COLLECTORS
WASTE COLLECTION SYSTEMS ASSESSED AND GOOD PRACTICES IDENTIFIED

Deliverable 3.4

Report on multiple criteria assessment of the studied waste collection systems and applicability of different methods for decision-support

Hanna Pihkola, Lauri Kujanpää (VTT)

Credits

The authors would like to thank project partners and all participants of the decision-making exercises for their contributions. Special thanks to Jean-Benoît Bel, Lucía Herreras & Twan van Leeuwen for their comments to the draft version of this report.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776745

Technical references

Grant Agreement N°	776745	Acronym	COLLECTORS
Full Title	Waste collection systems assessed and good practices identified		
Work Package (WP)	WP3		
Authors	Hanna Pihkola, Lauri Kujanpää		
Document Type	Report		
Document Title	D3.4. Report on multiple criteria assessment of the studied waste collection systems and applicability of different methods for decision-support		
Dissemination Level (mark with an « X » in the column to the far right)	CO	Confidential, only for partners of the Consortium (including the Commission´s Services)	
	PU	**Public X**	
	PP	Restricted to other programme participants (including the Commission Services)	
	RE	Restricted to a group specified by the Consortium (including the Commission Services)	

Document history

Version	Date	Partner	Author
Draft 1	21.02.2020	VTT	L. Kujanpää, H. Pihkola
Draft 2	06.03.2020	VTT	L. Kujanpää, H. Pihkola
Finalised report	29.03.2020	VTT	L. Kujanpää, H. Pihkola

Contents

1. Introduction

The aim of the COLLECTORS project is to identify and highlight existing good practices on the collection and sorting of packaging and paper waste (PPW), waste electrical and electronic equipment (WEEE) and construction and demolition waste (CDW).[1] The findings of the project should contribute to informed decision-making at local level, taking into account local and regional characteristics that may affect the success of different waste collection strategies and their implementation.

During the project, different methods for multicriteria decision-making (MCDM) were applied for gathering the views of the experts who work with waste collection at local or regional level, and in the producer responsibility organisations (PROs)[2]. MCDM methods are structured, analytical methods, which can be used for analysing complex decision-problems. Decisions related to waste collection are examples of multicriteria decision-making situations, in which the decision-makers are typically confronted with concerns related to regulatory demands, costs, environmental issues, user preferences, technical issues and feasibility.

MCDM exercises were conducted as part of dedicated expert workshops, in which the information collected during the project (as part of work packages 1, 2 & 3) was used as a starting point. The aim of the MCDM workshops was firstly to learn about the information needs and opinions of the actors, and to understand the potential impacts of regional and local characteristics for the selection of preferred waste collection systems. Secondly, the aim of the workshops was to provide the participants possibilities for knowledge exchange and learning about both, the use of MCDM methods, and the experiences of other regions.

Altogether three expert workshops were organized as part of the COLLECTORS project during 2019. The workshops took place in Warsaw, Brussels and Thessaloniki. This report presents the main

[1] In this report, the studied waste streams (PPW, WEEE and CDW) are discussed in a broad sense (for example, considering all possible streams of WEEEE, unless stated otherwise). Within the COLLECTORS case study reports, a more detailed examination on selected packaging waste streams, small WEEE (small household appliances, IT and lamps), and a few CDW examples was taken.

[2] According the Finnish Waste Act, "producer responsibility refers to companies' obligation to handle the waste management of products they have imported or manufactured when the products are discarded" (Waste Act 646/2011, Section 6). Producers may fulfil their responsibility by joining a producer responsibility organisation that will take care of managing the waste, by establishing a producer responsibility organisation together with other producers, or by managing the waste by themselves, in which case they will need to register and apply for related permits from the authorities responsible for waste management. Products that are covered by producer responsibility include: cars, vans and comparable motor vehicles, tyres, electronic and electronical appliances, batteries and accumulators, printing paper and paper for manufacturing other paper products, and packaging (referring to the packaging where the producer responsibility pertains to the packers of the products and importers or packaged products, but excluding the packaging producers) (Source: https://www.environment.fi/producerresponsibility).

findings from the COLLECTORS workshops and the MCDM exercises; analyses challenges related to studied decision-making situations and provides recommendations about the use of MCDM methods in the context of waste management and collection. The report is structured as follows:

- Chapter 2 presents the aim of the study and the main ideas and motivations related to the MCDM approach that was applied during the project.
- Chapter 3 presents the MCDM methodology on a general level and describes the specific methods that were applied in the workshops (more detailed methodology descriptions for interested readers can be found from the appendix).
- Chapter 4 discusses some of the common challenges related to decision-making in the context of waste management, as identified during the COLLECTORS project, and focuses on the findings from the workshop that was held in Thessaloniki in December 2019.
- Chapter 5 presents the results from the expert workshop related to PPW that was organised in Warsaw in June 2019.
- Chapter 6 presents the results from an expert workshop dedicated to WEEE, organised in Brussels in November 2019.
- Conclusions and recommendations about the use of MCDM methods in the context of waste management are presented in Chapter 7.

2. Aim of the study and the MCDM workshops

2.1 Background: Use of MCDM methods in the context of waste management

Development and use of different kinds of decision support tools and modelling frameworks for the purposes of waste management has been a popular research topic during the last decades. In their review of available waste management models, Morrissey & Browne (2004) indicate that the first modelling studies date back to 1970s. While the first modelling studies were optimization studies that considered issues like vehicle route optimisation, recent studies aim at holistically evaluating sustainability of alternative waste management strategies, and cover different aspects of sustainability, sometimes also addressing stakeholder needs (Achillas, Moussiopoulos, Karagiannidis, Banias, & Perkoulidis, 2013; Morrissey & Browne, 2004; Soltani, Hewage, Reza, & Sadiq, 2015).

First actual MCDM studies related to management of municipal solid waste (MSW) were published in 1991 (Achillas et al., 2013). Recent reviews on the use of multicriteria methods highlight how the use of MCDM methods in the context of waste management is getting more popular, and the number of studies published in scientific journals is increasing (Achillas et al., 2013; Goulart Coelho, Lange, & Coelho, 2017; Soltani et al., 2015). This is most likely due to increasing interest towards sustainability of waste management, and the tightening regulatory demands related to recycling.

However, it seems that existing MCDM studies are still struggling with the inclusion of relevant environmental, economic and social aspects, and related stakeholder views (Goulart Coelho et al., 2017; Soltani et al., 2015). Use of MCDM methods typically relates either on selection of optimal waste management strategy, or identification of optimal location for a recycling facility or landfill (Achillas et al., 2013; Goulart Coelho et al., 2017). While the number of MCDM studies related to waste management is increasing rapidly, existing studies are unevenly distributed between waste streams. The majority of the MCDM studies published in scientific journals have focused on management of municipal solid waste (MSW). When considering the waste streams that are of interest within the COLLECTORS project, only few studies related to CDW and WEEE management can be found from the literature, and MCDM studies related to different packaging waste streams are rare as well (Achillas et al., 2013; Goulart Coelho et al., 2017).

Morrissey & Browne (2004) categorise commonly applied waste management models to those based on cost-benefit analysis (CBA), those based on life cycle assessment (LCA), and those based on multicriteria decision-making (MCDM) techniques. Within COLLECTORS, all three types of assessment models have been applied, and the possibility to combine information and criteria from all three kinds of assessments was considered and tested in practice for PPW and WEEE management.

2.2 Aim of MCDM in COLLECTORS project

This study extends existing literature by applying MCDM in the context of packaging waste, WEEE and CDW, and by presenting a PPW case study in which information and criteria representing economic, environmental and social aspects was combined. While the MCDM studies including all three aspects of sustainability are getting more common, it seems that inclusion of social criteria is still rare, when compared to the number of studies using environmental and economic criteria (Goulart Coelho et al., 2017). Within this study, the importance of social criteria was discussed, and the challenges related to measurability and comparability of the social criteria was discussed by the experts during the MCDM workshops.

Previous studies have highlighted how many MCDM studies related to waste management are focused on mainly technical aspects related to the assessment process, and to the applied methodology, and forget to analyse the decision-making process itself, and how it should be organised (Morrissey & Browne, 2004). Thus in addition to the use of MCDM methods, one of the aims of this study was to consider the decision-making process in general, in order to understand how and when the methods of multicriteria decision-making could be used to support the process.

In this study, group decision-making methods were applied as participatory methods. This means, that the aim of the MCDM exercises was to create discussion among the participants and to learn from their views and experiences. The idea of the workshops was to organise an event in which the participants could exchange ideas and learn from the experiences of others. Thus, one of the important aims of the workshops was to serve as a learning exercise for all participants. The implementation of the MCDM methods was adapted and tailored according to each decision-making situation, and the main emphasis was on discussions rather than implementation of the methodology. Thus, compared to many of the MCDM studies that can be found from the literature (and that are focused on testing and further developing the MCDM methods and the underlying mathematical models), the aim of this study was to consider, how MCDM could be applied to support the decision-process, rather than merely taking a specific decision.

Background data for the MCDM exercises and studied decision-making scenarios was collected mainly from the COLLECTORS database (Deliverable 1.2) and from the case study reports (especially the LCA and CBA results, which are reported in detail in COLLECTORS deliverables D3.2 Report on the economic and financial performance of waste collection systems and D3.3 Report of

recommendations for improvement of single systems and optimum operation conditions). Additionally, findings from the social assessment (D2.5 Report on implemented solutions and key elements in selected cases for societal acceptance) and the report related to circularity assessment (D2.4 Report on solutions for tackling systemic and technical boundary conditions) provided important insights for planning the expert workshops.

Findings and conclusions from the MCDM exercises will provide input also for WP4, in which the results from the group exercises and criteria discussions will be thoroughly analysed and categorised. The aim of the analysis will be to identify potential patterns that are common to different waste streams, and to recognise challenges that should be overcome in similar decision-making situations. These results, and the recommendations related to criteria that could be used to support decision-making related to waste management, will be discussed in COLLECTORS deliverable D4.4 Report on generalized criteria to support decision-making.

2.3 Overview of the MCDM workshops included in this study

During 2019, data was collected from three expert workshops. Two of the workshops focused on multicriteria decision-making exercises, and one workshop discussed challenges related to decision-making on a more general level. One of the MCDM workshops was focused on actions and information needs related to collection of PPW, and another one was focused on WEEE collection. The third workshop applied a simplified decision-mapping technique, and discussed all waste streams (PPW, WEEE & CDW). The workshop participants were waste experts working for municipalities, municipal waste management companies, regional associations and representatives of the producer responsibility organisations. Additionally, a few of the experts worked in tasks related to regulations and monitoring.

Two of the workshops were organised as part of the COLLECTORS Regional working group (RWG) meetings. Open invitations to the RWG meetings were shared via the project website, social media channels and networks of the project partners. The intention was to invite participants representing various kinds of regions from different European countries, but with knowledge of the dedicated waste streams that were discussed in each meeting. The WEEE workshop was organised together with the WEEEForum, and all the participants were representatives of WEEEFroum member organisations from different European countries.

In addition to the three workshops organised in 2019, the findings of this study build on the results and experiences that were gained during the first MCDM exercise that was organised in Malta in September 2018. The results from this first exercise were reported in COLLECTORS deliverable 1.3 (Selection of 12 validated case studies), and only the main conclusions from the workshop are reflected in this report. The aim of the MCDM exercise in Malta was to evaluate the criteria that

could be used for identifying good practices in waste collection. After the workshop, these criteria were applied for preliminarily selecting potential good practice case studies from the COLLECTORS database. However, in addition to available database data and ranking of the waste collection systems, the selection of the case studies was affected by data gaps within the database, and the willingness of the regions to participate in the case studies.

All workshops organized during the COLLECTORS project, applied MCDM methods and discussed waste streams are summarised in Table 1. More information about the MCDM methodology is presented in Chapter 3, and in the Appendix.

Table 1 Overview of the MCDM workshops organised during COLLECTORS project

Workshop	Discussed waste streams	Applied methods	Aim of the workshop	Attendees	Discussed in
25.9.2018 Malta*	PPW, CDW & WEEE	MCDM: MAVT, PROMETHEE and SWING weighing	Evaluating and weighing criteria that could be used for identifying good practice WCS and analysing regional differences	Altogether 27 decision-makers (11 RWG members from 11 countries, local experts + project partners	Deliverable 1.3*
25.6.2019 Warsaw	PPW	MCDM: MAVT and SWING weighing	Improving collection of PPW, choosing a PPW management strategy and defining criteria for making informed decisions	9 RWG members from 9 countries + 8 COLLECTORS partners in supporting role	Chapter 5
21.11.2019 Brussels	WEEE	MCDM: Pairwise comparisons using AHP and SWING weighing	Proposing and prioritising means & criteria for improving WEEE collection in two regions	21 WEEE Forum members from 10 countries	Chapter 6
10.12.2019 Thessaloniki	PPW, CDW & WEEE	Decision-mapping + group discussions	Discussing typical decision-making challenges and applicability of different criteria for decision-support	10 RWG members from 9 countries	Chapter 4

* Main findings reported in COLLECTORS deliverable D1.3

3. Applied methods

3.1 Characteristics of MCDM methods

Methods of multicriteria decision-making can be used for breaking down complex problems into manageable components. This is helpful for prioritising for instance different waste collection strategies that can have divergent economic risks and anticipated capture rates in recyclable waste fractions. With the help of MCDM, different dimensions, such as environmental and economic impacts that are important for the decision-making context, may be considered and evaluated one at a time. With the help of group decision-making methods, opinions from several decision-makers (possibly having different values and preferences) can be collected and included in the decision.

The MCDM process consists of several steps that include:

1. Problem definition stage:
    a. Definition of the overall objective ("Goal") for the decision-making (such as "Improve the regional waste collection")
    b. Dividing the goal to several lower level objectives that describe different dimensions relevant for reaching the goal (such as increase material for recycling and increase local welfare)
    c. Defining the criteria that describe the performance of the alternatives in each selected dimension (such as capture rates of recyclable materials in tonnes/year and increase in local employment in number of new jobs)
2. Data collection stage:
    a. Defining the decision alternatives (e.g. collection strategies or technical solutions to be considered) and collecting data on their performance and characteristics (or relying on the expertise and judgement of the decision-makers for defining the options and evaluating their impacts)
    b. Creating a matrix that describes the performance of the alternatives on each selected criteria
3. Decision-making stage:
    a. Measuring the decision makers' preferences e.g. using criteria weights, according to a selected MCDM method
    b. Ranking of the decision alternatives according to a selected MCDM method.

Many different MCDM methods have been developed and studied in scientific literature (Soltani et al., 2015). The purpose of an MCDM method is to establish a ranking of the alternative options, based on available information on the alternatives themselves and the decision-makers' preferences. The problem definition stage and data collection stage presented above can be very similar regardless of the actual MCDM method applied. Moreover, MCDM methods can incorporate

a similar concept of criteria weights, which can measure for instance how much more important a better capture rate of a recyclable material is compared to lower costs of collection.

3.2 MCDM methods applied in COLLECTORS

Within the COLLECTORS project, the applicability of different decision-support methods was evaluated by experimentally solving different types of decision problems using multicriteria decision-making. Expert workshops were attended by invited experts and project partners. The MCDM workshops were organized at key moments in the COLLECTORS project, starting as a decision-support tool in selecting the 12 case studies for work packages (WPs) 2 and 3 (See also deliverable 1.3). At the same time, and in the subsequent workshops, MCDM exercises supported the critical evaluation of selected performance criteria for identifying good practices and pre-requirements for making informed decisions in waste management.

