City of Oslo, Agency for Waste Management

Recycling effect

Cost-effectiveness of various door to door collection solutions

The objective of the municipality of Oslo is for 50% of household waste to be recycled by 2018. It has been clear for a long time that this target cannot be achieved at this early a stage. This analysis is based on previous studies in which new measures were identified which could increase waste sorting by up to 50%. These measures are defined in this analysis as five different door to door collection solutions linked with household premises. A system dynamics model has been devised in order to examine the anticipated recycling effect. Costings have been compiled for the collection solutions, and they have been simulated and evaluated according to cost-effectiveness criteria. The solutions require a significant change in the collection system at household premises, compared to the current system. The best of these will achieve a recycling level of 50.9% by 2031. Further development of the present solution fares worst, with a recycling level of 46.8%. Missing information has been identified that will be crucial for successful implementation of a new collection system. Given this fact, four recommendations are put forward that should be pursued further if REN deems it appropriate to change its door to door collection system.

18.01.2017 – John Egil Nilssen (JEN), Maren Sylthe (MAS).
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Contents

1. Summary

The objective of the municipality of Oslo is for 50% of household waste to be submitted for recycling by 2018. 38% of waste was recycled in 2015. The forecast for 2016 stands at 39%, and questions are being asked about whether the 50% target is realistic given the current portfolio of measures. Renovasjonsetaten (REN, Agency for Waste Management) has previously carried out a study in order to identify new measures[1]. The conclusions from this work were summarised in a report entitled "Measures Package", and point out that a greater share of the waste collection should take place in residential areas, and that these changes will mainly be linked with how the household door to door collection solutions are structured.

As a consequence of this, five different door to door collection solutions have been devised, all of which involve "container systems[2]" including 2, 3 or 4 containers for sorted waste types and residual waste for each collection point. The container system is determined by the space available at the collection point. The difference between the container systems is based on which combinations of waste types are collected in which container. A system dynamics simulation model has been prepared in order to test the collection solutions. This model includes methods described in the "Measures Package" report. These methods are adapted to suit the individual collection solution and future recycling levels are simulated.

Costings have been compiled for the collection solutions, and they have been evaluated according to cost-effectiveness criteria. The effectiveness criterion is the recycling level in 2031. Sensitivity analyses have been carried out on the simulation results in terms of recycling, costs and cost-effectiveness. The collection solution with the best outcome range according to these criteria offers a recycling level of 50.9% in 2031. This collection solution requires a 2-container system different to the one currently in use in Oslo. Plastic packaging and paper/cardboard are collected in one container. Food waste and residual waste are collected in the other. If there is space for three waste containers, food waste and residual waste are separated and each placed in their own containers. The fourth waste container is used for glass and metal.

The collection solution equivalent to the current solution, with adaptations and extensions, offers the poorest option but achieves a recycling level of 46.8% in 2031.

Sensitivity analyses carried out do not change the rankings of the various collection solutions.

Implementation of a new collection solution in Oslo requires information about matters of which REN currently has little or no knowledge. This includes information on space available at collection points, appropriate household segments, incentives and adapted measures for encouraging higher levels of waste sorting and appropriate areas for piloting solutions and measures.

Given the above, we provide the following recommendations:

1. On the basis of these results, REN should make a decision on whether it considers it appropriate to alter the current collection solution. If this is desirable:

[1]Report entitled "Measures Package", REN file case 15/00725.

[2] The current collection solution consists of a "2-container system". This can be extended to include 3 and 4 containers.

2. REN should carry out further investigations with a view to implementing the primary collection solution 5, or alternatively collection solution 1
3. REN should start working on collecting and recording management information that it does not have
4. REN should start working on developing an appropriate, effective package of measures suited to the needs of Oslo
5. REN should start working on identifying and planning areas for appropriate piloting of the collection solution selected using associated measures

2. Background

One target of a waste disposal plan for the municipality of Oslo for 2006-2009 [3] was for a minimum of 50% of household waste to be recycled by 2014. In 2009, Renovasjonsetaten (REN) achieved a recycling rate of 29%. The primary measure for achieving this target of 50% was to introduce sorting of plastic packaging and food waste (KiO). KiO began in parts of the city in 2009, and all households in Oslo had been offered this type of sorting in 2012. 2013 was the first full year of operation. The recycling level achieved in 2013 was 37%. The forecasts for 2014 indicated no further increase, and it looked as though the effects of KiO had levelled out. In the budget for 2014, REN's attainment of its targets was postponed from 2014 to 2018[4]. The recycling rates for 2014 and 2015 were 37% and 38% respectively. In November 2016, the forecast for 2016 stands at 39%. One of the questions raised is whether the 50% recycling target is realistic and can be achieved, given the structure of the current portfolio of measures. REN has prepared an assessment[5] relating to this question. This assessment concludes that "The model and its criteria indicate current operations and likely development with the continuation of the current packages of measures, with no new measures. The current measures do not address the challenge, and attainment of the recycling target is unlikely without implementing new measures". The model used in the assessment has calculated a recycling level of 39% in 2018 and 46% in 2032.

As a consequence of this conclusion, work began on identifying new measures. The report "Measures Package"[6] is based on a literature study of 48 international articles relating to waste sorting and provides seven recommendations, six of which will involve changes to the current door to door collection scheme in Oslo. The study showed that if the recycling rate is to be improved, households have to avoid having to deal with multiple collection points. A greater share of collection should take place in residential areas. Changes to the collection scheme[7] will primarily be linked with how the waste collection solution at households is structured. The recommendations of the "Measures Package" report may be implemented in Oslo in a number of different ways, depending on the structure of the collection solution. One thing the recommendations all have in common is the fact that they require differentiation from the current collective scheme whereby everyone uses a collective two-container system with collection of three types of sorted waste. A differentiated collection solution involves collecting more types of sorted waste in residential areas, where

[3] City council case 239/06
[4] City Government budget proposal – Case 1, 2014
[5] Materialgjenvinning en systemdynamisk tilnærming. REN file case, 15/00725-7
[6] REN file case, 15/00725-8
[7] Regulation on the collection of household waste, Municipality of Oslo, § 2-2

possible. The "Measures Package" report does not quantify the potential recycling level if the recommendations are implemented.

3. Objective and purpose

The purpose of this work is to clarify the recommendations of the "Measures Package" report and quantify the effect of these on recycling levels. The recommendations of the "Measures Package" report are not specified down to the structure of the collection solution. Therefore, work on this report specifies different door to door collection solutions and the recycling effects are measured in relation to these. The results should give REN information relevant to its decision, indicating whether the current collection solution is appropriate and, potentially, the structure a modified solution should take. This work must provide a basis for future SMART[8] recycling targets, depending on the collection solution selected. The objectives of the project have been to:

1. Calculate the recycling level of various door to door collection solutions, including the current one
2. Develop a system dynamics simulation model for these solutions
3. Carry out costings of the solutions so that recommendations can be based on cost-effectiveness criteria
4. Recommend solutions

4. Work process

Working on the basis of the "Measures Package" report's recommendations, the work process is divided into four main stages.

1. To formulate door to door collection solutions
2. To develop a simulation model, including data applicable to all collection solutions
3. To acquire and justify specific data for each collection solution
4. To simulate, analyse and sum up the recommendations in a report

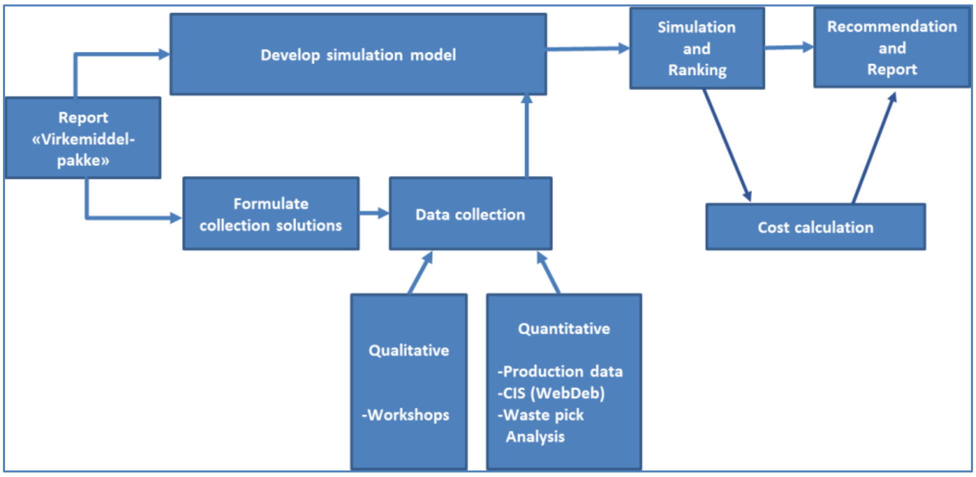

Figure 1 – Work process flowchart

[8] Specific, Measurable, Accepted, Realistic, Timed

Figure 1 shows the flow of work from left to right. The individual main steps will be described in greater detail below.

5. The door to door collection solutions

Emphasis has been placed on devising various collection solutions that are feasible in practice in Oslo. Five different collection solutions are described below. The collection solutions have been prepared as mutually exclusive alternatives. This will make it possible to simulate the recycling levels for each individual collection solution (selected as effectiveness indicators).

The terms “container system” and “waste sorting” are used in the formulation of the various collection solutions. A “collection solution” consists of several “container systems”. A “container system” is the number of containers at a collection point that are earmarked for the collection of sorted waste types and residual waste. “Waste sorting” means that residents sort – in their homes – waste types appropriate for recycling and place these waste types in the correct containers in the container system with which the household is linked.

5.1. The current collection solution in Oslo

Oslo currently has a 2-container system where food waste, plastic packaging and residual waste are collected in residual waste containers. Paper/cardboard are collected in the other containers. This collection solution involves approx. 115,000 waste containers set out, varying in size between 0.14 and 50 m^3. Most of the containers are 140-660 litres in size. These are used for collecting residual waste, food waste and plastic packaging, as well as paper/cardboard. These containers are positioned in residential areas at approx. 50,000 approved collection points. The containers are collected and emptied in the residential areas using bin lorries. Containers are collected no more than 5 times a week for residual waste, and as little as once a month for paper/cardboard. The emptying frequency is dependent on the type of waste placed in the container. Containers for residual waste must be emptied at least once a week, for hygiene reasons. Paper and cardboard containers are emptied less frequently, and these collections are controlled almost exclusively by the anticipated fill levels.

Containers for residual waste contain food waste packed in green bags, plastic packaging in blue bags and residual waste in shopping bags. The contents of the containers for residual waste are transported to Energigjenvinningsetaten (EGE, Waste to Energy Agency) for optical sorting, separating the green bags of food waste and the blue bags of plastic waste from the residual waste and sending these for recycling. Paper/cardboard is not packaged and is collected on separate routes before being transported directly to recycling plants.

Household waste in Oslo generates approx. 8.3 million container collections a year[9].

5.2. Criteria

Five different alternative collection solutions have been devised, all of which involve combinations of 2, 3 and/or 4-container systems at each collection point. When devising these collection solutions, emphasis has been placed on:

[9] WebDeb – REN’s customer information system

- The fact that space for more containers is limited. Any extension of the current 2-container system to 3 and 4-container systems must take into account space at current collection points
- Three types of waste that can be recycled are collected at present; food waste, plastic packaging and paper/cardboard. If there is a desire to extend the collection scheme to include several types of sorted waste, one should focus on significance, i.e. types of waste where the recycling potential is equivalent to more than 2000 tonnes per year[10] or a one percentage point increase in the recycling rate.
- If the collection scheme is to be extended, the collection solution must be dimensioned to accommodate all the new types of waste, not just those that are currently sent for energy recovery. For example, approx. 6000 tonnes of glass and metal are currently disposed of in residual waste. If a new collection solution includes collection of glass and metal, it must also be dimensioned – where implemented – to accommodate the greater amount of glass and metal which households currently dispose of at recycling points. Use of recycling points will cease when this type of waste is collected at households
- The collection solution should be flexible in order to accommodate any later change in terms of volume and container system depending on households' behaviour. The current flexible solution, involving plastic containers and coloured bags, will therefore be continued
- The municipality of Oslo continues its optical sorting solution

5.3. One thing collection solutions 1 to 4 have in common, unlike solution 5

All the collection solutions mix 2, 3 and 4-container systems. The types of waste to be collected in the third and fourth containers will vary depending on the collection solution.

For collection solutions 1 to 4 in the parts of Oslo which do not have space for more than two waste containers, the current 2-container system with paper in a separate container and food waste, plastic packaging and residual waste in the other will continue.

Solution 5's 2-container system has a waste container for plastic packaging and paper/cardboard, and another for food and residual waste.

5.3.1. Collection solution 1

Besides the current 2-container system, the composition of containers in areas with space for 3 or 4-container systems will include the following types of waste:

- Container 1 of 3 – Residual waste
- Container 2 of 3 – Plastic packaging and Food waste
- Container 3 of 3 – Paper and Cardboard
- Container 4 – Glass and Metal

[10] Textiles are omitted from the analysis despite the tonnage, which falls within the weight criterion. This is due to the fact that textiles are considered to be a flexible type of waste that may alternatively be included as part of the optical sorting system involving this type of waste being sorted into separate bags.

