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Report on generalized criteria to support decision-making

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Credits

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Contents

1. Introduction

Decisions related to waste collection are examples of multicriteria decision-making (MCDM) situations, in which the decision-makers are confronted with concerns related to regulatory demands, costs, environmental issues, user preferences, technical issues and feasibility. 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. 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.

Methods and approaches to MCDM have been developed since the 1970s (Köksalan, Wallenius, & Zionts, 2011). They commonly 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. The benefits of structured decision-support methods like MCDM relate to the need 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.

Use of MCDM in waste management related studies is getting more and more popular(Morrissey & Browne, 2004). However, most available studies focus on management of municipal solid waste (MSW), and only a few earlier studies related to waste electronical and electronic equipment (WEEE) and construction and demolition waste (CDW) can be found (Achillas, Moussiopoulos, Karagiannidis, Banias, & Perkoulidis, 2013; Goulart Coelho, Lange, & Coelho, 2017). MCDM studies evaluating paper and packaging waste (PPW) management strategies seem to be lacking almost completely. This study complements existing studies by focusing on criteria that could be applied for the (PPW), WEEE and CDW streams. In addition, this study presents multiple criteria that aim to address important aspects related to well performing waste collection systems. These aspects include various economic, environmental and social criteria that were recognised as important during the COLLECTORS project.

Decision-making related to waste collection is often affected by lack of precise or comparable data (D3.4, 2020). 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. Evaluation criteria can be used to guide data collection, but they are also helpful for considering, what kind of issues should be monitored, in order to better evaluate the performance of the waste collection system.

This report focuses on the evaluation criteria that were applied in the MCDM exercises during the COLLECTORS project. The exercises were attended by European experts from waste management

companies, waste agencies, municipalities and producer responsibility organisations (see Table 1 in Chapter 3). During the project, these criteria have been applied in different contexts and for different waste streams, and their applicability and importance has been evaluated by the waste experts who participated in the MCDM exercises.

The criteria discussed in this report could be applied in the context of MCDM studies, but also in other contexts, to support decision-making and monitoring activities related to waste collection. It is considered, that the developed criteria can help decision-makers and producer responsibility organisations (PROs) for identifying and integrating important aspects in their decision-making process when implementing new waste collection systems. The report complements COLLECTORS deliverable D3.4 ”Report on multiple criteria assessment of the studied waste collection systems and applicability of different methods for decision-support” where recommendations on the application of three different MCDM methods were made, and common challenges related to decision-making in the context of waste management were evaluated.

2. Aim of the study

This report presents examples and recommendations about informative criteria that could be used for monitoring the performance of a waste collection system, comparing collection systems in different regions and evaluating the impacts of alternative collection strategies (or means of collection). Additionally, this report includes recommendations about criteria that could be used for identifying potential benchmarks among other systems, taking into account relevant regional characteristics. Proposed criteria are presented together with expert evaluations regarding their usefulness, limitations and potential challenges in data collection or performance evaluation.

Proposed criteria were divided into six clusters that were identified as important for well performing waste collection systems. It is proposed, that good practice for decision-making would be to include at least one criterion representing each cluster in monitoring and decision-making related to waste collection. Once the system is more developed, more indicators may and should be added.

Proposed clusters include:

- Capture and recycling rates
- Degree of separation and quality
- Convenience & coverage
- Engagement & participation
- Environment, health & safety
- Socio-economic impacts

Proposed clusters are the same for all the waste streams studied in the COLLECTORS project, namely paper and packaging waste (PPW), waste electrical and electronic equipment (WEEE) and construction and demolition waste (CDW). However, there are some differences between definitions of individual criterion between the waste streams. In addition, the expert evaluations related to the importance of individual criterion or clusters of criteria varied to some extent, depending of the characteristics of the waste stream in question.

Recommendations related to the criteria presented in this report are based on a series of expert workshops and MCDM exercises that were organised during the COLLECTORS project. In addition, the findings build on the work of work package 1, during which the COLLECTORS webplatform[1] was

[1] The webplatform inclues information about 242 regional waste collection systems, see https://www.collectors2020.eu/tools/wcs-database/

built and the COLLECTORS case studies of well-performing regions, conducted as part of work packages 2 & 3.

This report is structured as follows:

- Applied methods, materials and main principles for data collection are presented in the following Chapter 3.
- Chapter 4 presents proposed clusters of the criteria for the three waste streams, and discusses findings from the MCDM studies in relation to other findings from the COLLECTORS project.
- Chapters 5 and 6 present main conclusions regarding the specific criteria that were applied within the MCDM exercises that were conducted during the project. Chapter 5 presents examples of criteria that could be used for identifying collection systems with similar local context (challenges etc.). Chapter 6 presents examples of criteria for benchmarking collection systems or comparing alternative waste management strategies.
- Chapter 7 presents the main conclusions and proposes a way forward in using and further developing the criteria in different contexts.

3. Methods and approach for criteria identification and clustering

3.1. Data collection

The COLLECTORS project has relied on participatory approach. This means that experts, external to the project consortium, have shared their knowledge and experience on benchmarking and assessing waste collection systems and strategies. The expert workshops organised as part of the project were referred to as Regional Working Group (RWG) meetings. The workshops included facilitated group discussions using open-ended questions and group-based multicriteria decision-making (MCDM) exercises. Both methods have contributed to the criteria identification and classification presented in this report. All the criteria applied in this study have therefore been identified from the information gathered from the COLLECTORS database (webportal), the case studies in WP2 and WP3, and the expert workshops in WP1 and WP3 (see Table 1).

The RWG meeting in Treviso identified and assessed what data should be included in the COLLECTORS database. In preparation for the case study selection from the COLLECTORS database, two workshops were organized together with international PRO associations/alliances WEEEForum (on WEEE) and EXPRA (on PPW) to preliminary discuss and evaluate what information should be considered in order to identify the best performing collection systems.

Table 1. List of workshops that contributed to the definition and evaluation of the criteria. In the applied methods, AHP stands for Analytical Hierarchy Process, MAVT for Multi-attribute Value Theory and PROMETHEE for Preference Ranking Organization Method for Enrichment Evaluation. These alternative methods for multicriteria decision-making are described in the COLLECTORS Deliverable D3.4. Definition of SWING weighting is presented in Chapter 3.3

Workshop	Discussed waste streams	Applied methods	Aim of the workshop	Attendees
21.3.2018 Treviso	PPW, CDW & WEEE	Group discussions + poster sessions	Suggest useful data contents for the COLLECTORS database	Regional Working Group
8.5.2018 Cyprus	WEEE	Questionnaires + discussions	How to define and identify best practice for WEEE collection?	PRO association members
27.6.2018 Brussels	PPW	Questionnaires + discussions	How to define and identify best practice for PPW collection?	PRO association members
25.9.2018 Malta	PPW, CDW & WEEE	MCDM: MAVT, PROMETHEE and SWING weighting	Evaluating and weighting 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
25.6.2019 Warsaw	PPW	MCDM: MAVT and SWING weighting	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
21.11.2019 Brussels	WEEE	MCDM: Pairwise comparisons using AHP and SWING weighting	Proposing and prioritising means & criteria for improving WEEE collection in two regions	21 WEEE Forum members from 10 countries
10.12.2019 Thessaloniki	PPW, CDW & WEEE	Decision-mapping + facilitated group discussions	Discussing typical decision-making challenges and applicability of different criteria for decision-support. Review of decision criteria in the COLLECTORS project	10 RWG members from 9 countries

3.2. MCDM exercises

After the data gathering stage, the contents of the database were assessed in the following RWG meeting in Malta, using MCDM to select 12 collection systems for further case studies. During the Malta workshop, the experts' preferences on the importance of the available information was measured quantitatively.

Two types of information were evaluated for decision-making during the Malta RWG workshops:

(i) general parameters regarding the regional characteristics where a waste collection system is operated and;
(ii) parameters that indicate the performance of the collection system.

The general parameters (i), such as local GDP, were considered in terms of how much they impact or influence the collection systems. This information was used to facilitate benchmarking of performances between collection systems that share similar local contexts. Results from this exercise are discussed in Chapter 5.

During the RWG meeting in Malta, dedicated workshop sessions were held for PPW, CDW and WEEE to collect the expert views on the general parameters. Dedicated sessions were also held for all waste streams regarding the use of collected information as criteria for ranking the collection systems in the database, based on available performance data.

The economic data from the cost-benefit analysis and environmental life-cycle assessment results from the case studies were used in an MCDM exercise during the RWG meeting in Warsaw. In the Warsaw workshop, the usefulness of the applicable case study results and data were both discussed and quantified using methods of MCDM. The decision-making scenario was a comparison of two PPW collection strategy options in one capital city in Europe. Results from the criteria weighting conducted in Warsaw are discussed in Chapter 6.2.

A third MCDM workshop was organized in Brussels regarding WEEE in a WEEEForum member meeting. The workshop differed from the previous MCDM workshops as the experts were asked to propose improvement actions to a WEEE collection system and to prioritize them using multiple criteria of their own choice. The exercise was carried out on two distinctly different regions, a large city on a high GDP region and a small city with low GDP. The decision-making scenario was designed to investigate how the emphasis on the types of decision criteria might differ according to the regional characteristics. Results from these exercises are discussed in Chapter 6.1.

3.3. Quantification of the importance of the criteria

During all MCDM workshops, the experts' preferences on the importance of different criteria were measured using a method referred to as SWING weighting. The criteria weights describe the importance given for a waste collection system's performance in a certain criterion, such as capture rate of plastics. In the SWING weighting method (Zardari, Ahmed, Shirazi, & Yusop, 2015), the expert/decision-maker gives the most important criterion a value of 100 points. Then he/she gives the next most important criterion 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.

