WASTECOSMART

# WASTECOSMART

**"Optimisation of Integrated Solid Waste Management Strategies for the Maximisation of Resource Efficiency"**

# Report
# Workshops Amsterdam

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# 1. Workshops Amsterdam

## 1.1. Introduction

The city of Amsterdam is participating in the EU project Wastecosmart which has the aim to "strengthen and increase the innovation capacity of regional research-driven clusters in resource efficiency through cooperation, research and technological development within the waste sector" (Wastecosmart, 2013). For this project, six research-driven clusters in six European countries (Cyprus, Hungary, Italy, Netherlands, Sweden and the UK) have been formed (Wastecosmart, 2013).

One of the aims of this project is to develop a decision support framework that can be used to show preferences among several possible management options that aim to increase recycling and to help reaching a decision on which one to choose. Multicriteria Analysis (MCA) was chosen as the appropriate instrument as it can be used to structure and determine preferences among alternative management options when multiple objectives and a number of stakeholders are involved. In combination with all partners from the EU project, the main objectives and a long-list of criteria have been developed. The list has been revised several times to take the input from all parties into account. The partners who want to carry out an analysis can now choose the criteria from the long-list of criteria which are applicable for their specific case.

Figure 1: The waste to energy plant in Amsterdam

The cluster from Amsterdam, consisting of members from the City of Amsterdam, the Amsterdam Economic Board, AEB Amsterdam and the Institute for Environmental Studies has set the goal to achieve a recycling quota of MSW of 65% until 2020. In order to achieve this, new strategies and

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management options need to be considered to find the best possible option for the city of Amsterdam. Four strategies have been developed that will allow to reach this goal. In order to select the most appropriate strategy, the approach of an MCA will be used to serve as a basis for the decision-makers. The decision-makers of this project are the members of the project. The decision needs furthermore to be approved by the city of Amsterdam.

Amsterdam has around 790,000 inhabitants and around 400,000 households. Approximately 398 kg MSW is produced annually and the current recycling quota is around 18% (Hultermans, 2014a). The remaining waste is incinerated in a large waste to energy plant.

So far the city has not been able to set off an increase in the recycling quota in an efficient way. For the new system, several factors need to be taken into account. First of all, all stakeholders need to be brought together and agree on the new system. Furthermore, the amount of waste recycled and the participation and acceptance from citizens has to be maximised.

#### 1.1.1. Workshop

For the Amsterdam case study two workshops were organized. The first workshop in February provided a tentative evaluation framework that served as input for the Framing workshop in Turin. The results of the Framing workshop and feedback from all partners were used in the second workshop in June 2014 (Figure 2). The June workshop is comparable with the workshops in Liverpool and Stockholm.

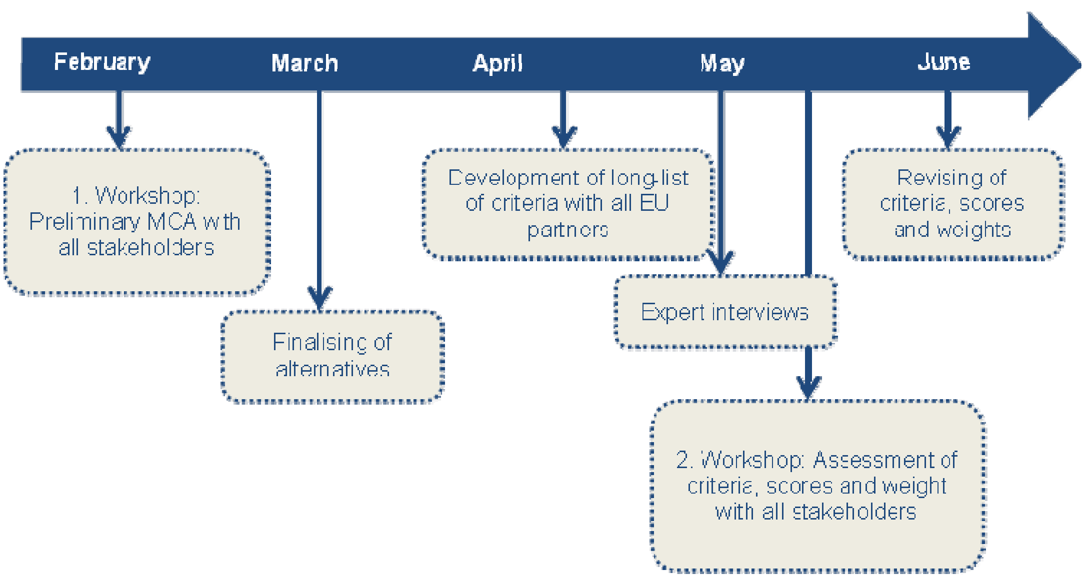


Figure 2: The Amsterdam workshops process..

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The first Amsterdam workshop was on February 18 2014 at the VU University of Amsterdam. The particpants of this workshop are listed below. Figure 3 shows the participants of the first workshop at work.

*Particpants in the first Amsterdam workshop.*

| | |
|---|---|
| Sietse Agema | Waste to Energy Company Amsterdam |
| Jos de Bruijn | Spatial planning departement Amsterdam |
| Riny de Jonge | Waste collection department Amsterdam Oost |
| Janneke Hoedemaekers | Amsterdam Economic Board |
| Rolph Hultermans | Haskoning waste and energy |
| Henk Groenendaal | Waste collection department City of Amsterdam |
| Frits Steenhuisen | CREM Coördinator Business Unit Waste management |
| Hanneke van Rhee | Spatial planning Department Amsterdam |
| Ron Janssen | VU University Amsterdam |

Figure 3: Participants of the first Amsterdam workshop at work.

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The second Amsterdam workshop was on February 18 2014 at the VU University of Amsterdam. The particpants of this workshop are listed below.

*Table 2 Particpants in the secondAmsterdam workshop.*

| | |
|---|---|
| Sietse Agema | Waste to Energy Company Amsterdam |
| Jos de Bruijn | Spatial planning departement Amsterdam |
| Riny de Jonge | Waste collection department Amsterdam Oost |
| Janneke Hoedemaekers | Amsterdam Economic Board |
| Rolph Hultermans | Haskoning waste and energy |
| Henk Groenendaal | Waste collection department City of Amsterdam |
| Frits Steenhuisen | CREM Coördinator Business Unit Wastemanagement |
| Maarten Bakker | Technical University Delft |
| Esther Bout | Waste collection department Amsterdam Zuid Oost |
| Michiel van Drunen | Amsterdam University College |
| Laetitia Müller | VU University AMsterdam |
| Ron Janssen | VU University Amsterdam |

## 1.2. Problem definition

In the following sections, the preparations for the actual MCA are described. This involves the determination of the alternatives to be considered, determining and defining the objectives and the respective criteria, and assessing the scores for each alternative to finally create an effects table.

### 1.2.1. Determination of alternatives

The four alternatives have been developed in four workshops by waste management experts from Amsterdam. All four alternatives take into account the waste streams glass, paper/cardboard, plastic, organic waste and textile. All other smaller waste streams fall under the residual waste stream. It was decided to look at mono-stream and multi-stream systems. Furthermore, it will be looked at if these two can be combined with post-separation of plastic.

The following figure 4 shows the four alternatives in a matrix where you can see how they are related to each other. Alternatives 1&3 are similar in a sense that they both have a focus on the collection of only mono-streams. Alternatives 2&4 are based on the collection of multi-streams. Alternatives 1&2 make use of source-separation of plastic whereas alternatives 3&4 make use of post-separation of plastic at the waste treatment facility. In the following sections, each alternative will be described individually.

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| | Mono-stream | Multi-stream |
|---|---|---|
| **Source-separation of plastic** | Alternative 1 | Alternative 2 |
| **Post-separation of plastic** | Alternative 3 | Alternative 4 |

**Figure 4:** Matrix of alternatives.

The choice of the alternatives has thereby been dependent on a few factors. First of all, the source-separation of organic waste plays a crucial role in the whole project as the share of organic waste in Dutch household waste is higher than 40%. Therefore, in order to reach the 65% recycling target, the collection of organic waste at source is very important (Hultermans, 2014b).

Secondly, the response and compliance from citizens with regard to recycling needs to be taken into account. It was estimated that a collection response by citizens, who separate their waste at source, of 80% is necessary in order to reach the 65% recycling target until 2020. However, this is an unrealistic estimation as Amsterdam has a current response of around 20%. It is very unlikely that the collection response will fourfold in this short period of time (Hultermans, 2014b). Therefore, a 50% response was chosen for this MCA which is still a very ambitious target for this short period of time.

The last factor is the density of containers that are placed. This is an important factor, especially for the calculation of costs, as there can be big variations between the alternatives when taking into account a high or low container density. The choice of the container density for each alternative was based on the exclusion criterion that the total costs of implementing the new system cannot be higher than those for the current system. The options with costs that are higher than for the current system were determined as not feasible. For alternatives 1&3 the high and the low container density was feasible. Therefore, the high density was chosen as this has benefits, e.g. shorter walking distances for citizens. For the alternatives 2&4 only the low density of containers was feasible and was therefore chosen for this analysis (Hultermans, 2014b).

The following two figures show a possible configuration of containers for the chosen alternatives. Depending on where the containers are placed, differences can occur especially regarding the walking distance for citizens. Figure 5 shows how the configuration for alternative 1 could look like. The blue boxes present apartment blocks in the city, the small coloured boxes and circles show the different kinds of containers and where they will be placed. For alternative 1, containers for residual and organic waste would be placed as closely as possible to the households. The numbers for all other containers are less than for residual and organic and therefore need to be placed centrally so that the walking distances are kept as low as possible. The configuration for the mono-stream with post-separation (alternative 3) would almost look the same, except that the red containers for plastic would be deleted as it will be collected together with the residual waste stream.