Collection Solution	Container System	Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste
1	2						
	3						
	4						

Table 1 – Collection solution 1

5.3.2. Collection solution 2

Besides the current 2-container system, the composition of containers in areas with space for 3 or 4-container systems will include the following types of waste:

- Container 1 of 3 – Residual waste and Plastic packaging
- Container 2 of 3 – Food waste
- Container 3 of 3 – Paper and Cardboard
- Container 4 – Glass and Metal

Collection Solution	Container System	Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste
2	2						
	3						
	4						

Table 2 – Collection solution 2

5.3.3. Collection solution 3

Besides the current 2-container system, the composition of containers in areas with space for 3 or 4-container systems will include the following types of waste:

- Container 1 of 3 – Residual waste and Food waste
- Container 2 of 3 – Plastic packaging
- Container 3 of 3 – Paper and Cardboard
- Container 4 – Glass and Metal

Collection Solution	Container System	Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste
3	2						
	3						
	4						

Table 3 – Collection solution 3

5.3.4. Collection solution 4

Besides the current 2-container system, the composition of containers in areas with space for 3 or 4-container systems will include the following types of waste:

- Container 1 of 3 – Residual waste, Plastic packaging, Food waste
- Container 2 of 3 – Paper and Cardboard
- Container 3 of 3 – Glass and Metal
- Container 4 – Plant waste and Garden waste

Collection Solution	Container System	Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste
4	2						
	3						
	4						

Table 4 – Collection solution 4

5.3.5. Collection solution 5

Alternative 5 involves a change to the current 2-container system. This change means that residual waste and food waste will be placed in one waste container, while paper/cardboard and plastic packaging will be placed in container number two. If there is space for 3 or 4-container systems, the containers will contain the following types of waste:

- Container 1 of 3 – Residual waste
- Container 2 of 3 – Plastic packaging and Paper/Cardboard
- Container 3 of 3 – Food waste
- Container 4 – Glass and Metal

Collection Solution	Container System	Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste
5	2						
	3						
	4						

Table 5 – Collection solution 5

5.3.6. The collection solutions overall

Collection Solution	Container System	Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste
1	2						
	3						
	4						
2	2						
	3						
	4						
3	2						
	3						
	4						
4	2						
	3						
	4						
5	2						
	3						
	4						

Table 6 – Summary of all collection solutions

6. Simulation model

A system dynamics simulation model has been devised in order to calculate the effect of the collection solutions on recycling levels. The starting point for the development of this model is the model described in the report entitled Materialgjenvinning, en systemdynamisk tilnærming[11] (MGS). Parts of the work in MGS are used in the new model, but it has been necessary to extend and adapt it in order to include the recommendations in the "Measures Package" report. As with the work on MGS, an enquiry was sent to Bent Erik Bakken (BEB) at DNV-GL for assistance linked with the development of a system dynamics model which includes the recommendations of the "Measures Package" report. REN received a positive response, and the following assignment description and progress were agreed:

[11] REN file case 15/00725-7

Scope of Work (the Work)

Bakgrunn:
Oslo kommune ved Renovasjonsetaten (REN) ønsker ytterligere å forbedre andelen av husholdningsavfall som materialgjenvinnes, til minst 50 %. Andelen synes å ha satt seg fast på under 40 %. REN ønsker å videreutvikle en systemdynamiskmodell som kan brukes til å analysere effekten av alternative tiltak i sin verdikjede.

Leveranse fra DNVGL:
DNVGL v/Senior Principal Scientist Bent Erik Bakken (BEB) skal støtte arbeidet med å videreuvikle og bruke simulerings-modellen. Denne skal brukes av REN til å gjennomføre en analyse av ulike tiltakspakker.

Bidrag fra REN:
Analysesjef John Egil Nilssen (JEN) er til stede på møter i DNVGL sine lokaler. Tar med alle data som modellen skal populeres med. Han har sin egen programvarelisens av iThink.

Fremdriftsplan:
Oppstart februar 2016. Avsluttes desember 2016. Hvert møte er planlagt som et 3 timers møte, der tilsvarende innsats går med til for- og etterarbeid. Tid mellom hvert møte 1-3 måneder.
Før Møte 1: JEN presenterer sin rapport om potenisielle nye virkemidler

Møte 1: Enighet om referansemodus og modell
Etterarbeid: JEN viderutvikler og BEB kvalitetssikrer modell
Møte 2: Modell spikres og plan for databehov legges.
Etterarbeid: JEN finner frem data
Møte 3: Datasett spikres
Etterarbeid: JEN legger inn data i modell og JEN&BEB simulerer referansemodus med modell, evt justerer modellen slik at dette kan produseres. JEN lager liste over 3 hypoteser om virkninger av tiltak som skal testes.
Møte 4: Analyse som tester tiltak og ser resultatene i lys av hypotesene.
Etterarbeid: JEN lager rapportutkast og BEB bidrar til denne.
Møte 5: Rapportutkast diskuteres, evt mindre modell-justeringer og/eller analysebehov avklares
Etterarbeid: Justeringer utføres og endelig modell sluttføres av JEN

Figure 2 - Description of the assignment (text in Norwegian)

The model can be divided into three main elements. Part 1 is a value chain where the waste enters households, is sorted, transported, sorted centrally and ends up in the correct processing form. Part 2 is a behavioural element that involves indirect effects that affect the attitudes of the people living in the households. Part 3 includes the model’s three decision variables. These include the direct and indirect effects on sorting behaviour arising when a new collection solution is introduced. A brief layout of the model is outlined below. For a more detailed description, please see “Appendix 1 – Simulation model”.

6.1. Value chain

Figure 3 shows the value chain for the flow of waste from when it enters households on the left, sorting and transportation in the middle and final processing on the right in the figure. This model uses historical data from 2010-2015 for waste volumes and sorting behaviour. Waste volumes from recycling stations are included but are not affected by changes simulated. The model only operates with the processing forms recycling and energy recovery. Recycling also includes waste that is sent for reuse. Energy recovery also includes waste that is sent to landfill. The link between the Value chain and the Behaviour element is made by means of the blue circles labelled “Sorting Growth” and “Growth2”.

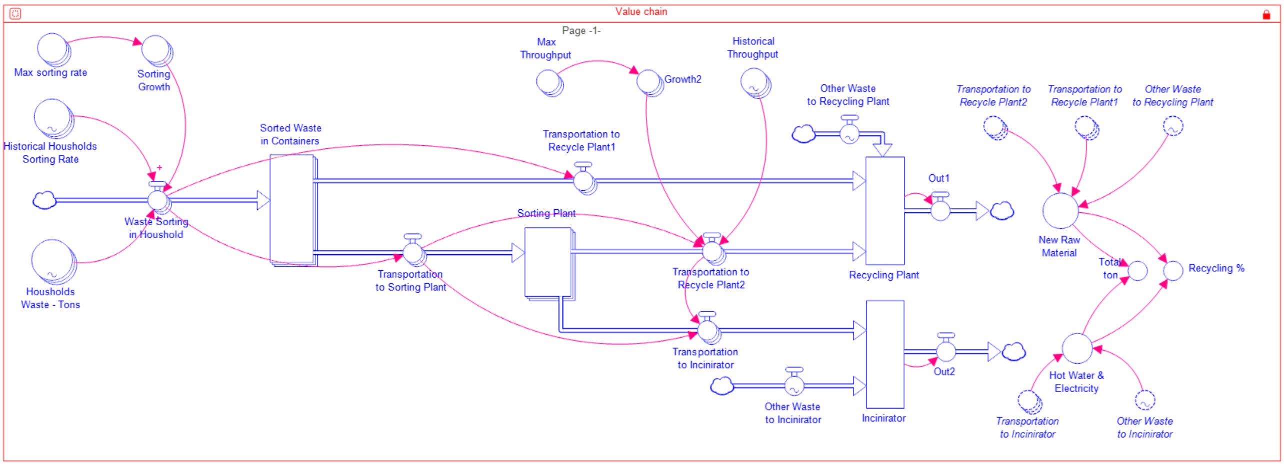

Figure 3 – Value chain

6.2. Behaviour element including decision variables

Figure 4 Shows how the “Measures Package” report’s recommendations are included in the model. The three red circles on the left in the figure are decision variables and represent the formulation of the collection solution. Changes in the decision variables influence sorting behaviour directly via “Changing in Sorting Behaviour” and indirectly via “Attitude”.

Attitudes in turn are influenced by the behavioural effects occurring collectively as a consequence of changes to the original collection solution. Changes that require added effort in the home, for example, give a negative effect seen via “Sorting complexity, Home”. Other steps include the use of the recommendations in the “Measures Package” report in order to counteract the negative effects arising. “Communication effort” and “Financial incentives” are examples of the latter.

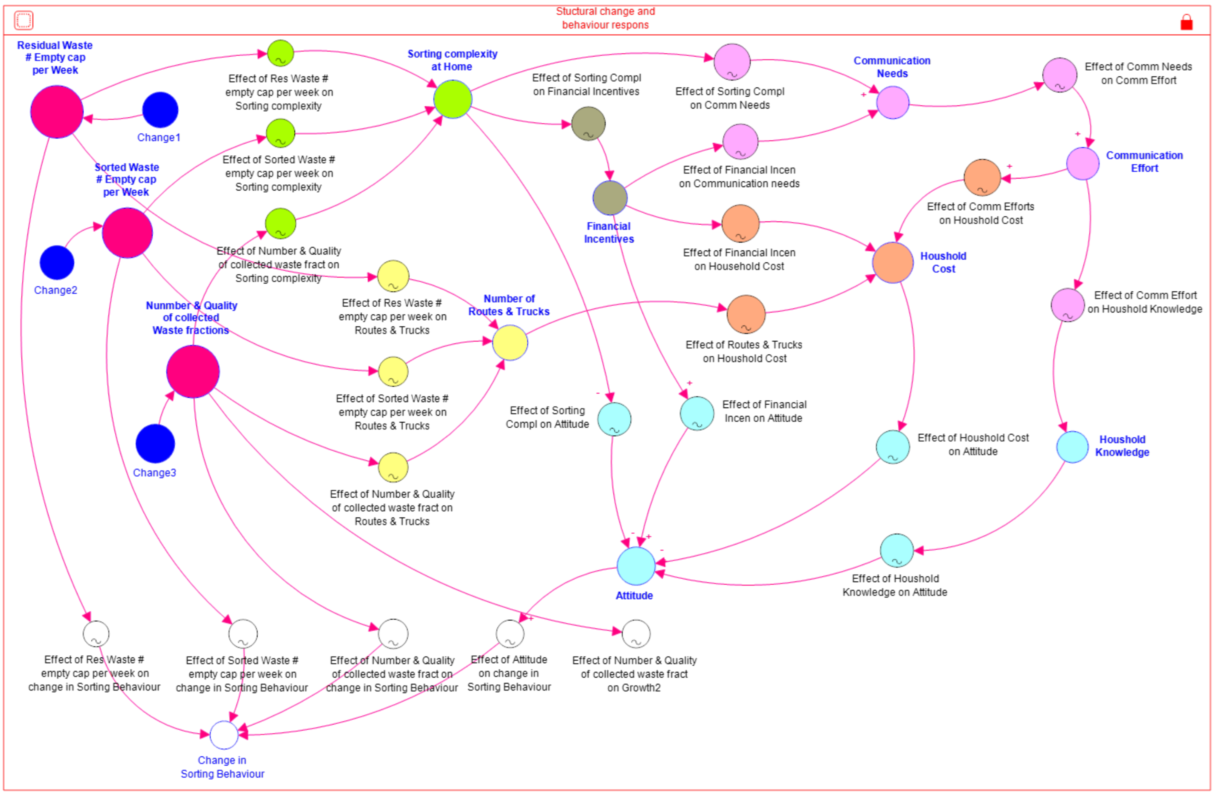

Figure 4 – Decision variables and behavioural contexts

6.3. Technical elaboration

This model takes into account the fact that changes take time, but also notes that the implementation of effective measures will begin in 2017. Therefore, time offsets have been added to decision variables[12] and the knowledge level of households until 4 years from 2017. In total, this means that the changes introduced in 2017 will not take full effect until approx. 2022. The simulation model is multiplicative and uses a scale from 0 to 2 in its calculations, the number 1 representing the current level. Numbers greater than 1 represent an increase in relation to the current situation, while numbers less than 1 correspond to a reduction. The model uses a set of functional forms devised in partnership with specialists at the Agency. Historical values have been added for waste types and sorting behaviour. Maximum values have been linked with the individual waste types indicating the extent to which it is possible to sort such waste and the extent to which wastage can be reduced for food waste and plastic packaging.

7. Method

This chapter describes the method used as a basis for the results. Input data and cost calculation are described in basic terms. For more in-depth information on these sections, please see "Appendix 2 – Input data" and "Appendix 3 – Calculation of costs".

7.1. Input data simulation model

Depending on the focus and structure of the collection solution, there are primarily three conditions[13] that influence the contribution to good sorting of waste. These conditions include reducing container capacity[14] when collecting residual waste, increasing container capacity when collecting sorted waste types, and finally a quality indicator. The three decision variables are adapted for the individual collection solutions and quantified individually. For the decision variables "Container capacity, Residual waste" and "Container capacity, sorted waste", meetings and group work have been conducted with the Agency's specialists in order to concretise changes to these decision variables. Input from this work forms the basis of the input data. The quality indicator is a calculated unit based on the number of sorted waste types collected from residential areas, as well as two types of wastage occurring in the value chain.

In Oslo, it is not feasible to deploy more waste containers all over the place as space and expansion options are limited at existing collection points. To assess the effects of the collection solutions described in *section 5*, therefore, it is necessary to estimate what share of the collection points can have a 2, 3 or 4-container system.

Oslo has approx. 50,000 approved collection points. The information in WebDeb has been reviewed, and the share of collection points that can use 2, 3 and 4-container systems has been estimated in cooperation with the Agency's specialists. These shares form the basis of the calculations of how much waste the container systems are receiving. *Table 7* summarises what share of collection points can have 2, 3 and 4-container systems, as well as the share of the weight of the waste that the container systems are expected to receive. For example, it is anticipated that approx. 38% of the

[12] SMTH3(1+STEP(Change3, 2017), 4, 1)
[13] REN file case, 15/00725-8
[14] Container capacity is the container volume multiplied by the collection frequency

city's collection points may comprise a 3-container system, and these are expected to receive approx. 74% of the waste volumes.

Container systems	Share of collection points	Share of weight
2-container	27 %	14 %
3-container	38 %	74 %
4-container	35 %	12 %

Table 7 – Shares per container system

The average of the groups' proposals for changes to the decision variables and quality calculation have been weighted using the "share by weight, waste per container system" from *Table 7*. The figures and results are shown in *Table 8*, and "Weighted average" per collection solution is used as input data for the simulation model.