The points for each criterion were taken as the average number given by the decision-makers. The average points were then normalized (so they add up to one). Although more accurate methods to elicit the criteria weight exist compared to SWING, such a trade-off weighting where the performance differences are better included in the decision, the method benefits from less time-consuming implementation. SWING method was therefore chosen, allowing time for more open and in-depth discussion during the workshops. The accuracy of the SWING method in establishing the comparable importance of the criteria within and MCDM exercise was considered sufficient.

Conclusions based on the importance of the criteria, as evaluated by the experts, are presented in this report. Original results related to quantification of the criteria have been presented in COLLECTORS deliverables 1.3 and 3.4.

3.4. Review and clustering of the criteria

The quantified preferences of the experts (collected during the MCDM workshops) were summarised and reflected against the supporting discussions held during the workshops. The workshops included six separate decision-making exercises in addition to dedicated sessions focusing on information needs for decision-making, knowledge sharing related to good practices, and use of social and environmental criteria for decision-making. All sessions were recorded for review and further analysis.

A final workshop was organized during the RWG meeting in Thessaloniki, where a session was dedicated for reviewing the preliminary clustering of the criteria. During the session, the experts were asked to give their preferences and comments on the general application of the criteria for decision-making in management of PPW, WEEE and CDW.

The experts further agreed with the presented grouping of the criteria into six categories. Based on their preferences, all of the six categories had relevance for decision-making related to waste

collection systems. Proposed clusters were further discussed by project partners during a project meeting in Thessaloniki. The recommendations presented in this report are based on findings from all the workshops organised during the project, and supported by the findings from other studies conducted during the COLLECTORS project.

4. Clustering of the decision criteria

This chapter discusses the criteria that were studied during the COLLECTORS project. Findings from the expert workshops and MCDM studies are discussed in relation to recommendations and conclusions from the COLLECTORS case studies.

Studied criteria were divided into six clusters that include:

- Capture and collection rates
- Degree of separation and quality
- Convenience & coverage
- Engagement & participation
- Environment, health & safety, and
- Socio-economic impacts.

Each cluster consists of several criteria, and it is recommended that criteria from each cluster should be included in decision-making related to waste collection. If required information is not available, efforts should be made for improving data collection in future. Proposed clusters are common for PPW, WEEE and CDW, and they describe aspects that are considered important for assessing, comparing and monitoring the performance of waste collection systems. Chapter 4.1 includes short introductions of the clusters, while chapters 4.2-4.7 present the main conclusions related to each cluster.

4.1. Introduction to the clusters

Capture and recycling rates

This cluster includes the criteria that describe how much of the generated waste is collected for recycling and gets recycled. These criteria include information on the waste flows, amounts of recyclables discarded in the mixed residual waste, amounts of separately collected recyclables and amounts of sorted waste rejected from recycling.

Capture rates indicate the amount of separately collected recyclable waste (as percentage) from the total amount of the waste fraction generated. Recycling rate takes into account the amount of rejects, and indicates the share of waste fraction recycled (as percentage) from the waste fraction generated. The capture and recycling rates should be assessed individually for all collected waste fractions (such as for glass and plastic, etc.).

Valued highly by the experts, the capture and recycling rate related criteria used during the MCDM workshops included capture rates for WEEE, CDW and for each PPW waste fraction. Capture rates were calculated as percentage, equalling the amount of separately collected waste, divided by the amount of generated waste). Collection rates of WEEE (absolute values in kg per no. of inhabitants) were also included. Additionally, the shares (percentage) of recyclable materials in residual waste were considered for PPW fractions, small WEEE and CDW from households, based on results of the most recent waste sorting analyses.

Degree of separation & quality

The criteria in this cluster measure how well a collection system produces sufficient quality raw material for the recyclers. These criteria describe the level of sorting and separation, and the share of contaminants (as weight percentage) in sorted waste. Examples of criteria include number of waste fractions collected at civic amenity sites (CASs), and number of fractions collected separately from households. The previously mentioned recycling rates or the share of material rejected from recycling are efficient indicators of how well a collection system is aligned with the requirements of the recyclers. However, as waste collectors might not have enough data to calculate actual recycling rates, criteria in this category can be used to complement the information related to capture rates. In the case of WEEE collection, scavenging of the valuable components prior to disposal lowers both the quality and the value of the collected waste. Therefore, the scavenging (as e.g. the share of large WEEE received non-intact) can be included here.

Criteria that were used during the MCDM workshops included the share (percentage) of material rejected after first treatment stage (CDW and PPW) and the number of waste categories collected at CASs (WEEE). The findings from COLLECTORS CDW case studies, together with findings from R4R project (R4R, 2014) highlight how high degree of separation of different waste fractions at CAS can lead to better performance in recycling, and reduce the amount of generated waste (D3.2, 2020).

Further quality-related criteria were considered important for PPW collection in the RWG workshops, but were not weighed during the MCDM exercises. The experts who participated in the RWGs emphasized the importance of using quality related criteria for all waste streams. It was considered important also for PPW, even if such criteria was not readily available, due to lack of related, publicly available data in the COLLECTORS database. Moreover, better monitoring of material flows in order to establish accurate recycling rates is needed for all waste fractions in future. With current practices, information about the waste flows (before and after collection) is not openly available.

Convenience & coverage

Easy access to collection points and convenience of the collection were among the most important elements when good practices for waste collection were evaluated and discussed during the RWG meetings. Similarly, increasing flexibility in collection services for PPW, and diversifying methods

and collection points for WEEE collection were among the good practices identified in the COLLECTORS case studies (D2.4, 2020). The findings from COLLECTORS RWG meetings, MCDM studies and case studies equally highlight that increasing the number of collection points, or using other means for improving accessibility to services, would be important for improving the capture and collection rates. Criteria applied in this cluster include for example the number and proximity of bring-points, no. of retailer/non-retailer bring-points, and civic amenity sites, availability of pick-up services and availability (and/or frequency of) mobile collection (for CDW and WEEE).

It should be noted that regional characteristics have a special role in this cluster. If possible, each criterion should be presented in relation to information about number of inhabitants or information about distances, in order to be more informative. However, local characteristics may affect this category significantly (even between similar regions), and comparisons between systems can be challenging. During the study, high variety in both collection systems and performances between regions with similar characteristics (such as densely populated cities) was recognised (ACR+, 2019; D3.4, 2020). For example, the experts who participated in the MCDM exercises highlighted how the number of civic amenity sites per inhabitant varies greatly between large cities, and does not alone explain differences in collection performances. Similarly, the analysis of the 135 PPW systems revealed how good capture rates can be achieved with different kinds of collection systems. However, it seemed that high density of bring points (number of bring points per km^2) had a positive impact on the capture rates, underlining the importance of proximity of the collection (ACR+, 2019).

Engagement & participation

Criteria related to engagement & participation describe how the expectations and feedback from the citizens are taken into account when planning or operating a waste collection system. At the very basic level, this cluster includes the availability of feedback gathering systems, but also information about information and awareness raising campaigns targeted to users of the waste collection systems. This cluster is closely related to the social acceptance of the waste collection systems, and it may include both quantitative and qualitative criteria. Developing quantitative or comparable criteria for measuring the social acceptance has proved to be challenging (see e.g. also Goulart Coelho et al., 2017), and consequently, social criteria might be less visible in decision-making. Also within the COLLECTORS database, the availability of information regarding these (social) aspects varied a lot between the regions.

Despite challenges in data availability and comparability, experts who participated to the COLLECTORS workshops underlined the importance of communication & feedback gathering activities. Even if the direct impact from these activities was considered difficult to measure, they were considered as essential elements for well performing collection systems. Without active participation of citizens, it would be impossible to achieve high performance. Similarly, the findings from the COLLECTORS consumer focus group discussions highlight that citizens are interested in

waste collection and would like to know more about the system and its impacts and benefits. Participation could increase commitment and motivation for sorting (See D2.5, 2020).

Environment, Health & Safety

Criteria related to environment, health and safety describe the environmental impacts and benefits related to waste collection and recycling. Both impacts and benefits can be comprehensively assessed with the help of life cycle assessment (LCA) (see e.g. D3.1, 2019; D3.3, 2019), but the use of the method requires extensive data collection and systematic monitoring of all waste flows in question. For PPW, the main emphasis in this cluster is on environmental impacts and benefits. For WEEE and CDW, the importance of criteria related to health and safety is highlighted.

Health and safety include criteria related to ensuring safe handling of collected waste and ensuring proper treatment and/or removal of hazardous substances. Criteria related to health and safety are closely related to cluster Quality and separation, and could be included under either of the two clusters. For WEEE, recovery of critical raw materials was considered to become important environmental criterion in future (even if it is currently difficult to measure or monitor).

Socio-economic impacts

Socio-economic criteria measure both the set-up and the operational costs of waste collection and treatment. Additionally, they describe potential impacts on the welfare of the region in terms of job creation and local GDP. The economic criteria include information on the income side of the waste collection, such as PRO fees and household waste fees.

The relevance of socio-economic impacts is high for monitoring the operation of waste collection systems and for strategy selection, including investment decisions. However, the use of socio-economic criteria for benchmarking between systems in different regions or countries is more challenging. This is due to many possible differences between the scale of the systems, but also within the economic environment, involving e.g. cost of labour.

Socio-economic impacts of collection systems and strategies considered during the decision-making exercises included costs (€/tonne collected or €/inhabitant, all waste streams), citizen waste fees (€/inhabitant or €/household, CDW and PPW), waste fees for PROs (€/tonne captured, PPW) and impact on local employment (number of jobs created, all waste streams) and GDP (€/inhabitant, WEEE).