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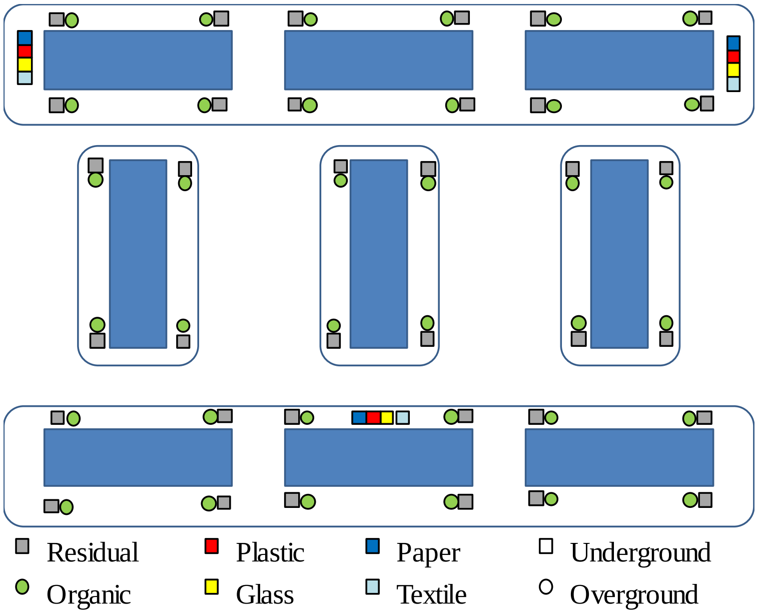


**Figure 5:** Configuration of containers for the mono-stream alternatives with a high container density (adapted from Hultermans, 2014a).

Figure 6 shows the configuration for the multi-stream alternative 2 with a low density of containers. The containers for residual waste and multi-streams are placed closely to the households but due to the low container density, the walking distance is higher than for the mono-streams. Alternative 4 would look exactly the same except that plastic would not be collected in the multi-stream containers but in the residual containers.

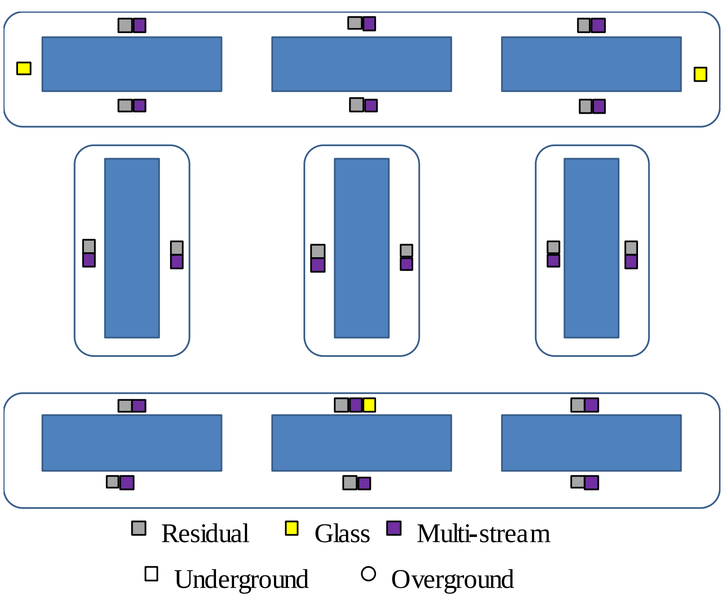


**Figure 6:** Configuration of containers for the multi-stream alternatives with a low container density (adapted from Hultermans, 2014a).

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### Source-separation in mono-streams

The first alternative (figure 7) is based on the collection of only mono-streams. All waste streams will be collected individually and containers will be provided for each waste stream. For most waste streams underground containers will be provided. Only for organic waste overground containers will be used as they can be put closer to the households to encourage people to separate their organic waste which is important for increasing the overall recycling quota. Furthermore, this is a cheaper alternative to the underground containers (Hultermans, 2014a). This alternative is the most similar one to the current situation except for the treatment of organic waste which is currently collected together with the residual waste stream.

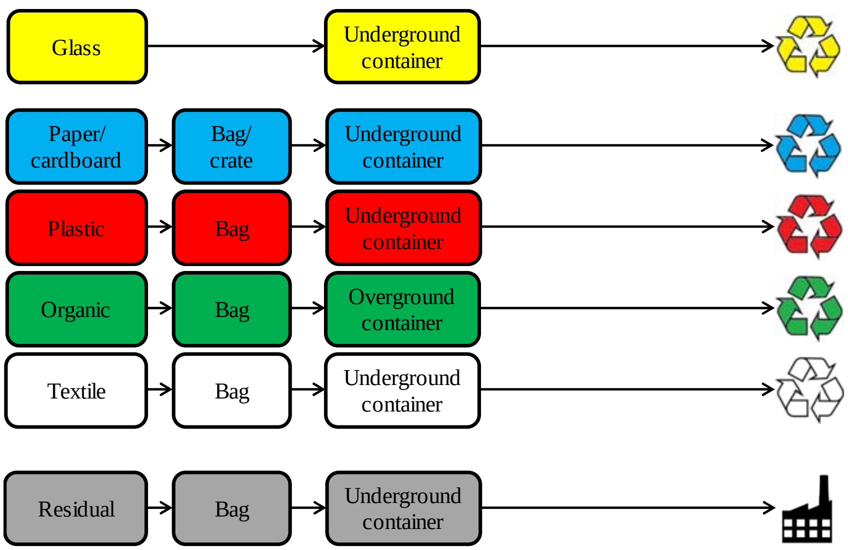


**Figure 7:** Source-separation in mono-streams (adapted from Hultermans, 2014a).

### Source-separation with mono- and multi-streams

The second alternative (figure 8) is based on a collection of mono- and multi-streams. All waste streams will be collected individually in bags. Three different kinds of underground containers will be provided. The first one is for glass only as the collection of glass with other waste streams is problematic. The second container will be a multi-stream underground container for the waste streams paper/cardboard, plastic, organic waste and textile. The waste streams are thereby collected as material streams. The third underground container is for residual waste only. After collection, the multi-streams will be sorted at the waste treatment facility so that each waste stream can then be processed individually.

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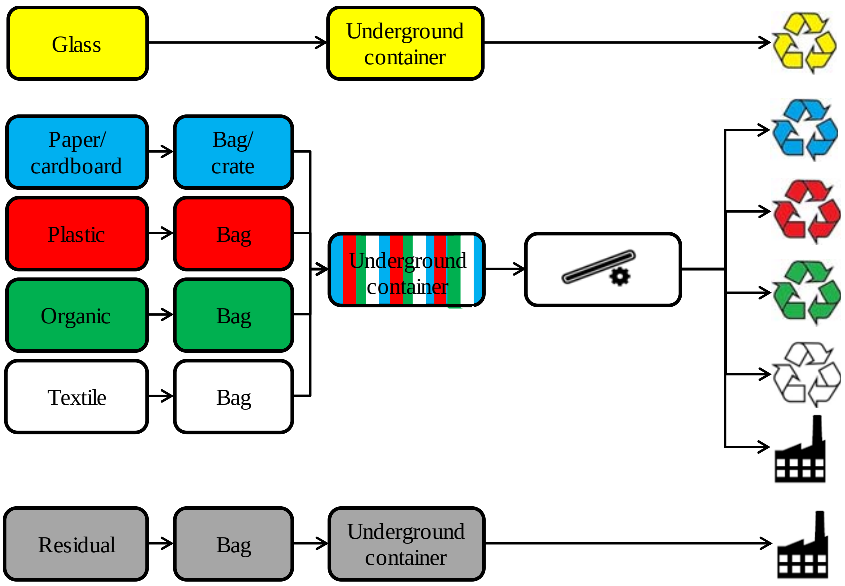


**Figure 8:** Source-separation with mono- and multi-streams (adapted from Hultermans, 2014a).

**Source-separation in mono-streams, post-separation of plastic**

The third alternative (figure 9) is similar to the first alternative with a high density of containers. The waste streams are collected in mono-streams in underground containers and an overground container for organic waste. The only difference to alternative 1 is that plastic and residual waste will be collected together as a volume stream and will later be separated through post-separation at the waste treatment facility.

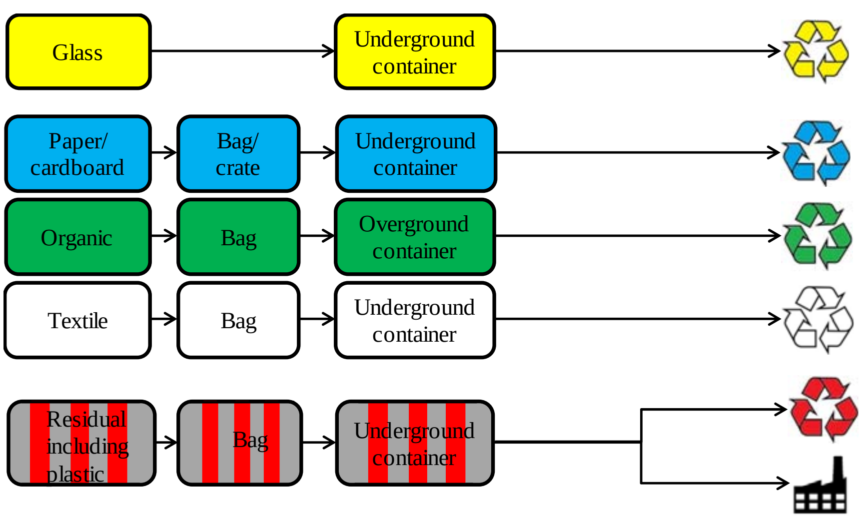


**Figure 9:** Source-separation in mono-streams, post-separation of plastic (adapted from Hultermans, 2014a).

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**Source-separation with mono- and multi-streams, post-separation of plastic**

The fourth alternative (figure 10) is similar to the second alternative as both are based on the collection of multi-streams. The difference is that in alternative 4, plastic will be collected together with the residual waste stream. Glass will be collected as a mono-stream in an underground container. Paper/cardboard, organic waste and textile will be collected as multi-streams in another underground container. At the waste treatment facility, these bags will be sorted and processed individually according to the respective waste stream. Residual waste and plastic will be collected together as a volume stream in an underground container and will be separated through post-separation at the waste treatment facility.