Collection solution	Container System	Share of Weight	Average cap. Resid. waste	Average cap. Sorted waste	Input Quality
1	2	14 %	0,97	1,09	1,00
	3	74 %	0,60	1,50	1,26
	4	12 %	0,54	1,58	1,68
Weighted average:			**0,64**	**1,45**	**1,27**
2	2	14 %	0,97	1,09	1,00
	3	74 %	0,79	1,29	1,49
	4	12 %	0,73	1,38	2,00
Weighted average:			**0,81**	**1,27**	**1,48**
3	2	14 %	0,97	1,09	1,00
	3	74 %	0,74	1,38	1,21
	4	12 %	0,68	1,47	1,69
Weighted average:			**0,76**	**1,35**	**1,24**
4	2	14 %	0,97	1,09	1,00
	3	74 %	0,93	1,17	1,50
	4	12 %	0,90	1,29	1,87
Weighted average:			**0,93**	**1,18**	**1,47**
5	2	14 %	0,74	1,38	1,01
	3	74 %	0,57	1,63	1,34
	4	12 %	0,51	1,72	1,78
Weighted average:			**0,58**	**1,60**	**1,35**

Table 8 – Input data for the simulation model

7.2.Cost calculation

Any change to or further development of the current collection solution will affect the cost structure for the Agency. The purpose of the cost calculation is not to calculate future budget sizes or future overall costs for the individual collection solutions. This work is limited to using cost and revenue drivers that can be influenced directly in relation to the various collection solutions and hence influence the cost structure for the collection solutions in different ways. When identifying cost and revenue drivers, these are defined in two categories, a and b.

a) Cost and revenue drivers that can be related directly to the collection solutions and that influence these in different ways:

- Transport, collection scheme
- Transport, drop-off scheme
- Purchasing of waste containers
- Purchasing of return points
- Optical sorting of coloured bags
- Postprocessing of plastic packaging

- Purchasing of coloured bags
- Communication with households
- Financial incentive schemes
- Sales of paper and cardboard
- Sales of glass and metal

b) For cost and revenue drivers that, in our opinion, are independent of collection solutions or largely use the same volumes, see “Appendix 3 – Cost calculation”.

One thing the drivers used in the cost calculations have in common is the fact that specific figures have been produced for the period 2010-2015. Historical values have been adjusted for inflation[15] to 2015 figures. Depending on patterns in historical development, either historical average figures or the figures for 2015 have been used as a basis for projections. An annual actual growth factor of 1.7% has been used in the projections. The figures are projected up to 2031 and constitute a baseline which forms an adaptation basis for the individual collection solutions. The baseline reflects the future net expenditure for the relevant cost and revenue drivers, with activity levels unchanged from 2015. Driver-specific adaptations are described in greater detail in “Appendix 3 – Cost calculation”.

The projections for the cost and revenue drivers are added together annually for the period 2016-2031. This produces an annual net expense for the individual collection solutions. The net expense is used to calculate the present value and annual annuity for the individual collection solutions. The annuity is used directly and indirectly as a cost component in the cost-effectiveness calculations.

7.3. Cost-effectiveness calculation

A cost-effectiveness calculation is used in the evaluation of the collection solutions. Using cost-effectiveness calculations requires targets to be achieved and the cost level for reaching the target to be identified. The alternative is to identify different cost levels for the various target compliance levels[16]. The cost-effectiveness indicates the ratio of anticipated results to the amount spent on the input factors and is a measure of the effects of individual initiatives viewed in relation to the resources invested[17]. We understand this as meaning that a consistent relationship is established between requirements for targets on the one hand and allocated resources for achieving these targets on the other.

Two key figures – cost-effectiveness 1 and cost-effectiveness 2 – are used in the evaluation of the cost-effectiveness calculation for the collection solutions.

Cost-effectiveness 1 use a fraction where the relative increase in recycling level (effectiveness component) is divided by the relative increase in costs (cost component). The most cost-effective collection solution is the one with the highest numerical value.

Cost-effectiveness 2 shows how much one percentage point in terms of recycling level costs per year on average. The most cost-effective collection solution is the one with the lowest numerical value.

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[15] The consumer price index from Statistics Norway has been used
[16] James R. McGuigan et al.
[17] Norwegian Government Agency for Financial Management

A more detailed description of how these two key figures are calculated can be found in *section 8, Results*.

7.4. Calculation period

In the simulation model, the measures start to take effect from 2017 and have full effect after 5-6 years. Handling the implementation of measures from 2017 is not realistic. It is preferable to have a period which means that the simulation results at the end of the period are valid, with a realistic implementation time for the measures. By selecting 2031 as the final time for the simulations, the measures should be implemented by 2025 at the latest so that the simulation results have included the effects of the measures. Therefore, the period 2017-2025 will be a time of opportunity for the implementation of measures, given the fact that implementation of the effects by 2031 at the latest is preferred. The report "Materialgjenvinning en systemdynamisk tilnærming[18]" [Recycling – A system dynamics approach] also simulates recycling levels up to 2032. Using the same period is preferable in order to achieve consistency between the simulation results of the two works.

For the cost calculations, it is preferable to have a period which is long enough to allow differences in cost structures between the collection solutions to emerge clearly. If this period is too short, the differences in cost structure will be too small, in our opinion. If the period is too long, the cost estimates at the end of the period will be too uncertain and of little value. A period of approx. 15 years ahead, in our opinion, will provide enough time to allow changes in cost structures to emerge and for these to be sufficiently valid at the end of the period.

Given this fact, we have decided on the period 2016-2031 as a basis for our cost-effectiveness calculations.

8. Results

Table 9 summarises the recycling levels for the collection solutions in 2031, with the associated annual annuity. Collection solution 5 is the solution giving the highest recycling level and the lowest annuity. Collection solution 4 is the solution giving the lowest recycling level and the highest annuity. This is also the solution that resembles the current collection solution most closely. More detailed comments on the results are provided below.

Collection Solution	Container System	Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste	Recycling rate 2031	Ranking recycling	Annuity in mill NOK	Ranking annuity
1	2							49,8 %	2	295,2	2
	3										
	4										
2	2							48,4 %	4	301,7	3
	3										
	4										
3	2							48,6 %	3	311,0	4
	3										
	4										
4	2							46,8 %	5	311,7	5
	3										
	4										
5	2							50,9 %	1	291,6	1
	3										
	4										

Table 9 – Collection solution, simulation results and ranking

[18] REN file case 15/00725-8

8.1. Recycling results

Figure 5 shows how the individual collection solutions will develop over time. The effect of the changes to be implemented in 2017 has been selected entirely for all the collection solutions between 2022 and 2023.

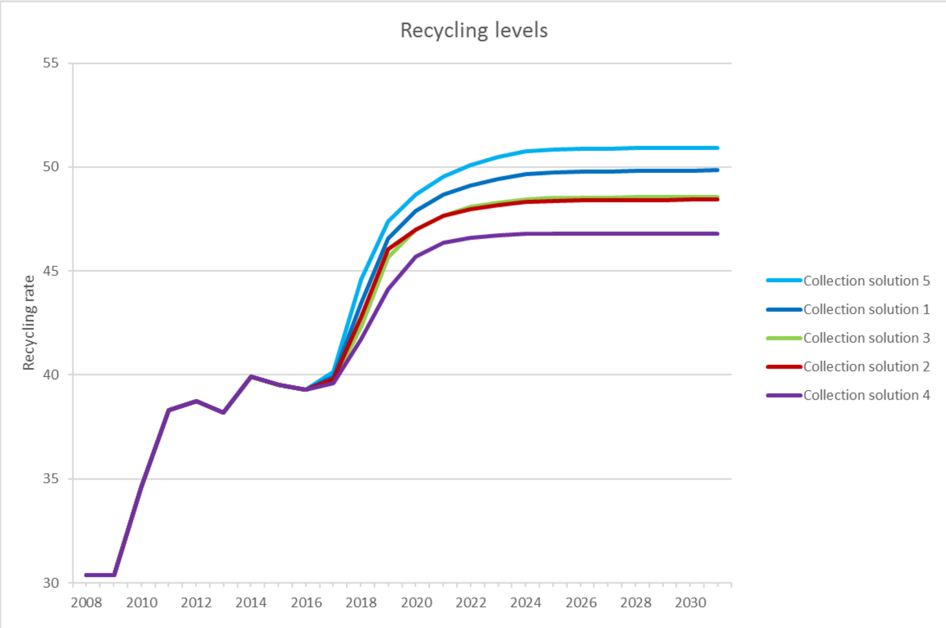

Figure 5 - Development of the collection solutions in terms of recycling level

The collection solution with the best outcome range, with a calculated recycling level of 50.9% in 2031, is number 5. Where there is space for 3 and 4-container systems (86% of the share by weight), the solution will have one waste container for residual waste and separate waste containers for sorted types of waste. This will avoid breakage of bags of sorted waste as a consequence of bulky waste, etc. being discarded in the same container. In addition, households will dispose of waste types suitable for recycling in separate waste containers for sorted waste types as a consequence of limited space in the residual waste container when a reduction in the residual waste container capacity is used as a measure. Collection solution 5 with a separate container for food waste will be able to eliminate food wastage currently occurring in the value chain as a consequence of the waste being transported directly to processing plants for recycling. Collection solution 5 also involves extending the collection scheme to add a waste type – glass and metal – but this will have only a minor effect on the recycling level. This is mainly due to two conditions. Firstly, households receiving a 4-container system will account for only 12% of the share by weight in Oslo, which means that of the glass and metal currently placed in the containers for residual waste, only 12% will be impacted. Secondly, people already sort of this type of waste to a great degree at present, so an increase in sorting behaviour beyond the current level will have a limited effect as we will fairly quickly reach the maximum amount of waste of this type that it is possible to sort; cf. the model description in "Appendix 1 – Simulation model". In the case of the 2, 3 and 4-container system, there will also be some degree of paper wastage as a consequence of plastic packaging, paper and cardboard been collected in the same container. This is due to the fact that poorly cleaned and wet plastic packaging will contaminate parts of the paper, thereby making it impossible to recycle all the paper. On the other hand, current plastic packaging wastage will be reduced slightly due to the fact that plastic packaging will be removed from the residual waste container and be collected together with paper instead. Despite the paper wastage, collection solution 5 is ranked as the best option.

Like collection solution 5, collection solution 1 will have separate waste containers for residual waste in the areas where there is space for a 3 and 4-container system, thereby avoiding breakage of bags containing sorted waste. Furthermore, there will be insufficient capacity in the residual waste container to allow households to avoid using their own waste containers for sorted waste types when a reduction in residual waste capacity is used as a measure. Food waste and plastic packaging will be collected in the same waste container, and there will therefore be some wastage as a consequence of the waste types being transported and undergoing preliminary sorting prior to the optical sorting operation, but this wastage will be less than is currently the case. As referred to for collection solution 5, collection of glass and metal will have only a minor impact on the recycling level. Collection solution 1 has a calculated recycling level of 49.8% in 2031.

Collection solutions 2 and 3 are ranked relatively equally, with calculated recycling levels of 48.4% and 48.6% respectively in 2031. One thing these alternatives have in common is the fact that they can reduce the container capacity for residual waste, because collection solution 2 has a separate container for food waste and collection solution 3 has a separate container for plastic packaging. Sorted waste types that do not have separate waste containers are collected in the residual waste container. These collection solutions will make it possible to slightly reduce container capacity for residual waste, and so households will have to sort more waste than they do at present. Furthermore, having a separate container for glass and metal will have a greater impact on the recycling level than in the case of collection solutions 1 and 5 as glass and metal will not be able to destroy the sorted bags mixed with the residual waste. The sorted waste types in separate containers can be transported directly to processing plants with no significant wastage in the value chain.

Collection solution 4, which is an adaptation of the current collection solution, is ranked as the collection solution with the poorest impact on recycling level. The calculated recycling level is 46.8% in 2031. This collection solution is similar to the current solution, where residual waste, plastic packaging and food waste collected in the same waste container, and so the extent to which wastage can be reduced for sorted waste types and container capacity for residual waste are limited. If there is space for a 3 or 4-container system (86% of the share by weight), a separate waste container for glass and metal will help to protect the sorted bags from breakage caused by sharp metal edges and broken glass, and thereby reduce some of the wastage. It will also be possible to remove more glass and metal from the residual waste than with the other collection solutions as this applies to a larger part of the city, and hence a larger share by weight. In addition, areas that can have a 4-container system (12% share by weight) will have a separate container for garden waste. This will also help to relieve the pressure on sorted bags and increase the sorting of sorted waste types that are not collected at present. The overall effect of having a separate container for garden waste will nevertheless be limited due to a small share by weight and a high level of sorting behaviour at present. Despite the fact that this solution will attempt to collect more waste types in residential areas, the solution will make an insufficient contribution to reducing residual waste container capacity and wastage in the value chain, thereby resulting in a lower recycling level than for the other collection solutions.

8.2.Cost calculation results

Figure 6 shows how the net expenditure for the individual collection solutions will develop over time. There will be a marked shift in 2021 and 2022 for three of the solutions due to reinvestment in optical sorting facilities. The various collections solutions require between one and three sorting lines. For the sake of comparison, the projection data for 2015 has been projected and shown as a baseline in the figure. The baseline reflects the future net expenditure for the relevant cost and revenue drivers, with activity levels unchanged from 2015.

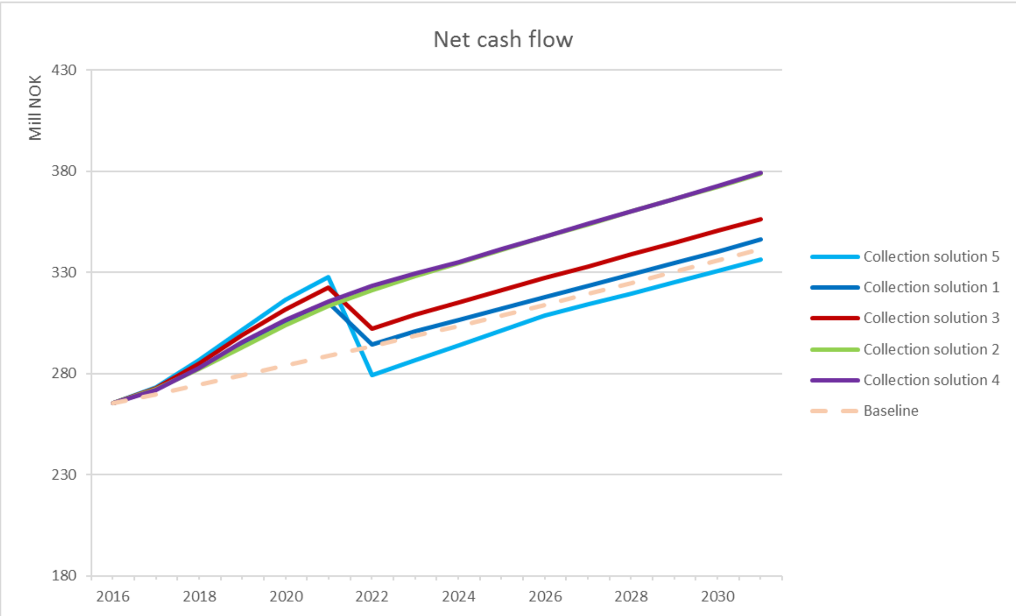

Figure 6 - Development of the collection solutions in terms of net expenditure

Collection solution 5 has higher annual net expenditure than the other solutions up until 2021. This is largely due to lower paper revenues. The solution will require reinvestment in only one optical sorting line as a consequence of the fact that plastic packaging, paper and cardboard will be discarded in the same container and that food waste will be collected in a separate container if there are three or four waste containers available. This will take place in 2021, and as a result expenditure development after this time will be slightly lower for this solution than for the other solutions.