The problem structuring at the MCDM workshops was designed in effort to create discussion on how local context (such as demographic, welfare and collection performance-related factors) affect the priorities in decision-making. Finally, the MCDM workshops were used to assess the applicability of MCDM methods in different kind of decision-making situations that are typical to waste management. The applicability is determined based on qualitative assessment of the discussions held during the workshops, and on the successfulness of the selected methods to produce a useful outcome.

The MCDM methods that were applied during the project were selected considering the availability of the background data on each of the waste streams, and the main aim of the workshop. The applied MCDM methods were **Multi-Attribute Value Theory (MAVT), Preference Ranking Organization and Method for Enrichment Evaluation (PROMETHEE) and Analytical Hierarchy Process (AHP),** all being well-established decision-making methods. The workflow and the organisation of the group decision-making were tailored for the purposes of the project. Contents of each workshop are explained further in the related sections of this report. The decision-makers' preferences on the importance of different criteria was measured using **SWING weighing** in all of the workshops. The applied methods are described in short below and in more detail in the Appendix.

SWING weighing method was applied in all of the workshops for criteria weighing. The weights described the importance given for a waste collection system's performance in a certain criterion, such as capture rate. In the SWING weighting method, the most important criterion is given a value of 100 points. The next most important criterion is given an importance of equal or smaller than 100 points, the third most important criterion an importance equal or smaller than the second criterion etc. This is continued until arriving to the least important criterion that has an importance of equal

or higher than zero. Although more accurate methods to elicit the criteria weight exists compared to SWING, such a trade-off weighing where the performance differences are better included in the decision, the method benefits from simple and less time-consuming implementation. This allowed time for more open discussion during the workshops.

Analytical Hierarchy Process (AHP) and **Multi-Attribute Value Theory (MAVT)** are two commonly used value-based MCDM methods for establishing the preference order of the alternatives. They use a fundamentally different approach for assessing the performances of the alternatives in the included criteria, but provide similar results as cardinal (i.e. describes which alternative is better and by how much) normalized scores for each alternative. AHP was applied in the Brussels workshop (21.11.2019), which focused on assessing WEEE collection improvements from a clean table without pre-defined alternatives. In other words, the experts who participated in the Brussels workshop both proposed what the alternatives should be and established how well the alternatives compare against each other. MAVT was applied in the case selection workshop (25.9.2018 Malta) and in the PPW workshop (25.6.2019 Warsaw). In the Malta and Warsaw workshops, decisions were made using a set of pre-defined alternatives and supporting performance data. In these two workshops, the decision-makers' role was therefore to decide between the importance of the presented criteria, when comparable data between the alternatives was available.

In the Malta workshop, an **outranking method PROMETHEE** (Preference Ranking Organization and Method for Enrichment Evaluation) was used as a complement to MAVT for ranking the alternatives. Similar to AHP and MAVT exercises, the criteria weights were elicited by SWING weighing. PROMETHEE was incorporated in order to have a reference method, which can establish a ranking despite random occurrences of missing performance data for the alternatives. Furthermore, it allowed comparing the applicability of the two MCDM methods in the same workshop setting, because establishing the preference functions in the PROMETHEE differ from how the value functions are assessed in the MAVT.

4. Challenges in decision-making process related to waste collection systems

4.1 Mapping of the decision-making processes

Challenges related to decision-making in the context of waste collection systems were discussed during all COLLECTORS workshops, but a dedicated discussion regarding common challenges was held during the workshop in Thessaloniki in December 2019 (see Figure 1). The aim of the workshop was to get a better understanding of the decision-making processes related to waste collection, in order to consider, where and how MCDM methods would be most useful. The workshop included a decision-mapping exercise in which the participants drew maps about a decision-making process they were familiar with. The participants were asked to describe the main phases related to this process and to name the actors who were involved in each phase. In addition, they were asked to describe the main challenges related to the process.

Figure 1.The COLLECTORS workshop with the regional working group in Thessaloniki, 10.12.2019

Ten experts representing nine different European countries and regions (Belgium, Norway, UK, Romania, Portugal, Spain, Italy, Greece, and Poland) participated to the workshop, and eight decision-making processes were presented and discussed. All participants had several years of professional experience from different tasks related to waste management either from the PRO side or from public organisations (cities and regional associations) or public waste management companies. The decision-making processes presented by the participants were related to different waste streams, ranging from PPW and biowaste to WEEE and CDW. The participants were advised to choose an example related to any waste stream or waste related decision-making process in which they had been involved. Thus, the focus of the workshop was slightly wider, compared to the COLLECTORS case studies, which focused on dedicated PPW, WEEE and CDW streams. However, in this context, it was considered that examples from all waste streams would be useful for the study.

Presented decision-making processes included for example:

- re-organising the collection of MSW and packaging waste and agreeing on the division of costs between the actors,
- organising locations for urban composting in order to separate biowaste,
- re-organising PPW collection in order to increase recycling rates,
- introducing a new fee for collection and treatment of municipal waste,
- establishing a new civic amenity site and organising the necessary infrastructure for waste collection, sorting and treatment.

Additionally, generic descriptions of a typical decision-making process from the point of view of a WEEE PRO and a municipal waste management company were presented and discussed.

In most of the discussed cases, European recycling targets were mentioned as important drivers for implementing changes in the existing systems. Consequently, increasing collection or recycling rates was among the main targets of the discussed decision-making processes. Many of the examples were related to the distribution of costs and responsibilities between the actors. Discussions related to costs are an important part of the process, when making changes to existing systems or building new systems. However, in addition to European legislation, other drivers, such as new ideas originating from the local waste management companies, the citizens or other local actors were highlighted. For example, it was mentioned that increased interest of citizens to improve waste sorting had sometimes initiated the change process, or speeded up the planned changes.

Examples of the drafted generic decision maps from the point of view of a PRO (Figure 2), a municipal waste management company (Figure 3) and a city (Figure 4) are presented below.

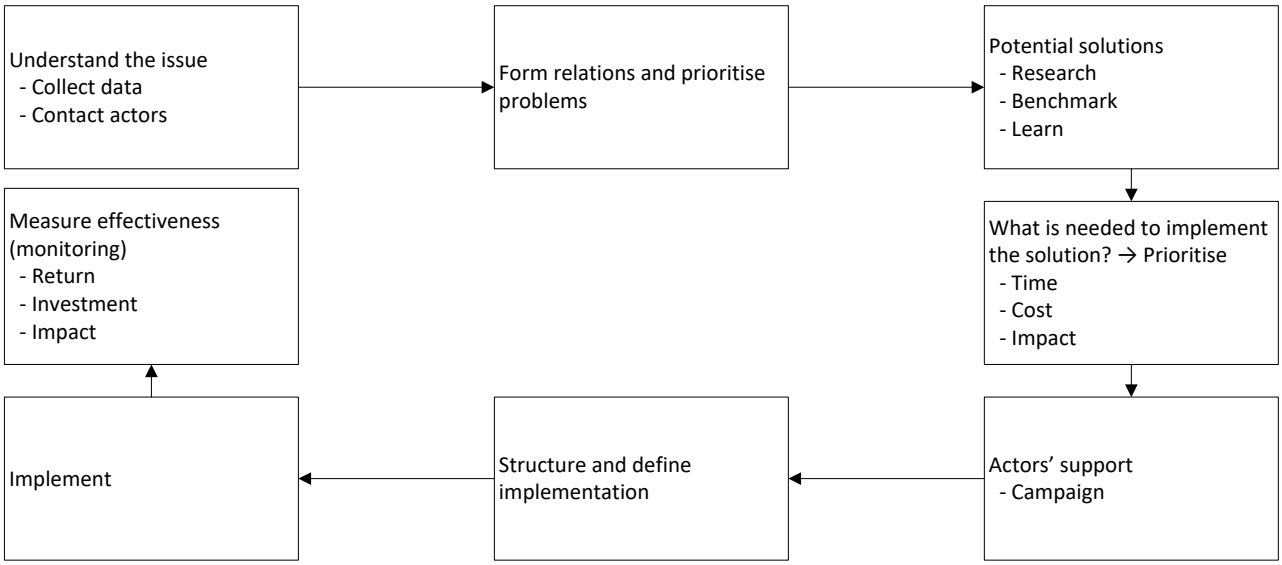

Figure 2 Generic decision-making process from a PRO point of view

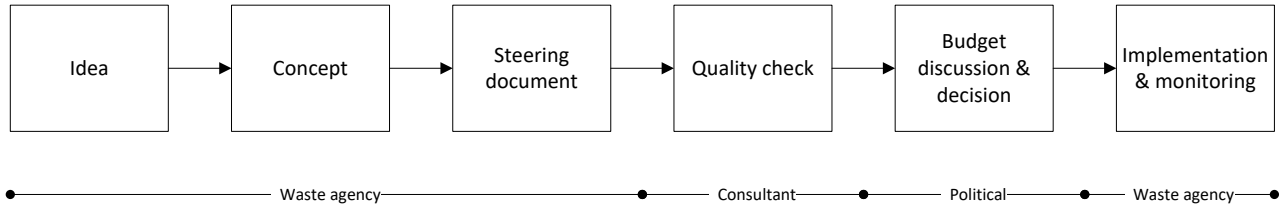

Figure 3 Generic and simplified decision-making process from a municipal waste management company point of view

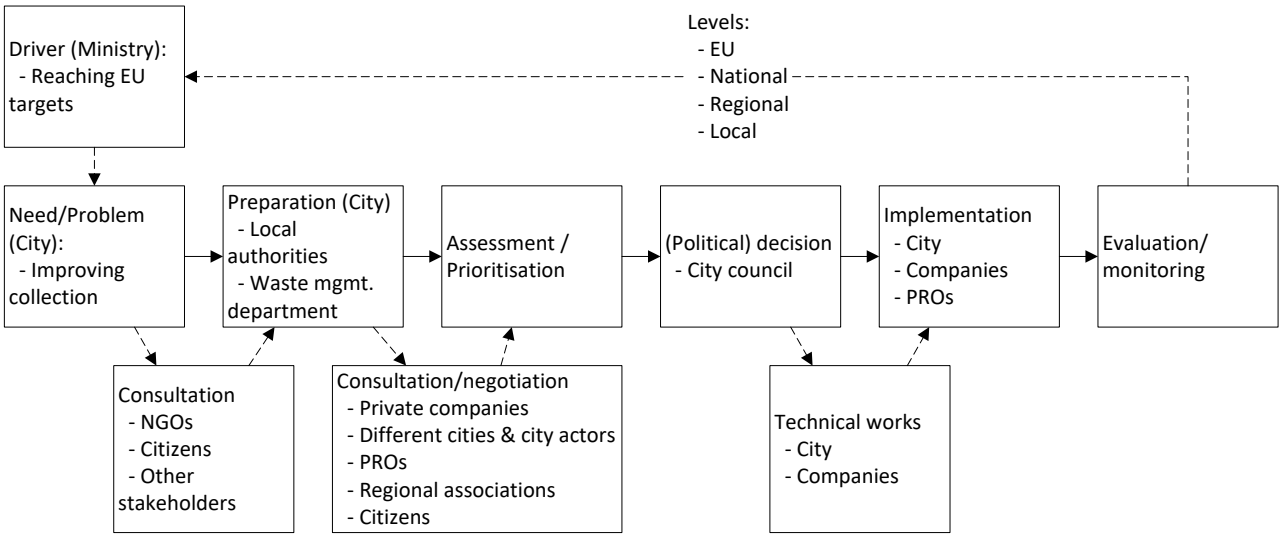

Figure 4. Generic and simplified decision-making process from a city point of view

4.2 Common challenges related to discussed decision-making processes

Main challenges described by the participants were related to the following topics:

- Understanding and defining the problem: how the problem should be addressed, what kind of options are available and where/how to find all necessary information,
- Coordinating activities: Reaching consensus and 'speaking the same language' with different actors (including different municipal actors/authorities but also PROs, and private companies involved),
- Engaging with citizens and others actors related to the process,
- Implementing the decisions in practice and finding practical ways for organising and monitoring performance.

In general, findings from the workshop indicate that making big changes to existing local or regional waste collection systems can be a long and complicated process, since consensus and acceptance has to be reached with many different actors. However, smaller adjustments that fall under the responsibility (and within the normal budget) of the local waste management company, might be implemented in a rather straightforward manner. At least part of the challenge, as described by the participants, related to the need for many coordinating activities during the process. Final decision-making phase and acceptance might be a more or less formal discussion or budget decision, but before that, several mid-term decisions are usually needed, and many informal decisions might take place during the preparatory phase.

The following subchapters shortly describe the above-mentioned decision-making challenges as identified in the context of the COLLECTORS expert workshops. From the point of view of MCDM methods, the findings from the workshops indicated, that it is important to consider the decision-making process as a series of connected events (that may take place in parallel), rather as one occasion. In addition, decision-making is often affected by lack of precise or comparable data. Occasions during which all necessary information (for well informed decision-making) would be available can be rare. In addition, different kind of struggles might be related in collecting and balancing between opinions of all related stakeholders.

Problem definition and lack of data

Several participants highlighted the importance of the problem definition phase. This is a phase in which a lot of data would need to be collected, in order to understand the current situation, and to find reasonable solutions for improvements. It was mentioned that problems usually consist of several sub-problems, which might need different kinds of solutions. For example, the reasons behind low WEEE collection rate might be related to both, low awareness of and lack of proper

infrastructure for collection. The problem definition phase is also important for defining what kind of options are put on the table for further discussions, and who will be involved in the process.

Interestingly, the examples discussed during the workshops varied to some extent, according to the timing of the consultation with stakeholders. In some occasions, it was part of the problem definition phase (before defining alternatives), and in some occasions, consultations were done when at least preliminary information about potential options was available. The timing of the consultation might affect, what kind of options actually enter the preparatory process. On the other hand, resistance to change might also act as a barrier for making any changes, if stakeholders are engaged early in the process.

One of the common problems that seems to increase complexity in the problem definition phase is related to lack of proper data from the collection and recycling chain. Challenges related to data availability have been highlighted in several contexts throughout the COLLECTORs project, especially during WP 1 when information for the COLLECTORs database (D1.2) was gathered, and later during the case studies in WPs 2 and 3.

Identified data gaps can be summarised as follows:

- Waste generation: information is missing regarding the composition of mixed fractions (sorting analyses are done in many different ways or not done at all), and information is missing on waste escaping the public service (illegal practices, amount of small WEEE stored at homes, etc)
- Waste collection: missing information from collection systems outside the public service (re-use organisations, take-back systems, private collection schemes...)
- Impurity rates of sorted fractions (it is often unclear to collectors how much of the collected waste is actually recycled and how much is rejected)
- End-use application of sorted fractions (it is often unclear to collectors where their collected waste is going and how it is further processed).

Sometimes, aggregated information about collected quantities might be available at national level, but it is not possible to apply this information for making assessments at local or regional level.

Data gaps in the collection and recycling chain might lead to unnecessary or suboptimal sorting or collecting activities. For example, the circularity analysis conducted in WP2 revealed an example, in which separate collection for different coloured glass fractions was in place, even if the receiving glass recycling facility had optical sorting technology in use (See deliverable 2.4).

The discussions conducted during the workshop highlighted that practices related to monitoring, reporting and data sharing between actors (for example in regards to quality of the waste, amounts being collected and recycled) may differ quite a lot between regions and countries. Reporting, monitoring and data sharing seem to be areas in which sharing knowledge about best practices would be helpful. In addition, increased interest towards circular use of raw materials increases the need for data sharing within the recycling chain in future.

Need for coordinating activities and reaching consensus

Many of the discussed challenges were related to different kinds of coordinating activities (cooperation between people and organisations) that are needed during the decision-making process. Described decision-making processes involved several actors: municipal actors (different city departments), public and private waste management companies, ministries, local policy makers, PROs, NGOs, transport companies and the citizens.