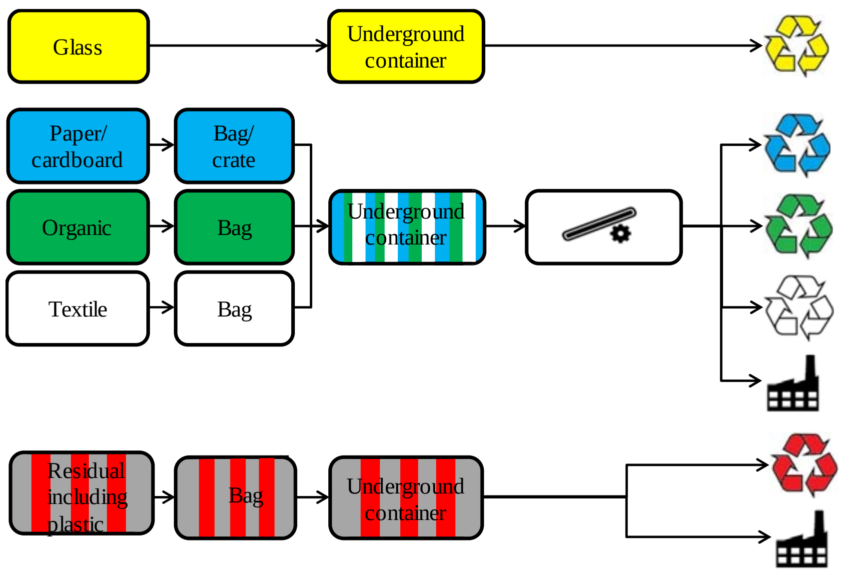


**Figure 10:** Source-separation with mono- and multi-streams, post-separation of plastic (adapted from Hultermans, 2014a).

### 1.2.2. Objectives and criteria

The following section deals with the main objectives and those criteria that have been chosen from the long-list of criteria (see annex E) that has been developed by the *Wastecosmart* partners. This list of criteria has been developed between the first and second workshop in Amsterdam. During the second workshop, this long-list was discussed with the stakeholders in order to see which criteria need general changes and which ones are applicable for the case in Amsterdam. Some criteria had to be left out for Amsterdam. E.g. the criterion 'minimise land use' was chosen to be left out as it refers to landfilling which is not even considered an option for Amsterdam as the lowest step in the waste hierarchy considered is the recovery of energy. The long-list of criteria for all EU partners was revised and finalised after the second workshop.

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The following value tree (figure 11) shows the graphical presentation of the multiple objectives of the project. In this top-down approach the overall objective is to maximise the overall waste management performance. Each objective is supported by a number of criteria. In the subsequent sections, the objectives with its criteria will be described in detail. The scores for all criteria can be found in the effects table (see figure 12).

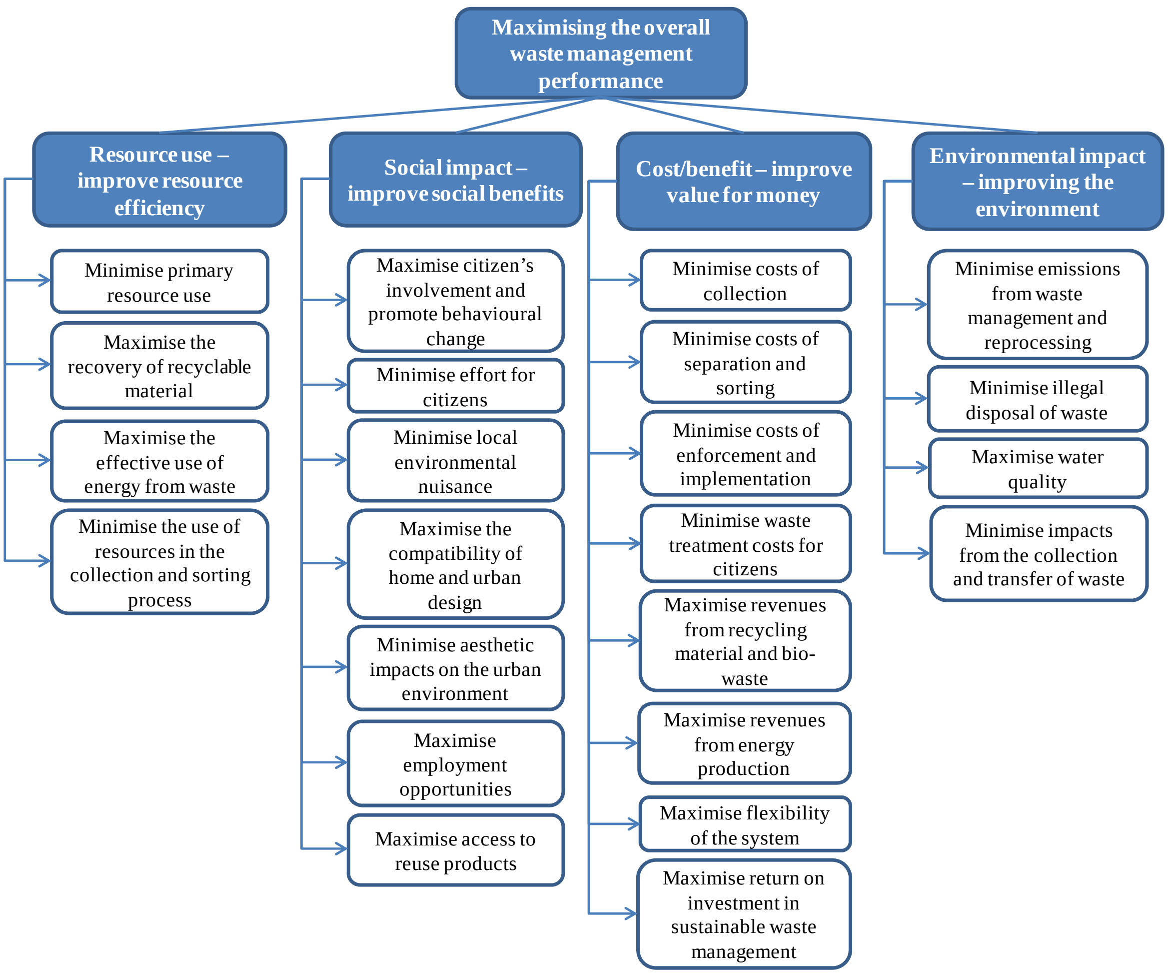


**Figure 11:** Value tree.

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**Objective: Resource use – improve resource efficiency**

The use of resources plays an important role in maximising the overall waste management performance. Following, all criteria from this objective are presented.

**Minimize primary resource use:** The primary resource use refers to all the primary materials and resources that are needed for the management and treatment of MSW. The resources needed for the collection process are not included into this criterion as they are already part of the criterion 'Minimize use of resources in the collection and sorting process'.

The two multi-stream alternatives score better than the mono-streams. This is due to the fact that the collection response by citizens will be higher for the multi system which in turn increases the shares of recyclable material and therefore reduces the primary resource use (Bakker, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| System is too complex, collection response by citizens decreases and leads to little shares of recyclable material; primary resource use is increasing. | Collection response by citizens stays the same; shares of recyclable material therefore do not increase; primary resource use is also staying as it is. | New system is working and the collection response by citizens increases slowly; hence shares of recyclable material will increase over time, primary resource use decreases. | System is working very well; a high collection response by citizens is leading to high shares of recyclable material and hence reduces primary resource use. |

**Table 1:** Scoring legend for the primary resource use.

**Maximize recovery of recyclable material:** The recovery of recyclable material depends on the volumes and quality of the different materials that arrive at the waste treatment facility.

Alternative 1 was allocated a zero and therefore has the lowest score from all alternatives because it requires high efforts and a high compliance from citizens as all waste streams need to be separated at source. When looking at the current collection response of around 20%, chances are high that people will mix the different waste streams and hence reduce the quality of recyclable material. Alternative 3 scores slightly better with one plus as the post-separation of plastic will be done more efficiently at the waste treatment facility than if people do it at home. The multi-streams generally score better as the shares will be higher due to an easier system of waste collection with only glass, residual and one multi-stream container. Alternative 4 scores even better than alternative 2 due to an efficient post-separation of plastic at the waste treatment facility (Bakker, 2014).

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| 0 | + | ++ | +++ |
|---|---|---|---|
| High efforts and compliance from citizens are needed; collection response does not increase; waste streams are barely separated and intermingled with each other. | High efforts and compliance from citizens are needed; collection response does not increase; waste streams are barely separated and intermingled with each other; post-separation of plastic increases overall shares and quality of recyclable material. | System is easy to understand and efforts reduced; people comply willingly and separate their waste streams; collection response increases; quality can be reduced due to unintended intermingled waste. | System is easy to understand and efforts kept to a minimum; people comply willingly and separate their waste streams; collection response increases; overall shares and quality are high due to post-separation of plastic. |

**Table 2:** Scoring legend for the recovery of recyclable material.

**Maximize the effective use of energy from waste:** This criterion refers to the output of energy from the treatment of waste. For all alternatives some residues will occur that cannot be recycled and therefore have to be treated thermally (Manders, 2013).

The differences between the alternatives are so marginal that all alternatives score the same. All of them have a high use of energy from waste and therefore were allocated two pluses (Bakker, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| Shares of energy production are very low due to very high shares and good quality of recyclable material; few residues are left over to be used for energy production. | Share of recyclable materials are high; there are still enough residues for a sufficient energy production. | Shares of recyclable materials are relatively low; there are enough residues left for an efficient energy production. | Low shares of materials are recyclable which increases energy production to a maximum; many residues are left. |

**Table 3:** Scoring legend for the effective use of energy from waste.

**Minimize use of resources in the collection and sorting process:** The use of resources in the collection and sorting process refers mainly to the resources used due to the numbers of containers placed and the number of trucks needed to collect the waste and bring it to the waste treatment facility. The number of containers is correlated with the number of trucks needed to pick up the waste from the containers and bring it to the waste treatment facility. Therefore, the number of containers used for the collection of MSW was chosen.

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The differences between the alternatives are very big due to the high container density chosen for alternatives 1&3 and the low density for containers 2&4.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Number of containers used for the collection of MSW | 25,731 | 8,692 | 24,941 | 8,692 |

**Table 4:** Use of resources in the collection and sorting process (Hultermans, 2014a).

**Objective: Social impact – improve social benefits**

The criteria from the social objective look at the different strategies mainly from the citizen's point of view. Taking their situation and needs into account is crucial in order to make the system work. The best system cannot work if the citizens are not confident with it and therefore do not comply as intended. Therefore, it has to be tried to limit negative impacts on the citizens as much as possible.

**Maximize citizen's involvement and promote behavioural change:** This criterion refers to the way citizens are encouraged in taking interest into the new system and how they are responding to it. Most important in order to maximise the involvement is to provide the citizens with information to increase understanding and motivation which in turn influences and increases the compliance of citizens.