Collection solution 1 also appears to be favourable in terms of expenditure. This solution will require reinvestment into two sorting lines, which means that expenditure will be reduced less in 2021 compared with collection solution 5, but more than for the other collection solutions.

Collection solution 2 is an interim solution in terms of expenditure. This will require reinvestment into two sorting lines but of all the collection solutions it will have the second-highest transport expenses for the collection scheme.

Collection solutions 3 and 4 are the same in terms of expenditure, but their structures are slightly different. They will both require reinvestment in three sorting lines. Collection solution 3 will have lower transport expenses for the collection scheme, but higher expenses for the transportation of glass and metal and the purchasing of return points compared with collection solution 4.

8.3.Cost-effectiveness results

Table 10 combines the recycling performance in *section 8.1* with the cost calculations in *section 8.2* and indicates the cost-effectiveness of the collection solutions by using two key figures, cost-effectiveness 1 and cost-effectiveness 2.

Cost-effectiveness 1 indicates the ratio of anticipated recycling level to costs used for the input factors in order to increase this. This figure provides a relative picture of how efficient the individual collection solutions are compared with the resource allocation. Maximising this figure with a view to achieving “cost-effectiveness” is a target.

Cost-effectiveness 1 is calculated according to the following formula:

$$\text{KE1}=\frac{\left(\frac{MG_{\text{2031Ln}}}{MG_{2015}}\right)}{\left(\frac{A_{\text{Ln}}}{FG_{2015}}\right)}$$

Formula 1 – Cost-effectiveness 1

Notation:

MG	Recycling level
Ln	Number of the collection solution
A	Annuity
FG	Projection data

When applied to collection solution 5, it looks like this:

$$1{,}15=\frac{\left(\frac{50{,}9}{39{,}5}\right)}{\left(\frac{291{,}6}{260{,}8}\right)}$$

By way of comparison, collection solution 4 has a cost-effectiveness of 0.99.

Cost-effectiveness 2 shows how much one percentage point in terms of recycling level costs per year on average during the calculation period. Attempting to minimise this figure with a view to achieving “cost-effectiveness” is a target. This figure is specified in NOK millions. Cost-effectiveness 2 is calculated according to the following formula:

$$KE2=\frac{A_{\text{Ln}}}{MG_{\text{2031Ln}}}$$

Formula 2 – Cost-effectiveness 2

Projection data in 2015 has been added to *Table 10* for comparison purposes.

	FG2015	L1	L2	L3	L4	L5
Cost-effectiveness 1 (max)	1	1.11	1.06	1.03	0.99	1.15
Cost-effectiveness 2 (min)	6.6	5.9	6.2	6.4	6.7	5.7

Table 10 – Cost-effectiveness results

The conclusion as regards the simulation results and cost calculation is that collection solutions 5 and 1 are the two most cost-effective solutions Collection solution 4 is the least cost-effective solution.

Please see “Appendix 4 – Cost-effectiveness summary” for further details on the results of the cost-effectiveness calculations.

8.4.Sensitivity analysis

The simulation results in *section 8.1* are based on a set of criteria. The purpose of the sensitivity analysis is to examine the sensitivity of the ranking of the collection solutions, the recycling levels of the simulation results and costs in respect of changes to the criteria specified[19]. The most important criteria used in the simulation are deemed to be the three decision variables container capacity for residual waste, container capacity for sorted waste and the quality indicator. An outcome range in respect of these criteria is used in the sensitivity calculations. In Table 11, these outcome ranges are named combination 1, 2, 3 and 4. The input data in combinations 1 and 2 has been amended to improve the recycling level. It is been amended in combinations 3 and 4 in order to reduce the recycling level.

Collection Solution	Data Combination	Yearly Annuity	Recycling rate	Cost-eff.1	Cost-eff.2
	Combination 1	308 202 758	52,4 %	1,12	5 880 725
	Combination 2	306 599 584	51,9 %	1,12	5 905 222
1	Sim. Result	295 245 026	49,8 %	1,11	5 924 044
	Combination 3	256 187 429	43,8 %	1,13	5 842 960
	Combination 4	229 748 141	25,9 %	0,74	8 877 896
	Combination 1	310 909 302	52,4 %	1,11	5 936 754
	Combination 2	311 661 419	51,2 %	1,08	6 089 348
2	Sim. Result	301 657 368	48,4 %	1,06	6 228 587
	Combination 3	294 489 000	39,2 %	0,88	7 512 271
	Combination 4	267 479 723	19,9 %	0,49	13 445 082
	Combination 1	326 047 201	52,4 %	1,06	6 223 917
	Combination 2	324 058 124	51,4 %	1,05	6 307 917
3	Sim. Result	310 988 747	48,6 %	1,03	6 403 587
	Combination 3	285 577 785	38,0 %	0,88	7 517 937
	Combination 4	261 429 146	20,5 %	0,52	12 732 377
	Combination 1	322 135 940	52,0 %	1,07	6 192 586
	Combination 2	322 143 504	50,1 %	1,03	6 424 980
4	Sim. Result	311 749 365	46,8 %	0,99	6 662 099
	Combination 3	291 382 579	31,2 %	0,71	9 347 306
	Combination 4	266 353 324	16,9 %	0,42	15 789 513
	Combination 1	300 445 169	52,4 %	1,15	5 731 221
	Combination 2	300 044 442	52,2 %	1,15	5 744 038
5	Sim. Result	291 563 360	50,9 %	1,15	5 724 390
	Combination 3	266 635 704	45,6 %	1,13	5 843 727
	Combination 4	233 422 827	29,3 %	0,83	7 968 574

Table 11 – Sensitivity analysis results

As can be seen in Table 11, collection solution 5 is the alternative offering the best cost-effectiveness in both the simulation results and the sensitivity analyses. Collection solution 1 comes in second place.

Collection solution 4 is last in both the simulation results and the sensitivity analyses.

Please see “Appendix 5 – Sensitivity analysis” for more details on the sensitivity analysis.

[19] Bøhren & Gjærum, p. 160

8.5. Conclusion

The conclusion as regards the simulation results, cost calculations and sensitivity analyses is that collection solutions 5 and 1 are the two most cost-effective collection solutions.

9. Lack of management information

Implementation of a new collection solution in Oslo requires information about matters of which REN currently has little or no knowledge. In our opinion, structured access to this information will be crucial to the potential success of an implementation. This information should include the following:

- *Collection points*. The Agency must know which collection points in Oslo have space for 2, 3 and 4-container systems. This collection point information must be unique and recorded for an address or other appropriate solution and include information on the container system, container sizes and waste types. It should be possible to link quality criteria to individual collection points.
- *Household segments*. The Agency needs an appropriate segmentation model in order to drive targeted information and communication and ensure that the message is received by the right people. The segmentation model should include the findings of the "Measures Package" report and combine these with the collection point information in the bullet point above.
- *Incentives*. A "financial incentive model" should be developed which is combined with full cost calculations, budgets and collection point information in the first bullet point.
- *Pilot*. It will probably be appropriate to "test" a new collection solution before it is rolled out. Appropriate areas for pilots should be identified and devices to ensure that errors and defects are rectified should be organised. A pilot will provide valuable feedback on what works and what needs to be improved and reimplemented before full rollout. The function criteria will be based on both measures and organisation capacity.

10. Sources of problems

The model device used is based on a series of criteria that may help to undermine the validity of findings and conclusions. The sources of problems that we ourselves are familiar with are described below.

- The entire model device is based on the recommendations in the "Measures Package" report functioning as intended and being representative of Oslo, and on REN having the capacity to develop and implement these. If these criteria are infringed, the results in the report will be invalid.
- The simulation model bases results on function forms and formulae. These are formulated to the best of our professional abilities. Errors or mistakes will give other results. The extent to which errors and mistakes will affect the ranking of the collection solutions is more uncertain, as shortcomings will have an equal impact on all collection solutions.
- Insofar as they are used, coefficients from the simulation model in the cost calculations will be used as a basis to ensure that the function forms for recycling and costs are approximately the same. This does not necessarily have to be the case. Again, whether errors and mistakes will affect the ranking results is uncertain; see the bullet point above.

- It is unlikely that the simulation model will come across correct recycling in 2031. However, the differences between the solutions are more robust. If something is wrong in one place, it will probably be wrong to a corresponding extent in the other solutions.
- In the model device, accrual of costs occurs in the same period as target attainment. Costs often accrue earlier than the results, but by how much is uncertain. This will probably not affect the ranking of the collection solutions.

Weaknesses have been pointed out which may impact on the conclusion. Nevertheless, we are of the opinion that this work uses the knowledge which REN currently possesses and that the results provide a correct impression of the development potential of the collection solutions. In our opinion, a further investigation with pilot operation is necessary. Data from work of this kind should be implemented in the model in order to check the validity and update the results so that correct decisions can be made prior to potential full rollout.

11. Recommendations

Given the above, we provide the following recommendations:

1. On the basis of these results, REN should make a decision on whether it considers it appropriate to alter the current collection solution. If this is desirable:
2. REN should carry out further investigations with a view to implementing the primary collection solution 5, or alternatively the secondary collection solution 1
3. REN should start working on collecting and recording management information that it does not have
4. REN should start working on developing an appropriate, effective package of measures suited to the particular needs of Oslo
5. REN should start working on identifying and planning areas for appropriate piloting of the collection solution selected using associated measures

Appendix 1 – Simulation model

1.1 Link between the “Measures Package” report and the simulation model

Categories in "Measures Package"	Findings in report "Measures Package"	Name in simulation model	Input and effect
Door to door collection scheme	Number of waste types	Number & Quality of collected Waste fractions	Decision variable, direct+indirect effect
	Container sizes	Residual Waste # Empty cap per Week	Decision variable, direct+indirect effect
	Closing refuse chutes	Omitted	
	Short distances from home to drop-off location	Sorting complexity at Home	Indirect effect on attitude
	Number of routes	Number of Routes & Trucks	Indirect effect on attitude
	Collection frequency	Sorted Waste # Empty cap per week	Decision variable, direct+indirect effect
User experience	Little interest, indifference, lackk of attention	Attitude	Direct effect on Change in Sorting Behaviour
	Positive perceptions and attitudes	Attitude	Direct effect on Change in Sorting Behaviour
	Discrepancy between intention and behavior	Attitude	Direct effect on Change in Sorting Behaviour
	Complicated waste sorting at home	Sorting complexity at Home	Indirect effect on attitude
	Bad smells in home	Sorting complexity at Home	Indirect effect on attitude
Demographics	Age	Omitted	
	Gender	Omitted	
	Etnisity	Omitted	
	Childs in housholds	Omitted	
	Housing	Omitted	
	Stay home with children	Omitted	
Laws and regulations	Laws and regulations	Omitted	
Communication	Clear and distinct and communicated directly	Communication Effort	Indirect effect on attitude
Knowledge	Good knowledge of waste disposel among population	Houshold Knowledge	Indirect effect on attitude
	Good knowledge among employees	Omitted	
Incentives	Pay as you throw	Financial Incentives	Indirect effect on attitude
	Finance	Financial Incentives	Indirect effect on attitude
	Tax	Financial Incentives	Indirect effect on attitude
New		Houshold Cost	Indirect effect on attitude
New		Communication Needs	Indirect effect on attitude
Drop-off schemes	Omitted		
Method	Omitted		
Quantify/measure	Omitted		

Table 12 – Link between the “Measures Package” report and the simulation model

1.2 Value chain

Figure 7 shows the value chain for the flow of waste from when it enters households on the left, sorting and transportation in the middle and final processing on the right in the figure. Historical annual values for waste volumes, sorting behaviour and throughput shares for the period 2010-2015 have been added. This data has been taken from REN’s production data and waste analyses. The data is essentially the same so as to ensure consistency between the work described in the report entitled “Materialgjenvinning en systemdynamisk tilnærming” (MGS)[20] and this work. The difference lies in the fact that MGS uses a merger of waste types to form a bag item named “Destructive waste” in the waste flow into households. This bag item is linked with a growth factor so that the waste volume increases slightly throughout the simulation period. In this work, the waste types into households are not merged into a bag item; instead, the individual waste types are used and no growth factor is associated with these waste types. The tonnage figures for the waste types for 2015 are used for the entire simulation period. Therefore, the simulation results will differ slightly between the models.

