular matter, then scenario 6 would be better although the differences with scenario 5 are small. Of these three scenario's 5 and 6 are realistic and number 7 is more theoretical, given the large investments that would be necessary to achieve this. The results of both realistic extended scenario's (5 and 6) are fairly similar for most parameters except the societal costs; the extended source separation scenario is about 18 mln Euro's less expensive as the extended recovery scenario. This implies that PPW recycling systems with maximal yields can be approached with various means; not the means itself, but the execution of those means are critical.

In this scenario study also the impacts of the abolishment of the deposit refund system for large PET bottles was studied (difference between scenario 3 and 4). This abolishment will led the PET bottles flow to the separate collection system, recovery system and MSRW incineration. The critical question is how this division over these waste handling systems will turn out to be. We roughly estimated that 70% of the large PET bottles will be separately collected or recovered and 30% will be incinerated. This could turn out to be both an under- and an overestimation; the sum of more than 400 different operational decisions made in the various municipalities and of the roughly 4000 supermarket owners will define the answer.

Nevertheless, we postulated that 70% of these large PET bottles will be separately collected or recovered and calculated the technological and logistical consequences. It was shown that the total societal costs can be reduced with 24 mln Euro, the amount of network transport kilometres can be reduced with 3.3 mln km, but that the amount of recycled products will be reduced with 10.5 kton and consequentially the environmental impact will be raised with +50 kg CO_2 eqv./1000 kg PPW. This shows that the abolishment of the deposit refund system will have a small positive effect on the overall costs and a small negative impact on the environmental impact. The magnitude of these changes can be compensated with additional collection efforts or recycling efforts.

References

- "Afvalverwerking in Nederland, gegevens 2011", Agentschap NL, Utrecht, augustus 2012.
- "Hergebruik en monitoring verpakkingen nader bekeken; kunststof en glas" ILT 16 maart 2012.
- A.A. Garforth, S. Ali, J.Hernandez-Martinez, A. Akah, "feedstock recycling of polymer wastes", Current Opinion in Solid State and Material Science, 8 (2004), 419-425.
- Agentschap NL, "Samenstelling van het huishoudelijk restafval, resultaten sorteeranalyses 2010", Utrecht, februari 2011.
- Besluit verpakkingen en papier en karton, gepubliceerd op 25 maart 2005.
- D.S. Achilias et al. "Chemical recycling of plastic wastes made from PE and PP" Journal of Hazardous Materials, 149 (2007) 536-542.
- E.U. Thoden van Velzen en M. Jansen, "Nascheiden van kunststofverpakkingsafval te Wijster" Wageningen UR FBR report 1296, 8 april 2011.
- E.U. Thoden van Velzen, H.E.J. Bos-Brouwers, "Analyse van het Nederlandse statiegeldsysteem voor PET flessen" Wageningen-UR, FBR report 1316B, 6 april 2012.
- E.U. Thoden van Velzen, J.J. Groot, H.E.J. Bos-Brouwers, "Kunststofverpakkingsafval van inzamelen naar spontaan hergebruik", Wageningen-UR FBR 26 maart 2012.
- E.U. Thoden van Velzen, M. Jansen, "Solvent extraction as additional purification method for post-consumer plastic packaging waste, FBR report 1261, Wageningen June 2011.
- Feitenrapport nascheiding, Ministerie IenM, 29 feb 2012
- Fost-Plus jaarverslag 2010.
- H. Krähling, M. Kern, "Kunststoffreiche Abfallströmen", Recycling Technology, Nov. 2009, 26-28.
- J. Brandrup, "Preparation of feedstock for petrochemical recycling – requirements imposed on plastics waste" chapter 5.1 in Handbook Plastic recycling, Brandrup (ed.) 393-412, Hanser, Hamburg 1986.
- Kostenonderzoek nascheiding kunststofverpakkingen, KPMG, 2010.
- L. Morice, R Bonnefoy, "Valorplast : Recyclage des emballages ménagers plastiques Bilan et Perspectives" Presentation 3rd June 2010.
- Landelijk afvalbeheersplan 2009-2021, hoofdstuk 14 "afvalscheiding", november 2009.
- M. Jansen; T. Pretz "Bewertung der Effizienz der Sortierung eines Kunststoffkonzentrats aus Hausmüll" Müll und Abfall, 2011, 2, 68-76
- NVRD benchmark afvalinzameling, Arnhem, nov 2010.
- Omrin persbericht november 2012: "Goede resultaten bij het nascheiden van kunststofverpakkingsafval"
- Raamovereenkomst 27 juli 2007
- Stichting Nedvang "Monitoring verpakkingen, resultaten 2010", Rotterdam, 7 september 2011.