The multi-streams score slightly better for this criterion than the mono-streams because the involvement of citizens is reduced due to the fact that all waste streams which are collected and separated at home can be thrown into the same container. This makes is easier for the people to comply as intended as there is no chance to throw it into the wrong container (Steenhuisen, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| System is very complicated and too complex for citizens to understand; citizens are not informed at all; they do not comply. | System is complicated; citizens do not agree with it or do not fully understand the benefits; they comply only partly. | System is complex but can be understood; citizens are well-informed and usually support it. | System is easily understood; citizens are well-informed; citizens strongly support it. |

**Table 5:** Scoring legend for citizen's involvement and promoting behavioural change.

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**Minimize effort for citizens to participate in waste prevention, reuse and recycling activities:** The effort that citizens have to take plays an important role, too. If the citizens perceive the effort as too high they are not likely to comply with the new system as intended. Apart from the in-house space which is part of a different criterion, the walking distance is a good indicator to show how high the efforts are. Bringing the waste out to the container is an effort that people do not like to take and therefore want to get over with as quickly as possible. The shorter the walking distance, the likelier it is that people will actually bring their waste to the correct container.

The mono-streams score slightly better than the multi-streams. This is mainly due to the choice of the container density. For the mono-stream alternatives a high density was chosen which reduces the average walking distance to the containers.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Walking distance in metres | 81 | 85 | 75 | 85 |

**Table 6:** Effort for citizens to participate in waste prevention, reuse and recycling activities (Hultermans, 2014a).

**Minimize local environmental nuisance**: The collection and treatment of waste is always connected with disturbance of citizens through environmental nuisance. This nuisance can arise in form of noise, odour, pests, dust and litter. The impact of the nuisance on the environment has to be limited because otherwise complaints will arise which will in turn discourage people to comply to the system.

Alternative 2 reaches the best score of three pluses because barely any disturbance occurs from that collection system. Alternative 4 scores slightly less with only two pluses due to higher nuisance that can occur due to the post-separation of plastic. The mono-stream alternatives 1&3 score only one plus as regular disturbance can occur which is mainly due to the placement of overground containers for organic waste close to the households (Steenhuisen, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| Strong and constant disturbance. | Regular disturbance due to noise, odour, pests, litter. | Weak disturbance every now and then, e.g. resulting from bad weather conditions. | Barely any disturbance at all. |

**Table 7:** Scoring legend for local environmental nuisance.

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**Maximize the compatibility of home and urban design with waste prevention, reuse and recycling activities:** This criterion is related to the in-house space that has to be provided by citizens in order to be able to separate all the waste streams as intended. It is important to notice that the in-house space in an average apartment in Amsterdam is only between 70-80 $m^2$. Compared to the average in-house space that can be found in the rest of the Netherlands, apartments in Amsterdam are 35% smaller than elsewhere (Hultermans, 2014a). Therefore, the number of collection devices needed in order to separate MSW as intended plays an important role. The more collection devices needed, the higher the inconvenience for citizens.

For this criterion, alternatives 3&4 score slightly better because they require only five separation devices per household whereas for alternatives 1&2 six separation devices are required to separate every waste stream as intended (Steenhuisen, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| Six separation devices needed. | Five separation devices needed. | Four separation devices needed. | Three or less separation devices needed. |

**Table 8:** Scoring legend for the compatibility of home and urban design.

**Minimize aesthetic impacts on the urban environment from waste management infrastructure:** This criterion refers to the entire infrastructure placed in the city which has a visual impact and uses public space. For all alternatives the use of underground containers is considered where possible. This already reduces the use of public space and the related aesthetic impacts.

Due to a lower container density for the multi-stream alternatives, these score better as they use less space than the mono-streams where a high container density was chosen. Another reason why the multi-streams score better is because only underground containers will be used whereas for the mono systems overground containers will be placed for organic waste.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Use of public space in $m^2$ | 27,000 | 13,000 | 26,000 | 13,000 |

**Table 9:** Aesthetic impacts on the urban environment from waste management infrastructure (Hultermans, 2014a).

**Maximize employment opportunities:** The creation of jobs is always a good indicator whether citizens accept a new project or not. This criterion refers to the total number of people employed. Thereby, it is important to note that this is the total number of people who would be working due to the chosen system without taking into account how many people are already employed for the current system.

The differences in the total number of jobs between the alternatives can be found in the container density. For alternatives 2&4 around 8,600 containers will be placed in the city whereas for alternatives 1&3 around 25,000 containers will be placed (Hultermans, 2014a). This makes a difference for the number of people employed in the collection of MSW. Small differences can also be found between the two mono-stream alternatives and the two multi-stream alternatives. This can be explained due to the fact that less people are needed for the two alternatives that make use of post-separation of plastic as this is usually an automatic process.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Number of jobs | 137 | 111 | 124 | 106 |

**Table 10:** Employment opportunities (Hultermans, 2014a).

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**Maximize access to reuse products:** One of the main objectives of this project is to reduce the overall resource use. This can be achieved by promoting facilities and shops that have a focus on reuse like second-hand shops or markets for reused products. Promoting these can eventually reduce the amount of resources used and the amount of waste produced. Regarding the new waste management system, it has to encourage people to reuse their waste for other purposes instead of throwing it away, e.g. using their organic waste as compost.

Currently, there are no differences between the alternatives as none of them promotes shops or markets for reuse products or provide incentives for people to somehow reuse at least some of their waste. Therefore, all alternatives got a score of zero (Steenhuisen, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| Shops and markets for reuse products are not promoted at all; system does not encourages people at all to reuse their waste; there is no incentive to reuse waste. | Shops and markets for reuse products are rarely promoted; system does only encourages people to reuse their organic waste; there is no incentive to reuse any waste. | Some shops and markets for reuse products are promoted; System encourages people to reuse parts of some waste streams; they receive a small incentive for the reuse. | Shops and markets for reuse products are highly promoted; system highly encourages people to reuse high amounts of their waste; they receive high incentive for the reuse. |

**Table 11:** Scoring legend for access to reuse products.

**Objective: Cost/benefit – improve value for money**

The cost/benefit objective covers all financial aspects and includes all main cost and revenue categories. It has to be mentioned that the costs that have been calculated are predicted costs and not real costs. That means that e.g. factors like fees for citizens were not taken into account. The following tables that show costs in Euros show the costs of collection per household and in total (for all 400,000 households in Amsterdam).

**Minimize cost of collection:** This criterion refers to all costs that are related to the collection of the different MSW waste streams from picking them up at the containers until bringing them to the waste treatment facility. These costs include e.g. running expenses for waste trucks and people employed.

The costs for alternatives 1&3 are higher than for the multi-stream alternatives as a higher container density was chosen which in turn increases the costs of collection.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Per household €/year | 77 | 63 | 70 | 60 |
| **Total mln €/year** | **30.8** | **25.2** | **28** | **24** |

**Table 12:** Costs of collection (Hultermans, 2014a).

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**Minimize cost of separation and sorting:** This criterion refers to all the effort that is needed for reaching clean waste streams at the waste treatment facility. Depending on the system that is chosen, separation and sorting of the waste streams is necessary.

Separation is therefore needed for alternatives 3&4 as the plastic has to be separated from the residual waste stream. Sorting is needed for alternatives 2&4 as the e.g. different coloured bags from the multi collection have to be separated from each other. Therefore, the costs for alternative 4 are the highest as sorting and separation is needed whereas for alternative 1 there are no expenses as no sorting or separation is needed.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Sorting** | | | | |
| Per household €/year | 0 | 7 | 0 | 6 |
| Total mln €/year | 0 | 2.8 | 0 | 2.4 |
| **Separation** | | | | |
| Per household €/year | 0 | 0 | 12 | 12 |
| Total mln €/year | 0 | 0 | 4.8 | 4.8 |
| **Total costs of sorting and separation** | | | | |
| Per household €/year | 0 | 7 | 12 | 18 |
| **Total mln €/year** | **0** | **2.8** | **4.8** | **7.2** |

**Table 13:** Costs of separation and sorting (Hultermans, 2014a).

**Minimize costs of enforcement and implementation:** This criterion is related to the costs that occur due to coordination, legislation and enforcement. There are differences in the implementation and coordination between the systems. These differences can mainly be traced back to the numbers of different containers needed and also to the space that they use. Also, the placement of overground containers for organic waste plays a role in how well the system can be implemented and enforced.

The multi-stream systems score the best with three pluses as the number of containers placed is much lower than for the mono-streams and also because they do not need overground containers for organic waste. The mono-streams on the other hand got the lowest score as they are much more complicated to implement. Not only more containers have to be placed, but it has to be evaluated carefully where which kind of container is put as containers for all the different waste streams are needed. The costs of enforcement on the other hand do not make that much of a difference between the alternatives (Hultermans, 2014b).

| 0 | + | ++ | +++ |
|---|---|---|---|
| System can only be implemented at high costs: high numbers of containers are needed, use of public space is maximised, system does not work well and is too complex to be enforced. | System is costly to implement, many different containers are needed, public space is used, enforcement measures work only to a certain extent. | System can be implemented at low costs; not many containers are needed, public space is used, system is working in general and is easy to enforce when needed. | System can be implemented at very low costs; low numbers of containers are needed, use of public space is minimised, system is working well so that there is no need for enforcement. |

**Table 14:** Scoring legend for costs of enforcement and implementation.

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**Minimize waste treatment costs for citizens:** The waste treatment costs for citizens relate to the total costs of the system which is eventually paid and financed by the citizens. Therefore, the total costs have been calculated as the sum of collection, separation, sorting and treatment from which the revenues from recycling materials have been subtracted.

When comparing the total waste treatment costs of the alternatives, it can be seen that the difference are only marginal. Each alternative has its advantages and disadvantages regarding the different types of costs but when calculating the total costs, all alternatives score more or less in the same range.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Costs of collection** | | | | |
| Per household €/year | 77 | 63 | 70 | 60 |
| Total mln €/year | 30.8 | 25.2 | 28 | 24 |
| **Costs of sorting and separation** | | | | |
| Per household €/year | 0 | 7 | 12 | 18 |
| Total mln €/year | 0 | 2.8 | 4.8 | 7.2 |
| **Costs of processing** | | | | |
| Per household €/year | 26 | 26 | 20 | 20 |
| Total mln €/year | 10.4 | 10.8 | 8 | 8 |
| **Revenues from recycling** | | | | |
| Per household €/year | 22 | 22 | 26 | 26 |
| Total mln €/year | 8.8 | 8.8 | 10.4 | 10.4 |
| **Total waste treatment costs** | | | | |
| Per household €/year | 81 | 74 | 76 | 72 |
| **Total mln €/year** | **32.4** | **29.6** | **30.4** | **28.8** |

**Table 15:** Waste treatment costs for citizens (Hultermans, 2014a).

**Maximize revenues from recycling materials and bio-waste:** This criterion is closely related to the overall aim of this analysis that is increasing the recycling quota and hence also maximising the revenues resulting from recycling waste materials. The amount of revenues is hereby depending on the shares and quantity of recycling material as well as the quality of recycling material including bio-waste.