[20] File case 15/00725

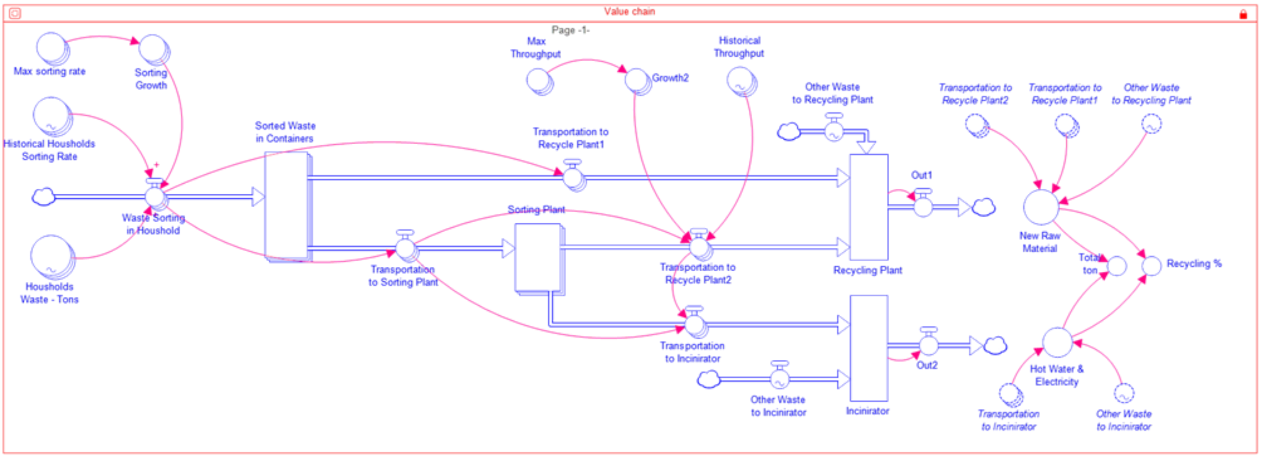

Figure 7 – Value chain

The first element in the value chain refers to what happens at the household until the waste is transported from the property. This includes “Households Waste - Tons” for the textiles, paper and cardboard, plants and garden waste, glass and metal, residual waste, food waste and plastic packaging waste types. Sorting coefficients for households’ “Historical Households Sorting Rate” have been added for the same waste types. Anything that is not sorted is placed in residual waste. Residual waste and sorted waste types are stored in waste containers, designated in the model as “Sorted Waste in Containers” before being transported further. A numerical value is also added indicating the extent to which it is possible to sort the individual type of waste, named “Max sorting rate” in the model. The behaviour element in the model is linked to the value chain by means of “Sorting Growth”. Regardless of how effective the measures implemented in the behaviour element are, sorting behaviour will not exceed the values entered in “Max sorting rate”.

Other elements in the value chain include the transportation and central sorting of waste. Food waste, plastic packaging and residual waste are transported to a central sorting plant where the waste types are separated. In the model, this is named “Transportation to Sorting Plant” and “Sorting plant”. The other sorted types of waste are transported directly to processing plants which recycle the waste, named “Transportation to Recycle Plant1”. Residual waste is transported from the central sorting plant to energy recovery plants, named “Transportation to Incinerator”. Food waste and plastic packaging is transported to processing plants for recycling, named “Transportation to Recycle Plant2”. There is wastage between containers at collection points and processing plants for food waste and plastic packaging. It is estimated that up to one-third of sorted food waste is destroyed during the transportation and sorting process and is included in residual waste as a result of this. The opposite of wastage is throughput, and this includes the share of sorted food waste and plastic packaging that arrives at processing plants for recycling. If the throughput increases, wastage is reduced accordingly. This is included in the model as “Throughput”. The throughput is affected by the behaviour element via “Growth 2”. “Max throughput” in the model includes numerical values indicating the maximum throughput; in other words, the fact that wastage can never be zero is taken into account. This corresponds to the data modelled in association with maximum sorting behaviour.

The third element in the value chain includes waste at the processing plant and calculation of recycling percentages. To ensure that the waste volumes that flow through the value chain are recognisable and can undergo quality assurance more easily in relation to historical data, two waste volumes occur for the correct processing method. These are defined in the model as “Other Waste to

Recycling Plant" and "Other Waste to Incinerator" and primarily include waste coming from REN's recycling stations. As a result, these are not part of the collection scheme.

The model only operates with the processing forms recycling and energy recovery. Recycling also includes waste that is sent for reuse. Energy recovery also includes waste that is sent to landfill.

1.3 Behaviour element

Figure 8 shows how the "Measures Package" report's recommendations are included in the model. The three red circles on the left in the figure are decision variables and represent the formulation of the collection solution. Two effects arise if these are changed beyond the current level. The first effect is that the decision variables impact directly on any change in sorting behaviour. The other effect is that they indirectly influence the attitudes of the population via a number of stages, which in turn influences sorting behaviour Parts of these stages have an adverse impact on attitudes due to the fact that the original collection solution is changed Other steps include the use of the recommendations in the "Measures Package" report in order to counteract the negative effects arising. This is described in greater detail below.

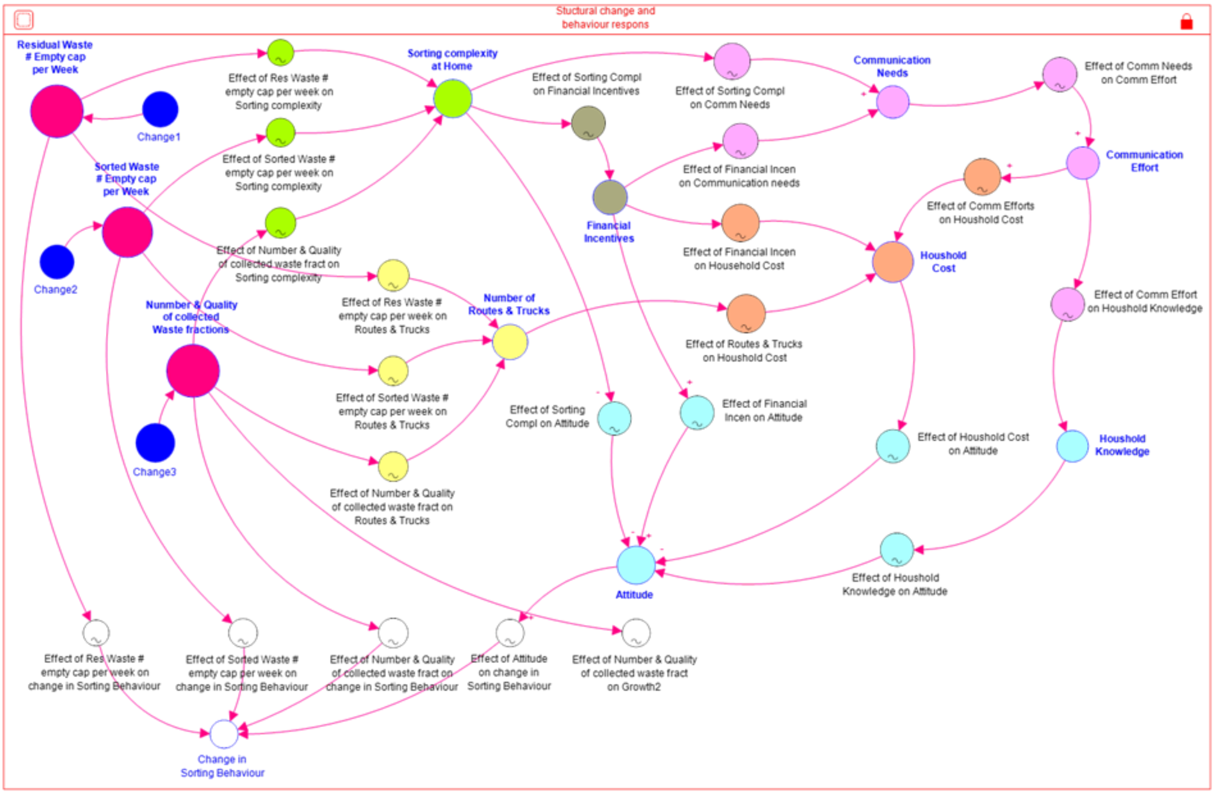

Figure 8 – Decision variables and behavioural contexts

The red circles represent the three decision variables and are named "Residual waste # container cap per week", "Sorted Waste # Empty cap per week" and "Number & Quality of collected waste fractions" in the model. Changes to the decision variables have both direct and indirect effects on sorting behaviour, named "Change in sorting behaviour". Changes in sorting behaviour affect the value chain via "Sorting Growth". The extent of the effect of the individual decision variables is dependent on the functions formulated in the circles marked "~" and starting with the name "Effect of…".

In addition, the decision variable “Number & Quality of collected waste fractions” affect the model’s “Throughput”. This is linked to the value chain via “Growth2”.

The “Measures Package” report’s recommendations regarding a new collection solution may, for example, increase the complexity of sorting within households, which will have an adverse impact on attitudes. If the number of routes and vehicles in Oslo also increases as a consequence of changes to the collection solution, this will result in a cost increase for households. This may also be perceived as negative and hence contribute to a further reduction in support for the new collection scheme. Two measures are used to compensate for the negative development in the example above. The first is to use clear, distinct and targeted communication campaigns to increase knowledge levels among households, which in turn will have a positive impact on attitudes. The other is to use financial incentives which will have a positive impact on attitudes if they are implemented correctly. The implementation of incentives will further increase the need for communication, and both the introduction of financial incentives and an increase in communication initiatives will increase costs for these households more than would have been the case without these measures. This may help to reinforce the negative attitudes. Despite this development, with a communication initiative and financial incentives the effects on attitudes will be better than if these measures are not implemented.

Appendix 2 – Input data

2.1 Calculation of shares

Of the approx. 50,000 approved collection points in Oslo, approx. 21,500[21] points are linked with "individual houses[22]". Individual houses are deemed to have sufficient space to increase the number of containers at collection points. Therefore, they may change from a 2-container system to a 3 or 4-container system. Approx. 20% of "house" collection points are deemed only to have space for a 3-container system due to increased density and space problems for houses as well. The remaining 80% is deemed to have space for a 4-container system per collection point. Approx. 35% of all collection points have space for a 4-container system.

Collection points that are not linked with houses, that have multiple residual waste containers and other collection units or one residual waste container which is more than 340 litres in size can use substitution. Substitution means that if there are multiple residual waste containers or other collection units, some are replaced with containers for sorted waste. If there is one residual waste container larger than 340 litres, this can be replaced with a smaller residual waste container and supplemented with another container for sorted waste types to compensate for the volume that has been removed. 15% of the collection points that are not associated with houses, with one residual waste container less than or equal to 340 litres, have space for a 3-container system. In addition, 20% of the collection points belonging to houses have space for a 3-container system. In total, approx. 38% of all collection points in Oslo have space for a 3-container system.

85% of the collection points that are not linked with individual houses with only one residual waste container less or equal to 340 litres, as well as one waste chute, waste extractor, container cabinet, lift and hook, hatch or bags, are not covered by substitution due to the small capacity of the residual waste container or a waste infrastructure with a lack of flexibility. These will continue with the current 2-container system and constitute approx. 27% of all collection points.

The individual collection points receive various quantities of waste. The challenge with the share of collection points in *Table 13* is that they do not fully reflect the waste volumes that the container system will receive. The collection points covered by 2 and 3-container systems are linked to cooperatives and co-owners where there are lots of households using the same collection point. Therefore, these collection points have large waste containers or large numbers of waste containers and will receive more waste for collection point than collection points with a 4-container system where all the containers are linked with individual houses. Therefore, a calculation is needed which shows the share of the waste – a share by weight – that the individual container systems are expected to receive. The share of waste by weight per container system is used as weights when calculating input data for the decision variables, cf. *Table 19 – Input data for simulation model*. The "share of collection points per container system" is used as a distribution key to calculate the "share of waste by weight per container system". This distribution key determines the availability of space in Oslo when "share of waste by weight per container system" is calculated. As the share of waste by weight per container system influences the decision variables by means of weighting, this brings about a change in sorting behaviour and hence the simulated recycling level. Therefore, distribution

[21] Source: WebDeb
[22] is defined as: Individual houses + flats split vertically and horizontally.

of the waste volumes for container systems which is as correct as possible appears to be a good prerequisite for ensuring that calculated recycling levels are as valid as possible.

	Totalt	Enebolig	Ikke enebolig
Standplasser	49 205	21 539	27 913
Tømmevolum	40 848 380	6 128 100	34 720 280

	Antall standplasser	Vektandel (tømmevolum)
Andel eneboliger som kun har plass til 3 beholdere, jfr møte 08.07.16	20 %	20 %
Eneboliger som kun har plass til 3 beholdere, jfr møte 08.07.16	4 308	1 225 620
Eneboliger med plass til 4 beholdere	17 231	4 902 480
Andel eneboliger med plass til 4 beholdere	35 %	12 %
IKKE enebolig, alle størrelser	27 913	34 720 280
Ikke eneboliger med EN restbeholder <= 340 liter, avfallsbrønn og -sug, containerskap, L&K, luke eller sekk	15 694	6 502 200
hvor av restbeholder <= 340 liter	15 030	4 111 400
hvor av avfallsbrønn og -sug, containerskap, L&K, luke eller sekk	664	2 390 800
Andel med én beholder mindre eller lik 340 liter som har plass til tre beholdere, jfr møte 12.08.16	15 %	15 %
En beholder mindre eller lik 340 liter hvor man har pass til tre beholdere , jfr møte 12.08.16	2 255	616 710
Beholder sitt "to beholder system"	13 440	5 885 490
Andel som beholder sitt "to beholder system"	27 %	14 %
Mulighetsrom for substitusjon, ikke eneboliger	12 219	28 218 080
Eneboliger som kun har plass til 3 beholdere	4 308	1 225 620
Kan ha 3 beholdere fra "to beholder system"	2 255	616 710
Sum substitusjons mulighet	18 781	30 060 410
Andel substitusjon (3 beholdere)	38 %	74 %

Beholdersystem	Andel standplasser	Vektandel
4-beholdersystem	35 %	12 %
3-beholdersystem	38 %	74 %
2-beholdersystem	27 %	14 %
	101 %	100 %

Table 13 – Summary of shares per container system (text in Norwegian)

Table 13 summarises what share of collection points can have 2, 3 and 4-container systems, as well as the share of the weight of the waste that the container systems are expected to receive. For example, it is anticipated that approx. 38% of the city’s collection points may comprise a 3-container system, and these are expected to receive approx. 74% of the waste volumes.

A future situation in which Oslo uses a differentiated container system is based on a distribution of the share by weight per container system as summarised in *Table 13 – Summary of shares per container system*.

2.2 Container capacity, residual waste

It is desirable to reduce the container capacity for residual waste as much as possible without this causing littering problems or contamination of sorted types of waste. The container capacity for residual waste as a function of container volume and collection frequency per week and can be accumulated to give annual volumes. The question is; to what extent can container capacity be reduced for each collection solution? Group work involving Agency specialists was organised in order to answer this question. The people present were divided into three groups that discussed the collection solutions and came up with suggestions for reductions in container volume and collection frequency on the basis of these discussions. The results are displayed as values less than or equal to 1, where 1 means that no changes are made to container capacity for residual waste compared with the current level. Values below 1 correspond to a reduction in container capacity compared with the present. For example, group 3's suggestion for collection solution 1, a 2-container system, was that the residual waste capacity could be reduced by 10% to 90% of the current level. The average calculation of groups' input forms the basis for the input data for the model; see *Table 14*.