For example, when trying to find a location for a new civic amenity site or sorting centre (in order to improve sorting and reduce landfilling), there is a need to find a suitable location which would be accepted by the different departments of the city, and by the near-by residents and companies. Issues related to availability of the service (transport and logistics) need to be considered, and permits related to environment, health and safety have to be acquired. Availability of necessary trucks and other equipment has to be ensured by discussing and negotiating with potential service providers and contractors.

A specific example related to potential causes of internal disagreements between different city departments/responsibles (and mentioned at least a few times during different COLLECTORS workshops) was related to agreeing on the location, appearance and size of the rubbish bins or bring points in public places and parks. It was pointed out how demands related to visual appearance of the bins might be in conflict with their necessary size and usability, leading to problems related to littering.

These examples highlight, how organising waste collection is not only a technical or cost related issue (even though agreeing on the costs is a central part of the process), but relates to many other activities within the cities, such as architecture and other city planning. Changing a waste collection system is social challenge that requires cooperation between experts from many different fields. If a consensus is not reached, or if the participating stakeholders reject a proposal, there might be a need to start a new process from the beginning. Thus, the decision-making process might be repeating in circles, going back to the planning phase unless an acceptable solution is found during the planning and consultation phases.

In the workshop, collecting feedback and reaching consensus between different actors were considered challenging and often laborious, but important. It was emphasized, that a lot of time is often spent in getting the participants to speak the same language. This challenge is closely linked to the problem definition phase: how the different actors interpret the problem, what kind of changes would be required in activities of each organisation, and who will need to pay the costs. From administrative point of view (highlighted by the municipal actors), it was pointed out how finding and implementing new solutions often falls under the responsibility of several departments, which increases the complexity of the task. There might also be conflicting regulations that hinder the process. From the PRO's point of view, the challenge might be related more on finding and

activating good partners for cooperation, and acquiring acceptance, as the PROs usually lack any formal power for enforcement, and are dependent on cooperation with other actors.

Citizen engagement

Engagement with residents was seen as a special task that requires attention and resources, but challenges related to this topic were not discussed in detail in this context. However, on a more general level, understanding consumer behaviour, consumer acceptance and easy access to waste collection were highlighted as essential elements when making changes to waste collection, in order for the system to succeed. One of the participants especially highlighted that it is likely that problems will follow later, unless some kind of acceptance is reached during the preparatory process.

Issues related to citizen engagement and social acceptance were one of the topics, in which knowledge exchange related to good practices was considered useful. Examples of different approaches tested in different countries and regions were shared in each workshop. Currently, different cities and regions each conduct their own studies, and learning from the experiences of others (to avoid same mistakes) was considered useful. Cultural differences were expected to pay some kind of role, but in general, similar challenges in reaching the attention of people and making the collection easy to reach, were described in all regions. For more information about social acceptance and stakeholder engagement related to waste collection, see COLLECTORS deliverable 2.5 'Report on implemented solutions and key elements in selected cases for societal acceptance'.

Implementing the decisions and monitoring performance

The implementation phase requires further coordination activities between the actors working in the recycling value chain. During the workshops, the importance of the monitoring activities was highlighted, together with challenges related to measuring performance of both current and new systems. In order to monitor the performance, more information about waste generation and composition, the complementary flows (that are currently unknown) and about the end-use of collected materials would be needed. This would also require increasing information exchange across organizational boundaries in future, as different actors are each responsible for their own part of the value chain, and the overall picture might be lacking.

4.3 Potential role of MCDM as decision-support in waste management

Previous studies related to use of MCDM in the context of waste management propose, how MCDM studies are often focused on building the models and weighing the criteria, and understanding of the decision-process as a whole might be lacking (Morrissey & Browne, 2004). The aim of the MCDM

studies has most often related to choosing a preferred waste management strategy, or location for a waste treatment plant or landfill (Goulart Coelho et al., 2017). The findings from this study indicate that MCDM could be useful for the problem definition and idea generation phases, but also for collecting input and reaching consensus between different actors (See also Bachér, Pihkola, Kujanpää, & Mroueh, 2018; Soltani et al., 2015). Based on the discussions held during the COLLECTORS workshops, both are important and challenging phases when considering the decision-making process as a whole.

Besides actual decision-making, MCDM can be can be used for structuring the discussion and sharing the views of the participants. Structured discussion can be helpful for finding consensus, or reaching a compromise between different actors. During all COLLECTORS workshops, a lot of time was dedicated for discussion, and for collecting the views and arguments of the participants. This way, the participants had a chance to learn from the responses of others, and exchange ideas of good practices.

Additionally, it is considered that MCDM could be especially helpful for the problem definition phase, for collecting ideas and comparing the effectiveness of alternative options, and understanding their interlinkages. In this kind of situation, main emphasis is not on building a mathematically solid decision-support model or matrix, but collecting expert opinions in a structured way. This way, the methods can be applied in a situation in which background data or performance data is missing, and alternative approaches are considered for further studies. However, a sensitivity analysis of the final MCDM results and the proposed criteria weights is always recommended. An example for such an MCDM exercise related to WEEE is presented in Chapter 6. The purpose of MCDM studies should therefore not be restricted to well-informed situations such as final investment decisions. The purpose of an MCDM study may well also be to increase consensus within a group of actors on the appropriate options how to move forward towards a shared goal.

In principle, MCDM methods could also be used for collecting the views of the citizens, in a focus group or similar context. This would be an interesting topic for future studies. In addition, inputs collected from citizens by other means could be used as an input for the MCDM, or for weighing the criteria. Waste management experts, who participated in the COLLECTORS workshops, highlighted the need for citizen engagement in many occasions throughout the project, and pointed out that new means for such processes could be useful.

5. MCDM workshop related to paper and packaging waste

5.1 Aim and content of the workshop

A dedicated workshop focusing on PPW collection was held in Warsaw in June 2019 as part of the COLLECTORS RWG meeting (see Figure 5). The aim of the workshop was to discuss and to prioritise available options for improving PPW collection, based on the data collected during the COLLECTORS project. Additionally, the idea of the workshop was to discuss criteria that should be used for informed decision-making, and to provide a learning exercise to all participants.

The aim of the MCDM exercise was to select a preferred waste collection strategy to a fictive case region in which the capture rates were below the median values, when compared to other systems that were included in the COLLECTORS database (D1.2). The starting points for the strategy selection were the current situation (performance of the region) and two pre-defined propositions for new collection strategies. The proposed two strategies were drafted using the criteria, performances and collection strategies from the five COLLECTORS PPW case studies representing well-performing regions.

Figure 5. The COLLECTORS workshop with the Regional Working Group members at Warsaw, 25.6.2019

As part of the exercise, the participants proposed actions that they considered useful for improving the performance of the system, and modified and selected a new waste collection strategy for the region, based on two pre-defined options. Additionally, the workshop included discussion about the environmental, economic and social criteria that were considered important for choosing between the alternative options for improving collection rates.

During the workshop, criteria derived from the five PPW case studies of COLLECTORS were weighted using the SWING method, and additional criteria were proposed and weighted by the participants. Finally, the preferred collection strategy was selected based on criteria weights, using an MCDM method Multi-Attribute Value theory (MAVT), and the result of the exercise was discussed together with the participants. The main emphasis of the discussion was to consider how the performance of the waste collection system could be improved, and on the other hand, how (based on what kind of information, or criteria) the performance of the system, or the proposed improvement options, could be evaluated.

Answers to the specific questions related to the MCDM (criteria weighing) were inserted in an excel sheet, in which the MCDM method (MAVT) was integrated. During the exercise, the participants could follow from the screen how their answers contributed to the weight of each criterion, and how the result from the exercise was formulated. They could also hear and see the answers from other participants, ask questions and comment on the outcome.

Nine experts representing different European countries that included Lithuania, Poland, Romania, Ireland, England, Greece, Croatia, Norway and Belgium participated to the workshop. All experts had several years of experience in working with waste management in their regions, either at local, regional or national level. All participants represented large European cities, most of them being capital regions. In addition to the invited experts, 10 COLLECTORS project partners participated to the discussions, and provided background information related to COLLECTORS database and case studies.

5.2 Assumed decision-making-scenario & case study description

The case study description and the alternative waste collection strategies (together with their assumed impacts) were compiled based on information that was available in the COLLECTORS database (D1.2), and in the case study reports. Some adjustments to the data were necessary and expert estimations were used to modify the data. Thus, the fictive case study was loosely based on information collected from existing waste collection systems. The case description, together with all the information that was presented to the participants at the beginning of the workshop, is presented in Table 2.

Table 2 Description of the PPW case study discussed during the workshop in Warsaw

Regional characteristics
• This capital region is located in inland. • Number of inhabitants is 1,752,000, and the size of the area is 525 km^2. Population density is 3,338/km^2. • The share of detached or semi-detached houses in the region is 15%. Total number of households is 759,110. • The region has a reasonable amount of tourist visits (5.1 overnight stays per inhabitant per year). • GDP per capita is 22,800€ (EU average GDP/capita is 32,000€).
Performance figures related to waste collection
• MSW generation per capita per year is 348 kg (EU average is 467 kg). • Current capture rates* are: Glass 18.5%, Paper 39.5%, Plastic 15.2%, Metal 68.5%. • The capture rates are below the median level, when compared to the 135 other regions documented in the COLLECTORS database. • Possible reasons for low capture rates (according to the OECD Environmental performance review 2018) are cheap landfilling and burning of waste to heat households. • Estimates on the shares of separate collection rates from total waste generation range between 5-15%. It is estimated that around 10% of collected materials are rejected from recycling.
Description of the waste collection system
• The local authority subcontracts a non-profit company. They are responsible for waste management services, including waste collection, its transport and treatment. • Door to door collection for paper & cardboard, plastics & metals. Separate collection for paper and biowaste, co-mingled for plastics & metals (coverage ~ 100% of households). • Glass is collected at bring points and CAS. Some bring points + CAS collect also paper, metals and plastics. No specific collection for composite materials. • The door-to door collection was implemented five years ago, previous system was based on bring points. Collection frequency for paper, plastics and metals from family-house zones is every 4 weeks, and from block houses once a week. Biowaste is collected once a week, from March to December. • Collection of dry recyclables is free of charge to consumers. A separate fee for residual waste and separate collection of biowaste is charged (the system has PAYT elements). • A deposit scheme for glass bottles is in place, but no information about the collected quantities was available.
Description of the bring system
• Number of bring points for glass: 304 (of which 122 are for glass only)   • Number of inhabitants per glass bring point: 5,765 (= 26.5/100,000 inh.) • Number of bring points for paper, metals & plastic: 182

• **Number of inhabitants per bring point: 9,360** • **Number of bring points for glass: 304 (of which 122 are for glass only)** • **Number of inhabitants per glass bring point: 5765 (= 26.5/100,000 inh.)** • **Number of bring points for paper, metals & plastic: 182** • **Number of inhabitants per bring point: 9,360**		
Implementation of the collection system - Collected quantities (kg/per capita)		
	2011	**2015**
Paper & packaging	5.6 kg/capita	14.1 kg/capita
Plastic	2.7 kg	6.9 kg
Metal	0.5 kg	1.1 kg
Glass	3.3 kg	2.7 kg
Bio-waste	-	11 kg
Capture rates at the case study region*	**Median values in the COLLECTORS database**	**European circular economy targets for 2025**
• **Glass 18.5%** • **Paper & cardboard 39.5%** • **Plastics 15.2%** • **Metal 68.5%**	• Glass 68.0%, • Paper & cardboard 58.0% • Plastics 18.5% • Metal 27.6%	• Glass 75% • Paper & cardboard 85% • Plastics 55% • Ferr. metals 80%, Aluminium 60%

*Capture rates for the PPW streams were calculated as follows: separately collected amount/(amount in residual waste + separately collected amount)*100. Amount in residual waste was estimated based on the most recent result of a waste composition analysis.

Proposed improvement actions for PPW collection

The experts revised the situation in the case region, and were asked to propose their views on improvement actions that should be considered for the region. The case region had low household waste fees (although having low GDP) and the sorting analysis revealed that significant amount of recyclable materials ended up in the residual waste bin. The experts also took notice that the landfilling was cheap and that the waste bins were kept on the kerb-side, without any restrictions to access them.

The experts commented that it is very hard to get high capture rates with uncontrolled kerbside collection. The collection system for residual waste was considered too easily accessible for recyclable waste fractions. At the same time, the pay-as-you-throw mechanism for residual waste should be strengthened in order to create a stronger link between individual responsibility and the

amount of residual waste generated. Landfilling tax was proposed as an efficient driver to reduce the residual waste generated. However, it was also noted that in order to be effective, landfill tax should be gradually increasing. It was also proposed to diversify the sizes of bins to encourage better segregation of recyclable waste. The frequency of the collection should be considered, based on the fill rates of the bins. This would require changes in the current system, but would increase flexibility of the service and possibly allow collecting waste from a larger area at a time, if people would put out only those bins that need to be emptied.

The number of recycling-points (bring-points) should be increased. The experts took notice that the glass capture had not increased in the region although door-to-door-collection of other recyclables had been introduced, which usually serves to increase the awareness on recycling in general. Therefore, awareness rising and education measures should be taken in conjunction with increasing the number of bring-points for glass.

Finally, monitoring activities should be improved to provide information to steer the collection system. The rather low waste generation numbers indicated a possibility that part of the waste was not collected at all but for instance burned in household stoves. Without such details on the present state of the collection system, it is more challenging to produce optimal solutions to improve the system.

Discussed waste collection strategies

After discussing potential improvement options, the pre-defined, alternative new waste collection strategies for the case region were presented and discussed. Preliminary strategies were formulated prior to the workshop, based on information collected from the COLLECTORS case studies and the database. Based on the discussion and comments from the participants, some modifications and adjustments to the proposed strategies were made. After the modifications, the two strategies became quite similar, but the differences in assumed performance of the two options were retained. The final, modified strategies that were applied in the MCDM exercise are presented in Table 3.

Table 3 Alternative PPW collection strategies discussed during the workshop

	Strategy A	Strategy B
Separation of PPW	Promote source separation, continue single collection of glass & paper, continue co-mingled collection of metals & plastics	Increase co-mingling, start collecting drinking cartons+plastics+metals together (door to door), achieve synergy in collection

Door-to-door collection	Invest more in flexibility of door-to-door collection, employ some more drivers	Continue separate collection of paper, start co-mingled collection drinking cartons+plastics+metals (door-to-door)
Bring points	Increase nr. of bring points for all fractions	Increase nr. of bring points for glass
Other investments		Invest in sorting technology (build new sorting facility)
Awareness raising and participatory actions	Increase education to reduce impurities Employ new waste counsellors, organise campaigns Implement a customer feedback system	Increase education Employ new waste counsellors, organise campaigns Implement a customer feedback system
Economic incentives	Implement a higher waste fee for residual waste, strengthen PAYT elements (more incentives for recycling), implement a landfill tax	Keep residual waste fee at current level
Estimated impacts	Increases collection costs more, but reduces waste processing costs (buy as service) Potential for higher industry fees due to better quality recyclables	Increases cost of collection less, but increases cost of waste processing

Criteria used for decision-making

The next phase in the workshop included discussions on criteria that would be important for evaluating the estimated performance of the alternative waste collection strategies, and making informed decisions. The pre-defined criteria, based on information derived from the previous

phases of the project, and the exercises held during the COLLECTORS workshop in Malta, were presented to the participants. The decision criteria were selected from the indicators used in the LCA and CBA case studies (See COLLECTORS deliverables 3.3 for the full LCA results and 3.2 for the CBA results). Both of the studies shared a mass balance data, from which the capture rates and recycling rates were taken as potential performance indicators.