The revenues from recycling material and bio-waste are higher for alternatives 3&4 as the post-separation of plastic is nowadays very efficient and will therefore lead to a much higher quality than when separated at the source by citizens.

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Per household €/year | 22 | 22 | 26 | 26 |
| **Total mln €/year** | **8.8** | **8.8** | **10.4** | **10.4** |

**Table 16:** Revenues from recycling materials and bio-waste (Hultermans, 2014a).

**Maximize revenues from energy production:** The revenues from energy production are closely linked to the amount and the composition of the waste streams. This criterion is therefore closely related to the criterion 'revenues from recycling materials and bio-waste'.

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The revenues from recycling material and bio-waste are higher for alternatives 3&4 (see criterion above) which means that a higher quantity is recycled which in turn leaves less material that can be used for the energy production. Therefore, the energy production is higher for 1&2 as the numbers of recycled material are lower and more residues will be left that can be used for incineration (Hultermans, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| High collection response by citizens is leading to high shares or recyclable material; low shares are left for incineration leading to low revenues from energy production. | Shares of recyclable material are increasing at a fast rate; shares for incineration are in turn decreasing; revenues from energy revenues are decreasing, too. | Collection response by citizens increases very slowly; shares of recyclable material are growing; still, it is leading to high revenues from energy production. | Low shares of recyclable material leading to higher shares of material incinerated; this in turn increases revenues from energy production to a maximum. |

**Table 17:** Scoring legend for revenues from energy production.

**Maximize flexibility of the system to include new waste streams:** This criterion refers to how flexible the system is and how possible future adjustments can be implemented. Thereby, it is taken into account if future waste streams can be added or not. Furthermore, the flexibility depends on where the containers can be placed.

The flexibility of the multi systems is much higher than for the mono systems. It is easy to include new waste-streams into the multi system. The effort to include new waste streams into the mono-system is, however, very high. The whole infrastructure needs to be changed, e.g. new containers for each waste stream need to be placed and collection routes/ schedules have to be adapted. The post-separation alternatives score slightly better than the respective other ones as waste-streams can be added more easily to the existing post-separation line (Hultermans, 2014b).

| 0 | + | ++ | +++ |
|---|---|---|---|
| The system is highly inflexible; new containers have to be placed; collection routes and schedules need to be developed completely new. | The system is not very flexible, new waste streams can be included if post-separation lines at the waste treatment facility are available where new waste stream can be treated. | The system is very flexible, new waste streams can be included without placing new containers or changing collection schedules. | The system is highly flexible, new waste streams can be included without placing new containers or changing collection schedules; post-separation lines at the waste treatment facility are available where new waste streams can be added for treatment. |

**Table 18:** Scoring legend for flexibility of the waste management system to include new waste streams.

**Maximize return on investment in sustainable waste management:** The return on investment in sustainable waste management has been calculated by subtracting the revenues from recycling material and bio-waste from the total costs. In this case, the lower the numbers of the return on investment the better meaning that the recycling rates are higher.Similar to the total waste treatment costs, the differences between the alternatives are only marginal.

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| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Total costs mln €/year | 32.4 | 29.6 | 30.4 | 28.8 |
| Revenues from recycling material | 8.8 | 8.8 | 10.4 | 10.4 |
| **Return on investment in sustainable waste management in mln €/year** | **23.6** | **20.8** | **20** | **18.4** |

**Table 19: R**eturn on investment in sustainable waste management (Hultermans, 2014b).

**Objective: Environmental impact – improving the environment**

The criteria from this objective try to minimise the impact from the collection and treatment of waste on the environment. For this objective, the different emissions that occur as well as the possibility that waste is disposed illegally, either on the streets or into water plays the most important role.

**Minimize emissions from waste management and the reprocessing of secondary materials**: This criterion refers to the average emissions that are emitted due to the management and processing of material. The emissions considered are particles, $CO_2$, $CH_4$, $NO_x$ and $SO_x$.

Alternatives 3&4 have the lowest score of the alternatives with only one plus as the post-separation of plastic requires a lot of effort, leading to a much higher amount of emissions than the treatment of plastic that has already been separated at source. Alternatives 1&2 score three pluses as the emissions of the treatment of waste are kept to a minimum. This is due to the fact that all waste streams are already separated at the source and no separation is needed any more at the waste treatment facility (Jonkers, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| Only few waste streams are separated at the source; post-separation of the rest of the waste streams creates very high emissions. | Most waste streams are separated at the source; post-separation of plastic is responsible for high emissions. | All waste streams are separated at the source but are often intermingled and need further treatment which increases emissions. | All waste streams are separated at source as much as possible; no separation of waste streams is needed anymore. |

**Table 20:** Scoring legend for emissions from waste management and the reprocessing of secondary material.

**Minimize illegal disposal of waste:** The success of the implemented system will have an influence on the amount of waste that gets disposed illegally. If the system works well, meaning that it is easy to understand and convenient for the citizens, they are likely to comply which in turn reduces illegal disposal of waste.

For this criterion, the multi-stream alternatives score the highest because it is easy for citizens to comply. Apart from glass, all bags can be thrown into the same container making it easy for citizens. For the mono-streams, people have to be more aware where they put their waste. Therefore, it is more likely that a certain number of people will dispose their waste illegally as they perceive the efforts as too high (Jonkers, 2014).

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| 0 | + | ++ | +++ |
|---|---|---|---|
| Waste system does not work well at all; the system is too complicated; the efforts for citizens are too high; a lot of waste is illegally disposed on the streets. | Waste system works but there are some major flaws in the implementation of the system; efforts are high; waste is regularly disposed on the streets. | Waste system works well; with some initial efforts it is easy to understand; other efforts are also manageable; little waste is illegally disposed on the streets. | Waste system is working as intended, meaning that it is easy to understand and that efforts are as low as possible; no waste is illegally disposed on the streets. |

**Table 21:** Scoring legend for illegal disposal of waste.

**Maximise water quality:** This criterion is related to the criterion above 'Minimise illegal disposal of waste'. It has also to do with the success of the implemented system, only that here the impact of a non-successful system on the quality of water is analysed. For the case in Amsterdam this means either pollution of the water in the numerous canals or pollution of groundwater.

The scores of the alternatives are the same as for the criterion above. The multi-streams get the highest score of three pluses as it is the most convenient system for the citizens whereas the other two alternatives score a bit less with only two pluses due to a more complex system which might influence people to dump their waste into the canals (Jonkers, 2014).

| 0 | + | ++ | +++ |
|---|---|---|---|
| Water quality in canals and groundwater is negatively influenced; a lot of waste is dumped into the water; residues from waste materials seep into the groundwater. | Water quality in canals and groundwater is regularly influenced; waste is regularly dumped into the water and residues from waste materials seep into the groundwater. | Water quality in canals and groundwater is good; in rarely cases waste is dumped into the water or residues from waste seep into the groundwater. | Water quality in canals and groundwater is very good; it is not influenced by illegal dumping into water or through the collection and treatment of waste. |

**Table 22:** Scoring legend for water quality.

**Minimise impacts from the collection and transfer of waste:** This criterion includes all the $CO_2$ emissions from waste being collected in the city until it is unloaded at the waste treatment facility. The $CO_2$ emissions have been calculated by taking the driving distance of the waste trucks per year and an estimated diesel use of 70 litres for 100km. The high diesel use is due to a permanent stop-and-go process for collecting the waste and also due to the traffic in the city (Hillmer, 2005).

The differences between the alternatives can here again be traced back to the numbers and density of containers placed. Furthermore, the distribution of containers plays a role as there are variations between the four alternatives of where the containers are placed.

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| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| Kilometres driven per year | 1,400,000 | 1,300,000 | 1,240,000 | 1,070,000 |
| Diesel use/ 100km = approx. 70 litres | | | 0 | |
| **$CO_2$ emissions/tonnes/year** | **2322.6** | **2156.7** | **2057.1** | **1775.13** |

**Table 23:** $CO_2$ emissions from collection and transfer of waste (Hultermans, 2014a; Dekra, 2014).

### 1.2.3. Effects table

The effects table is the result of the first step 'problem definition'. It shows the four alternatives (the columns), the four main objectives with their respective criteria (the rows) and the scores (the cells) (Janssen *et al.* 2013). The current situation has been added as a reference scenario to the MCA but will not further be dealt with in this analysis.

The effects table that was developed during the first workshop was only a preliminary version and was used to get a first overview and to make the stakeholders familiar with the MCA approach. For some participants this process was confusing and did not appear very straightforward. This was partly due to the fact that during the first workshop all criteria were allocated a 0/+++ score without scoring legends but also because for most of the stakeholders this was the first time that they were involved into an MCA.

After the first workshop, questionnaires were sent out to the participants and a few other waste management experts where each one was asked to provide some quantitative scores for the criteria that are related to their field of expertise. The aim was to develop a new and more comprehensive effects table to be used for the discussions with the four interviewees. The response from the participants, however, was relatively low and only few responded by providing scores. Therefore, many scores had to be taken from the effects table that had been developed during the first workshop. These scores were then assessed again by the interviewees. The expert interviews played a crucial role in bringing the analysis forward. The experts assessed the criteria and the previous scores. Some criteria were determined by them as not applicable, for some they made suggestions how to formulate them in a better way. The four experts also explained the reasoning how and why the alternatives scored in the way they did. One of the main results from the expert interviews was a comprehensive and complete effects table.

This revised effects table was used as a basis for the second workshop where the criteria and scores were discussed again. This part of the workshop was not easy as all participants wanted to give their opinions on certain criteria which resulted in long discussions that sometimes were straying from the actual topic. The criteria and scores from each objective were discussed one by one. It was agreed on that some criteria are not important for this case. Most discussion potential was, however, found when the scores of the criteria were assessed. Some participants did not agree with the scores that have been set by the experts and these criteria were critically looked at again. Especially the criteria that were measured with a 0/+++ scale provided discussion potential. For this kind of scale it is important to agree on how the criterion is defined and how the scoring legend should look like which had not been done prior to the workshop. Some definitions were provided during the discussions and some scores were changed accordingly as the discussion with all stakeholders provided new and different perspectives on how to allocate the scores.