Waste type & Containers						Collection Solution	Container System	Residual waste									
								Group 1			Group 2			Group 3			Average
Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste			Volume (1=todays level)	Frequency (1=todays level)	Basis Indata	Volume (1=todays level)	Frequency (1=todays level)	Basis Indata	Volume (1=todays level)	Frequency (1=todays level)	Basis Indata	
							2	1,00	1,00	**1,00**	1,00	1,00	**1,00**	0,90	1,00	**0,90**	**0,97**
						1	3	0,80	0,95	**0,76**	0,60	0,80	**0,48**	0,55	1,00	**0,55**	**0,60**
							4	0,75	0,90	**0,68**	0,55	0,80	**0,44**	0,50	1,00	**0,50**	**0,54**
							2	1,00	1,00	**1,00**	1,00	1,00	**1,00**	0,90	1,00	**0,90**	**0,97**
						2	3	0,90	1,00	**0,90**	0,80	0,85	**0,68**	0,80	1,00	**0,80**	**0,79**
							4	0,85	0,95	**0,81**	0,75	0,85	**0,64**	0,75	1,00	**0,75**	**0,73**
							2	1,00	1,00	**1,00**	1,00	1,00	**1,00**	0,90	1,00	**0,90**	**0,97**
						3	3	0,80	0,90	**0,72**	0,80	1,00	**0,80**	0,70	1,00	**0,70**	**0,74**
							4	0,75	0,85	**0,64**	0,75	1,00	**0,75**	0,65	1,00	**0,65**	**0,68**
							2	1,00	1,00	**1,00**	1,00	1,00	**1,00**	0,90	1,00	**0,90**	**0,97**
						4	3	0,99	1,00	**0,99**	0,95	1,00	**0,95**	0,85	1,00	**0,85**	**0,93**
							4	0,95	1,00	**0,95**	0,93	1,00	**0,93**	0,83	1,00	**0,83**	**0,90**
							2	0,80	0,90	**0,72**	0,80	1,00	**0,80**	0,70	1,00	**0,70**	**0,74**
						5	3	0,70	0,95	**0,67**	0,60	0,80	**0,48**	0,55	1,00	**0,55**	**0,57**
							4	0,65	0,90	**0,59**	0,55	0,80	**0,44**	0,50	1,00	**0,50**	**0,51**

Table 14 – Future container capacity, residual waste

2.3 Container capacity, sorted waste

Unlike container capacity for residual waste, it is desirable to increase container capacity for sorted types of waste. On collection day, the fill levels of these containers should not exceed 90% so as to ensure that there is always space to discard this type of waste in the correct container. The container capacity for collection of sorted waste types is also a function of container volume and collection frequency per week, and as with residual waste it can be accumulated to give annual volumes. The question here is; to what extent can container capacity be increased for each collection solution? As for residual waste, the working methodology was included in the workshop described. The results are displayed as values greater than or equal to 1, where 1 means that no changes are made to container capacity for sorted waste types compared with the current level. Values over 1 correspond to an increase in container capacity compared with the present. For example, group 2's suggestion for collection solution 1, a 2-container system, was that the container capacity for sorted types of waste could be increased by 10% in relation to the current level. An average of the input from the groups provides the basis for input data; see *Table 15*.

Waste type & Containers						Collection Solution	Container System	Sorted waste									
								Group 1			Group 2			Group 3			Average
Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste			Volum (1=dagens nivå)	Frekvens (1=dagens nivå)	Grlg inn data	Volum (1=dagens nivå)	Frekvens (1=dagens nivå)	Grlg inn data	Volum (1=dagens nivå)	Frekvens (1=dagens nivå)	Basis Indata	
							2	1,00	1,00	**1,00**	1,00	1,10	**1,10**	1,05	1,10	**1,16**	**1,09**
						1	3	1,15	1,00	**1,15**	1,20	1,50	**1,80**	1,40	1,10	**1,54**	**1,50**
							4	1,20	1,05	**1,26**	1,30	1,45	**1,89**	1,45	1,10	**1,60**	**1,58**
							2	1,00	1,00	**1,00**	1,00	1,10	**1,10**	1,05	1,10	**1,16**	**1,09**
						2	3	1,05	1,15	**1,21**	1,40	1,00	**1,40**	1,15	1,10	**1,27**	**1,29**
							4	1,10	1,20	**1,32**	1,50	1,00	**1,50**	1,20	1,10	**1,32**	**1,38**
							2	1,00	1,00	**1,00**	1,00	1,10	**1,10**	1,05	1,10	**1,16**	**1,09**
						3	3	1,10	1,15	**1,27**	1,50	1,00	**1,50**	1,25	1,10	**1,38**	**1,38**
							4	1,15	1,20	**1,38**	1,60	1,00	**1,60**	1,30	1,10	**1,43**	**1,47**
							2	1,00	1,00	**1,00**	1,00	1,10	**1,10**	1,05	1,10	**1,16**	**1,09**
						4	3	1,05	1,05	**1,10**	1,10	1,10	**1,21**	1,10	1,10	**1,21**	**1,17**
							4	1,10	1,10	**1,21**	1,30	1,10	**1,43**	1,12	1,10	**1,23**	**1,29**
							2	1,15	1,00	**1,15**	1,00	1,50	**1,50**	1,35	1,10	**1,49**	**1,38**
						5	3	1,25	1,15	**1,44**	1,20	1,50	**1,80**	1,50	1,10	**1,65**	**1,63**
							4	1,30	1,20	**1,56**	1,30	1,45	**1,89**	1,55	1,10	**1,71**	**1,72**

Table 15 – Future container capacity, sorted waste

2.4 Quality indicator

The quality indicator is made up of three individual indicators that are each evaluated individually in relation to collection solutions and container systems. Maximising all indicators is desirable. The first is the number of waste types collected. The current 2-container system is designed for collection of three types of sorted waste at households; food waste, plastic packaging and paper. If this is extended by one or two types of waste, this will correspond to an increase of 33% and 66% respectively. The results are shown under “number” in *Table 18*.

The second indicator is linked with a change in wastage. The current collection solution operates with significant wastage for plastic packaging and food waste. A summary of the Agency’s waste analyses and production figures indicates that up to one-third of sorted food waste is destroyed between the waste container and the processing plant. The various collection solutions will have different influences on this wastage. Throughput is the opposite of wastage and indicates how much of the food waste and plastic packaging that arrives at the processing plant. If wastage is reduced, throughput will increase to the same extent as the reduction in wastage. All the collection solutions have been reviewed, and a subjective assessment has been carried out on the extent to which wastage can be reduced by introducing a given container system as shown in *Table 16*.

Collection Solution	Container System	Sorted waste types in container that influence wastage	Wastage reduct. Plastic pack.	Wastage reduct. Food waste
1	3 og 4	1) Plastic pack. & food waste	50 %	50 %
2	3	1) Food waste 2) Glas/Metal	20 %	95 %
2	4	1) Food waste 2) Glas/Metal	35 %	95 %
3	3	1) Plastic pack. 2) Glass/Metal	95 %	5 %
3	4	1) Plastic pack. 2) Glass/Metal	95 %	30 %
4	3	1) Glass & metal	30 %	30 %
4	4	1) Glass & metal 2) Garden waste	30 %	30 %
5	2	1) Plastic pack. Papir	90 %	5 %
5	3 og 4	1) Plastic pack., papir 2) Food waste	90 %	95 %

Table 16 – Wastage reduction for food waste and plastic packaging

Table 16 summarises the assessments linked with wastage reduction for food waste and plastic packaging in relation to the current solution.

New wastage is then calculated for the individual collection solutions. The following formula is used to arrive at the results in the “change, throughput” column in *Table 18*.

$$\sqrt[3]{\left(\frac{GSp}{NSp} * Wp\right) \leq 1 + \left(\frac{GSm}{NSm} * Wm\right) \leq 3}$$

Formula 3 – Calculation of wastage indicator

<u>Notation:</u>

GS Old wastage
NS New wastage
W Weight
p Plastic packaging
m Food waste

The weights in *Formula 3* are calculated according to the wastage tonnage for plastic packaging and food waste. Plastic packaging accounts for 0.25 and food waste 0.75 in wastage shares in *Table 17*.

Waste type	Wastage in ton	Weights
Food waste	4 967	0,75
Plastic pack.	1 685	0,25
Total wastage	6 652	1

Table 17 – Wastage weights

The maximum values <=1 and <=3 in *Formula 3* are used to reduce the sizes of the coefficients. In some of the container systems, dividing old wastage by new wastage gives values of 5 for plastic packaging and 15 for food waste, and these have to be toned down for adaptation to the model's scale value. Maximum values of 1 and 3 respectively are used to reflect the ratio of plastic packaging to food waste in this division.

The root value of 3 in *Formula 3* is determined according to the size of the other input data values so that internal reconciliation of scale values between all input data is taken into account.

The third indicator is linked with a change in paper quality. In collections solutions 1-4, the paper is collected in separate containers as at present. This will result in no changes compared with the current solution and so give a value of 1. In collection solution 5, plastic packaging and paper are collected in a separate container. As a consequence of wet and poorly cleaned plastic packaging, it is likely that parts of the paper will be contaminated and so be unsuitable for recycling. The share of contamination is assessed subjectively and gives a value less than 1 as a consequence of the wastage. The results can be found under "change, paper quality" in *Table 18*.

The three indicators are then multiplied together to give a final value per container system, known as "basic input data" in *Table 18 – Quality indicator*.

Waste type & Containers								Quality indicators – Number & Quality on sorted waste			
Residual waste	Plastic pack.	Food waste	Papir waste	Glass/ metal waste	Garden waste	Collection Solution	Container System	No. Waste types	Change throughput	Change paper quality	Basis Indata
							2	1	1,00	1,00	**1,00**
						1	3	1	1,26	1,00	**1,26**
							4	1,33	1,26	1,00	**1,68**
							2	1	1,00	1,00	**1,00**
						2	3	1	1,49	1,00	**1,49**
							4	1,33	1,50	1,00	**2,00**
							2	1	1,00	1,00	**1,00**
						3	3	1	1,21	1,00	**1,21**
							4	1,33	1,27	1,00	**1,69**
							2	1	1,00	1,00	**1,00**
						4	3	1,33	1,13	1,00	**1,50**
							4	1,66	1,13	1,00	**1,87**
							2	1	1,19	0,85	**1,01**
						5	3	1	1,57	0,85	**1,34**
							4	1,33	1,57	0,85	**1,78**

Table 18 – Quality indicator

2.5 Calculation of input data

The above tables[23] provide three sets of numerical values for each of the decision variables for every collection solution. These numerical values are weighted using "Share of waste by weight per container system" from *Table 13 – Summary of shares per container system.* The results of the calculations are summarised in *Table 19*. The weighted averages for each collection solution and decision variable are used as input data for the model.

Collection solution	Container System	Share of Weight	Average cap. Resid. waste	Average cap. Sorted waste	Input Quality
1	2	14 %	0,97	1,09	1,00
	3	74 %	0,60	1,50	1,26
	4	12 %	0,54	1,58	1,68
		Weighted average:	**0,64**	**1,45**	**1,27**
2	2	14 %	0,97	1,09	1,00
	3	74 %	0,79	1,29	1,49
	4	12 %	0,73	1,38	2,00
		Weighted average:	**0,81**	**1,27**	**1,48**
3	2	14 %	0,97	1,09	1,00
	3	74 %	0,74	1,38	1,21
	4	12 %	0,68	1,47	1,69
		Weighted average:	**0,76**	**1,35**	**1,24**
4	2	14 %	0,97	1,09	1,00
	3	74 %	0,93	1,17	1,50
	4	12 %	0,90	1,29	1,87
		Weighted average:	**0,93**	**1,18**	**1,47**
5	2	14 %	0,74	1,38	1,01
	3	74 %	0,57	1,63	1,34
	4	12 %	0,51	1,72	1,78
		Weighted average:	**0,58**	**1,60**	**1,35**

Table 19 – Input data for simulation model

[23] *Table 14 – Future container capacity, residual waste, Table 15 – Future container capacity, sorted waste, Table 18 – Quality indicator*

Appendix 3 – Cost calculation

Category a) Drivers that can be related directly to the collection solutions

1. "Transport, collection solutions" Uses a recognised amount in 2015 with a supplement for the annual growth factor. Adaptation of the individual collection solution involves multiplying a calculated expense per year by an annual coefficient[24] emerging from the simulation model.
2. "Transport, glass and metal" relates to the transportation of glass and metal from return points to finishers and will be terminated for parts of Oslo where glass and metal are to be included as part of the collection scheme. Transportation of glass and metal packaging is tonnage-driven. Figures per year adjusted for inflation are divided by the tonnage collected per year in order to come up with a transport expense per tonne, as projected. The projected tonnage price was then multiplied by the tonnage per year for the various collection solutions taken from the simulation model[25]. The calculated expense was then multiplied by the share by weight for the percentage of Oslo that will still be using the drop-off scheme for glass and metal.
3. "Containers" and the purchasing of these have varied throughout the period, and as a result of this the average value is used and projected up to 2031. The calculated value per year is multiplied by the volume changes taken from the work. An average of the input from the groups is used. This is then weighted in relation to the shares by weight.
4. "Containers glass and metal" and purchasing of these varies, and so an average value is used as a basis for projection. In the collection solutions that will have collection schemes for glass and metal, the purchasing of and remuneration for return points for parts of Oslo where services will be rolled out will be terminated. The projected value is multiplied by the same shares by weight as in section 2 above.
5. "Optical sorting of Plastic pack. & food waste" A need for reinvestment in a new optical sorting plant is expected during the period. The number of sorting lines needed will vary depending on the collection solution. The starting point for the calculations is REN's sorting expense in 2015, which is projected. This expense covers operating expenses for three sorting lines. The need for the number of lines guides sorting expenses for the future. The collection solutions involving collection of plastic packaging or food waste in separate containers have less need for optical sorting than the solutions where the waste is mixed in one container. The need for reinvestments will be controlled by the tonnage for sorting and the age of existing facilities. It is assumed that reinvestment will take place in 2022 or 2023. The tonnages from the simulation model[26] are extracted for the various collection solutions for this period. If the tonnage for sorting is below 50,000 tonnes, reinvestment in one line will be necessary. If the tonnage is between 50,000 and 100,000 tonnes, reinvestment will be required in two lines; and tonnage greater than 100,000 tonnes will require reinvestment in three lines.
6. "Treatment of plastic pack." involves bailing, transporting and selling plastic packaging. The average net revenue is used as a projection basis. Projected values are multiplied by the tonnage per year for the various collection solutions taken from the simulation model[27]. For collection solution 5, it is assumed that there will also be a sorting expense per tonne in order to separate

[24] This coefficient is named "Number of routes, vehicles" in the simulation model
[25] This coefficient is named "Transp to proc plant[Glass Metal]" in the simulation model
[26] Tonnage of Food, Plastic and Residual waste to Sorting plant from the simulation model.
[27] This coefficient is named "Transport to proc plant2 [Plastic]" in the simulation model

plastic packaging from paper and cardboard. This expense is estimated and projected with an annual growth factor and multiplied by the tonnage in question.