Criteria performances for strategy B were taken or interpolated (based on capture rates) from the case study with high degree of co-mingled collection of PPW. Similarly, the criteria values for strategy A were based on the average performances of the cases with similar degree of source separation. Global warming potential was included as the only environmental criterion, as there were no real trade-offs between the case performances in different environmental impact categories that were included in the COLLECTORS LCA studies and the LCA results correlated strongly with the recycling rates. This interdependency between the capture rate and the environmental performance was known and discussed prior to the actual decision-making during the workshop.

The economic performances of the improvement strategies were based on D3.2 Assessment of socio-economic and financial performance of 12 selected case studies. In the report, indicators such as the investment costs, operational costs and revenues for the cases are assessed and further calculated as profitability indicators such as net present values.

Before starting the actual criteria weighing exercise, the importance and usability of the proposed criteria were discussed, and modifications were again made based on the feedback received. During the discussion, participating experts proposed to add criteria related to proximity of the bring points (coverage of collection), existence of citizen feedback system and increasing local employment. Possible units for the proximity criteria would be the number of bring-points, coverage of door-to-door collection and the average distance to a bring-point. The criterion related to citizen satisfaction would be measured via a system of complaints and phone surveys. These criteria (that can be considered to represent relevant social aspects) were not included in the original proposal, due to lack of related performance data. In general, comparable data describing social impacts of the waste collection systems was difficult find (See Deliverable 1.3), even if possibility to include such information was included in the COLLECTORS database (See D1.2).

A full list of criteria applied in the decision-making exercise (and the assumed performance data) is presented in Table 4.

Table 4. The applied decision-making criteria and performances of Options A and B in the PPW collection improvement case.

Criterion	Target	Current	Strategy A	Strategy B	Unit
Capture rate - Glass	maximize	19	86	77	%
Capture rate - Paper	maximize	40	85	58	%
Capture rate - Plastics	maximize	15	57	35	%

Capture rate - Metal	maximize	34	78	42	%
Set-up costs	minimize	-	3.0	5.0	€/capita
Total operational costs	minimize	21.4	34.0	30.5	€/capita
Processing costs	minimize	17.5	20.0	24.8	€/capita
Collection costs - plastic & metals	minimize	305.6	380.9	286.7	€/tonne
Collection costs - paper & cardboard	minimize	91.5	121.7	84.6	€/tonne
Collection costs - glass	minimize	62.2	92.8	82.1	€/tonne
Collection costs - residual waste	minimize	234.5	311.8	273.9	€/tonne
Waste fee - Citizens	minimize	38.7	53.0	43.3	€/household
Waste fee Glass - Industries	maximize	53.5	97.5	53.5	€/tonne
Waste fee Paper - Industries	maximize	59.7	116.0	55.4	€/tonne
Waste fee Metal - Industries	maximize	444.6	656.3	444.0	€/tonne
Waste fee Plastics - Industries	maximize	335.2	782.0	313.7	€/tonne
Global Warming Potential	minimize	57.6	40.4	45.4	kg CO2-eq/capita
Proximity (n. of bring points, door-to-door coverage and distance to bps.)*	maximize	-	1	0	-
Citizen satisfaction (system for complaints, phone surveys)*	maximize	-	0	1	-
Employment*	maximize	-	1	0	-

*The criteria that were added during the decision-making workshop were only given normalized performance scores (1 indicating superiority over 0).

5.3 Results from the workshop

Feedback and discussion on the decision criteria

At the beginning of the MCDM exercise, the decision-makers (DMs, or participants) were presented a list of indicator values that included all the available decision-making criteria (See Table 4). Some of the indicators were overlapping on purpose[3], for instance the indicators included Capture rate, Share of recyclable materials rejected from recycling due to poor quality and overall Recycling rates, even if the Recycling rate was calculated based on the two previous indicators. The decision-makers were then able to choose which indicators they considered more appropriate.

It was pointed out how in this case, use of results from the sorting analysis for calculating the capture rate would add uncertainty to the performance figures. This was due to experiences of the

[3] In the MCDM methodology, all criteria should be non-redundant (independent and not overlapping with each other), in order for the evaluation approach to work properly. In this case, partly overlapping criteria were included in the discussion, in order to understand, whether they had different kind of information value, and which of the criteria would be considered most useful for decision-making purposes.

experts related to challenges in organising the sorting analyses in a harmonised and representative way. Practical experiences had revealed how the results of the sorting analysis were affected by many factors that caused large variety in the results (such as timing of collecting the samples, and the company conducting the analysis). However, from among available criteria capture rates were still considered as most appropriate indicators because they measure well the performance of the organisation in charge of the collection. Furthermore, compared to the actual recycling rate, the capture rates can be assessed more reliably, due to uncertain or unavailable information on the actual flows of the material after collection. Capture rate does not indicate how the collection system influences the quality of the waste, however.

The decision makers emphasised the benefits of basing decisions on recycling rates, but noted that without better monitoring practices this data is not reliable enough. As the EU targets will be based on recycling rates, such monitoring practices need to be implemented. First step forward could be to monitor the collection properly, adding identification chips into waste bins and measuring the weights of each container etc. Additionally, it would be important to harmonise the way sorting analyses are conducted.

From the waste management company point of view, the decision makers preferred the cost indicators to be adjusted according to tonnages instead of number of inhabitants. However, the criterion describing the costs per household or citizen would be relevant from a political point of view. For instance, the cost per tonne of residual waste collected is generally higher the less residual waste is collected. At the same time, the cost per inhabitant may decrease. Therefore, the choice of the right decision criterion must be made taking into account the broader context. From the economic criteria, the decision-makers preferred to include industry fees per tonne and waste fee per capita as decision criteria.

The use of the criterion related to greenhouse gas emissions (Global warming potential) in decision-making was discussed. According to the participating experts, its role has not yet been substantial. However, the feeling was that its importance would be growing in future, and some examples and plans related to use of GHG information were shared. The arguments not favouring the use of GHG emissions were that it is difficult to understand in the waste management context and is not useful information for the public due to complexity of the calculations. As there seems to be a negative correlation between recycling rates and GHG emissions, concentrating only on the recycling rate already gives the same message as information on GHG emissions would. The experts would nevertheless involve more environmental indicators into decision-making, not just the climate impacts but also other LCA indicators. It was considered important that when environmental information is considered, it should cover more environmental aspects than just climate impacts.

Based on experience, the proximity of the bring-points or bins, capture rates and satisfaction of the citizens correlate with each other. Therefore, the experts suggested to include a proximity criterion, such as distance to nearest bring-point, in the decision-making. Feedback gathering mechanisms, such as phone surveys, were considered important and widely applied. However, the role of

feedback surveys in decision-making should be evaluated for biases and people's resistance to change. Among typical biases are people's tendency to overevaluate their own performance in segregating waste. An example on resistance to change was given from a region that implemented a pay as you throw system. Initially, the citizens were going much against the change as they were content on the prevailing household fees. However, after a few months the citizens were very much in favour of the new pay as you throw system, because households now paid only for their own waste. It was commented during the discussions that citizen engagement possibly has a greater role in policy evaluation rather than in policy-making.

Decision-making using SWING and MAVT

The decision-makers were presented two pre-defined alternatives for improving PPW collection in the case region. Both options had comparable performance estimates in 17 criteria (see Table 4), including anticipated capture rates, costs, climate impacts and social aspects. After the decision-makers had considered the performance of the two improvement options in the presented criteria, they were asked to give weights to each criterion. The criteria weights were elicited using the SWING method. The weights describe the importance of each criterion, in relation to other criteria, for achieving the goal (improving PPW collection in the case study region).

The decision-makers gave their preferences in turn, while the others were allowed to comment if desired. Because of the time allowed for elaborating on the local case scenario, criteria performances and open discussion on reliability and relevance of information, the decision-makers were able to adjust their own preferences accordingly. Results from criteria weighing are presented in Figure 6.

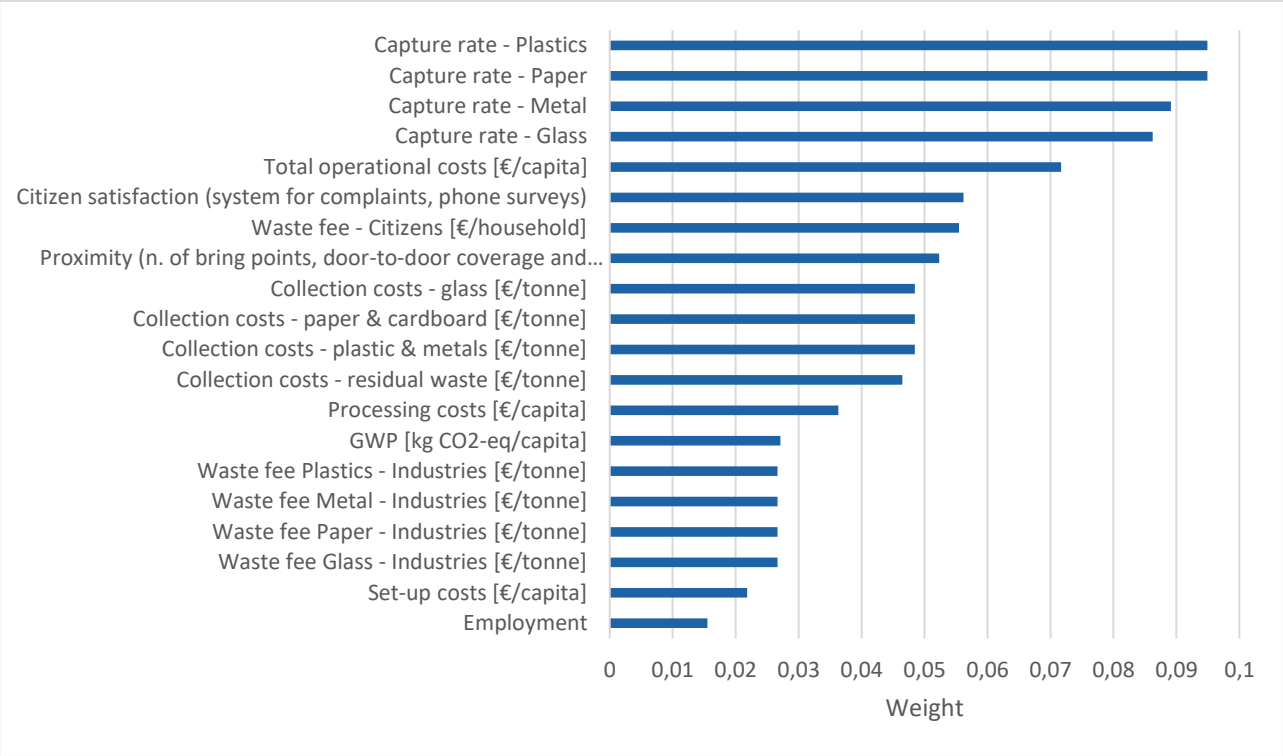

Figure 6 Normalized criteria weights for prioritizing PPW collection improvement options. The criteria weights describe the comparable importance of the included criteria, based on the decision-makers' preferences (higher weight means higher importance). Together with the performances of Strategy A and B in each criterion, the weights determine the overall scores of the two alternatives.

The highest weights were given to the capture rates, especially the capture rates of plastics and paper (See Figure 6). The importance of total operational costs followed behind the capture rates. The weight of the total operational costs was higher than the collection costs per each separate material stream. The waste fees paid by the industries, set-up and processing costs and the employment effects received below-average weights. The citizen satisfaction, proximity of bring-points and waste fees from households were considered more important than average. The citizen satisfaction and proximity of bring-points were criteria that were added during the workshop, and the unit of performance was more open for interpretation compared to the pre-defined criteria. This may have affected the answers of the decision-makers. For instance, if the average distance to a bring-point was considered a measure of the proximity criterion, the decision-maker probably had a good confidence in the accuracy of the value, and was confident that a close proximity to a bring-point always has a desired effect on the PPW collection. Regarding the weights given to different economic indicators, the decision-makers were able to consider their contributions to annual monetary flows.

In the MAVT method applied, these criteria weights serve as factors that multiply the performances of the alternatives in the criterion concerned. The overall value of the alternatives will then be the sum of these products. The overall values of the two alternatives, as a result of the MCDM exercise are presented in Figure 7.

The results show that the Strategy A received a higher score than the Strategy B due to better performance in the four most important criteria; capture rates of plastics, metals, glass and paper. Together with better performance in the proximity criteria, the score of Option A would have already been higher than Option B, which was in turn a better performer in many well-valued criteria including citizen satisfaction, household waste fees, collection cost per each waste stream and total operational costs.

Figure 7. Overall values (scores) of PPW collection improvement strategies A and B. The scores are a measure of how good the two strategies are, compared to each other. The scores indicate both the order of priority and the difference between the two alternatives, and are products of the criteria weights given by the decision-makers and the criteria performances.

5.4 Discussion: Experiences from the applied MCDM approach

A large part of the Warsaw workshop was reserved for reviewing the case region and the pre-defined improvement strategies. The presented information sparked a good discussion on what actions the experts would propose for the case region and what further information would be needed.

The experts wanted to know more details about the current situation in the case region than the presented information, including where the bins are typically located and how the waste flows are monitored. The experts were therefore interested in finding the root causes behind the presented performance of the case collection systems, such as why the amount of recyclable fractions in the residual waste was high.

During the discussion, the decision-makers were able to draw their conclusions on the knowledge gaps and the quality of the available information and evaluated the usefulness of the decision criteria accordingly. Based on the level of information available, the experts underlined the necessity of good monitoring and reporting practice for the case region. Due to data uncertainties, the experts for example chose to rely on capture rates which were considered more reliable in this case compared to recycling rates. Recycling rates would have otherwise been preferred as they are also indicators of the quality of the collected waste.

Useful criteria for environmental, social and economic performance were also discussed. While the experts pointed out limitations to the use of environmental criteria, such as greenhouse gas emissions, such indicators should however be included in decision-making. The experts preferred the use of economic criteria that indicated the costs per capita and per household over the costs per collected tonne of waste. Citizen satisfaction and proximity of the bring points were also valued high, suggesting that well performing collection systems should be based on the needs of the citizen.

6. MCDM workshop related to waste electrical and electronic equipment

6.1 Aim and content of the workshop

A dedicated workshop related to WEEE collection was organised together with the WEEEForum in Brussels in November 2019 (see Figure 8). The aim of the workshop was to discuss what kind of actions could be done to improve WEEE collection, and what kind of criteria could be used for prioritising these activities. In order to distinguish between the priorities in developed and less mature collection systems, parallel groups were organised to discuss the situation in two different, fictive case study regions. Descriptions of the case regions were derived (with some modifications) from the COLLECTORS database. The first group considered potential means for improving WEEE collection in a small city that was located in a rural area. The second group proposed options for improving WEEE collection in a large, densely populated city. Both regions had rather low collection rates in relation to similar systems included in the COLLECTORS database.

Figure 8. The COLLECTORS workshop at WEEEForum event, Brussels 21.11.2019

Within the exercise, a multicriteria method called Analytic hierarchy process (AHP) was applied. AHP was chosen, as not much quantified information about the performance of different WEEE collection methods was available in the COLLECTORS database[4]. This information would have been necessary for comparing the options using either of the previously tested value-based methods. Additionally, previous experience had shown, how AHP was successful in promoting discussion between the participants (Bachér et al., 2018). However, it was also recognised that the use of pairwise comparisons would restrict the amount of options that could be discussed during the workshop, due to amount of time that would be needed for the comparisons (prioritising each option in relation to each criteria).