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After the second workshop the set of criteria was finalised. Some were reformulated and a definition and scoring legend was added for all of them. The result of this process is shown in the effects table in figure 12.

| | C/B | Unit | CS | SM | SMM | SMP | SMMP |
|---|---|---|---|---|---|---|---|
| **Resource use - improve resource efficiency** | | | | | | | |
| Min primary resource use | | 0/+++ | + | ++ | +++ | ++ | +++ |
| Max recovery of recyclable material | | 0/+++ | 0 | 0 | ++ | + | +++ |
| Max the effective use of energy from waste | | 0/+++ | ++ | ++ | ++ | ++ | ++ |
| Min use of resources in the collection and sorting process | − | no. containers | 24941,00 | 25731,00 | 8692,00 | 24941,00 | 8692,00 |
| **Social impact - improve social benefits** | | | | | | | |
| Max citizen's involvement and promote behavioural change | | 0/+++ | + | + | ++ | + | ++ |
| Min effort for citizens to participate in waste prevention etc. | − | m | 81,00 | 81,00 | 85,00 | 75,00 | 85,00 |
| Min local environmental nuisance | | 0/+++ | +++ | + | +++ | + | ++ |
| Max the compatibility of home and urban design | | 0/+++ | 0 | 0 | 0 | + | + |
| Min aesthetic impacts on urban enviro. from waste manag. infrast | − | m2 | 26000,00 | 27000,00 | 13000,00 | 26000,00 | 13000,00 |
| Max employment opportunities | + | fulltime equivalent | 137,00 | 137,00 | 111,00 | 124,00 | 106,00 |
| Max access to reuse products | | 0/+++ | 0 | 0 | 0 | 0 | 0 |
| **Cost/benefit - improve value for money** | | | | | | | |
| Min costs of collection | − | mln €/year | 25,60 | 30,80 | 25,20 | 28,00 | 24,00 |
| Min costs of separation and sorting | − | mln €/year | 0,00 | 0,00 | 2,80 | 4,80 | 7,20 |
| Min costs of enforcement and implementation | | 0/+++ | 0 | 0 | +++ | 0 | +++ |
| Min waste treatment costs for citizens | − | mln €/year | 37,20 | 32,40 | 29,60 | 30,40 | 28,80 |
| Max revenues from recycling material and bio-waste | + | mln €/year | 2,64 | 8,80 | 8,80 | 10,40 | 10,40 |
| Max revenues from energy production | | 0/+++ | + | + | + | 0 | 0 |
| Max flexibility of the system to include new waste streams | | 0/+++ | ++ | 0 | ++ | + | +++ |
| Max return on investment in sustainable waste management | − | mln€/year | 23,60 | 23,60 | 20,80 | 20,00 | 18,40 |
| **Environmental impact - improving the environment** | | | | | | | |
| Min emissions from waste manag. & reprocessing of sec. material | | 0/+++ | ++ | +++ | +++ | + | + |
| Min illegal disposal of land | | 0/+++ | ++ | ++ | +++ | ++ | +++ |
| Max water quality | | 0/+++ | ++ | ++ | +++ | ++ | +++ |
| Min impacts from the collection and transfer of waste | − | CO2 tonnes/ year | 2000,00 | 2322,60 | 2156,70 | 2057,16 | 1775,13 |

**Figure 12:** Problem definition: effects table.

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**Standardisation, weighting, ranking**

The next step in the MCA involves the standardisation of all criteria to either a common dimension or a dimensionless unit before the alternatives can be compared. For most criteria interval standardisation was chosen. With this type of standardisation each criterion is scaled according to its relative position on the interval between the highest and lowest performance. For all the monetary criteria goal standardisation was chosen. The scores of the highest (37.20 mln €) and the lowest value (0 mln €) were chosen and all other scores scaled between these two values. This type of standardisation determines to which extent an objective is reached (Van Herwijnen & Janssen, 2004). The standardisation and weighting is shown in figure 13.

Following, all criteria and objectives were allocated a certain weight. The weight determines the relative importance of the criteria and objectives in the MCA. The assessment of the weights is a critical part of the MCA. To some extent it always involves subjectivity and a change in weights may result in a different outcome of the final ranking (Van Herwijnen & Janssen, 2004).

The weight within the objectives (weight level 2) was set by the interviewed experts for their respective field of expertise. The weight was set by having them rank the criteria according to their order of importance. DEFINITE can then calculate the weight automatically. This way of setting the weights was chosen as not all experts are familiar with the DEFINITE programme and the setting of weights in this context. The ranking according to the order of importance therefore provided an easily understandable way of setting weights. The weights for all criteria that have been calculated by DEFINITE can be seen in figure 13.

The criteria from the resource use objective were ranked by Maarten Bakker from TU Delft. He determined the use of primary resources as the most important criterion from this objective, followed by the recovery of recyclable material, the effective use of energy from waste and finally the use of resources in the collection and sorting process (Bakker, 2014).

The criteria from the social objective were ranked by Frits Steenhuisen from CREM in Amsterdam. He determined the effort for citizens to participate in waste prevention, reuse and recycling as most important, followed by the access to reuse products, the involvement of citizens and the compatibility of home and urban design. The other three social criteria were equally ranked on the last position (Steenhuisen, 2014).

Rolph Hultermans from Royal Haskoning in Nijmegen ranked the criteria from the cost/benefit objective. The waste treatment costs for citizens were ranked on the first position as these imply the total costs of the system that have to be paid and financed by the citizens. This criterion is followed by the flexibility of investment, the return on investment in sustainable waste management, the revenues from recycling material and bio-waste, the costs of implementation and enforcement, the costs of collection, the costs of separation and sorting and finally the revenues from energy production (Hultermans, 2014b). The ranking for this objective had to be adjusted afterwards due to the fact that most of the criteria are monetary criteria which should be allocated the same weight. The three remaining criteria with a 0/+++ scale were adjusted due to the magnitude that they have and due to the ranking that was determined by Rolph Hultermans.

The criteria from the last objective were ranked by Niels Jonkers from IVAM at the University of Amsterdam. He determined the emissions from waste management as most important, followed by the illegal disposal of waste, the water quality and finally the impacts from collection and transfer of waste which has a rather small impact in contrast to the other emissions (Jonkers, 2014).

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The weights for the objectives (weight level 1) were set equally for all four objectives. As a second part of the workshop the weights for the criteria and objectives were assessed to see if all participants agree. The weights for the criteria were assessed within the objectives first. Whereas the discussion of the scores had resulted in a lot of disagreement between the participants, the discussion on how to weight the criteria was dealt with very quickly as all participants mostly agreed with the weights that had been set by the interviewed experts. The weights for all objectives were tested in a sensitivity analysis.

The following figure shows the standardised table with the allocated weights for the criteria and objectives. Following the cost/benefit and unit columns, the standardisation method is shown in column three. The next two columns show the minimum and maximum range for each criterion. Weight level 1 is the weight that was set for the objectives, weight level 2 is the weight that was set for the criteria. The last column shows the overall weights for each criterion for the analysis which is calculated by DEFINITE by multiplying weight level 1 with weight level 2.

| | C/B | Unit | Standardization method | Minimum Range | Maximum Range | Weight level 1 | Weight level 2 | Weight |
|---|---|---|---|---|---|---|---|---|
| **Resource use - improve resource efficiency** | | | | | | 0,250 | | |
| Min primary resource use | | 0/+++ | interval | ++ | +++ | | 0,520 | **0,130** |
| Max recovery of recyclable material | | 0/+++ | interval | 0 | +++ | | 0,271 | **0,068** |
| Max the effective use of energy from waste | | 0/+++ | interval | ++ | ++ | | 0,146 | **0,036** |
| Min use of resources in the collection and sorting process | - | no. containers | interval | 8692,00 | 25731,00 | | 0,063 | **0,016** |
| **Social impact - improve social benefits** | | | | | | 0,250 | | |
| Max citizen's involvement and promote behavioural change | | 0/+++ | interval | + | ++ | | 0,156 | **0,039** |
| Min effort for citizens to participate in waste prevention etc. | - | m | interval | 75,00 | 85,00 | | 0,370 | **0,093** |
| Min local environmental nuisance | | 0/+++ | interval | + | +++ | | 0,046 | **0,011** |
| Max the compatibility of home and urban design | | 0/+++ | interval | 0 | + | | 0,109 | **0,027** |
| Min aesthetic impacts on urban enviro. from waste manag. infrast | - | m2 | interval | 13000,00 | 27000,00 | | 0,046 | **0,011** |
| Max employment opportunities | + | fulltime equivalent | interval | 106,00 | 137,00 | | 0,046 | **0,011** |
| Max access to reuse products | | 0/+++ | interval | 0 | 0 | | 0,228 | **0,057** |
| **Cost/benefit - improve value for money** | | | | | | 0,250 | | |
| Min costs of collection | - | mln €/year | goal | 0,00 | 37,20 | | 0,113 | **0,028** |
| Min costs of separation and sorting | - | mln €/year | goal | 0,00 | 37,20 | | 0,113 | **0,028** |
| Min costs of enforcement and implementation | | 0/+++ | interval | 0 | +++ | | 0,069 | **0,017** |
| Min waste treatment costs for citizens | - | mln €/year | goal | 0,00 | 37,20 | | 0,113 | **0,028** |
| Max revenues from recycling material and bio-waste | + | mln €/year | goal | 0,00 | 37,20 | | 0,113 | **0,028** |
| Max revenues from energy production | | 0/+++ | interval | 0 | + | | 0,113 | **0,028** |
| Max flexibility of the system to include new waste streams | | 0/+++ | interval | 0 | +++ | | 0,255 | **0,064** |
| Max return on investment in sustainable waste management | - | mln€/year | goal | 0,00 | 32,70 | | 0,113 | **0,028** |
| **Environmental impact - improving the environment** | | | | | | 0,250 | | |
| Min emissions from waste manag. & reprocessing of sec. materia | | 0/+++ | interval | + | +++ | | 0,521 | **0,130** |
| Min illegal disposal of land | | 0/+++ | interval | ++ | +++ | | 0,271 | **0,068** |
| Max water quality | | 0/+++ | interval | ++ | +++ | | 0,146 | **0,036** |
| Min impacts from the collection and transfer of waste | - | CO2 tonnes/ year | interval | 1775,13 | 2322,60 | | 0,063 | **0,016** |

**Figure 13:** Multi-Criteria Analysis: standardisation and weighting.

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The last part of this step includes the final ranking of the four alternatives. DEFINITE determines the final scores as follows: after the criteria scores have been standardised and the weights attributed, the weights are multiplied by the standardised scores. Then, the resulting scores are added up and now present the total scores for each option (as can be seen in the rows two to five in figure14). Finally, the total scores and ranking (first row) is determined (Van Herwijnen & Janssen, 2004).