4.2. Capture and recycling rates

EU law seeks to harmonize the national requirements regarding recycling rates. The Directive (EU) 2018/852 amending Directive 94/62/EC on packaging and packaging waste sets minimum recycling rate targets for plastic, wood, ferrous metals, aluminium, glass and paper & cardboard. The Directive

2012/19/EU on waste electrical and electronic equipment (WEEE Directive) requires that Member States meet a minimum annual WEEE collection rate[2]. Regarding CDW, the Waste Framework Directive 2008/98/EC establishes a target of 70% to be recycled by 2020[3]. The capture rates[4] are therefore particularly essential criteria for benchmarking or evaluating the performance of waste collection systems. The high importance, and current limitations, of these criteria are also evident based on the MCDM workshops held during the project. Reaching the European recycling targets are among the most important drivers for improving waste collection at local level (D3.4, 2020).

According to the experts, the WEEE Directive's targets are among the main drivers for improving WEEE collection practices. As the targets are expressed as capture rates, these are important indicators for WEEE collection performance. However, more WEEE is collected than is reported as collected. The market of WEEE collection is partly in the hands of entities that choose not to report those volumes, and therefore part of WEEE collection remains unaccounted for. The performance information may, for that reason, not always be comparable between collection systems from different EU countries.

According to the PPW experts interviewed during the project, the capture rates are used in all phases of decision-making, from evaluation of ideas to benchmarking of operation. The capture rates measure directly the efficiency of a collection system, or the impact of an improvement action in PPW management. National or regional targets for PPW collection may also be expressed as capture rates. The capture rates of all PPW fractions are highly important criteria from a local waste collection point of view, which was also emphasized in the group discussions. However, the capture rate does not indicate how much of the collected waste will be recycled in the end. In addition, it is important to note that share of recycling has been measured and reported in many different ways. It has been possible to report (as recycling) the amount of materials entering the sorting or recycling facility and ignore the amount of potential rejects. This has directed the attention towards capture rates, and not so much on quality of collected materials.

A well performing waste collection system should be aligned with the requirements of the recycling industry in order to maximise the value of recycling. During the MCDM workshops, the experts would have preferred to benchmark collection systems based on the eventual recycling rates, but it was challenging due to limitations in data availability. As the new Directive 2018/852 amending the old packaging and packaging waste directive sets recycling targets for each PPW fraction, the assessment of the actual recycling rates becomes necessary.

[2] From 2016, this was 45% of total weight of electrical and electronic equipment that was sold in the past 3 years and, from 2019, this target increased to 65%, which is equivalent to a target for collection of 85% of the total WEEE generated. In April 2017, the European Commission adopted Implementing Regulation (EU) 2017/699. This sets out the methods to calculate the weight of EEE sold in the market of each EU country and the quantity of WEEE generated by weight in each EU country.

[3] https://ec.europa.eu/growth/content/eu-construction-and-demolition-waste-protocol-0_en

[4] In this study, the term capture rate has the same meaning as collection rate in the WEEE Directive.

In order to know the capture and recycling rates of a waste collection system, all of the waste material flows have to be monitored, including the total amount (mass) of a waste fraction generated, the amount separately collected, the amount rejected from recycling and the amount ending up as mixed residual waste.

Regarding WEEE collection, monitoring of scavenged amounts of valuable components from WEEE, illegal trade and treating of WEEE in unlicensed plants impose additional challenges and requirements for monitoring. In practice, detailed data regarding all waste streams may be very limited on a regional level, and the generated or collected amounts have to be approximated based on sorting analysis of mixed residual waste samples. The shares of recyclable waste fractions are commonly used to monitor the operation of a waste collection system, according to the experts interviewed during the project. However, sorting analyses provide information about only a part of the flows not collected for recycling. Consequently, benchmarking performance between different regions (and even within a region) remains challenging without common rules for sorting analyses. Regional practices for these analyses differ in terms of frequency, number of samples, scope of recyclable waste fractions, etc.

The experts who participated in the study suggested that the amount of PPW in mixed residual waste is an indicator for potential improvements. As such, it was considered a valuable criterion for assessing the collection system's performance during operation. Part of the recyclables found in mixed residual waste may be unfit for recycling due them being polluted upon disposal, however.

The share of small WEEE in residual waste collected is also relevant criterion for both benchmarking and monitoring the operation of WEEE collection systems. Furthermore, the WEEE Directive obliges EU countries to minimise the amount of WEEE discarded in municipal residual waste. Nevertheless, there is only limited amount of regional and reliable up-to-date data for the purpose, based on the WEEE collection system inventory and the MCDM exercises held during the COLLECTORS project. To get accurate data on unsorted quantities for waste fractions that only represents a small share of residual waste, several samples are usually needed for the composition analysis.

CDW from households includes large and bulky objects, which are unlikely to end up in mixed residual waste. However, smaller CDW fractions may end up in residual waste. According to the experts' views, the share of CDW in residual waste is nevertheless a useful indicator for the operational phase of CDW collection. To address the above-mentioned limitations, the share of CDW in mixed residual waste could include the amount of unsorted CDW from households. If possible, the amount of illegally disposed CDW (dumping and illegal backfilling) should also be considered, but might be difficult to evaluate in practice.

4.3. Degree of separation & quality

The evaluation of PPW, WEEE and CDW collection systems needs to take into account that the sorted recyclable waste fractions should be of adequate quality for recycling. Moreover, the

collection and recycling should be aligned to create as much value as possible, while fulfilling the recycling rates set by law. One of the conclusions from the COLLECTORS case studies was that regional PPW collection practices are often driven by "the waste push" rather than the requirements of the recycling value chain (D2.4, 2020). The results also underline that a yield-versus-purity trade-off exists. It may not always be taken into account in strategy selection, and citizens and authorities may rely over-optimistically on the possibility to solve the quality challenges economically by sorting and recycling technology. Similar opinions were presented during the expert interviews regarding the quality criteria for recyclable waste. According to the experts, more effort is needed to monitor the quality of collected recyclables and the final destination of the streams. In a study by ACR+(2019), data on the subsequent destination of the sorted PPW was retrieved for roughly half of the 135 assessed collection systems, and data on the quality of the separated materials was available from one third of the systems only.

Possible criteria to evaluate the quality of collected streams address the level of sorting during collection, purity of the separated waste and rejection rates from recycling. Some information that only indirectly relate to quality of collected waste may be considered as proxies for quality. These can be for instance treatment costs and the share of waste obtained through certain channels that are known to affect the waste quality. Use of such proxies must be considered case-by-case, and may not be comparable enough for benchmarking waste collection systems from different regions.

The criteria used in the MCDM workshops to describe quality differed between the three waste streams. For WEEE, the level of sorting was measured by the number of WEEE categories collected at CASs. Regarding CDW and PPW, the shares (percentage) of material rejected after first treatment stage were used. Additionally, the importance of further measures for quality-related performance, such as the share of contaminants (as weight percentage) in sorted waste were pointed out during the expert interviews.

According to the experts interviewed during the project, the number of separately collected PPW fractions is useful information for planning of a collection strategy, and should be included as one of the recommended decision-making criterion for PPW management. Similarly, the level of sorting (such as the number of categories separately collected in CAS) is useful as a complementary factor in WEEE strategy selection. Furthermore, the experts considered that the level of sorting will affect the depollution (removal of hazardous substances or avoiding hazardous substances in material treated for recycling) and treatment performance of both WEEE and CDW.

Regarding PPW, the degree of separation (or the level of sorting) could be measured by the share of waste collected through deposit schemes, from separate collection (door-to-door and bring-points) or from commingled collection of easily separated light PPW fractions. However, good quality materials can also be captured via commingled collection. According to the five COLLECTORS PPW case studies, collecting plastic, metal and drink cartons together did not seem to influence the quality of the collected fractions, while there was an economic benefit in such commingled collection (D2.4, 2020).

Scavenging, the removal of valuable components prior to intended management of the waste, affects the quality of collected WEEE. For instance, missing refrigeration device compressors negatively affect the value of the sorted materials. Scavenging of these compressors creates also environmental damage through CFC emissions into the atmosphere. During the expert evaluation of the clustered decision criteria, scavenging was proposed to be included as a criterion for benchmarking of WEEE collection performance either as a quality- or capture rate-related criterion.

Based on the COLLECTORS Deliverable 2.4 "Report on solutions for tackling systemic and technical boundary conditions" and supported by the expert evaluations on the criteria, quality of collected WEEE through retail bring-points is in general higher compared to WEEE received through municipal collection points (non-retail bring-points and CASs). This would seem to be due to better control and surveillance at the retailer bring-points regarding the condition and sorting of the received WEEE. The surveillance also reduces the level of scavenging. Therefore, the share of WEEE collected at the retail bring points (or vice versa) may be considered as a proxy for estimating the performance of a WEEE collection system in terms of quality.

4.4. Convenience & coverage

Easy access to the collection system and coverage of the collection services describe the convenience of the system for the users. This category is linked with both capture rate and quality of the collected materials. According to experts who participated to the study, the accessibility and coverage-related criteria provide a useful description of a situation in a certain region. However, they might currently not be used systematically in decision-making. Findings from the COLLECTORS WEEE case studies show that turning retailers into collection points and introducing mobile collection (D2.4, 2020) are effective measures that increase collected quantities in scarcely populated areas. Both increased the convenience of collection to citizens.

Similarly, the analysis of the 135 PPW systems showed that high density of bring points (number of bring points per km^2) increased the capture rates of PPW. Additionally, capture rates of PPW seemed to be higher in regions, in which collection of PPW was more frequent compared to collection of mixed residual waste. Increasing frequency and flexibility of PPW collection was also among the good practices highlighted in the COLLECTORS case studies (D2.4, 2020).