7. “Coloured bags” varies, and so an average bag price has been calculated including transport per tonne of packaged food waste and plastic packaging. The calculated bag price is projected and multiplied by the tonnage for food waste and plastic packaging per year and collection solution, taken from the simulation model[28].
8. “Communication” has varied, and so an average value is used as a basis for projection. The projected value per year is multiplied by a coefficient[29] which emerges in the simulation model per year and collection solution.
9. “Incentives” do not exist at present. Therefore, the potential extent of the expense in 2015 has been assumed. The assumption value is projected. The projected expense per year is multiplied by a coefficient[30] which emerges in the simulation model per year and collection solution.
10. “Sales paper and cardboard” uses the tonnage price in 2015 as its starting point. This is projected and multiplied by the paper tonnage per year for the various collection solutions taken from the simulation model[31]. It is assumed for collection solution 5 that there will also be a sorting expense per tonne in order to separate paper and cardboard from plastic packaging. The sorting expense per tonne is the same as that described in section 6 “Postprocessing of plastic”.
11. “Sales glass and metal” calculates a tonnage price in 2015. This is projected and multiplied by the development in total tonnage for collected glass and metal packaging per year for the various collection solutions taken from the simulation model[32]. In this case, there is no differentiation between collection schemes or drop-off schemes.

Category b) Drivers that are independent of collection solutions

1. Romerike Biogas plant is assessed to have high fixed costs regardless of how much food waste REN supplies. The tonnage price per unit may vary, but the total cost over time is expected to remain virtually constant, irrespective of the amount of food waste supplied to the plant.
2. The energy recovery plants of the Energy Recovery Agency are deemed to have high fixed costs and are kept outside the cost calculation for the same reason as indicated above.
3. Households should be segmented in our opinion, but this should be done prior to any implementation. In addition, it will probably be the same for all the collection solutions. The cost driver will not affect the collection solutions in different ways and is therefore kept outside the cost calculation.
4. Adaptation of ICT and WebDeb Emerges as a function of section 3 and other conditions that are driven to a limited extent by the differences in the collection solutions. Therefore, the cost driver is kept outside the cost calculation.
5. An increased need for administration at REN is deemed to be an equal need irrespective of the collection solution selected, and so it is kept outside the cost calculation.

[28] These coefficients are named “Transport to Sorting plant[Food]” and “Transport to Sorting plant[Plastic]” in the simulation model

[29] This coefficient is named “Communication initiative” in the simulation model

[30] This coefficient is named “Financial incentives” in the simulation model

[31] This coefficient is named “Transp to proc plant[Paper]” in the simulation model

[32] This coefficient is named “Proc plant[Glass Metal]” in the simulation model

Appendix 4 – Summary, cost-effectiveness

SUMMARY COST - EFFECTIVENESS					PERIOD 2016 - 2031
	Collection solution 1	Collection solution 2	Collection solution 3	Collection solution 4	Collection solution 5
Cost-efficiency 1 (max)	1,11	1,06	1,03	0,99	1,15
Cost-efficiency 2 (min)	5 924 044	6 228 587	6 403 587	6 662 099	5 724 390
Yearly Annuity (NOK)	295 245 026	301 657 368	310 988 747	311 749 365	291 563 360
Yearly Additional Cost (NOK)	34 478 485	40 890 826	50 222 206	50 982 823	30 796 819
Cost/revenue base 2015 (NOK)	260 766 541	260 766 541	260 766 541	260 766 541	260 766 541
Recycling rate 2031	49,84 %	48,43 %	48,56 %	46,79 %	50,93 %
Add. recycling rate 2015 til 2031	10,31 %	8,90 %	9,03 %	7,26 %	11,40 %
Recycling rate 2015	39,53 %	39,53 %	39,53 %	39,53 %	39,53 %
Drivers - yearly annuity 2016-2031					
Treatment plastic packaging	-2 133 110	-2 097 298	-1 953 840	-1 901 867	-909 679
Sales papir and cardboard	-15 672 790	-15 624 028	-15 629 214	-15 528 167	-8 579 676
Sales glass and metal	-4 374 072	-4 355 378	-4 357 582	-4 313 358	-4 383 068
Sum revenue	-22 179 972	-22 076 705	-21 940 637	-21 743 392	-13 872 423
Transport collection solutions	188 577 211	196 144 275	189 068 662	198 214 827	192 412 694
Transport glass and metal	9 704 449	9 661 002	9 666 100	3 989 574	9 725 440
Containers	6 229 861	6 435 089	6 423 133	6 420 035	6 277 263
Containers glass & metal	1 638 335	1 638 335	1 638 335	720 730	1 638 335
Optical sorting of Plastic pack & food waste	68 767 844	68 767 844	85 709 992	85 709 992	51 825 697
Colured bags	19 724 762	18 152 163	18 468 211	16 563 578	20 728 754
Communication	21 701 499	21 847 523	20 901 563	20 823 035	21 744 842
Incentives	1 081 038	1 087 842	1 053 390	1 050 985	1 082 759
Sum costs	317 424 999	323 734 072	332 929 385	333 492 757	305 435 783
Sum	295 245 026	301 657 368	310 988 747	311 749 365	291 563 360
Drivers - percentage of income and costs					
Treatment plastic packaging	9,6 %	9,5 %	8,9 %	8,7 %	6,6 %
Sales papir and cardboard	70,7 %	70,8 %	71,2 %	71,4 %	61,8 %
Sales glass and metal	19,7 %	19,7 %	19,9 %	19,8 %	31,6 %
Transport collection solutions	59,4 %	60,6 %	56,8 %	59,4 %	63,0 %
Transport glass and metal	3,1 %	3,0 %	2,9 %	1,2 %	3,2 %
Containers	2,0 %	2,0 %	1,9 %	1,9 %	2,1 %
Containers glass & metal	0,5 %	0,5 %	0,5 %	0,2 %	0,5 %
Optical sorting of Plastic pack & food waste	21,7 %	21,2 %	25,7 %	25,7 %	17,0 %
Colured bags	6,2 %	5,6 %	5,5 %	5,0 %	6,8 %
Communication	6,8 %	6,7 %	6,3 %	6,2 %	7,1 %
Incentives	0,3 %	0,3 %	0,3 %	0,3 %	0,4 %

Key figures	Explanation
Cost-efficiency 1 (max)	Cost-effeciency 1 use the relative increase in material recycling ratio (efficiency component) divided by the relative increase in costs (cost component). The most cost-effective collection scheme is the one who comes out with the highest numerical value.
Cost-efficiency 2 (min)	The cost-effeciency 2 shows how much one percentage in recycling rate costs on average per year. The most cost-effective collection scheme is the one that comes out with the lowest costs.

Table 20 – Key figures

Appendix 5 – Sensitivity analysis

The purpose of the sensitivity analysis is to examine how sensitive the collection solutions are to changes to the criteria defined. Changes in the criteria will change the input data for the simulation model. The evaluation of the collection solutions focuses on the following:

1. Is there any change in the order of ranking between the collection solutions?
2. Which collection solutions offer the best performance?
3. How do the collection solutions develop as a result of the changes made?

5.1 Multiple simultaneous changes

The sensitivity analysis begins by examining how changes to the three decision variables will affect the recycling level and cost-effectiveness. We will then examine how changes to the shares by weight linked with the 2, 3 and 4-container systems will impact on the recycling level.

5.1.1 Decision variables

The simulation results use input data as shown in Columns "Weighted average" and Basic input data" in *Table 21*. The question now asked is, "how sensitive are the recycling level and cost-effectiveness calculation of the simulation results to changes in the decision variables, given the fact that the shares by weight are fixed?". To examine this, we first have to prepare new sets of input data to provide a basis for the simulation of new recycling levels. After that, we calculate the annual net expense and annuity for the individual recycling results. The calculated recycling level and annuity are converted to cost-effectiveness calculations 1 and 2. This forms the evaluation base for this sensitivity calculation.

A weighted average and basic input data are used as a starting point when preparing new sets of input data. We then devise outcome ranges of +/- 25% and +/- 50% in relation to values used in simulation results; see *Table 21 – Outcome ranges, decision variables*.

Outcome ranges decision variables	Residual waste					Sorted waste					Quality				
	-50%	-25%	Weighted average	+25%	+50%	-50%	-25%	Weighted average	+25%	+50%	-50%	-25%	Input	+25%	+50%
Collection solution 1	0,32	0,48	0,64	0,80	0,96	0,72	1,09	1,45	1,81	2,17	0,64	0,96	1,27	1,59	1,91
Collection solution 2	0,41	0,61	0,81	1,01	1,22	0,64	0,96	1,27	1,59	1,91	0,74	1,11	1,48	1,85	2,22
Collection solution 3	0,38	0,57	0,76	0,96	1,15	0,68	1,01	1,35	1,69	2,03	0,62	0,93	1,24	1,55	1,86
Collection solution 4	0,47	0,70	0,93	1,16	1,40	0,59	0,88	1,18	1,47	1,76	0,74	1,10	1,47	1,84	2,21
Collection solution 5	0,29	0,44	0,58	0,73	0,88	0,80	1,20	1,60	2,01	2,41	0,67	1,01	1,35	1,68	2,02

Table 21 – Outcome ranges, decision variables

To establish a consistent set of input data, the outcome ranges are compiled into four combinations for each collection solution; combinations 1, 2, 3 and 4. The purpose of combinations 1 and 2 in relation to the simulation results is to increase the recycling level of the collection solutions. The purpose of combinations 3 and 4 is to reduce the recycling level.

Combinations 1 and 2 use a reduction of - 50% and - 25% in the decision variable for residual waste in relation to the weighted average, and an increase of + 50% and + 25% in the decision variables for sorted waste types and quality. For example, combination 1 for collection solution 1 will be a reduction of - 50% in the decision variable for residual waste and an increase of + 50% in the decision variables for sorted waste types and quality. This constitutes input data 0.32 for residual waste, 2.17 for sorted waste and 1.91 for quality; see *Table 21*.

Combinations 3 and 4 are the least favourable combinations in terms of recycling level and involve an increase of + 25% and + 50% respectively in the decision variable residual waste. The decision variables sorted waste types and quality are reduced accordingly by - 25% and - 50%. Here, combination 4 for collection solution 1 will be an increase of + 50% in the decision variable residual waste and a reduction of - 50% in the decision variables sorted waste types and quality. The input data is 0.96 for residual waste, 0.72 for sorted waste types and 0.64 for quality.

The results from the simulations are summarised in *Figure 9* and show how changes to the decision variables affect the recycling level.

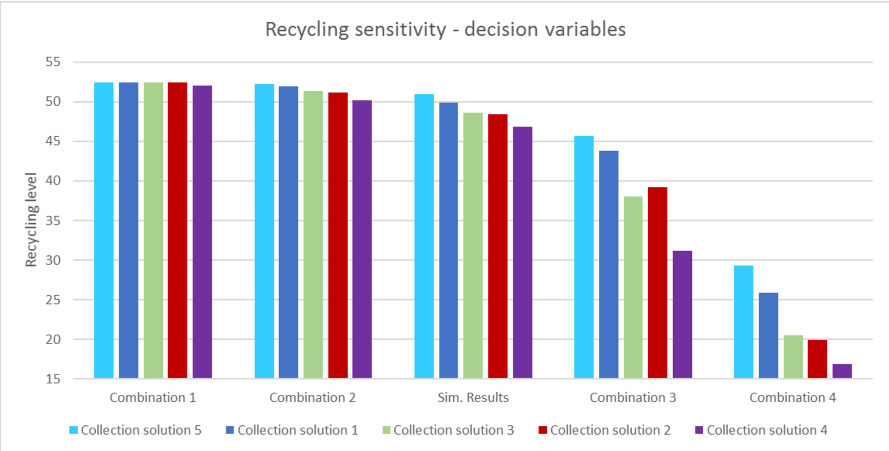

Figure 9 – Recycling sensitivity, simultaneous changing of 3 decision variables

These simulations provide an insight into three conditions. Firstly, the order of ranking of the collection solutions is maintained throughout the entire outcome range. The order of ranking is primarily insensitive to changes in the decision variables when all of them are changed simultaneously. Collection solutions 2 and 3 are the exception to this, but for these the difference is so small that they should be regarded as equivalent.

Secondly, collection solution 5 has already exceeded 50% recycling in the simulation results, while collection solution 1 requires only small improvements. Alternative action 4, on the other hand, which has the poorest ranking, requires 50% improvement in all decision variables in order to reach the same level.

Thirdly, combinations 1 and 2 give an increase in recycling level that is less than the reduction in combinations 3 and 4. When the decision variables are improved beyond the simulation results, the sorted waste types will reach their values to the extent to which waste can be sorted. The recycling level is levelled out quickly as a result of this. The model has no corresponding values built in for unfavourable outcomes, and hence the “downside” is greater than the “upside” when input data leaps of up to +/- 50% are used. The recycling level has an increasingly diminishing form as a result of this, which gradually makes it more difficult to increase the recycling level. Starting from a recycling level of approx. 40%, going from combination 3 to the simulation results will bring about an “improvement” of approx. 25% in the decision variables, contributing approx. 7 – 9% recycling. A further “improvement” of approx. 25% in the decision variables (from the simulation results to combination 2) will only help to increase recycling by approx. 1-2%.

The recycling results from *Figure 9* can be used to estimate the costs and cost-effectiveness calculations 1 and 2 can be performed; see *Table 22*.