Once the ranking was made it was presented to the participants and they were asked if the ranking made sense in their opinion. All of the participants are experts in the field of waste management and could therefore easily detect if there was a major mistake in an allocated score as this can have a direct influence on the outcome of the ranking. E.g. some of them discovered that some of the scores allocated for the current situation were wrong as it scored too high in the resource use objective which resulted in a better overall ranking than it should have. DEFINITE supports several graphical features that can be used to show not only the overall result but also to split the result up into a ranking for each objective individually. This allows seeing what the ranking is based upon and how the overall result is reached. Furthermore, it was looked at if there would be changes in the ranking if some objectives were allocated a higher weight than the others.

The final ranking is shown in figure 14. It can be seen that alternative 2 has the best overall score (0.64) and is therefore on the first position, followed by alternative 4 (0.56). The scores of alternative 1 (0.26), the current situation (0.25) and alternative 3 (0.23) are relatively low compared to the other two alternatives.

In the ranking you can see that trade-offs have to be made. Alternative 2 which is ranked first scores very high in the environmental objective and the resource use. However, it lacks behind in the social objective. Alternative 4 scores similar to alternative 2 but compared to alternative 2 lacks behind in the environmental objective and therefore scores less good in the final result. All alternatives score similar for the cost/benefit objective. The mono-streams lack behind for the resource use objective. Alternative 3 also scores badly in the environmental objective.

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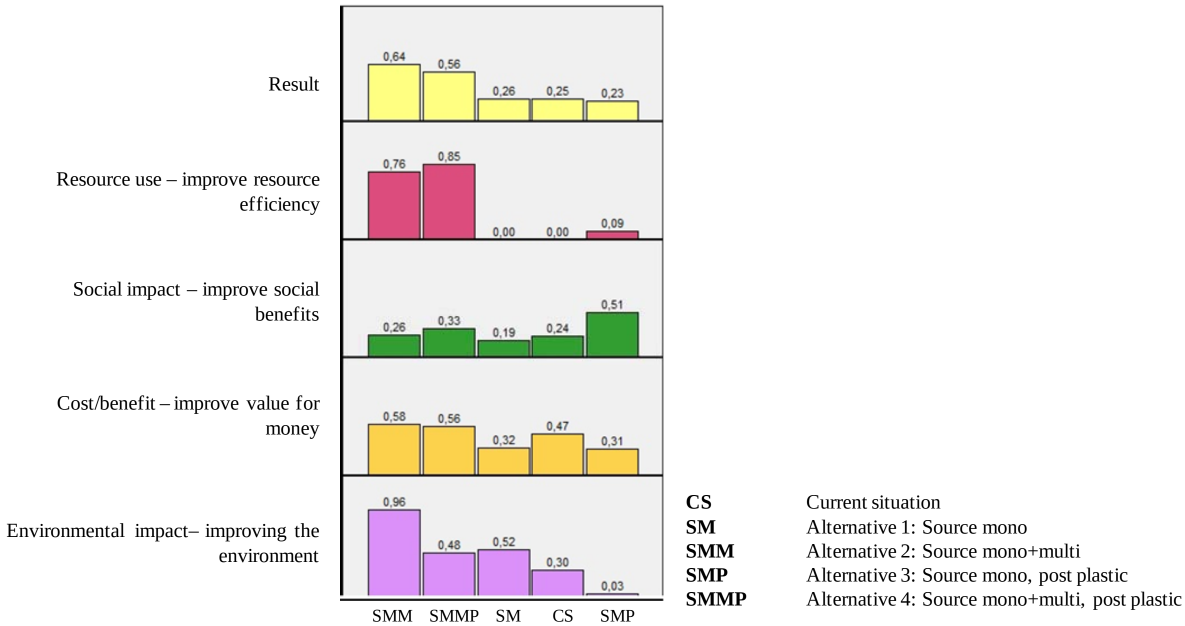


**Figure 14:** Multi-Criteria Analysis: ranking of the alternatives.

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## Sensitivity analysis

In the following section, the sensitivity of the ranking to uncertainties in scores and weights will be analysed. Variations in weights and scores may result in a different outcome of the ranking. Therefore, the robustness of the data is tested by making use of a sensitivity analysis (Van Herwijnen & Janssen, 2004).

The first step in checking how sensitive the outcome of the ranking is was to have a look at the different perspectives for the objectives. For the MCA analysis all four objectives were weighted equally. Figure 15 shows how the alternatives would have been ranked if there was a change in the weights for the objectives. Each row shows a different weighting where the objectives one after another have been allocated the weight of 0.5 whereas the remaining three were equally weighted with 0.166. It can be seen that the outcome is not very sensitive as alternative 2 scores best for all perspectives, always followed by alternative 4. The mono-stream alternatives are more sensitive to changes in the weights. E.g. the perspective for the social objective shows that if it had been allocated a weight of 0.5, there would have been a change in the last three positions although the differences in scores are marginal.

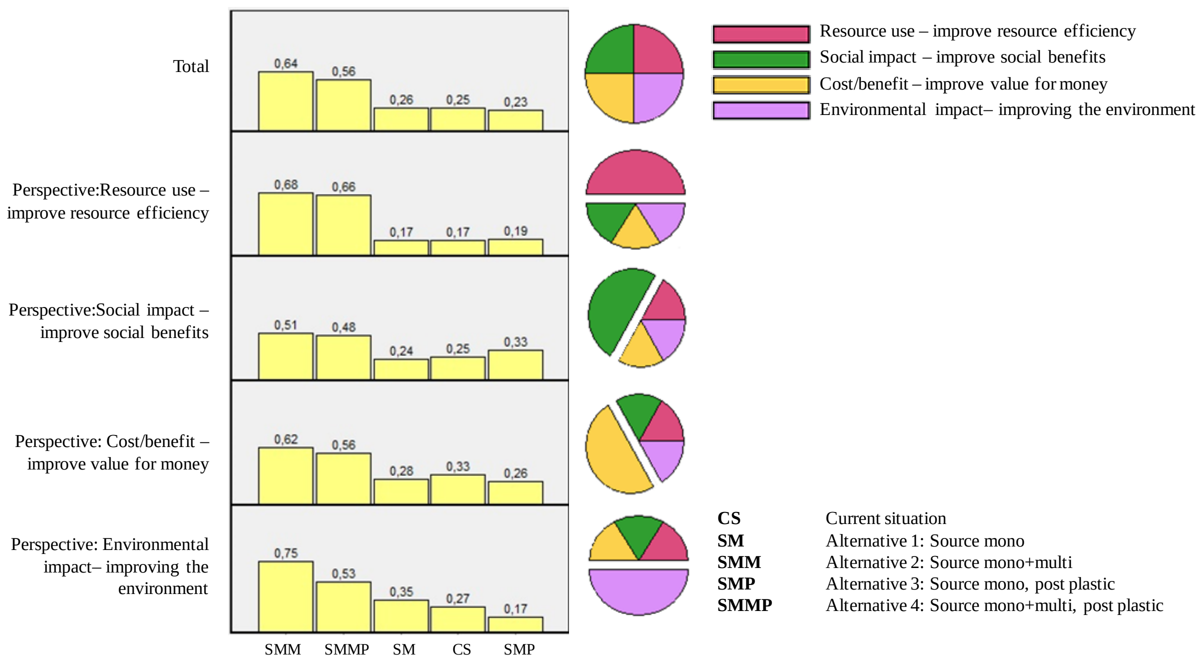


**Figure 15:** Ranking of alternatives for the different perspectives.

The sensitivity was also checked by using the Monte Carlo Analysis. The Monte Carlo Analysis is a computer-based mathematical analysis that detects risks in quantitative analyses and decision-making processes (Palisade, 2014). Testing the uncertainties for each score individually, would have exceeded the scope of this thesis by far. Therefore, the Monte Carlo Analysis allows to show the sensitivity on score uncertainty for the overall ranking. Figure 16 shows the Monte Carlo Analysis for a score uncertainty of 50%. It can be seen that the two first ranked alternatives are very stable which is represented in the circle's size in the last column of the diagram. Alternatives 1&3 which were ranked on the last positions are, however, very unstable. A change in scores is therefore likely to change the ranking of these alternatives.

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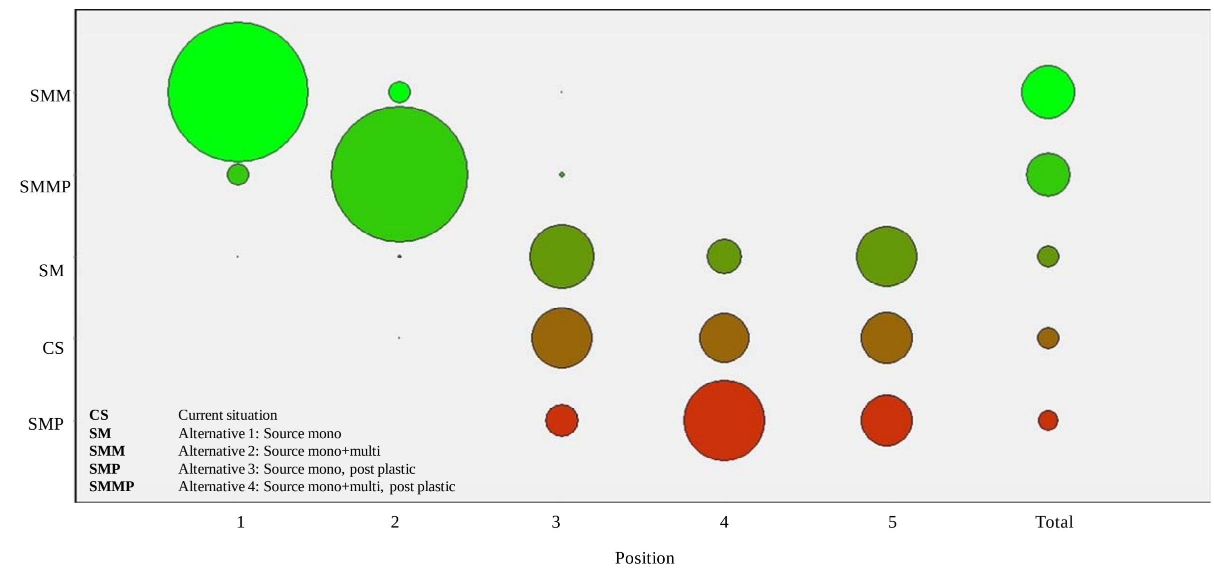


**Figure 16:** Result of Monte Carlo Analysis for score uncertainty of 50%.

A second Monte Carlo Analysis was made for a weight uncertainty of 50%. The result looks similar to the first analysis. Alternatives 2&4 which scored on the first two positions are not very sensitive to changes in scores or weighting. Alternatives 1&3 and the current situation are, however, more sensitive to changes in weighting.