In addition, the experts who participated within the MCDM workshops highlighted how the location of a waste bin or a bring point affects the collection performance. Good practices shared during the workshops indicated for example, that waste bins that were located inside the buildings usually increased capture rates, compared to bins that were located in the yards. Experiments in Norway related to locations of the bins also revealed how changing the location of a bring point by 200 meters (to better match with the routes that people are using when passing by), increased collected quantities.

Challenges in this cluster of criteria relate to comparability of data, as proximity or convenience is usually a combination of many different factors and characteristics. This category is also closely linked with citizen engagement and participation, as citizens' involvement is necessary, in order to develop successful practices. What works in one region does not necessarily work the same way in other regions, even if they would share some similarities. However, regions could still learn from experiences of others. Another common challenge to all waste streams in this category (being even more difficult for the bulky streams of WEEE and CDW) relates to finding necessary space for collection points. The experts mentioned this as a significant limiting factor, together with costs of organising the collection points.

4.5. Engagement & participation

Citizen participation is considered to be closely linked with the capture rate: if the citizens are actively engaged, motivation goes up and the capture rate typically improves as well. The findings from COLLECTORS WP2 studies indicate, how citizens feel more engaged and motivated to sort their waste, when they had a chance to participate in planning of the system, or to provide direct feedback. People can be motivated to participate by implementing pay as you throw elements or other economic incentives, providing information about the environmental benefits achieved through collection activities, and engaging the consumers in planning of the collection systems (D2.5, 2020).

Existence of a feedback gathering system as such does not improve the performance of a system, but systematic feedback collection can be helpful for understanding the needs of the citizens, and consequently improve performance. Experiences of the waste management experts highlighted how surveys conducted after changes to the collection systems, such as improving the location, types and sizes of the bins, can improve the collection performance by creating a sense of "ownership" through participation of the citizens. Even small changes to the appearance or location of the bins have proved to affect the amounts collected.

In addition to collecting feedback, constant communication between the waste management companies and citizens is needed to spread the information on local sorting and recycling systems. Even with mature collection systems, active communication with inhabitants is needed for preserving the quality of the collected PPW, and to keep up the performance on a high level. In case of developing systems, active communication is even more important, and several information channels should be used. Especially in the case of targeted collection events, pop-up or mobile collection services, active communication is required so that people will find the service. This is especially relevant in the case of WEEE and CDW, for which the need for collection is more irregular.

The COLLECTORS MCDM studies highlight that criteria related to citizen engagement and participation were important, but difficult to compare. In addition, it is not easy to quantify the direct contribution of engagement or communication activities. However, this was a topic in which

benchmarking of good practices and learnings from other systems was considered useful. In addition, citizen engagement (in one form or another) was considered as a necessary element for reaching good performance in waste collection, regardless of the waste stream in question.

4.6. Environment, Health & Safety

Environmental criteria applied during the project were mostly derived from the life cycle assessment (LCA) studies conducted in COLLECTORS (D3.1, 2019; D3.3, 2019). Use of LCA for evaluating the environmental performance of waste collection extends the viewpoint to cover the whole life cycle of studied materials or products. Consequently, the benefits achieved through more efficient waste collection, sorting and recycling can be included in the assessment. Examples of potential environmental criteria include the impacts on climate change (greenhouse gas emissions), eutrophication (e.g. nitrogen or phosphorous emissions), or air pollution (e.g. particulate matter emissions) (see also D3.1, 2019; D3.3, 2019). These criteria may be applied to all waste streams, but the significance of different environmental impact categories may vary between the waste streams, and depend on local conditions.

The findings from COLLECTORS LCA studies reveal how increasing the capture rate is an efficient means for improving environmental performance for most of the studied waste streams (D3.3). Consequently, in this study, most environmental impact indicators applied in the LCA correlated with capture rates, which could be used as a proxy for environmental impacts as well. Due to this correlation, the climate change impact (measured as greenhouse gas emissions per kg waste generated) was applied as a representative of environmental criteria during the COLLECTORS MCDM workshops.[5]

The waste management experts who participated in the MCDM studies considered that it would be important to have comprehensive understanding of all environmental impacts, and thus preferred using environmental criteria as part of decision-making. However, they also pointed out, that the contribution of waste collection vs. other life cycle phases was sometimes considered difficult to evaluate, and especially difficult to communicate towards citizens (D3.4, 2020). Even if not directly used for decision-support, information about environmental impacts is important for understanding how changes in collection might affect the life cycle impacts related to collected waste. Additionally, this information is important for motivating citizens to sort their waste and to increase understanding about impacts of waste management (D2.5, 2020)

Based on the views of the participating experts, the use of environmental criteria (such as greenhouse gas emissions) as part of decision-making related to waste management was not yet

[5] In MCDM methodology, overlapping (redundant) criteria should not be used, and due to strong correlation with the capture rate, most of LCA based criteria were considered redundant. However, this does not reduce the information value of LCA results, which was considered to be important for informing citizens and understanding the situation as a whole. LCA can reveal important, system level impacts that are not visible if only local level impacts are considered.

common, but it was expected to gain more importance in the future. The experts also emphasized the need for local environmental information. Addressing local environmental impacts via LCA is possible, if efforts are made to collect necessary local data.

For WEEE and CDW, the criteria related to safe handling and removal of hazardous substances were considered essential (also due to regulatory requirements), but these cannot be thoroughly covered with LCA studies, and require separate monitoring activities. Especially for CDW, participating experts evaluated, that efficient removal of hazardous substances, such as asbestos, mercury and lead would be even more important than the capture rate as such. However, lacking information about the exact content and hazardousness of the materials is one of the bottlenecks currently preventing both re-use and recycling activities.[6] According to the interviewed experts, dedicated companies commonly take care of hazardous waste treatment, and detailed knowledge might be lacking from the municipal waste management company. This is one of the areas in which monitoring and information exchange activities should be developed in the future.

The findings from MCDM related literature indicated that environmental criteria applied in MCDM studies are often simplistic and even qualitative, and use of LCA results is not yet very common (Goulart Coelho et al., 2017). Goulart Coelho et al. (2017) consider qualitative or simplistic criteria less reliable and useful compared to LCA results. However, the experiences from COLLECTORS project highlight, how data related to waste flows and collection systems is often inconsistent and defective, and use of quantitative data might suffer from many uncertainties. Use of qualitative or descriptive information could be equally useful, if it allows integrating environmental aspects in decision-making. Qualitative information can be included in value based MCDM methods as rating scales. Within methods like the analytic hierarchy process (AHP, see e.g. D3.4), use of both qualitative and quantitative criteria is possible. For management or monitoring purposes, qualitative information can be used as a starting point for more systematic data collection, which could ultimately allow conducting LCAs or applying other more comprehensive and detailed assessment methods.

The share of environmental impacts related to the waste collection phase is usually quite small compared to the impacts originating from the whole life cycle of products (see D3.3, 2019). Therefore, a small increase of environmental impacts in the collection phase can be acceptable if it leads to more significant improvement in overall environmental performance, for example via improved capture rates(D3.3, 2019). Thus, increasing local environmental impacts related to transport might be acceptable and beneficial, if the total impacts related to materials can be decreased. An exception to this is the CDW stream, in which long transports should be avoided due to high volumes and heavy weight of the material (D3.3, 2019). Additional environmental benefits might be achieved by reducing losses in the sorting and recycling phases, by improving the quality of collected material (D3.3, 2019). Systemic, life cycle view is important for understanding the

[6] This challenge is currently tackled for example by the Information for Recyclers (I4R) platform which seeks to bring that information together in one place. The platform is developed by APPLiA, DIGITALEUROPE and the WEEE Forum.

interlinkages between different life cycle phases, and avoiding burden shifting, as increasing capture rates without considering impacts on quality of the collected stream might lead to problems in the recycling stage (D2.4, 2020).

For dedicated CDW streams (e.g. bricks) and WEEE streams (e.g. small WEEE and IT equipment) significant improvements can be achieved by promoting re-use activities (D3.3, 2019). Thus, criteria related to enabling or increasing re-use would be relevant for both CDW and WEEE. These criteria could be qualitative or quantitative, or category indicators (such as existence of policies or services promoting re-use).

4.7. Socio-economic impacts

PPW, WEE and CDW collection systems have socio-economic impacts, which can be quantified for decision-making on collection strategy selection. During the COLLECTORS project, the cost and financing structure of 12 case studies were assessed using Cost-Benefit Analysis (CBA) (D3.2, 2020). Furthermore, the impacts on local welfare in terms of job creation and local GDP increase potential were discussed in expert interviews and decision-making workshops.

Cost-efficiency, taking into account both the set-up and the operational costs are obviously important for assessing the performance of collection strategies. The cost-efficiency can be presented as costs per inhabitant or costs per collected amount of waste, depending on the context of the evaluation. Furthermore, the costs can be expressed as total costs of the system per waste fraction and divided per each collection or treatment stages. The cash flow of a collection system can be assessed over any period and expressed as a net present value taking into account the current or future investments and the time value of other costs and revenues. The waste management experts saw the use of cost criteria in decision-making and monitoring of the operation of collection systems as a normal practice for all assessed waste streams.

Assessment of collection and treatment costs together with how the costs are financed provides useful complementary information such as the share of costs financed by waste fee from inhabitants. For collection of recyclable PPW in the five case studies, as much as 23-57% of the costs was financed by the household waste fees (D3.2, 2020). Other financing cash flows included in the COLLECTORS CBA case studies were value from the recovered materials and the EPR fees. The treatment costs together with the value of recovered material can give an indication of the quality of collected and separated material, as gathered from the expert interviews during the project. What is included in an economic assessment, however, is always determined by the required scope of the study.