The workshop was designed to act as a simulation of an early stage assessment of improvement alternatives, prior to availability of comparable data on potential improvement options. No other information than the case region descriptions were available for the experts. Therefore, the evaluations and priorities were solely based on their individual expertise and judgement.

During the exercise, the participants defined 3-4 actions that they considered potential for improving collection rates in their case region. Additionally, the participants defined criteria that could be used for evaluating the importance and prioritising between the proposed improvement actions. Finally, the proposed criteria were weighted using the SWING weighing method. Thus, the main focus of the workshop was to learn what the participants considered as important for improving the collection rate in different local circumstances, and to understand the criteria that would guide their decision-making in these contexts. In addition, the aim was to provide a learning exercise to all participants, and a possibility for exchanging ideas and experiences from different regions.

Method for decision-making using SWING and AHP

Upon agreeing the set of improvement actions and the evaluation criteria, the groups were asked to make a round of pair-wise comparisons using the Analytical Hierarchy Process (AHP) (Saaty, 1980). In the pair-wise comparisons, all the improvement actions were compared against each other, two at a time, in how well they perform in each criterion. For example, option ’Organizing awareness raising campaigns’ was compared against option ’Increasing permanent bring-points’, considering, how much they would improve Collection rates (criterion). An evaluation scale of 1-9 was used, with following definitions:

- 1: The options perform equally well
- 3: One option is moderately better performing than the other
- 5: One option is strongly better performing than the other
- 7: One option is very strongly better performing than the other

[4] Compared to the information on the PPW systems that were included in the COLLECTORS database, less information could be found concerning the WEEE collection systems.

- 9: One option performs extremely better that the other

The pair-wise comparisons produce ratios between the improvement actions, which in practice indicate how well they perform towards the goal, in relation to other improvement actions. These ratios were normalised, so they add up to one. Consequently, the normalized performances of the actions under each evaluation criteria were obtained. The perceived performances of each improvement action in each criteria was based solely on the expert judgement and intuition of the working group members, and discussions between the group members. Moreover, the voting was open and the group was asked to contest their arguments within the group during the voting.

After the AHP, the criteria weights were elicited. The criteria weights indicate the importance of each evaluation criteria, and they were used as factors together with the AHP results to calculate the final scores of the WEEE collection improvement options. The criteria weights depended on the individual preferences of the group members, but were possibly influenced also by the perceived differences in the reliability of the pair-wised comparisons under the criteria. This was incited by eliciting the criteria weights after the AHP. The criteria weights were elicited using the SWING method, as time constraints did not allow for carrying out the pair-wise comparisons between the criteria, according to the AHP method.

6.1 Description of the case region A: small city

Region A (see Figure 9) is an inland city, with a municipality area size of 496 km^2 and 161, 000 inhabitants (population density 325 inhabitants/km^2). The city has a more densely populated historical centre, surrounded by compact suburbs with housing that is more detached and industrial zones and farms. The local gross domestic product 5,380 €/capita is well below the EU average. The city is located by a river route, has a harbour and is therefore not considered as a remote area. The river runs on a national border.

Figure 9. A view on the city in Region A (Map data: Google, Maxar Technologies)

The municipality has concluded a contract with one of the WEEE PRO for the collection of WEEE on its territory. The PRO collects WEEE from households upon request (phone call) or through a network of retail points. There are 14 retailer bring points in the region (11,487 inhabitants per bring point). Collection is free for the citizens. In 2017, total amount of WEEE collected in the region was 215 tons (1.3 kg/inhabitant), including WEEE from households & similar sources. The collection rate in the region is low compared to EU average. The EU-28 average in 2017 was 8.0 kg of collected WEEE per inhabitant[5].

There have been developments made in the collections system in the recent years, and the system is not considered yet mature. The frequency of mobile collection (free pick-up service) has increased due to request from the municipality from once a month to daily circulation. Mobile collection accepts all kinds of WEEE. There are no ongoing participatory actions for citizens to improve the collection, and no mechanism for collecting regular customer feedback was in place.

The estimated capture rate of WEEE was 12.5%[6] in 2017. Some WEEE most likely ends up in MSW (share of metals 3.3%). The development of collected WEEE quantities between 2011 and 2017 is presented in Figure 10.

[5] Eurostat estimate on WEEE collected per inhabitant in 2017, Source: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee&lang=en

[6] The capture rate for WEEE was calculated as follows: Amount of WEEE collected (kg/capita)/(Estimated WEEE generation in country (kg/ capita, based on the BiPRO study 2014)+ amount of WEEE in residual waste (based on waste composition analysis)*100

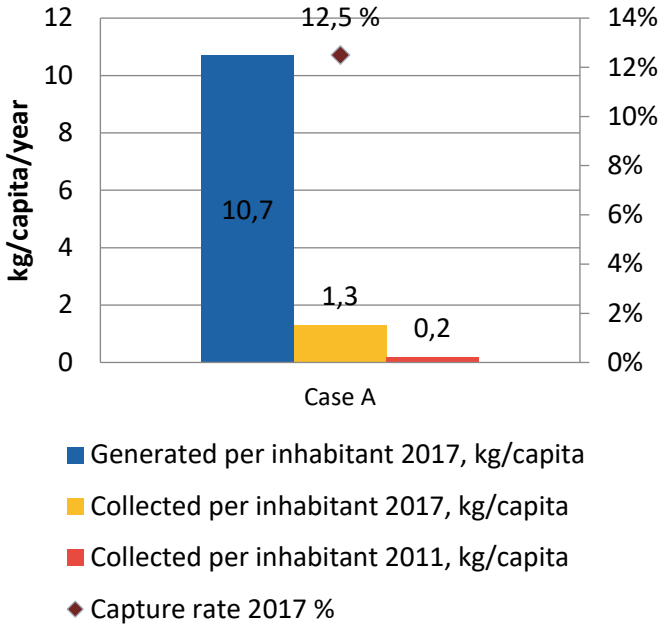

Figure 10 Collected WEEE quantities in region A

6.2 Results from the workshop, group A: small city

Proposed improvements actions (small city)

The current case region situation and possible improvement actions were assessed by a group of ten experts working within the field of WEEE producer responsibility organisations and coming from seven different countries (France, Romania, UK, Portugal, Greece, Czech Republic and Malta). The group agreed to propose four actions to improve the WEEE collection in the case region:

- Increase municipal permanent collection points
- Enforcement of better practices with surveillance of iron scrap yards receiving WEEE
- Define and regulate a single channel collection for WEEE
- Arrange awareness raising campaigns

The current WEEE collection relying on mobile collection was considered an ineffective use of labour and resources, as only 200 tonnes were collected per year. In turn, an increase in collection points was suggested. The decision-makers' (DMs) references to very successful practices in Portugal and Czech Republic on involving for instance local firefighters and sports clubs to arrange collection in return for compensation and monetary reward. In Malta, arranging the collection of small WEEE

items in schools and public buildings has been proven a good solution. All the logistics and payments are handled by the local schemes or the municipality in charge of the WEEE management.

Due to the increasing on-line sales of WEEE appliances, new practices of WEEE collection should also be considered. The DM's proposed that WEEE bring-points could be organized at post-offices where the packages are collected. Another solution would be to make contract with the courier companies to accept the old equipment when bringing in the new. The experiences regarding the latter approach varied. For instance, the couriers can face local regulatory barriers if they do not have a clearance for transporting waste (such as in Portugal).

Fighting illegal collection of WEEE was proposed as an important strategy (in conjunction with awareness raising and the availability of discarding options). Experiences (in Romania) showed that increasing the surveillance at the scrap yards and imposing fines upon wrong disposal of waste gives good results. For the case region, a defined single channel collection route for the WEEE was considered the most appropriate, together with surveillance in order to conform to regulations. In practice, a single channel collection would be achieved by obliging WEEE management exclusively to PROs (i.e. mandatory handover). Such details on the best strategy was not discussed, however. The motivation for the single channel collection was to ensure that the WEEE collected by the PROs have material value, and are not missing the valuable components such as fridge compressors. Fighting illegal trade of waste materials was considered cost-efficient when the measures and practices are in place, but the challenge lies in whether the municipalities have resources to establish and impose such measures. The DMs commented that in a small city such as in the case scenario, changing current practices (such as increasing surveillance) could be difficult due to established culture among the actors who all know each other.

Political will in ensuring that all the value in waste material is recovered in a single defined collection channel can be lacking, the DMs presented. This stems from what is being perceived as desired practices by the local inhabitants regarding discarding WEEE. Following the wording of a DM in the working group for Region A, "*The Government sometimes allows a less severe attitude completely as long as the public are pleased*", while the blame for low capture rates can be nevertheless directed on to the schemes. Naturally, the fault is not in how the WEEE is discarded by the citizens, if for instance scavenging of valuable metals occurs after the WEEE has been collected. The possibly limited capacity of regional authorities to regulate or enforce the most appropriate collection strategy was not discussed. The undesired or illegal practices referred to during the discussion were related to illegal collection of WEEE disposed of in the kerbside, unauthorised private collection schemes by scrap dealers or WEEE sent to non-authorized dismantling facilities. Addressing these issues likely requires separate and tailored actions. Such actions were not defined in detail during the workshop.

The GDP in the case scenario was very low. Therefore, the appropriate collection strategies would be such that no extra cost (driving etc.) would be brought on to the inhabitants. Improving the availability, i.e. investing in a more number of WEEE bring-points, was considered an important

action, which contains little risk economically. The availability of bring-points was also considered as a prerequisite for any successful results from surveillance of better practices or awareness raising campaigns.

The financial risks regarding awareness raising campaigns were considered higher. The impacts of awareness raising campaigns are uncertain and somewhat difficult to measure, while the campaigns require considerable investment. Moreover, the effect of awareness raising depends on the availability of easy discarding options. Nevertheless, the awareness raising campaigns were still considered to fulfil a certain role that is needed for well performing capture of valuable recyclables. Awareness raising campaigns were criticised of being more effective for daily and weekly occurring PPW collection compared to WEEE where the timing of the campaign and the discarding of waste can be years apart. Supporting evidence for such argumentation was not presented, however.

Proposed criteria (small city)

Similar to the improvement actions, the experts were asked to define three to four different evaluation criteria that would be the most useful for measuring the improvement in WEEE collection. The working group for Region A suggested that collection costs per tonne of WEEE, climate impacts and increase in local employment and GDP should be considered. The economic and socio-economic criteria were considered relevant due to the low GDP in the region. The arguments why climate impacts should be included or excluded varied based on the system boundaries that were perceived relevant; some group members highlighted the importance of efficient transport etc., while others saw the climate impact as more redundant with the capture rates. Although limiting the scope to local greenhouse emissions was proposed to deal with the issue, the question was raised up again during the pair-wise comparisons of the improvement actions. The final criteria that were used in the decision-making were:

- The cost of WEEE collection, €/tonne collected
- Climate impacts, kgCO_2eqv/tonne collected
- Collection increase, tonnes/year
- Social impacts (increase in local employment & GDP)

The experts were unanimous in agreeing that the increase in collected tonnages should be the main criterion. One of the experts pointed out that in the end the environmental impacts depend on the collection increase, which would be correct if the environmental impacts from displacing the production of virgin raw material by recycled materials is taken into account. Life-cycle assessments of the case studies show that there is a strong negative correlation between the greenhouse gas emissions and the recycling rate, due to the importance of the extraction and production of new raw materials (COLLECTORS Deliverable 3.3). Such a relationship between two decision criteria would lead to double counting of benefits. To avoid the criteria being redundant, the criterion on climate impacts was intended to include only local direct emissions. This way, the environmental criterion is decoupled from the capture rate, and becomes meaningful for the decision-making. As

the collection system only accounts for a small parts of the climate impacts of waste recycling, other relevant local environmental impacts could be used in the decision-making. The decision-makers however chose to include climate impacts as a criterion, which might have been affected by having to rely on own expertise and judgement rather than LCA results applicable for the case region.

Both the costs and greenhouse gas emissions per collected tonne of WEEE were intended as criteria describing the efficiency of the system. The economic performance was considered relevant also due to the low GDP in the case region. The experts argued that any collection strategy on the region should be as cost-efficient as possible in order to succeed. The selected economic criterion, costs per tonne of collected WEEE, indicates the cost efficiency for the operator of the collection system. Therefore, it does not directly indicate costs for households, although the decision-makers mentioned that the costs to citizens should be as low as possible.

The social impacts, including increase in local jobs and GDP were also proposed to be included in the decision-making. They were considered especially relevant due to the small size of the region together with low GDP. The experts suggested that in the local circumstances of the case region, the waste collection, recycling or reuse could potentially have a notable effect on the local economy as new investments and number of jobs. More information on the economic structure of the region, for instance presence of recyclers and users for secondary raw materials would be needed, however. Access to good quality WEEE and the requirement of specific technical expertise were mentioned as limitations or challenges to the reuse of WEEE, which would otherwise have good impact on the local employment.

Decision-making in group A (small city)

Regarding the lower level objectives (criteria) in the Region A, the working group gave the highest weight to the collection increase, followed by cost of collection and climate impact. Increase in local employment and GDP received the lowest weights, likely because it was argued during the discussions whether the impact would be substantial or not in the region (see Figure 11). The differences between the criteria weights were not very large however, and all criteria were supported by most in the working group.

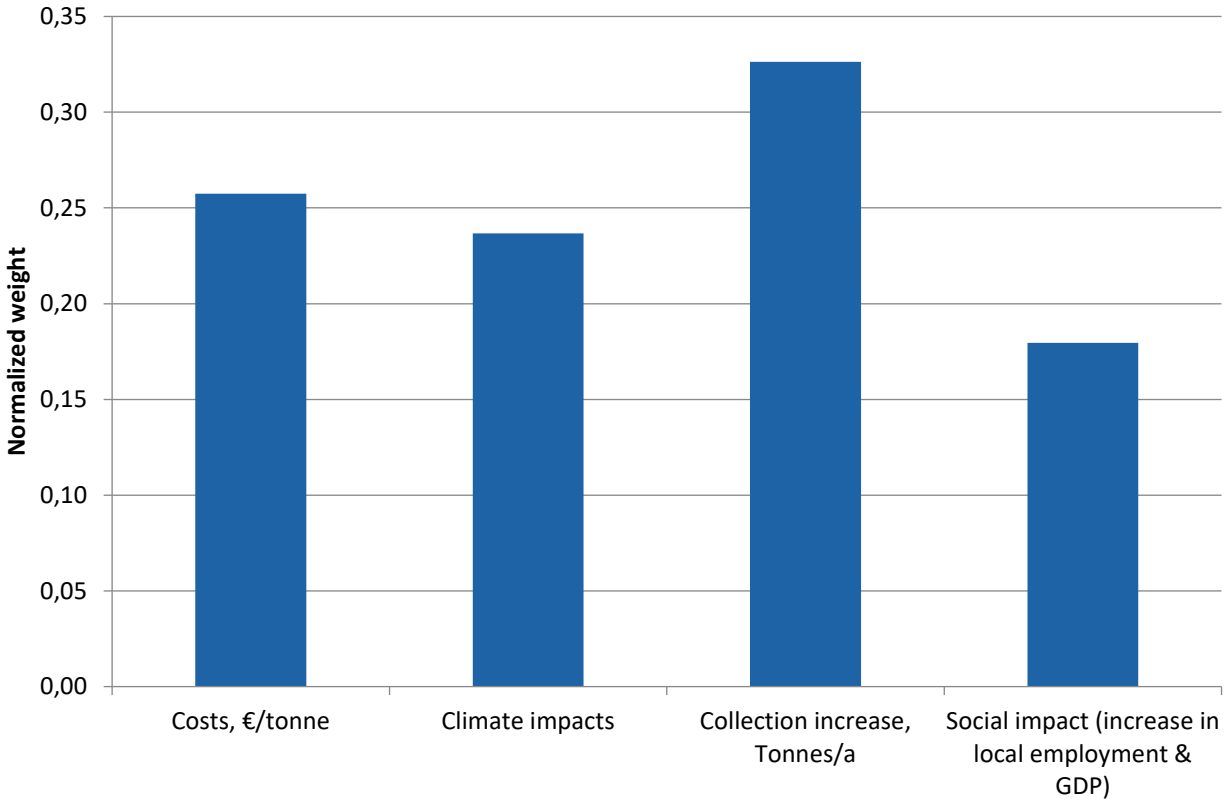

Figure 11. The criteria weights in the working group for Region A. The criteria weights describe the comparable importance of the included criteria, based on the decision-makers' preferences (higher weight means higher importance). Together with the performances of the proposed improvement actions in each criterion, the weights determine the overall scores of the alternatives.