Collection Solution	Data Combination	NPV	Yearly Annuity	Recycling rate	Relativ incr. in Costs	Relativ incr. in Recycl. rate	Cost-eff.1	Cost-eff.2
1	Combination 1	3 746 223 263	308 202 758	52,4 %	1,18	1,33	1,12	5 880 725
	Combination 2	3 726 736 595	306 599 584	51,9 %	1,18	1,31	1,12	5 905 222
	Sim. Result	3 588 721 253	295 245 026	49,8 %	1,13	1,26	1,11	5 924 044
	Combination 3	3 113 973 778	256 187 429	43,8 %	0,98	1,11	1,13	5 842 960
	Combination 4	2 792 602 626	229 748 141	25,9 %	0,88	0,65	0,74	8 877 896
2	Combination 1	3 779 121 475	310 909 302	52,4 %	1,19	1,32	1,11	5 936 754
	Combination 2	3 788 263 506	311 661 419	51,2 %	1,20	1,29	1,08	6 089 348
	Sim. Result	3 666 663 652	301 657 368	48,4 %	1,16	1,23	1,06	6 228 587
	Combination 3	3 579 531 702	294 489 000	39,2 %	1,13	0,99	0,88	7 512 271
	Combination 4	3 251 232 302	267 479 723	19,9 %	1,03	0,50	0,49	13 445 082
3	Combination 1	3 963 123 557	326 047 201	52,4 %	1,25	1,33	1,06	6 223 917
	Combination 2	3 938 946 212	324 058 124	51,4 %	1,24	1,30	1,05	6 307 917
	Sim. Result	3 780 087 140	310 988 747	48,6 %	1,19	1,23	1,03	6 403 587
	Combination 3	3 471 215 349	285 577 785	38,0 %	1,10	0,96	0,88	7 517 937
	Combination 4	3 177 687 168	261 429 146	20,5 %	1,00	0,52	0,52	12 732 377
4	Combination 1	3 915 581 945	322 135 940	52,0 %	1,24	1,32	1,07	6 192 586
	Combination 2	3 915 673 879	322 143 504	50,1 %	1,24	1,27	1,03	6 424 980
	Sim. Result	3 789 332 488	311 749 365	46,8 %	1,20	1,18	0,99	6 662 099
	Combination 3	3 541 772 972	291 382 579	31,2 %	1,12	0,79	0,71	9 347 306
	Combination 4	3 237 540 858	266 353 324	16,9 %	1,02	0,43	0,42	15 789 513
5	Combination 1	3 651 929 298	300 445 169	52,4 %	1,15	1,33	1,15	5 731 221
	Combination 2	3 647 058 437	300 044 442	52,2 %	1,15	1,32	1,15	5 744 038
	Sim. Result	3 543 970 374	291 563 360	50,9 %	1,12	1,29	1,15	5 724 390
	Combination 3	3 240 973 201	266 635 704	45,6 %	1,02	1,15	1,13	5 843 727
	Combination 4	2 837 268 659	233 422 827	29,3 %	0,90	0,74	0,83	7 968 574

Table 22 – Sensitivity analysis results, cost-effectiveness 1 and 2

Table 22 shows correlation between developments in recycling levels and costs. If the recycling level increases, costs increase; and vice versa. For the cost-effectiveness calculations, the main pattern is for combinations 1 and 2 to maintain or increase cost-effectiveness and combinations 3 and 4 reduce this, compared with the simulation results. Accommodation 3 in collection solution 1 is an exception to this; cost-effectiveness increases compared with the simulation results despite the fact that both recycling and costs are reduced. This is explained by the fact that the recycling level increases by more than the reduction of the costs.

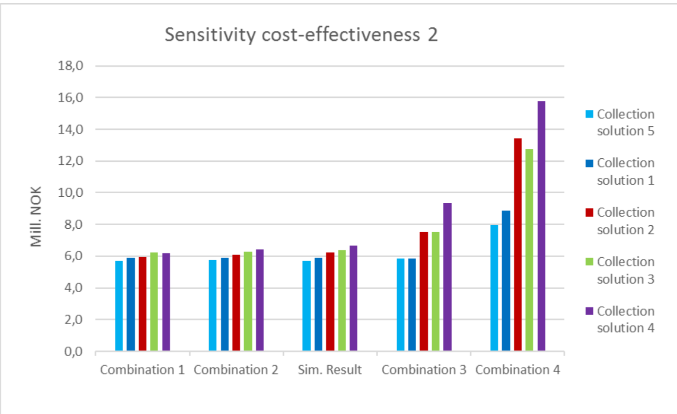

Figure 10 – Sensitivity, cost-effectiveness 2; changes to 3 decision variables

The conclusion in relation to the initial question is that the order of ranking from the simulation results is maintained. Collection solutions 5 and 1 are ranked highest in all outcome ranges and vary least when changes are made to the criteria.

5.1.2 Container system shares by weight

The simulation results are based on distribution of household waste by 14% of the share by weight to collection points with 2-container systems, 74% of the share by weight to collection points with 3-container systems, and 12% of the share by weight collection points with 4-container systems. The question asked is "how sensitive is the recycling level for the simulation results as regards changes in the shares by weight?". An outcome range for changes as shown in *Table 23* has been devised in order to examine this.

	Container system		
Outcome range	**2 containers**	**3 containers**	**4 containers**
Outcome range 1	12 %	37 %	51 %
Ourcome range 2	0 %	92 %	8 %
Sim. Result	14 %	74 %	12 %
Outcome range 3	8 %	92 %	0 %
Outcome range 4	51 %	37 %	12 %

Tabel 23 – Changes, shares by weight

The individual outcome range generates a new set of input data for the three decision variables for the individual collection solutions. The results from these simulations are summarised in *Figure 11*.

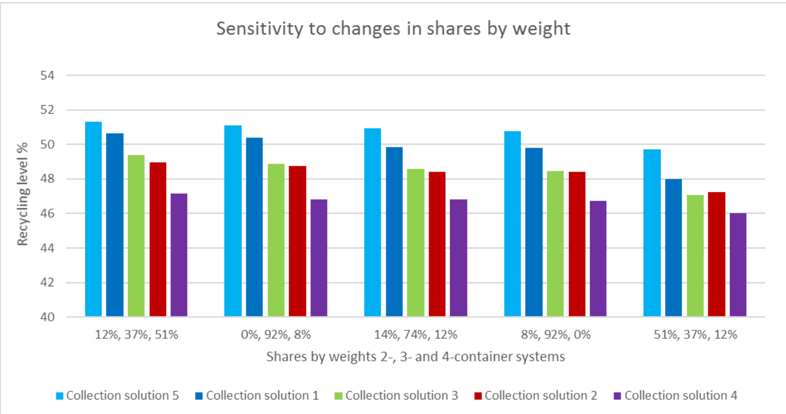

Figure 11 – Sensitivity to changes in shares by weight

The conclusion in relation to the initial question is that the order of ranking from the simulation results is mainly maintained. Collection solutions 3 and 2 are to be regarded as equivalent.

Collection solutions 5 and 1 are ranked highest in all outcome ranges, with the highest recycling levels.

Collection solutions 5, 2 and 4 are more robust in respect of changes to shares by weight. Collection solutions 1 and 3 are affected most by the changes and will experience the greatest impact if 3 and 4-container systems are not rolled out.

The sensitivity of the recycling results in the case of modified shares by weight lies within the results from the consideration of sensitivity linked with the change in the decision variables. It is assumed that this also relates to the costs linked with the collection solutions. Therefore, no separate cost-effectiveness calculation will be prepared for this sensitivity assessment. Please see *Table 22 –*

Sensitivity analysis results, cost-effectiveness 1 and 2 for interpolation[33] of costs and cost-effectiveness in relation to collection solutions and recycling levels.

5.2 One change – the others fixed

The decision variables are dependent on one another to a certain extent. For example, there is not much opportunity to reduce residual waste capacity without increasing the capacity of sorted waste types. However, examining whether changing a decision variable will affect the order of ranking of the collection solutions and potentially identify the sensitivity to such a variable is of interest. The question now asked is, "how sensitive is the recycling level of the simulation results to changes in a decision variable when shares by weight and the other two decision variables are maintained?". In this context, "maintain" means that the decision variables assume the values used in the simulation results. It is important to note that the various collection solutions have different input data for the values to be maintained.

Cost-effectiveness calculations of the sensitivity results are omitted as a consequence of the dependency between the decision variables.

Table 21 – Outcome ranges, decision variables and the four different combinations described in Appendix 5.1.1 are used as a basis. Like Appendix 5.1.1, The purpose of combinations 1 and 2 is to increase the recycling level, while the purpose of combinations 3 and 4 is to reduce the recycling level compared with the simulation results.

5.2.1 Residual waste capacity

The following data from *Table 21 – Outcome ranges, decision variables* is used as an example of input data for combination 1, collection solution 1 for residual waste capacity; residual waste 0.32, sorted waste 1.45 and quality 1.27. The figures for sorted waste and quality are maintained. For residual waste, the figures are changed in accordance with the outcome ranges in *Table 21*. The results from these simulations are summarised in Figure 12.

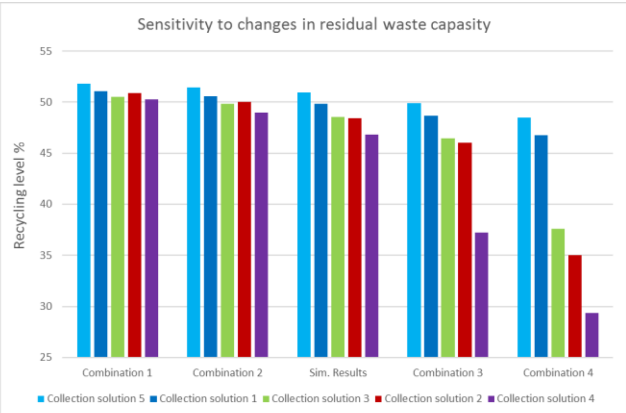

Figure 12 – Sensitivity to changes in residual waste capacity

The conclusion in relation to the initial question is that the order of ranking from the simulation results is maintained.

[33]Estimation of a value between known values

Collection solutions 5 and 1 are ranked highest in all outcome ranges and vary least when changes are made to the residual waste capacity.

If the residual waste capacity increases beyond the simulation result (combinations 3 and 4), this will have a significant adverse impact on the recycling levels for collections solutions 3, 2 and 4.

5.2.2 Capacity, sorted waste

The same principle as that described above is continued. The following data from *Table 21 – Outcome ranges, decision variables* is used as an example of input data for combination 2, collection solution 1 for sorted waste capacity; sorted waste 1.81, residual waste 0.64 and quality 1.27. The figures for residual waste and quality are maintained. For sorted waste, the figures are changed in accordance with the outcome ranges in *Table 21*. The results from these simulations are summarised in Figure 13.

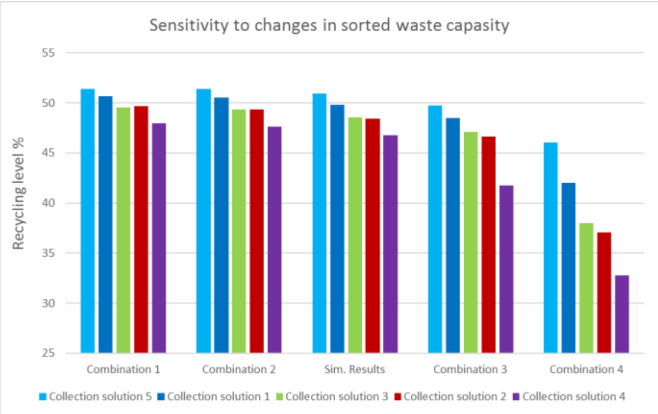

Figure 13 – Sensitivity to changes in sorted waste types

The conclusion in relation to the initial question is that the order of ranking from the simulation results is maintained.

Collection solutions 5 and 1 are ranked highest in all outcome ranges and vary least when changes are made to the container capacity for sorted waste.

A significant reduction in container capacity would have an adverse impact on recycling levels for all collection solutions.

5.2.3 Quality indicator

The same principle as that described above is also continued here. The following data from *Table 21 – Outcome ranges, decision variables* is used as an example of input data for combination 3, collection solution 1 for the quality indicator; quality 0.96, residual waste 0.64 and sorted 1.45. The figures for residual waste and sorted are maintained. For quality, the figures are changed in accordance with the outcome ranges in *Table 21*. The results from these simulations are summarised in Figure 14.

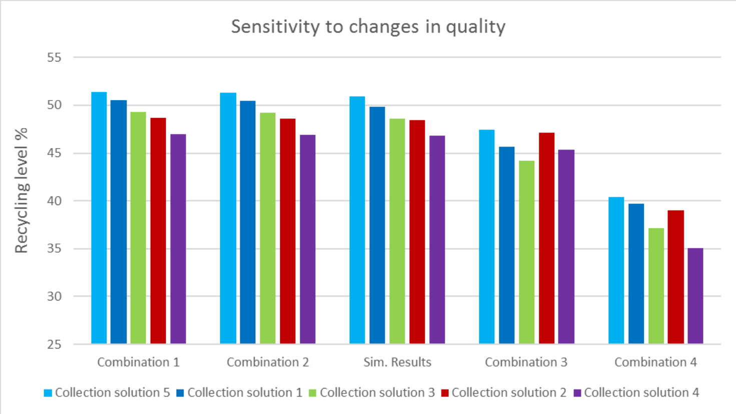

Figure 14 – Sensitivity to changes in waste quality

The conclusion in relation to the initial question is that the order of ranking from the simulation results is maintained for development that enhances the quality beyond the simulation results. The rankings for collection solutions 3, 2 and 4 are changed for quality poorer than the simulation results. These are therefore regarded as being more sensitive to such development than the other two collection solutions.

Collection solutions 5 and 1 are ranked highest in all outcome ranges, with the exception of combination 3. Collection solution 2 fares better than collection solution 1 here.

Collection solution 2 varies least in terms of changes in quality. Collection solutions 3 and 4 vary most.

Collection solutions 5 and 1 also offer the best performance here. If it were necessary to define a priority between collection solutions 2 and 3, solution 2 would be selected due to having the least variation and the fact that it exceeds collection solution 1 in one combination. Collection solution 4 fares worst.

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