PPW, WEEE and CDW collection and treatment together with the complete recycling value can contribute to regional employment and GDP. During the project, these impacts and their value for decision-making in collection strategy selection were discussed together with regional waste management experts. Especially the job creation related to reuse of WEEE and CDW was seen as an

important aspect to consider in strategy selection. Prevention and reuse of CDW was seen as a wide topic, involving the construction and demolition sector and new ways of organising construction projects. Processing and separating CDW at source requires work, and improves the quality by avoiding mixed and crushed CDW. Within the WEEE collection, reuse activities may be organised via social enterprises, thus creating additional benefits for the society.

According to expert views, job creation usually has value for local elected representatives, and thus should be relevant especially from policymakers' point-of-view. However, number of jobs related to waste collection proved to be a difficult indicator for benchmarking between collection systems and comparing collection strategies. This was due to many different ways in reporting the number of people employed by waste collection. In addition, it was also pointed out that less jobs could sometimes mean increased efficiency. Conflicting views and low level of detail related to available data was indicated as generally lower perceived importance of the criterion in the conducted decision-making exercises.

5. Recommended criteria for identification of regions with similar challenges and context

This chapter presents the main conclusions from the criteria discussions and weightings conducted during the COLLECTORS RWG meeting at Malta, in September 2018 (For more information, see D1.3, 2018). The aim of the exercise was to identify criteria that could be used for identifying waste collection systems that are likely to face similar challenges. The possible criteria were gathered from the COLLECTORS database on waste collection systems. Criteria proposed by the expert participants were also included. The importance of the criteria were evaluated during expert panel in the course of the meeting where multicriteria decision-making was used to select the 12 case studies for in-depth studies.

The first selection of the criteria was done based on data coverage. From among the criteria included within the COLLECTORS database, general criteria describing regional characteristics and having information available for most of the systems were included in the evaluation. The criteria evaluated during the MCDM (see Table 2) can be used to identify collection systems that are most useful for benchmarking and comparing waste collection strategies across regions.

The criteria presented here were assessed based on eliciting expert preferences. They were not validated by statistical assessment. However, the statistical analyses conducted for the PPW systems during later parts of the project revealed, how at least partly similar findings were made. In general, the studies show, how municipal waste generation is a result of many different factors. Identifying single factors that would explain differences in waste generation or in collection performance is difficult (ACR+, 2019; Tallentire & Steubing, 2020). The waste management experts who participated in the MCDM underlined the same thing.

When looking at the expert estimations on the potential importance of the criteria presented here, amount of tourism was among the most important criteria for PPW. GDP per capita was considered important criterion for both WEEE and CDW collection, while its importance was low in terms of other available criteria for the collection of PPW. Similarly, the population density was an important criterion for both WEEE and CDW collection. The two criteria with highest importance for PPW collection were the level of tourism and commuting (measured as overnight stays per capita) and

the total municipal solid waste generation in the region. These criteria were not considered for the WEEE or CDW collection systems.

Somewhat in line with the expert estimations presented in Table 2, an analysis of the 135 PPW collection systems conducted by ACR+ (2019) showed that high number of tourist visits seemed to correlate with increased PPW waste generation. This confirms amount of tourism as a meaningful criterion for identifying potential benchmarks, especially among regions with very high number of tourists compared to number of regular inhabitants. From the other evaluated criteria, high population density and low GDP areas had slightly lower capture rates compared to other areas. The analysis of the same PPW systems conducted by Tallentire & Steubing (2020) (using country as a fixed factor, and looking individually at all studied PPW streams) found that GDP and population density correlated to some extent with capture rates of glass and plastics. Compared to PPW systems, much less information about the WEEE and CDW systems were available for the COLLECTORS database, and available data was more fragmented. Therefore, similar analysis on potentially important regional criteria could not be conducted in a meaningful way.

When considering the results presented by ACR+ (2019) and Tallentire & Steubing (2020), GDP should probably be added among the most important criteria for PPW as well. On the other hand, the findings by ACR+ also highlighted, how higher GDP seems to affect amount of PPW generated, especially for paper and paper packaging waste. The type of housing, which is indicated by the share of detached and semi-detached houses, was considered highly relevant criterion for CDW management, and it has also relevance for organising PPW collection. It should be noted that some of the criteria received lower scores due to poor availability of data, assumed uncertainty related to available data, and challenges in comparability, even if they were otherwise considered important.

Table 2. Summary of assessed criteria for determining similar context between collection systems, for benchmarking. The importance is determined based on criteria weights elicited from an expert panel by voting. The scale is High - Medium - Low, indicating whether the criterion weight was at the 66th percentile (High), at the 33rd percentile (Low) or in between (Medium) during a decision-making exercise.

Waste stream / criterion importance	WEEE	PPW	CDW
High	Population density, (No. of inhabitants per km^2) Local economy, (GDP per inhabitant)	Level of tourism and Commuting, (Overnight stays per inh. per year Total MSW generation, (Kg / capita / year)	Local economy, (GDP per inhabitant) Type of housing, (Share of detached and semi-detached houses in %)

			Population density, (No. of inhabitants per km^2)
Medium	Estimated WEEE generation per capita, (Kg / capita / year) Area size, (km^2) Area characterization, (remote/not remote, coastal/inland/island) Type of housing, (Share of detached and semi-detached houses in %)	Type of housing, (Share of detached and semi-detached houses in %) Population, (No. of inhabitants) Population density, (No. of inhabitants per km^2)	Area characterization, (remote/not remote, coastal/inland/island) Population growth, (% increase per year) Population, (No. of inhabitants) Expatriates, (No. of expatriates) Growth of GDP, (% increase per year) Scope of CDW collected, (no. of separate fractions collected at CAS)
Low	Population, (No. of inhabitants) Households, (Total no. of households) Household size, (average no. of persons per household) Estimated WEEE generation, (Total in tonnes)	Local economy, (GDP per inhabitant) Area size, (km^2) Area characterization (remote/not remote, coastal/inland/island) Households, (Total no. of households) Household size, (average no. of persons per household)	Area size, (km^2) Households, (Total no. of households)

6. Recommended criteria for benchmarking of waste collection systems and evaluation of collection strategies

This chapter presents the main conclusions from the criteria discussions and weightings conducted during the COLLECTORS RWG meetings at Malta (2018) and Warsaw (2019) and the WEEE workshop held in Brussels, in November 2019 (For more information, see D3.4). Chapter 6.1 discusses criteria relevant for WEEE, and Chapter 6.2 criteria relevant for PPW. Criteria for CDW are presented in Chapter 6.3. A short summary covering findings for all waste streams is included in Chapter 6.4.

6.1. Waste Electrical and Electronic Equipment from private households

Evaluation criteria regarding WEEE collection were used in two MCDM exercises during the project, one focusing on benchmarking of collection systems and the other focusing on early stage evaluation of collection improvement actions. During the decision-making workshop on the early stage prioritisation of improvement actions, the participating experts were asked to freely define a set of preferred evaluation criteria. The only constraint, other than ensuring the set of criteria were operational for comparing the improvement actions, was to limit the number of criteria to a maximum of four (due to time limits). The criteria assessed during the two workshops are summarized in Table 3.

The criteria with highest importance for benchmarking or assessment of collection strategies regarding WEEE include the collection (capture) rates, share of WEEE in mixed residual waste and the removal of hazardous substances from the collected waste. The WEEE collection systems and strategies should also be evaluated with criteria relating to the collection methods (retailer/non-retailer bring points and CASs), as it has a recognised effect on the quality of the received WEEE. Other criteria that are important for strategy selection based on the preferences and arguments of

the experts were socio-economic criteria (including the costs of collection and the impact on regional welfare, indicated by the number of jobs created and increase in regional GDP per capita).

The environmental performance of WEEE collection was also considered an important criterion for strategy selection, and the experts proposed the use of climate impacts for decision-making concerning WEEE, together with efficient removal of hazardous substances, and recovery of critical raw materials. The correct definition of the system boundary where greenhouse gas emission are estimated is challenging, however. Throughout the project, the use of also other environmental impacts than global warming potential was suggested. Given sufficient resources for the assessment of local environmental impacts, such criteria is important for assessment of alternative waste management strategies in a regional context. Benchmarking the environmental performance of waste collection systems across regions would be more challenging using such criteria, due to limitations in comparability. Finally, the importance of accessibility to WEEE collection was emphasised by the experts. The number of bring points (in relation to number of inhabitants) for instance, was considered relevant for reaching higher capture rates.

Table 3. Summary of assessed criteria for benchmarking of WEEE collection systems and prioritising alternative collection strategies.