Taking into account both the pair-wise comparisons of the proposed improvement actions and the criteria weights, increasing the number of permanent municipal collection points received the highest score and therefore should be prioritised for Region A (See results in Figure 12). Although the option received the lowest score in climate impacts (and would therefore have the highest local greenhouse gas emissions), the highest priority was reached due to highest cost efficiency and collection increase. Enforcement of better practices and surveillance of yards receiving WEEE had the second highest score, this time due to lowest greenhouse gas emissions and good increase in collected amounts of WEEE. Promoting regulated single channel collection received lower scores in climate impacts due to increased transportation. The awareness raising campaigns were considered controversial during the discussions, and it received the lowest scores due to poor performance in all three criteria. Pair-wise comparisons between the alternatives in improving local employment and GDP was not carried out due to time limitations. Therefore, the final score is limited to using three criteria instead of four.

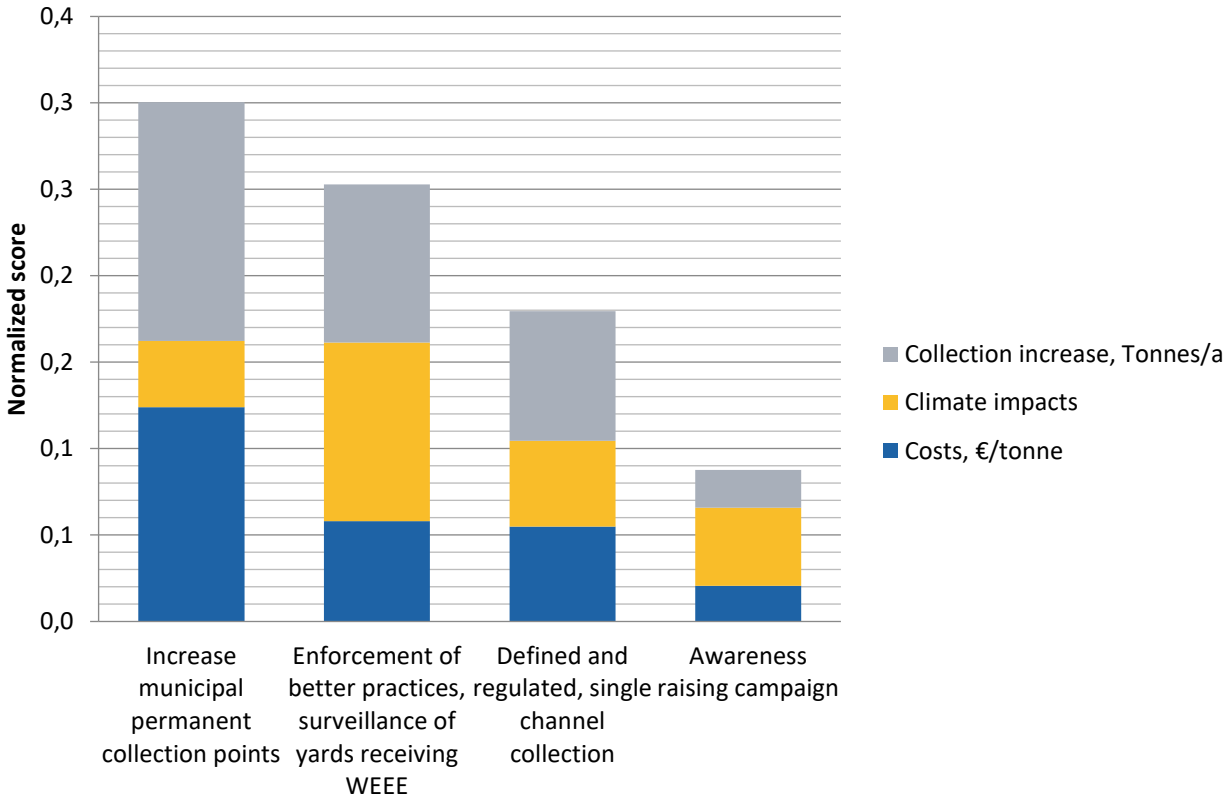

Figure 12. The scoring of the alternatives for Region A. The scores are a measure of how good the proposed actions are, compared to each other. The scores indicate both the order of priority and the difference between the alternatives, and are products of the criteria weights and performances according to judgement of the decision-makers.

6.3 Description of the case region B: large city

Region B (see Figure 13**Error! Reference source not found.**) is a large and non-remote city on a coastal region, with a busy harbour. The area size is 755 km^2 and the number of inhabitants is 1,800,000 (2,397 inhabitants/km^2). The city is widespread, with 75% multifamily houses. The local GDP 61 000€/inhabitant is well above the European average.

Figure 13. A view on the Region B (Map data: Google, Maxar Technologies)

In the case region, public bodies are responsible for organizing waste collection and PROs are responsible for waste management related to WEEE. Several schemes operate in the area and the collection systems are considered to be fully developed. The collection is organised through a combination of civic amenity sites (12 locations), retail- and non-retail bring-points, mobile collection (stopping in 160 locations, 4-5 times per year) and on- demand door-to-door collection (with a fee). There are 745 retailer bring points (one per 2,457 inhabitants), which need to accept small WEEE without an obligation of purchase. The non-retail bring points amount to 132 (one per 13,500 inhabitants). Customer feedback is collected regularly via annual phone surveys.

Regarding waste prevention, a non-profit company organizes selling and re-use of functional devices. Roughly, 30% of the devices collected from commercial actors and public organisations are directed to reuse.

In 2017, the total amount of WEEE collected in the region was 11,500 tonnes. Share of WEEE in mixed residual waste is 2.1% (based on results of a waste sorting analysis). The WEEE capture rate

in 2017 was 29.2%. The development of collected quantities (in kg/capita) between 2011 and 2017 is presented in Figure 14.

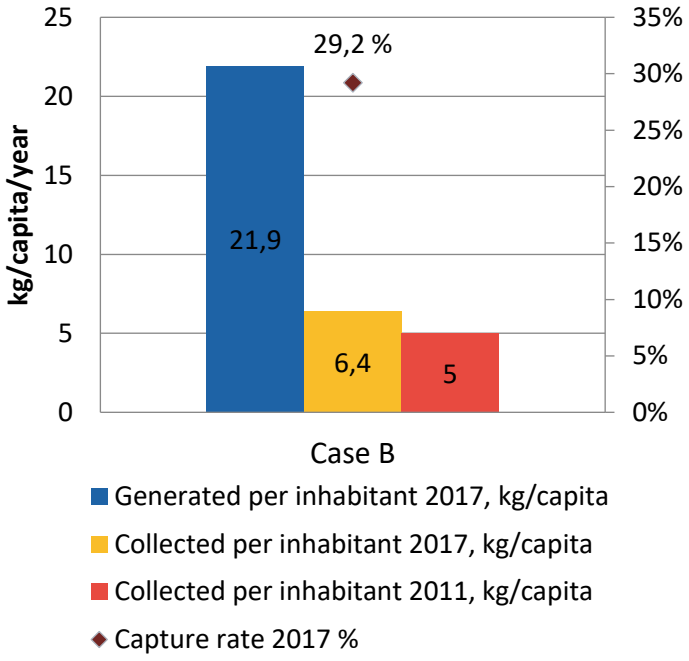

Figure 14 Collected WEEE quantities in region B

6.4 Results from the workshop, group B: large city

Proposed improvements actions (large city)

Seven experts from six different countries (France, Portugal, Malta, Norway, Luxembourg and Belgium) participated in this group discussion. Most of the participants had experience from working in PROs (management and operational departments) in capital regions within their own countries. Specific challenges that were highlighted in relation to regional characteristics in this case (large, densely populated city) were related to lack of space for organising additional collection points (either temporarily or permanently) and existence of efficient informal collection networks. In addition, it was pointed out that it would be important to make collection as easy as possible for consumers. In big cities, people might avoid driving cars for transporting their WEEE, and thus collection should be close to people, and easily accessible. However, this mostly concerns small WEEE, as collection of large household appliances should be organised in other means (preferably,

by retailer take-backs schemes, but some variation between the participant's countries in organising the take-back-schemes was recognised).

The number of civic amenity sites in this case study was considered to be rather low, compared to number of citizens living in the area. However, it was agreed that without knowing the details related to the locations of the collection sites, and organisation of other collection network, it was difficult to evaluate whether the collection network had good enough coverage. Based on the experiences of the participants, density of the collection points is often lower in big cities, and also the collection rate might be lower compared to more rural or less densely populated areas. In many big cities represented in the group, so-called informal collection efficiently picks up large household appliances from the streets and sells them to scrap dealers. This way, the equipment may end up either in responsible or non-responsible treatment by the scrap dealers, and sometimes to unknown locations. In addition, the warehouses for collecting the devices from retailer take-back-schemes (1:1) may locate outside the city area and consequently documented in other regions.

During the discussion, four main improvement actions were named, based on experiences gained in different countries. Proposed actions included both, concrete actions that could be implemented or initiated by the PRO (together with other actors) and more general improvement actions related to the operational environment and to the implementation of policies related to WEEE. In general, the policy framework was considered to have a significant impact on how the collection could be organised and the responsibilities related to WEEE collection met.

Proposed improvement actions that were included in the exercise were:

- Increasing no. of alternative collection points for small WEEE,
- Cooperation between different actors in organising the collection,
- Mandatory contracts with certified scrap dealers for segregated processing,
- Efficient policy with enforcement.

In this theoretical exercise, and from a practical point of view for obtaining quick results, it was pointed out that in order to maximise the collection rate (total collected mass), it would be most efficient to focus on collection of large household appliances, which have the highest weight. As opposed to smaller, often low value appliances that may be wrongly disposed in the mixed residual waste or hibernating in households (making it hard to get even low volumes back), large appliances are known to be attractive for the scrap sector. In general, it was considered that most efficient means for increasing collection of (especially large) WEEE would be to have binding contracts with scrap dealers[7], which would oblige the scrap dealers to segregated processing of all the WEEE they

[7] In the context of this discussion, scrap dealers refer to facilities performing treatment operations for scrap and other types of (metal based) waste, such as for example end of life vehicles. WEEE flows that may end up in these facilities have been often reported and identified in EU Member States (CWIT). In such facilities, dedicated treatment of WEEE (including proper depollution) is often not performed because WEEE is treated (and reported) as scrap. In some countries, scrap dealers are not allowed to treat WEEE, however, acceptance of WEEE mixed with scrap may happen.

receive. This action was considered to be closely related and partly overlapping with efficient implementation and policy enforcement (in practice the WEEE Directive, which is implemented in many different ways in different countries).

In addition to contracts with scrap dealers, it was proposed that the policy framework should be implemented, or enforced, in a way that would involve all actors working with electric and electronic devices, and not only the producers, in order to be effective. For example, the companies responsible for disassembly, cities and other actors who regularly handle large amounts of devices, should have the responsibility to ensure, that devices that go through their hands finally end up in proper treatment (certified treatment operators). Enforcement of policy was considered also to include decent resources for authorities monitoring treatment of WEEE in both, certified and non-certified facilities.

In general, the work of scrap dealers in handling and separating valuable parts from WEEE was considered important, but challenges were recognised in monitoring their performance and securing proper treatment. Additionally, existence of binding agreements or economic incentives for safe and proper treatment of WEEE (separately from other metal scrap) was considered necessary. Some countries have systems in which the PROs and scrap dealers make contracts about the price and treatment of different WEEEE streams, and fines or other sanctions may be used in case improper treatment is noticed. However, not all countries have systems that would allow the PROs to use any incentives towards the scrap dealers. In addition to increasing the collection rate, having incentives that could be used to push the operators towards proper and safe handling was considered necessary to ensure that hazardous substances are properly treated. This way, also the critical raw materials could perhaps be better recovered in the future.

Some of the examples shared during the discussion highlighted how PROs have dedicated prices paid to scrap dealers, for taking care of hazardous streams, such as incineration of plastics with brominated flame-retardants. This was considered efficient both for monitoring the flows that are handled, but also for making sure that harmful substances are properly treated. It was even proposed, that from an environmental point of view, it could be more efficient, in case PRO activities would be dedicated to those streams that contain most harmful substances. As those are the ones in which most problems occur, unless there is some kind of economic incentive for their treatment. However, it was also mentioned, that it would not feel fair to pay extra money for proper treatment of WEEE to facilities that are currently not acting according to law.

From an environmental point of view, it was also considered important to make sure that small WEEE ends up in recycling streams instead of the mixed residual waste stream. For this purpose, it was proposed that the PROs could be active in initiating cooperation between different actors (such as municipalities, housing companies, residents and the social community), in order to test and to establish new means for both temporary and permanent collection in apartment buildings or within the city area. Participants shared experiences from different kinds of experiments related to organising separate collection of small WEEE, and collection of small WEEE together with some

other waste streams. These included using separate bags for WEEE collected together with other recyclables or mixed waste, or introducing a new bag in which small WEEE could be collected together with textiles or some other recyclable stream. In addition, experiences were shared regarding organising sorting centres within apartment buildings, and having small WEEE and batteries collected from big office buildings. However, issues related to separation and sorting, and financing the collection, were still considered challenging, and required additional efforts and creativity from actors participating in collection.

In general, permanent or long-term collection points were considered more effective, compared to mobile collection (in case proper locations with decent transport/connection possibilities could be identified). The weakness of mobile collection was related to irregularity of availability for consumers. Efficient mobile collection was considered to require significant communication activities, in order to catch the citizens' attention.

Proposed criteria (large city)

When considering what kind of criteria would be important for evaluating any improvement options, altogether four criteria were proposed. These included:

- the impact on collection rate,
- ensuring easy access to collection for consumers,
- securing that hazardous substances are removed,
- recovery of critical raw materials.

However, due to limited time that was available for the discussion and the pair-wise comparisons, it was agreed to combine removing harmful substances and recovering critical raw materials as one criterion. It was considered that both criterions were related to environmental responsibility. Current challenges (lack of proper technologies and tools) in recovering the critical raw materials were acknowledged too.

Decision-making in group B (large city)

The results from criteria weighing for Region B are presented in Figure 15. For Region B, the most important criteria was related to safe handling and recovery of critical raw materials (improving environmental performance), followed by the increase in capture rate. The smallest weight was given to improving the accessibility of the WEEE collection. The results from criteria weighting reflected rather well the points that were made during the discussion, even if it was recognised that some of the proposed actions were actually overlapping. For example, it was considered, that mandatory contracts with scrap dealers could be considered as part of policy enforcement. In case more time for the workshop would have been available, these two criteria would have need to be either combined or re-defined, in order to avoid redundancy. However, as the aim of the exercise was rather to test the AHP approach and to created discussion, this redundancy was considered acceptable.