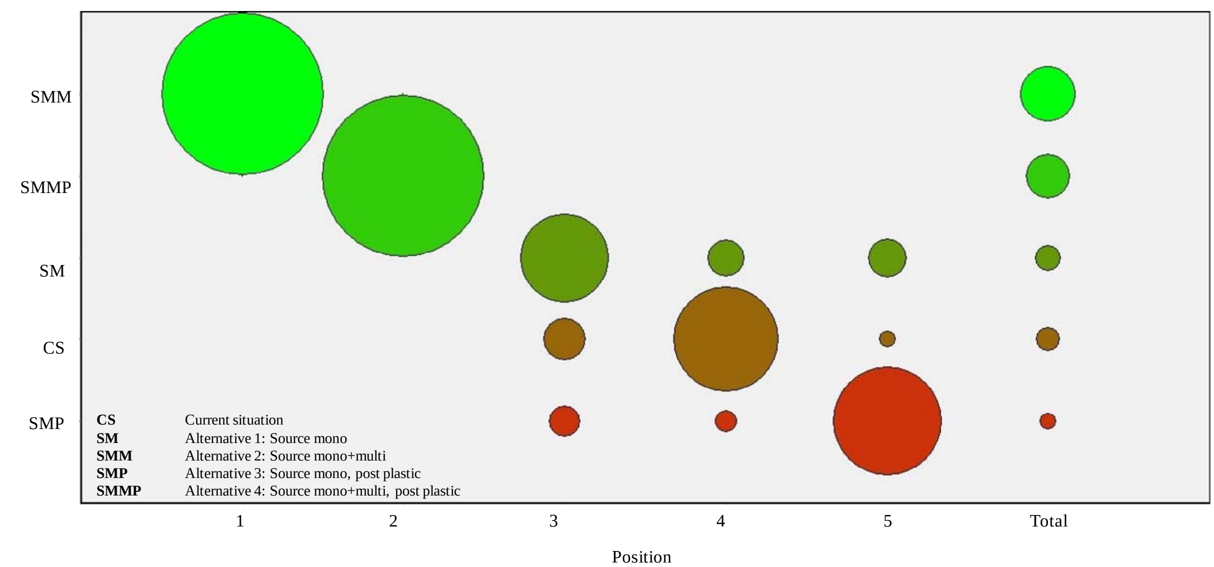


**Figure 17:** Result of Monte Carlo Analysis for weight uncertainty of 50%.

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## 1.3. Discussion

The decision for an ideal management system for MSW is not an easy one. The MCA is a decision support tool that delivers a basis for decision-makers but does not necessarily present the best and only solution. Therefore, the results from the MCA have to be interpreted carefully and it has to be recognised that this analysis comprises some limitations.

First of all, the project of developing a decision support framework for all partners from the EU project is an ongoing process. The same goes for the MCA in Amsterdam which is relying to a big part on the workshops that have been carried out. The workshops have shown to be a good platform to bring together and involve all relevant stakeholders. Due to this complex project, one workshop was not enough to fit everything in, also, because further research had to be carried out. The workshops have therefore been an ongoing process which is not yet finished. Consequently, the MCA presented in this thesis is only a preliminary version due to the limited amount of time available and as more research has to be carried out to reach a final result.

For some criteria, indicators were chosen that might not fully represent the targeted criteria. This was the case for some criteria which comprised several aspects which could not all be fitted into one score or where not enough data was available. This was the case, e.g. for the criterion 'Minimize effort for citizens to participate in waste prevention, reuse and recycling activities' where the average walking distance to the waste collection devices was chosen as an indicator on how high the efforts are. For those cases where an indicator had to be chosen, the one with the highest importance and highest data reliability was taken.

Furthermore, there is always some subjectivity involved when allocating weights to the criteria and objectives. In order to keep subjective influences as low as possible, the weights within each objective that were determined by the experts in the interviews were discussed in the following workshop to ensure that the other stakeholders agreed on them. The sensitivity of the weights of the objective to uncertainties was tested in a sensitivity analysis which showed that differences in the objective weights would not influence the first two positions in the ranking.

When choosing the alternatives, choices between a high and low container density as well as a collection response of 50% or 80% had to be made. In this analysis, only four scenarios could be compared to each other as it would otherwise have exceeded the scope of this thesis although when taking into account all possible scenarios for the container density and response, 16 scenarios are available that could have been used for this analysis Therefore, it is likely that the choice of different scenarios would have resulted in a different ranking as the differences between the scenarios in e.g. costs, benefits and walking distance are relatively high.

However, despite these limitations that need to be taken into account, this analysis reveals some interesting results. The final ranking shows that the source-separation with multi-streams scores best in the overall ranking, followed by the source-separation in multi-streams combined with post-separation of plastic. The multi-stream alternatives score better in most of the objectives compared to the mono-streams.

The collection of multi-streams is an interesting approach that has not yet been used in many countries or municipalities. Therefore, not many examples are available of how well the system works in practice so that assumptions could be made of how well it could work in Amsterdam. It can be assumed that the multi-streams make life easier for citizens to put their waste into the right container as only one type of container will be placed together with glass and residual containers. On the other hand, the multi-stream alternative which scores best in the overall result as well as alternative 1 are heavily relying on the involvement and compliance of the citizens.

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In both cases, citizens have to separate all six waste streams at home which requires a lot of effort and takes much in-house space. When looking at the current collection response of separated waste from citizens which is around 20%, it is questionable if choosing one of these two alternatives would be a good approach for the next years. These systems can achieve high recycling rates but only if it can be assumed that there is a collection response between 50-80% or even higher. The collection response plays a crucial role in reaching the 65% target of recycling MSW and it should therefore be a priority to increase its number in the next years. Hence, in this case alternatives 3&4 would be more suitable in increasing the collection response as both alternatives include the post-separation of plastic. This reduces the in-house space and effort for citizens at least to a certain percentage. Given the fact that the differences in costs between all alternatives are only marginal and taking into account the necessity of increasing the collection response first, it could be considered to choose alternative 4 as an interim solution that could encourage citizens to separate their waste step-by-step. The advantage of the multi-streams is that they are very flexible in including new waste streams so in the long-term, when the number of people separating their waste as intended has increased, a switch could be made to the preferred multi-stream system where citizens separate all waste streams at the source.

Selecting a new management strategy for the city of Amsterdam has shown to be a difficult task as it involves the evaluation of criteria from multiple objectives such as environmental impacts, social impacts, benefits and costs and resource use. The aim of this thesis was to provide a basis for decision-makers on which strategy to choose for the city of Amsterdam. This was done by making use of an MCA as it is a useful tool to assess available data and to gain insights into how each alternative performs on the developed criteria and objectives. The advantage of the MCA has been that all factors from all the different stakeholder's objectives could be taken into account without having to trade-off certain criteria for others. The MCA has therefore proven to be a particular useful tool in supporting the stakeholders in the process of reaching a decision. Although there were always many discussion points which sometimes slowed down the process of the workshops, the MCA was a good tool to present preliminary results to the stakeholders and helped to discuss them. Especially the graphical presentation tools from the DEFINITE programme were useful in presenting the results and made it easier for the stakeholders to understand the whole process.

In the end, it will be up to the decision-makers how the results from the MCA will be interpreted and which alternative is the preferred one that will be chosen in the end.

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## 1.4. Conclusion and recommendation

Recycling of MSW is an important step in saving natural resources and limiting negative impacts on the environment. Various MSW management systems are available which can be combined and implemented in various ways. Generally speaking, the most appropriate option for the future will be source-separation for at least those waste streams that make up the highest shares of MSW. Source-separation is the most suitable way when aiming for a recycling rate that comes close to 100%. Source-separation can thereby be combined with any other imaginable management option depending on what the overall objectives are. The crucial point regarding the choice of a system is to take into account all stakeholders who are involved and also keeping in mind the characteristics of the city where the system will be implemented. Also, there is always the influence from typical waste management problems which have to be analysed in order to overcome them and keep negative influences as low as possible.

The case study on Amsterdam has shown that the MCA has been a good tool in bringing together the stakeholders and getting them involved into the whole process of the analysis. The workshops have shown to be a good platform to encourage the exchange of perspectives and information between stakeholders. The combination of MCA and workshops has allowed to involve them into the whole analysis and provide them with insights on which alternative could be implemented in Amsterdam.

Furthermore, the case study has shown that the implementation of source-separation with a multi-stream collection would be an appropriate system to implement to increase the recycling quota in the city. It scores high in the resource use and environmental objectives and only has some flaws in the social objective, e.g. high walking distances. The outcome of the sensitivity analysis has shown that the result is not very sensitive to changes in scores or weights. The two alternatives which were ranked on the first two positions are not sensitive to uncertainties in scores or weighting. Only the last ranked alternatives have shown to be sensitive to uncertainties in scores and weights. Still, the overall result can be described as stable and reliable.

The recommendation for the case in Amsterdam would be to further investigate the options of the multi-stream system. The ranking of the MCA has shown that it has advantages in many aspects, but now the different combination possibilities of this system need to be further analysed. When choosing the multi-stream system, it needs to be considered if the citizens are already ready to separate all waste streams at source or if it would be better to combine it with post-separation for one or two waste streams. It is a very flexible system which can be helpful in increasing the overall collection response by citizens. Furthermore, it should be tested if a change in the container density would lead to an even higher ranking of the multi-stream alternative or if trade-offs would have to be made regarding costs and social aspects. This research serves as a recommendation for the decision-makers but it is important to keep the limitations of this study in mind and making an extensive analysis of the multi-stream system before a final conclusion can be made.

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