Cluster	WEEE Criteria	Comments
Capture and recycling rates	WEEE capture rate, (%) WEEE collection rate, (maximising collection, tonnes/year or tonnes/capita).	Maximising collection was the most or the second most preferred criterion (out of four included) for early phase prioritisation of improvement actions. The importance was higher on a region with less developed WEEE collection systems and lower capture rates. The capture rate was considered to be of highest importance (out of nine criteria included) for benchmarking of WEEE collection systems. The capture or recycling rates of WEEE were uncertain as what is put on the market on local level is an estimation and more monitoring of the WEEE flows is needed. Lifetimes of small WEEE also vary, which complicates the estimation of capture rates from what is put onto the market. The experts proposed the use of a criterion measuring the amount of scavenging (such as the share of large WEEE received non-intact, or the related material flows) in the collection system. During the Malta workshop on benchmarking of WEEE collection systems, the experts from a compliance scheme

		suggested that WEEE ending up to scrap dealers should be included as a criterion.
	Share of WEEE in mixed residual waste, (%)	The criterion received the second highest weight (out of nine criteria included) for benchmarking WEEE collection systems. WEEE in mixed residual waste can be unreliable because of lack of data. WEEE may not be included as a category in the sorting analyses, and they cover only small WEEE.
Engagement & participation	Existence of feedback gathering system, (yes/no)	Was used for benchmarking waste collection systems, based on varying level of qualitative information available on the systems. Was among the criteria with lowest weight (8. in importance out of nine included) in the MCDM exercise.
Environment, Health & safety	Climate impact	Climate impact was among the four preferred criteria for early phase prioritisation of improvement actions regarding WEEE collection on a case region with developing collection system.
	Getting the hazardous substances out of the loop and critical materials recycled	Criterion was the most preferred criteria (out of four included) for early phase prioritisation of improvement actions regarding WEEE collection on a case region with mature collection system (a large city with a high local GDP).
Socio-economic impacts	Increase in local employment, (Number of direct jobs) Increase in local employment and GDP, (as total value for the local economy)	Number of direct jobs received the lowest weight out of nine criteria included for benchmarking of WEEE collection systems. Data availability was low regarding the jobs in the benchmarked systems. Impacts to employment and local GDP received the lowest weight among the four preferred criteria for early phase prioritisation of improvement actions on a case region with developing WEEE collection system (a small city with low local GDP). Job creation was mentioned as one positive effect of WEEE reuse activities, and inclusion of employment effects in evaluation of collection systems and strategies were in general supported during the experts' interviews.
	Total costs of WEEE collection, (€/tonne)	Collection costs were the second most important criterion out of four included for criteria for early phase

		prioritisation of improvement actions on a case region with developing WEEE collection system. The importance of the cost criterion was emphasized by the experts because of the low GDP at the region.
Degree of separation & quality	Number of WEEE categories collected in CAS	The criterion was used for benchmarking WEEE collection systems, and received lower-than-median weight (among nine included) according to the expert preferences during the MCDM exercise.
	Share of WEEE collected in CAS in relation to total WEEE collected	The criterion was considered of medium importance (out of nine included) for benchmarking WEEE collection systems. During the COLLECTORS workshops, the experts from PROs indicated that the quality of WEEE received through retail bring-points is in general of better quality compared to other sources. Therefore, it is useful to know the ratio between retail and CAS collection. An altogether different expert argument from a take-back scheme was presented according to which a good collection system would not necessarily need much WEEE collection at CASs. CAS is a storage facility, which can incur extra costs. Therefore, from a producer point of view, it would be better if the consumer would give the WEEE directly to the producer via retailers.
Convenience & coverage	Number of inhabitants / 1 retailer bring point	The criterion was considered of medium importance (out of nine included) for benchmarking WEEE collection systems. Proximity (such as bring-points / km^2) could be also considered for benchmarking of accessibility to WEEE collection.
	Number of inhabitants / 1 non-retail bring point	Same as above.
	Easy access to collection (for consumers)	Criterion was among the preferred criterion (third in importance out of four included) for early phase prioritisation of improvement actions regarding a mature collection system on a high GDP region.

6.2. Paper and Packaging waste from households

Capture rates of separate recyclable waste fractions were considered the most important criteria for evaluation of PPW collection systems or strategies during the two MCDM workshops. One of the MCDM workshops focused on benchmarking of PPW collection systems, and in the other workshop, an improved PPW collection strategy was selected for a case capital region in Europe. The assessed criteria in the two workshops are summarised in Table 4. Closely related to capture rates, the shares of recyclable PPW fractions in the mixed residual waste are good indicators of the operational performance and the improvement potential of a PPW collection system.

As with all the considered waste streams, the quality of collected waste needs to be measured and monitored. During the workshops on PPW collection, the experts pointed out that they would prefer to base their decisions on recycling rates instead of capture rates, but the data gaps limit their use. Due to the focus of the COLLECTORS project on the waste collection phase, the use of capture rates is recommended together with complementary criteria on the quality of the collected material. The PPW quality-related criteria, which were recommended by the experts during the MCDM workshops and other RWG sessions are the Recycle or Rejection Rate (w%) from Collected PPW for each fraction (Glass, Paper & cardboard, Metal and Plastics), and the Share (w%) of contaminants per separate PPW fractions.

The citizen engagement and participatory actions were considered in general even more important for PPW collection compared to the other waste streams involved.

Socio-economic criteria should be included in the assessment of PPW collection systems and strategies. For benchmarking between regions or countries, they are difficult to compare due to different economic context, however. Both the annual waste fee to households, if targeted for reducing unsorted waste, and the total operational costs per capita were given high weight in the decision-making situations concerning strategy selection.

Table 4. Summary of assessed criteria for benchmarking of PPW collection systems and prioritising alternative collection strategies.

Cluster	PPW Criteria	Comments
Capture and recycling rates	Capture rates of Plastic, Paper & cardboard, Glass and Metal, (%)	In the two MCDM workshops for benchmarking of PPW collection systems and for selection of a PPW collection strategy, the capture rates were the four most important criteria. The capture rates of plastics and paper received slightly higher weight compared to other capture rates in both workshops.

		Capture rates or information on the collected amounts of composite materials were also considered relevant by the RWGs for strategy selection.
	Shares of Plastic, Glass, Paper & cardboard and Metal in mixed residual waste, (%)	The shares of plastic, glass and paper received medium weight for benchmarking of collection systems. The participated experts gave lower weight to the share of metals in mixed residual waste. Importance of the shares of recyclables in mixed residual waste for operational monitoring was further emphasized by the RWGs. Based on the inventory of PPW collection systems in the COLLECTORs database, the data availability was better regarding the share of recyclables in mixed waste, compared to capture rates.
Engagement & participation	Citizen satisfaction, (Existence of feedback gathering system or a system for complaints and conducting regular phone surveys)	Criterion was used for both benchmarking and strategy selection. Existence of feedback gathering systems were among the criteria that were weighed less important compared to other criteria for benchmarking (8. most important out of 11 included). The weighting was affected by the data incomparability and availability in the decision-making situation. In a strategy selection context (focusing on choosing a collection strategy out of two alternatives for a case region), however, the decision-makers gave a similar criterion high weight (6. most important out of 20 included). According to the experts, communication with the citizens is important for a well-functioning waste collection system. The communication should go both ways: Quality-related recommendations to the inhabitants and complaints etc. to waste collectors.
Environment, Health & safety	Global Warming Potential, (kg CO_2-eq/capita)	Even as the use of environmental data to support decision-making was according to the interviewed experts important, the global warming potential received low weight in a strategy selection situation (15. most important out of 20 included). Argumentations for the preferences included that the GWP is largely redundant (explained and determined by) with the capture and recycling rates, and moreover, such indirect effects are challenging to communicate to stakeholders (including citizens).

		Use of local environmental impacts in collection strategy selection or assessment was supported by RWGs on several occasion.
Socio-economic impacts	Annual waste fee per capita or per household, (€/capita or €/household)	The criterion received high weight for strategy selection (7. most important out of 20) and low weight for benchmarking collection systems (10. most important out of 11 for benchmarking). Household fees, when purpose is to increase costs of disposing unsorted waste (as Pay-as-you-throw etc.), were considered more as drivers rather than criteria in many expert arguments. They were nevertheless considered important for well performing collection systems Benchmarking collection systems from different countries and regions is challenging using economic criteria. Adjusting the criteria appropriately, such as by purchasing power of the region, may be needed to use such criteria for benchmarking. The incomparability reduced the weight of annual waste fees during the MCDM workshop for benchmarking.
	Total operational costs (€/capita)	The participating experts considered the total operational costs the most important criteria after capture rates for PPW collection strategy selection (5. most important criterion out of 20 included).
	Collection costs per PPW fraction (Plastic & metals comingled, Paper & cardboard comingled and Glass), (€/tonne)	The collection costs per each PPW fraction received medium weight in the context of choosing between two presented alternative collection strategies for a case region. The criteria are relevant for monitoring the operation of a collection system, however, according to the participated experts.
	Collection costs of residual waste, (€/tonne)	Same as above.
	Processing (not including the treatment during recycling) costs (€/capita)	The comments on the processing costs are similar to those on collection costs, based on the MCDM exercise on strategy selection. The processing costs may increase with less source separation and can be considered as trade-off costs with commingled collection of PPW fractions. In the absence of better information on recycling rates, the processing costs

		per PPW fraction may be considered as proxies that give indication about the quality of the collected material.
	Set-up costs, (€/capita)	Set-up costs were among the least valued criteria for PPW strategy selection (19th most important out of 20 criteria). Operational costs were considered more relevant.
	Industrial waste fees for Glass, Paper & cardboard, Metal and Plastics, (€/tonne)	The PRO fees received low importance compared to other criteria, when used for PPW collection strategy selection. They were not considered during the MCDM on benchmarking of collection systems, as information was not available. The use of industrial waste fees for benchmarking would face similar challenges as other economic criteria, such as the need to adjust monetary flows with appropriate information on the regional welfare. Moreover, there may be regional differences to the role of stakeholders in financing the collection. According to findings in the Deliverable 3.2 "Assessment of socio economic and financial performance of 12 selected case studies", when capture rates were increased in the case PPW collection systems, the waste fee decreased, as well as the incineration revenues, and was compensated by an increase in recovered material revenues and PRO fees.
	Employment impacts, (no. of direct jobs)	Employment was considered politically relevant information, but very difficult to use for decision-making for both strategy selection and system benchmarking. Employment was difficult to assess, data was not well available and the impacts have trade-offs with cost-efficiency and productivity. The employment impact of PPW collection received the least weight in both MCDM workshops for benchmarking and strategy selection.
Convenience & coverage	Proximity, (no. of bring points, door-to-door coverage and distance to bps.)	A criterion indicating the proximity and convenience of PPW collection to the citizen received medium weight for strategy selection (8. most important out of 20 included). During the MCDM workshop for benchmarking collection systems, the number of bring points was suggested for as a criterion for benchmarking.