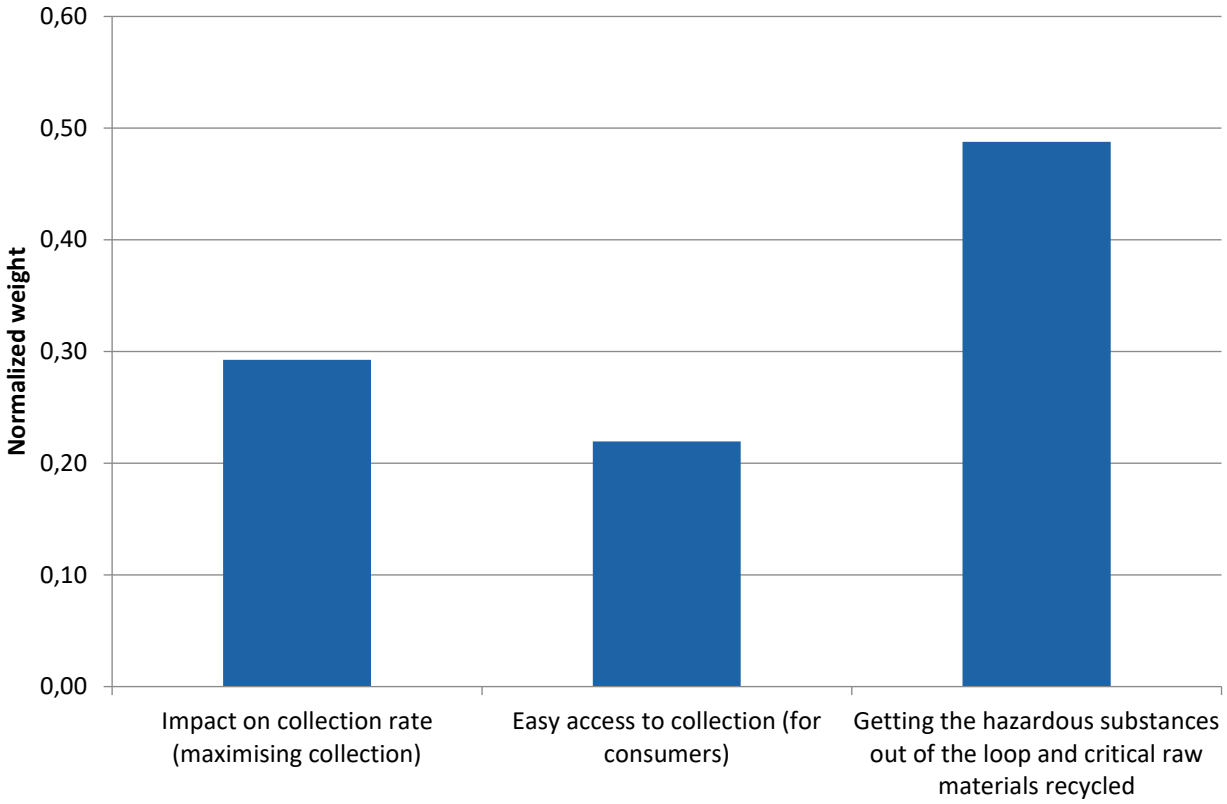

Figure 15 The criteria weights in the working group for Region B. The criteria weights describe the comparable importance of the included criteria, based on the decision-makers' preferences (higher weight means higher importance). Together with the performances of the proposed improvement actions in each criterion, the weights determine the overall scores of the alternatives.

In general, the experts agreed that the most important thing would be to ensure safe handling of WEEE, and in future also to make sure that critical raw materials are recovered during the process. The cost of the activities was not included as a criterion in this exercise, as it was mentioned, that cost as such would not be important, but what could be achieved with certain cost. For example, the cost of the activity would be estimated in relation to its assumed impact on performance, how much resources or efforts the implementation of the activity would require, or how easily it could be transferred to different areas or throughout the country. Easy access to consumers was considered relevant especially for collecting small WEEEE, and the importance of that criterion was highest when evaluating activities related to organising alternative collection points and increasing cooperation, which would/could ultimately end up in new kinds of collection practices or locations.

Combined results from criteria weighing, and prioritisation of the improvement options in group B are presented in Figure 16. Efficient implementation of policy received the highest score for Region B, because the group considered it had the highest potential to improve environmental performance together with good potential in increasing the collection rate (see Figure 16). Imposing mandatory contracts with certified scrap dealers for segregated processing received the second highest score due to good performance in both, improving environmental performance and

collection rate of WEEE. Increasing number of alternative collection points for small WEEE and encouraging more cooperation between actors involved in the collection both had better scores in improving accessibility to the WEEE collection.

In general, the results from group B reflect that means dedicated especially towards small WEEE have a lower impact on collection rate, and the means targeted towards large WEEE would be more efficient in increasing collection, and getting hazardous substances out from the loop. The highest priority was given to removing harmful substances and improving the recovery of critical raw materials, as it was considered that those are the principal objectives of WEEE recycling. However, in practice, and purely from the point of view of a PRO, it is also important to aim at maximising the collection rate. It was mentioned, that in Europe, the problem is not so much the WEEE ending up in forests or lakes, but the improper treatment that does not recover (loses) low value raw materials, and does not perform proper depollution of harmful substances, unless it is economically profitable to do so. In addition, there are challenges related to following the fate of the complementary flows that are currently not documented.

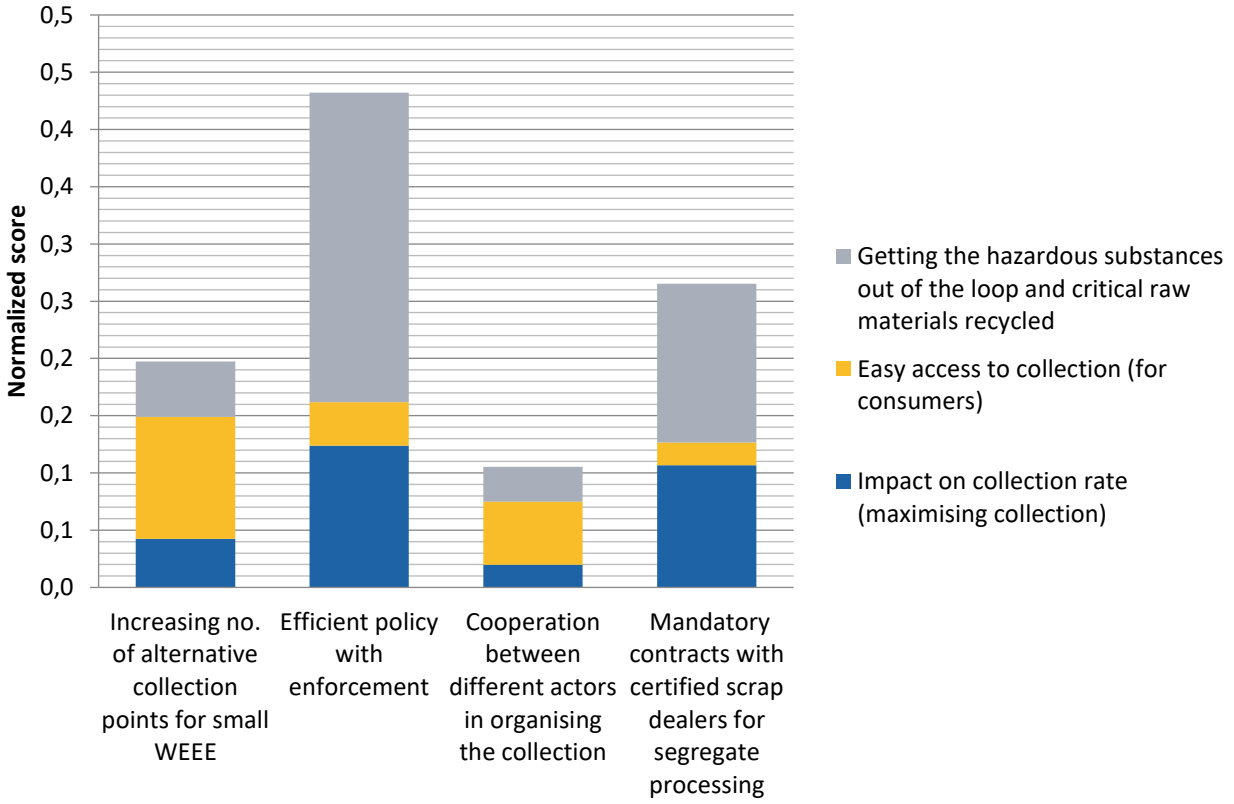

Figure 16. The scoring of the alternatives for Region B. The scores are a measure of how good the proposed actions are, compared to each other. The scores indicate both the order of priority and the difference between the alternatives, and are products of the criteria weights and performances according to judgement of the decision-makers.

6.5 Summary of the results from groups A & B

During the workshop, the two working groups were asked to discuss what could be done to improve WEEE collection in the two case regions. This included discussing potential improvement actions), and considering what kind of criteria are important for selecting the most effective improvement actions for the regions and prioritising the actions using multicriteria decision-making. Findings from both groups are summarised in Table 5 (proposed criteria) and Table 6 (proposed improvement actions).

Table 5. Proposed criteria for evaluating improvement options in WEEE collection in Regions A and B.

Type of objective	Region A	Region B
Material recovery	Collection increase, Tonnes/a	Impact on collection rate (maximise collection)
Cost efficiency	Costs, €/tonne	
Environmental	Climate impacts	Getting the hazardous substances out of the loop & improving recovery of critical raw materials
Socio-economic	Social impact (increase in local employment & GDP)	
Social		Easy access for consumers

Both working groups proposed actions to make WEEE collection more convenient and accessible for the inhabitants (See Table 6). In region A, establishment of municipal permanent collection points was proposed. Increasing alternative collection points for small WEEE was proposed for Region B, and increasing cooperation between different actors was also proposed as a means for finding new kinds of solutions for WEEE collection. Awareness raising campaigns were proposed by the working group focusing on the less developed region A.

Most of the proposed actions in both working groups targeted the avoidance of material and economic efficiency of the collection. In Region A, the working group thought that the collection and logistics should be in the hands of defined and regulated channels. Furthermore, more surveillance was proposed to avoid scavenging and loosing valuable materials from the intended recycling scheme. Proposed actions for Region B were quite similar, except for less focus on single channel collection and more on improving co-operation between different actors involved in the collection.

Table 6. The proposed actions for improving WEEE collection in the regions A & B.

Goal	Region A	Region B
Make collection more convenient for inhabitants	Increase municipal permanent collection points	Increasing no. of alternative collection points for small WEEE
Avoid losses of material from the intended recycling loop and ensure material and economic efficiency of the collection.	Enforcement of better practices, surveillance of yards receiving WEEE	Efficient policy with enforcement
	Defined and regulated, single channel collection	Mandatory contracts with certified scrap dealers for segregated processing
		Cooperation between different actors in organising the collection
Influence consumer behaviour	Awareness raising campaign	

6.6 Discussion: Experiences from the applied MCDM approach

The duration of the workshop was limited to two hours, and despite of good time keeping and planning, Group A had to leave one of the criteria (effect on local GDP and employment) outside the scope of the pair-wise comparisons, in order keep the timing. Group B realised during the discussion, that some of the actions and criteria actually presented different viewpoints to similar issues, and were overlapping. Based on the experiences from the workshop, it is possible to do a simple MCDM in a rather short time slot. However, perhaps half-a-day would be a more suitable duration, as it would allow doing some iterations during the exercise.

In the designed workshop setting, the AHP functioned as a method for contesting the individual ideas and views of the decision-makers. The structure of the approach, from definition of alternatives and criteria to pair-wise comparisons and criteria weighing was applied in practice without problems. However, it took some time before the participants understood the logic of the exercises. One of the challenges was that no screen was available, and thus the participants could not see the evaluation matrix, as it was only included within the laptop of the facilitator, who inserted the answers within the matrix. However, the participants could see the answers of other persons when sharing the results (scores from 1-9) on a post it note. This provoked a lot questions and discussion, especially when the opinions were very much divided. This also highlighted, how due to varying regional circumstances, the participants could sometimes come up with very different prioritisations, which was also accepted after explaining the arguments of each participant.

During the intensive two-hour workshop the participants got familiar with some basic ideas of the MCDM methodology, and backed their views by experiences of their own countries and regions, thus creating knowledge sharing. Individual contributions varied between workshop participants, but arguments against and in support of the presented views were abundant, and both of the groups were able to establish a ranking of WEEE collection improvement options. In addition, there was vivid discussion and exchange of experiences, turning the session into a dynamic learning activity for participants and COLLECTORS partners.

As with any MCDM methods, comparing the importance of either alternatives in a criterion or the criteria against each other is difficult to initiate. The accurate definition of performance parameters, such as cost per tonne of WEEE collected needed often to be brought to attention of the decision-maker. The DMs (Region A) commented on the challenge to incorporate local situation, such as the scale of collection, into their estimates on the performances. In the end, we do not know the extent to which the DMs answers are based on intuition affected by fundamentally different local situations (availability bias), in any case the insights from the MCDM exercise present a valuable result to the COLLECTORS project.

The environmental impacts were especially challenging to compare (Region A), due to unclear system boundaries. For instance, the environmental impact of an awareness raising campaign was difficult to establish, as the direct emissions and effect to collection rates were considered hard to measure. On the other hand, in region B, the discussion on potential impacts was (without problems) kept on an abstract level, without much discussion on system boundaries etc.

In order to propose reasonable improvement actions for the region, good information on the economic structure of the city is needed. Such information would include the types of industries in the region for example, and if there are recycling facilities available. This information affects for instance how much of the added value from waste management is created within the local economy. In smaller regions, the effect on local job creation and GDP can have more pronounced impacts from recycling and reuse compared to larger regions where such effects might be more levelled.

Naturally, to know the details of current waste flow in the case region is important. For instance, how the formal WEEE collection is organised and how is ensured currently that no WEEE ends up in scrap yards is critical information for coming up with better solutions tailored for the region in question. The challenge is, however the lack of monitoring or the availability of such information. Moreover, the material flows are not static and information from past years may not have predictive accuracy regarding the future. As cities and regions develop and changes in land-use are made, fluctuations in the amounts of new EEE brought to markets and in the reuse amounts and the amounts of WEEE can occur.

7. Conclusions & discussion

This study draws conclusions from the qualitative and quantitative results of four decision-making-workshops held during the COLLECTORS project. The aim of the MCDM workshops was firstly to learn about the information needs and opinions of the actors, and to understand the potential impacts of regional and local characteristics for the selection of preferred waste collection systems. Secondly, the aim of the workshops was to provide the participants possibilities for knowledge exchange and learning about both, the use of MCDM methods, and the experiences of other regions.

During the study, different MCDM methods were tested for various purposes that included:

(i) determining a ranking of well performing waste collection systems for case study selection (during the workshop in Malta, see D1.3),
(ii) experimenting the selection of a waste collection strategy in a local context, and based on the COLLECTORS case study results (economic, environmental and social criteria) (during the PPW workshop in Warsaw, see Chapter 5)
(iii) using MCDM as a framework for creating and assessing ideas for improving collection (during the WEEE workshop in Brussels, see Chapter 6).

Additionally, a decision-mapping exercise was conducted, in order to increase understanding of the decision-process as a whole, and consider typical challenges related to decision-making in the context of waste management (workshop held at Thessaloniki, see Chapter 4).

7.1 Applicability of MCDM for decision-support in the context of waste collection

In this study, different MCDM methods were applied in situations with changing data availability and local contexts. The study aimed at drawing conclusions on the benefits and shortcomings of the methods in these situations. Similarly to the vast literature related use of MCDM in the context of waste management (See Chapter 2), the experiences from the COLLECTORS workshops confirm that MCDM is useful for formulating priorities between the goals and actions in waste management. However, this study was different from many previous studies, as MCDM methods were used for creating knowledge sharing and increasing understanding of the problem, rather than merely taking a decision, or prioritising activities (even if prioritisation was done as well).