6.3. Construction and demolition waste with a focus on wastes that are managed by public authorities

Criteria for evaluating CDW collection were used in one MCDM workshop focusing on benchmarking of collection systems (see **Error! Reference source not found.**). The criteria for strategy selection and benchmarking were further discussed during separate RWG sessions in the course of the COLLECTORS project. Similar to other waste streams, the capture rates of CDW fractions have a high relevance for benchmarking of collection systems and assessing CDW collection strategies. The removal of hazardous substances, such as asbestos is also very important for CDW. As the capture rates of CDW are high, the presence of hazardous substances determine the recyclability of the collected waste. The recycling rates can be monitored by the amount of rejects before material recycling.

The experts underlined the use of collection costs of CDW in decision-making. Collection costs mainly consist of the operation of the CASs and transport of the CDW fractions to recycling facilities (D3.2, 2020). The waste fees per household or inhabitant was considered an important socio-economic criterion. The relevance of the impact on local employment in evaluation of CDW collection was supported in the Regional Working Group meetings, due to labour intensity of CDW treatment for recycling.

Accessibility and coverage of the CDW collection was also considered important for benchmarking, and can be measured using e.g. Number of inhabitants per CAS and the Availability of pick-up service as criteria.

Table 5. Summary of assessed criteria for benchmarking of CDW collection systems.

Cluster	CDW Criteria	Comment
Capture and recycling rates	Capture rates, (Relative quantity of separately collected material - for different CDW fractions)	Capture rates were among the most preferred criteria (fourth most important out of 12 included) for benchmarking of CDW collection systems.
	Share of CDW in mixed residual waste, (%)	CDW from households includes often bulky and heavy objects, which are unlikely to be disposed in the mixed residual waste. The share of CDW in mixed residual waste was among the least valued criteria, during the MCDM where CDW collection systems were benchmarked. However, none of the criteria got an exceptionally low weight (the weight of the least valued criterion was roughly 60% of the most valued criterion).
Engagement & participation	Existence of feedback gathering mechanisms, (yes/no)	Criterion was used for benchmarking waste collection systems, based on varying level of qualitative information available on the systems. Existence of feedback gathering mechanisms was among the criteria with medium weight (7. in importance out of 12 included) in the MCDM exercise.
Environment, Health & safety	Hazardous substances removed before treatment, (unit of measure was undefined)	Removal of hazardous substances was weighed against other criteria during an MCDM exercise for benchmarking CDW collection systems. The criterion received a low weight compared to other criteria (9th most important out of 12 included), affected by the limited comparable data available on the benchmarked collection systems.
Socio-economic impacts	Created jobs per CDW collected, (exact unit of measure was undefined)	Employment impacts were among the criteria least valued (10^{th} most important out of 12 included) by the experts when CDW collection systems were benchmarked.
	Capital expenses per CDW collected, (exact unit of measure was undefined)	Capital expenses were among the criteria with medium weight for benchmarking between CDW collection systems (8. in importance out of 12 included) in the MCDM exercise.
	Operational costs per CDW collected, (exact unit of measure was undefined)	Operational costs received slightly higher weight compared to capital expenses for benchmarking between CDW collection systems (6. in importance out of 12 included) in the MCDM exercise.

	Fee to be paid by citizens for municipal waste management, (breakdown (estimate) of share of CDW stream and per relevant CDW fraction, where possible)	The household or citizen waste fee was considered highly important by the experts during the MCDM exercise for benchmarking of CDW collection systems. The criterion was the third most important out of 12 criteria included. Based on the argumentation from both CDW and PPW benchmarking exercises, the high weight given to the household waste fees, regardless of data availability, were partly caused by good experiences from PAYT schemes and the expected effect of targeted waste fees in reducing unsorted waste.
Degree of separation & quality	Share of CDW rejected after 1st treatment for recycling, (%)	Share of rejected CDW from recycling was among the criteria with medium weight for benchmarking between CDW collection systems (5. in importance out of 12 included) in the MCDM exercise. A possible criterion for measuring the degree of separation and quality of collected CDW would be the number of CDW fractions collected per CAS (this was one of the good practices in one of the two CDW collection case studies during the project).
Convenience & coverage	Collection coverage, (Percentage of households / area covered by separate collection system)	Collection coverage was the least valued criterion for benchmarking CDW collection systems out of 12 criteria included (receiving 60% weight compared to the most important criterion).
	Number of inhabitants per CAS, (-)	Having a high data availability among the benchmarked CDW collection systems, the number of inhabitants per CAS was considered the most important criterion by the experts who participated to the MCDM exercise.
	Availability of pickup service, (yes/no)	Availability of pick-up service for CDW was the second most preferred criterion (out of 12 included) for benchmarking collection systems.

6.4. Concluding remarks for all waste streams, based on expert evaluations

Based on the results from the workshops with experts from waste management companies, waste agencies, municipalities and producer responsibility organisations, the capture and recycling rates

were the most essential criteria for benchmarking waste collection systems or evaluating strategies. This applies to all waste fractions within the three waste streams considered (PPW, WEEE and CDW). The share of PPW, small WEEE and small CDW materials in mixed residual waste were also regarded as highly valuable criteria for benchmarking and monitoring the operational performance of waste collection systems.

Criteria measuring how well a collection system is aligned with the rest of the recycling value chain should be used, including data on how much of the captured waste fractions are recycled. Such available data, including information on the quality of the separate materials was found to be limited. During the decision-making workshops on PPW strategy selection, the experts indicated that they would prefer to base their decisions on recycling rates instead of capture rates but had more confidence on the data describing the latter. In order to benchmark collection systems from different regions or countries, better monitoring and reporting practices need to be developed.

In addition to the capture or collection rates, the quality of the collected material has to be taken into account for all considered waste fractions. The importance of the use of quality criteria in the assessment of collection systems and strategies was underlined throughout the workshops. Together with the capture or collection rates, the shares of PPW or CDW fractions rejected before recycling can be used to measure the quality. The quality of WEEE is susceptible to collection as undamaged material is most often received through retailers and B2B sources, the latter being outside the project scope. The quality of the WEEE collected in civic amenity sites increases when WEEE is segregated. Therefore, the share of WEEE and the number of WEEE categories collected at CASs can be used as proxies for waste quality. The waste quality has a different meaning for WEEE and CDW compared to PPW. The quality of WEEE and CDW affects the depollution performance and removal of hazardous substances during treatment. This affects the recyclability of the material and causes environmental and health impacts. How well the critical raw materials are recovered from small WEEE will of course be limited also by the availability of technology. The quality of PPW can be measured by the shares of contaminants in the separately collected waste fractions.

Easy access to waste collection and coverage of separate collection are factors that both increase the capture rates and increase the quality of collected waste. PPW and WEEE collection both benefit from the ease of access, which is increased by the number of bring-point and can be measured as proximity (e.g. average distance to a bring point). Coverage (share of area or households) of door-to-door collection per waste fraction is an important criterion to assess the performance of PPW collection.

Pick up services for large WEEE are commonly organized by retailers in connection to home deliveries of new appliances. The availability of pick-up service was not considered as a criterion for assessing WEEE collection systems or strategies during the project, due to issues related to data availability. Based on the relevance of door-to-door collection of PPW and pick-up service of CDW, the WEEE collection systems can be benchmarked using the availability of pick-up service as well.

A well-functioning waste collection system addresses the needs of citizens. Collection systems can be benchmarked using the availability of feedback systems or regular phone surveys in case of all the thee waste streams. Through engagement and participation actions, the citizen satisfaction regarding the waste collection can be improved, which ultimately can result in better capture and recycling rates. Although citizen satisfaction could be seen as a social impact, engagement and participation actions were seen as proxies for better capture rates. During the decision-making workshops, the citizen satisfaction (measured by the level of citizen engagement actions) was valued highly by the experts in PPW collection strategy selection.

Regarding socio-economic impacts, the cost of collection is an important evaluation criterion for both strategy selection and monitoring. The costs should be broken down to at least operational and set-up (investment) costs. During the decision-making workshops on PPW collection, the operational costs were further broken down to each separately collected waste fraction (glass, paper & cardboard commingled and plastics & metals commingled), which can be recommended as a principle for WEEE and CDW as well. Collection costs of residual waste (€/tonne) can be included as a criterion to assess PPW collection systems or strategies. It should be noted that the cost of residual waste collection tends to increase with separate collection of recyclables. Finally the processing costs (€/capita) of collected PPW fractions, referring to processing such as sorting of commingled fractions usually by the organization in charge of the collection, can be used as a proxy indicating the quality of the collected waste. Furthermore, the quality of the collected waste is indicated by the income from material sales.

The impacts to employment as a number of new jobs can be included as a criterion for assessing collection strategies regarding all three waste streams. The experts gave higher weight to employment impacts when assessing WEEE or CDW collection compared to PPW collection. The job creation potential is considerable in the reuse schemes for WEEE and processing of CDW. The impact on employment and local GDP were considered important especially for regions with low GDP.

The criteria on environment, health and safety should focus on the local emissions of PPW collection, and efficient removal of hazardous substances from WEEE and CDW. During the workshops on WEEE and PPW collection, the experts gave somewhat low weight on climate impacts, due to their strong positive correlation with capture rates.