The findings from the study indicate that it is important to consider the decision-making process as a series of connected events, rather than as one occasion. In the context of waste collection, decision-making seems to be often affected by lack of precise or comparable data. Filling in existing

data gaps requires systematic efforts, implementing monitoring activities and cooperation (data exchange) between actors in the recycling value chain. This is necessary for improving all stages of the decision-making process in future.

When considering the decision-making process as a chain of connected activities, the findings from the study indicate, that in addition to actual decision-making situations (prioritising and choosing between available options), MCDM methods could be useful for the problem definition and idea generation phases, but also for collecting input and reaching consensus between different actors. During all COLLECTORS workshops, a lot of time was dedicated for discussion, and for collecting the views and arguments of the participants. This way, the participants had a chance to learn from the responses of others, and exchange ideas related to good practices. All the workshops were characterised by vivid discussion and knowledge sharing. The topics of the discussions also revealed the regional, legal and demographic contexts in which the experts were working.

Based on the experiences gained in the study the following recommendations can be made;

- Multiple criteria (reflecting diversity of economic, environmental and social aspects) should be included in expert-driven decision-making in waste management (as was indicated by the experts' preferences collected during the MCDM workshops).
- Problem definition and data gathering stages require the most time and effort, and are prerequisites for informed decision-making. These phases also create the majority of added value related to using structured decision-making methods (the journey is important for reaching the best available destination).
- Carrying out MCDM workshops at early stages in strategy selection reveals knowledge gaps and indicates priorities for further assessments (decision-making as non-final and iterative process).

All approaches to MCDM incorporate a definition of an ultimate goal, alternatives to choose from and a set of evaluation criteria. These can be considered as pre-requisites for informed decision-making, and their assessment requires the most of the effort in MCDM. Exercises need to be carefully prepared, and workshops facilitated. In addition, knowledge about the MCDM methods is necessary, and dedicated software is most likely needed, especially if large amounts of data are used, or in case many participants are present. However, structuring of the decision-problem and definition of the criteria can already be useful, and can be conducted without specific tools and with very basic knowledge about the methods.

The experiences from the workshops revealed, how MCDM can be used for creating discussion and collecting different kinds of inputs from participating decision-makers. When enough time is dedicated for each participant to provide her input, it ensures that everyone's input is included in the outcome. However, the exercises also require that participating experts are committed in conducting the exercise, and pay attention to all the details that are related to the exercise. In addition, it is important to reserve enough time for making sure that all participants understand the questions and the provided background information in a similar way.

The benefits of structured methods relate to the need to for systematic consideration of the desired goals from the point of view of multiple criteria. This usually reveals knowledge gaps, but also interlinkages (possibly related problems) that need to be considered. However, the need for the structured analysis may also feel burdensome for the participants, as all steps of the assessment have to be carefully conducted. Sometimes this can create a feeling of repetition and make the process look rigid.

When evaluating the results of an MCDM exercise, it is important to note that results from a group decision-making are always related to the context in which they were produced. Thus, the results from one exercise cannot directly be generalised as applicable to different contexts. However, the results may reveal aspects that are interesting and important, and they may apply in other contexts as well. This report presents the main findings from the MCDM exercises conducted during the COLLECTORS project, but the analysis of the applied decision-criteria and their usefulness for decision-making in different contexts continues in Deliverable D4.4 Generalised criteria to support decision-making.

When applying group decision-making, the composition of the group is very essential for successfully conducting the exercise. In this study, all exercises required a lot expertise and personal judgment from the participants. All decision-makers who participated in the exercises had several years of professional experience from different tasks related to waste management. In addition, the participants represented many different countries and regions, which can be seen as an advantage. It is considered, that the high level of expertise of the participants increases the usability and information value of the results. However, since all participants were experts working either in municipal waste management or within producer responsibility organisations, the results reflect the point of view of the cities, regions and the producers, and important aspects from the point of view of other stakeholders might be lacking. This seems to be a common challenge in MCDM studies, in which the stakeholders who usually participate in the studies are experts working in municipal waste management, either at national or regional level (See Soltani et al., 2015).

Several MCDM methods were applied during the project. When considering the use of the methods for different purposes, use of AHP can be recommended for the problem definition and idea generation phases, when quantitative data about the performances of different options is still lacking. What is important to note is that use of AHP is most practical in situations when the amount of discussed options and applied criteria is limited. When choosing a waste collection strategy, or prioritising options in a situation when potential performance of the alternative options is known, several MCDM methods can be applied. In this project, applied methods included MAVT and PROMETHEE. What is important to note is that different methods differ in how they deal with missing data. These and some other specific technical aspects related to MCDM methods are further discussed in the following chapter.

7.2 Specific aspects related to applied MCDM methods

Handling large amounts of alternative options and criteria

MCDM methods PROMETHEE and MAVT were applied for ranking the waste collection systems in the COLLECTORS database during the Malta workshop. Both methods worked well in a situation where there are a large number of both alternatives and evaluation criteria. The number of alternatives (in this case all the collection systems in the database per waste stream) is practically unlimited when using these methods, as there are no pair-wise comparisons of alternatives which require case-by case elicitation of preferences. Regarding the workflow of the decision-making, PROMETHEE and MAVT differ in the process of establishing the value functions (MAVT) and preference functions (PROMETHEE). Based on experimenting the elicitation of these functions during the project workshop, they present comparable challenges and benefits to the process. Both PROMETHEE and MAVT can incorporate criteria weights. Therefore, the differences between these two methods are in practice in the calculation steps that do not necessarily come across to the decision-maker.

Handling data gaps

PROMETHEE as a procedure is immune to missing data on performance of an alternative in a certain criterion; when comparing two alternatives without all the data needed, it considers the two equal regarding the criterion. This has to be taken into account when interpreting the ranking, where the lack of data may not be evident. When using MAVT, the overall scores can only be calculated after agreeing on how to deal with missing data. Possible strategies are to omit alternatives with missing data or to use median or average values for the data gaps. Our approach (presented in D1.3) was to use both PROMETHEE and MAVT side-by-side and compare the rankings after all the missing data were replaced by average performances. The final ranking was then formed as the average of the two MCDM methods. The difference between the two rankings using PROMETHEE and MAVT was moderate.

WEEE collection improvement strategies were ranked during the Brussels workshop using AHP in a decision-making exercise and relying solely on expertise and judgement of the participants. The selected MCDM method worked well in structuring the conversation, and four improvement actions were prioritised based on three criteria over the course of two hours. With larger amount of alternatives or criteria, a prioritisation using AHP would be too burdensome task to carry out in one session. The pair-wise comparisons of alternatives in regarding each criterion revealed conflicting views of what are the appropriate scopes for individual criteria. For instance, should the environmental impacts be assessed on local level only or should the benefits from increased

recycling rates be included. Agreement on the exact definitions of the criteria should be made before comparing the alternatives, but how an expert estimates the performances during AHP is always subjective. Nevertheless, a major challenge in the presented approach to use AHP to rank alternatives without predefined criteria or data is in how well the goal and criteria can be defined in limited time.

Value functions in MAVT

The Warsaw workshop focused on making informed decisions on PPW improvement strategies in a major city with less than average collection rates. In creating the case scenario and the two alternative collection improvement strategies, the results from the LCA and CBA case studies of well performing PPW collection systems were used. The case region was selected from the COLLECTORS database, including the data on the current status of the PPW collection. Missing data was replaced by assumptions, and the details of the case region were modified to ensure anonymity of the region. The LCA and CBA indicators from the case studies were taken as the evaluation criteria for decision-making.

First improvement strategy was based on a case study with more separately collected waste fractions and deposit schemes for bottles, which resulted in better quality of recovered waste and higher recycling rates. The second improvement strategy incorporated case study results of a collection system that relied more on co-mingled collection of recyclables, resulting in lower operational costs but somewhat poorer performance regarding rejected waste amounts from recycling due to lower quality.

Due to the good amount of criteria and information available for the prioritisation, MAVT and SWING weighing were used to establish the overall scores of the two options. MAVT incorporates value functions which describe how a change in a criterion affects the value perceived by the decision-maker. The value functions applied during the Warsaw workshop were assumed linear, leaving more time for assessment of the information given to the decision-makers and for discussing further information needs. Based on the experience from the Malta meeting, where effort was made to establish the value functions for each criterion, the decision makers did not have strong preferences to change the linear value functions, or felt that it was not possible to provide such functions. As a consequence, there were only few changes to the functions. This was in part due to the uncertainties involved regarding the criteria data. Moreover, the discussion on the problem definition, challenges and what information would be needed was more important than focusing on the fine-tuning of the MCDM method. Therefore, only the criteria weights were elicited during the Warsaw workshop, and the purpose of the MAVT was only to provide a method to establish the overall values of the two PPW collection improvement strategies. For this purpose, the MAVT is a solid foundation. In a real situation, a sensitivity analysis of the MCDM results would be needed to assess the robustness of the ranking of the alternatives.

References

Achillas, C., Moussiopoulos, N., Karagiannidis, A., Banias, G., & Perkoulidis, G. (2013). The use of multi-criteria decision analysis to tackle waste management problems: a literature review. *Waste Management & Research*, *31*(2), 115–129. https://doi.org/10.1177/0734242X12470203

Bachér, J., Pihkola, H., Kujanpää, L., & Mroueh, U.-M. (2018). Advancing the circular economy through group decision-making and stakeholder involvement. *Detritus*, *04*, 22–35. https://doi.org/10.31025/2611-4135/2018.13741

Brans, J. P., Vincke, P., & Mareschal, B. (1986). How to select and how to rank projects: The Promethee method. *European Journal of Operational Research*, *24*(2), 228–238.

Dyer, J. S., & Sarin, R. K. (1979). Measurable Multiattribute Value Functions. *Operations Research*, *27*(4), 810–822. https://doi.org/10.1287/opre.27.4.810

Goulart Coelho, L. M., Lange, L. C., & Coelho, H. M. (2017). Multi-criteria decision making to support waste management: A critical review of current practices and methods. *Waste Management & Research*, *35*(1), 3–28. https://doi.org/10.1177/0734242X16664024

Keeney, R. ., & Raiffa, H. (1994). Decisions with multiple objectives–preferences and value tradeoffs. In *Behavioral Science*. https://doi.org/10.1002/bs.3830390206

Morrissey, A. ., & Browne, J. (2004). Waste management models and their application to sustainable waste management. *Waste Management*, *24*(3), 297–308. https://doi.org/10.1016/j.wasman.2003.09.005

Saaty, T. L. (1980). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26.

Soltani, A., Hewage, K., Reza, B., & Sadiq, R. (2015). Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. *Waste Management*, *35*, 318–328. https://doi.org/10.1016/j.wasman.2014.09.010

COLLECTORS Deliverables

D1.2 Webplatform: database on waste collection systems. Available at: https://www.collectors2020.eu/tools/wcs-database/

D1.3 Selection of 12 validated case studies. Available at: https://www.collectors2020.eu/wp-content/uploads/2019/06/COLLECTORS_D1.3_SelectionOfCaseStudies.pdf

D2.4 Report on solutions for tackling systemic and technical boundary conditions. Available at: https://www.collectors2020.eu/results/analysis-of-boundary-condition/

D2.5 Report on implemented solutions and key elements in selected cases for societal acceptance. Available at: https://www.collectors2020.eu/results/analysis-of-boundary-condition/

D3.2 Report on the economic and financial performance of waste collection systems. Available at: https://www.collectors2020.eu/results/

D3.3 Report of recommendations for improvement of single systems and optimum operation conditions. Available at: https://www.collectors2020.eu/results/environmental-impact/

Appendix Description of selected MCDM methods

Multi-Attribute Value Theory (MAVT)

MAVT (Dyer & Sarin, 1979; Keeney & Raiffa, 1994) builds on the axiomatization of decision maker's preferences (i.e. has a solid mathematical foundation). The decision maker's preferences are modelled as value functions. A value function $v_i^N(x_i)$ transforms any measured variable x_i (e.g. greenhouse gas emissions or the capture rate of a recyclable material) to a number representing its subjective value to the decision maker. Note, that the $v_i^N(x_i)$ is not necessarily linear. For instance, one might appreciate 5% increase in a capture rate more if the original rate is 70% rather than 10%.

In MAVT, the overall value of an alternative is calculated by using the additive value function:

$$V(x) = \sum_{i=1}^{n} w_i v_i^N(x_i)$$

Where

$V(x)$ is the overall value of an alternative,

$v_i^N(x_i)$ is the normalized value of a criterion measure of an alternative and

w_i is a weight given for a criterion.

When the performance of all alternatives has been assessed regarding each criterion, worst performance levels x_i^0 and best performance levels x_i^* are known for each criterion.

$$v_i^N(x_i^0) = 0$$

and

$$v_i^N(x_i^*) = 1$$

apply for the normalized value functions.

Criterion weights w_i reflect the increase in overall value when the criterion performance is changed from the worst level x_i^0 to the best x_i^*. The following equation applies for the criteria weighs:

$$\sum_{i=1}^{n} w_i = 1$$

Therefore, to use MAVT to arrive at the best decision once the problem is formulated, the value functions $v_i^N(x_i)$ first have to be defined. Secondly, the criteria weighs w_i must be elicited. Finally, the alternative with the highest overall value $V(x)$ should be chosen.

Analytical Hierarchy Process (AHP)

In AHP (Saaty, 1980), a decision-maker forms local priorities by comparing the importance of each same level elements (alternatives or criteria) against each other regarding each element on the next level upwards (lower levels objectives, criteria or the main objective). The number of levels in the hierarchy depends on how the problem is structured. In the simplest case, there are three levels from top to bottom: the goal, the criteria and the alternatives. The decision-maker is first asked to compare all the alternatives against each other regarding their performances in each criterion. Once this is done, the importance of each criterion is compared against the other criteria towards achieving the goal. This way, both the performance of the alternatives and the weights of the criteria are elicited by pair-wise comparisons.

Saaty (1980) proposed a fundamental scale from 1 (equally important) to 9 (extremely more important) for the comparison of same level elements.

Preference Ranking Organization and Method for Enrichment Evaluation (PROMETHEE)

PROMETHEE (Brans, Vincke, & Mareschal, 1986) is a popular outranking method for multi-criteria decision making. It differs from the value-based AHP and MAVT methods in the sense that alternatives are pairwise compared to asses whether one alternative is at least as good as another. An alternative finally outranks another if it performs better in more criteria or in the most valued criteria and equally as good in the rest. In case of missing performance data, the performances are considered equal in the pair-wise comparisons. The performance data (meaning for instance annual greenhouse gas emissions) of the alternatives is evaluated in three major steps: (i) establishing a preference function for each criterion; (ii) calculating the preference index and preference flows and; (iii) ranking the alternatives. PROMETHEE can apply criteria weights similar to the AHP and MAVT.

COLLECTORS Consortium

PNO CONSULTANTS www.pnoconsultants.com	BIPRO www.bipro.de	VTT www.vttresearch.com
VITO NV www.vito.be	UNIVERSITEIT LEIDEN www.centre-for-sustainability.nl	ACR+ www.acrplus.org
ZERO WASTE EUROPE www.zerowasteeurope.eu	WEEE FORUM www.weee-forum.org	EUROCITIES www.eurocities.eu

COLLECTORS
WASTE COLLECTION SYSTEMS ASSESSED AND GOOD PRACTICES IDENTIFIED

www.collectors2020.eu

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776745