7. Conclusions and recommendations

7.1. Main conclusions

This study has presented findings from the decision-making exercises and expert workshops that were organised during the COLLECTORS project. The focus of the work was on identifying and evaluating criteria, which can be used to evaluate PPW, WEEE and CDW collection systems. Studied criteria were clustered under six different themes:

- Capture and recycling rates
- Degree of separation and quality
- Convenience & coverage
- Engagement & participation
- Environment, health & safety
- Socio-economic impacts

Together, the clusters represent multiple objectives that constitute a well performing waste collection system. In order to make informed decisions related to waste collection, it is recommended that at least one criterion from each cluster should be included in decision-making at local or regional level. Efforts should be made in order to eventually increase the number of criteria that describe performance of the system within each cluster. The criteria presented here could be applied in local studies that apply methods of multicriteria decision-making, or for regular decision-making, management and monitoring activities. MCDM methods could be applied for weighting and prioritising between different waste management and collection options, or for collecting stakeholder views (D3.4, 2020).

Even if studies using MCDM and multiple criteria for evaluating waste management options are getting more common, applying criteria and finding information from multiple aspects can still be challenging. In a previous study, Achillas et al. (2013) reviewed the criteria that were applied in 37 MCDM studies that focused on selection of optimal waste management strategy, and were published between years 2006-2010. Identified criteria seemed to match rather well with the clusters applied in this study. However, there was quite a lot of variety between the coverage of criteria applied in different studies. Most of the 37 studies that were included in the sample used criteria related to costs (capital & operational) (32) and environment (30), while use of criteria

related to other categories similar to those used during this study, such as employment (9), population affected or served (5) were more rare. Criteria related to safety and public health, and social acceptance were used approximately in one third of the studies, similarly with criteria related to technical reliability. While most studies seemed to include criteria from 4-5 categories (of the studied 13), some studies including up to 7-8 criteria categories were found. Unlike our study, Achillas et al. (2013) identified additional criteria related to waste-energy recovery, diversion of landfill and land demand, which were not addressed or discussed during COLLECTORS, due to focus in waste collection phase, instead of actual waste treatment or recycling.

Goulart Coelho et al. (2017) reviewed 260 MCDM studies that were published in scientific journals between years 1981-2016. Criteria most commonly applied in MCDM studies were environmental and economic. Only 48% of the studies were able to address environmental, economic and social criteria, and in many cases, environmental and social criteria included qualitative or simplistic information. Most challenges were reported in using quantitative criteria for the social assessment (Goulart Coelho et al., 2017). Interestingly, while the environmental criteria were among the most commonly applied, only 10% of the 260 articles reviewed by Goulart Coelho et al., (2017) applied life cycle assessment (LCA) based information for evaluating environmental performance.

The findings from the COLLECTORS MCDM studies and expert workshops highlight that decision-making related to waste collection is often affected by lack of precise or comparable data (D3.4, 2020). 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. Together, the findings from the COLLECTORS project provide practical examples of how general decision-support methods like MCDM (D3.4, 2020), cost-benefit analysis (D3.2, 2020) and life cycle assessment (D3.1, 2019; D3.3, 2019) can be used for analysing the performance of different kinds of collection systems at a regional level. However, the findings from the project equally highlight how lack of data is currently restricting the use of these and other similar structured methods, and makes comparing performances of different kinds of collection systems and strategies difficult.

The criteria presented in this report (and applied within the COLLECTORS database) aim to make at least partial comparison between different systems and collection strategies possible, even if the results have to be considered taking into account relevant regional characteristics, and uncertainties in applied background data. The findings from the COLLECTORS MCDM studies revealed (see D3.4, 2020), that local waste management experts understand well the challenges related to missing and uncertain background data. Despite these challenges, they are capable of analysing potential problems and making informed judgements about improvement options. However, the experts also feel that reporting and monitoring practices should be improved in future, and that they are necessary for properly analysing current situation, and identifying the problems that need to be tackled. (D3.4, 2020).

The need for more efficient monitoring practices, and harmonizing terminology and reporting related to waste flows has been identified by many projects (See e.g.BiPRO/CRI, 2015; Huisman et

al., 2015). Effective monitoring of local systems is necessary for evaluating whether the national and European recycling targets are achieved. However, monitoring is important also for improving collection rates at local level. The findings from COLLECTORS project identified that good performance can be achieved with different kinds of collection strategies, but detailed knowledge about the existing system and its functioning is necessary, in order to find the best solutions for improving the situation. Thus, improving monitoring and reporting practices and increasing transparency are essential for improving performance. Public reporting makes also the benchmarking between systems easier.

In this study, LCA based information was applied within the environment, health and safety cluster, and information from the cost benefit analyses (CBA) studies was applied within the socio-economic cluster. Most of the criteria applied information collected for the COLLECTORS webplatform. Some challenges related to availability of comparable social and socio-economic criteria were faced. Despite lacking background information and challenges in comparability of the data, waste management experts who participated in the study emphasized the importance of including social criteria within decision-making and monitoring activities. Based on the experiences gained in this study, it is recommended that in all criteria clusters, both quantitative and qualitative information can be used. This makes it easier to include important social aspects in decision-making. The criteria and methods used in the COLLECTORS workshops may also serve as examples of possible procedures for incorporating such data in participatory decision-making (see D3.4, 2020).

The findings from the project indicate that proposed criteria differ in data availability. Some variation may take place due to differences in current monitoring practices, maturity of the collection system and how the collection has been organised. Some of the criteria are already part of existing monitoring systems, some require further adjustments or monitoring activities, while some are expected to gain more importance in future, due to changing recycling targets and emphasis in policies related to circular economy.

The findings from the study and cross-analysis of the criteria indicated that the importance of the criteria, as perceived by the decision-maker, may vary according to the purpose of the assessment. In this study, the criteria were applied for both comparing the performances between collection systems (benchmarking) and for comparing the performances of alternative collection strategies for a case region. Moreover, whether the purpose of the evaluation is to benchmark waste collection systems between regions or select a strategy for a case region, sets different requirements for the units of measure.

In benchmarking, the criteria need to be comparable between regions that may have different amount of inhabitants, varying area sizes and large differences in generated amounts of waste, etc. Therefore, the units of measure in benchmarking are generally ratios (such as costs/inhabitant). The study further discussed the challenges in comparing socio-economic performances of waste collection systems between regions with different economic environment. Criteria between benchmarking and strategy selection may differ also according to available resources and methods

for acquiring data. The COLLECTORS project has given practical examples of applying LCA and CBA methods in regional case studies. These methods provide detailed information that can be used as support for waste management strategy selection. However, this kind of detailed regional information is incomparable, or at least limited in comparability, between separate case regions (see D3.2, 2020; D3.3, 2019). Benchmarking waste collection systems within a larger sample will have to rely on publicly available data (for which large differences were detected between regions). The results point out the importance of developing both monitoring and reporting practices related to recyclable waste materials. This is important and necessary also considering the goals of the new European Circular Economy Action Plan (European Commission, 2020).

In addition to the goal of the study, the opinions and backgrounds of the participating experts affect the outcome of the study. In this study, the regional context, such as regional welfare, seemed to affect the preferences of decision makers. While this report has aimed to point out such findings, more research would be needed to present reliable correlations between e.g. regional context for strategy selection, the preferences on the criteria weights and the backgrounds of the decision-makers.

The criteria presented in this report may be used as an example or as a starting point for more extensive data collection, but also for benchmarking purposes. However, careful problem structuring and definition of the most applicable evaluation criteria, fitting the purpose and the context of the evaluation, should be done in each case before the assessment. Keeney and Raiffa (1976) present a general rule for selecting and defining a set of criteria for a decision with multiple objectives. According to the five principles, the set of criteria should be (in the context of this study):

1. Complete, covering all the necessary objects of the analysis;
2. Operational, so it should be possible to judge each alternative (strategy or waste collection system) against each criterion;
3. Decomposable, meaning that the decision problem can be broken to and solved in pieces and the criteria evaluated independently;
4. Non-redundant to avoid double-counting of performances;
5. Minimal, including only criteria that reflect the objectives of the analysis and the effect associated with the consequences of each alternative.

The criteria need to be able to be independently weighted and evaluated. Decision maker's preferences of performance levels in a criterion should not depend on performance in another criterion (i.e. preferential independence). This should apply between all subsets of the criteria (i.e. mutual preferential independence). Moreover, decision maker's preferences considering a change in a criterion performance should not depend on the performance levels in other criteria (i.e. difference independence). In practice, it was difficult to comply with all these rules for each criterion in a participatory approach. However, the process was important for learning purposes, and for identifying meaningful criteria in each case.

7.2. Limitations of the study

Aside from complementary results from other COLLECTORS work packages and literature, the usefulness and weights of the presented decision-criteria are based on opinions of several experts working in waste management. Relying on the same participatory approach, where expert preferences and insights are elicited during a limited amount of workshops, this report shares the limitations reported in Deliverable (D3.4, 2020). When summarizing the criteria weights from several MCDM exercises, 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. In this report, effort was made to present the expert preferences and opinions preserving the connection to the decision-making context. Moreover, the summarized results regarding the criteria and their weights from the MCDM workshops were presented to the final RWG meeting for review, which contributed to the general conclusions on the criteria clusters presented in Chapter 4. Additionally, the findings from expert evaluations where reflected with findings from the COLLECTORS case studies.

The decision-making exercises and workshops required a lot of expertise and personal judgement 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 is 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).

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Glossary

AHP:

Analytical Hierarchy Process (an MCDM method)

CAS:

Civic amenity site

CBA:

Cost-Benefit Analysis

CDW:

Construction and demolition waste

Circular economy:

A circular economy minimises resource input, waste, emissions and energy leakage. It can be achieved through long-lasting design, maintenance, repair, reuse and recycling. It contrasts to a linear economy which extracts resources, uses them, then throws them away.

EEE:

Electrical and electronic equipment. Equipment dependent on electric currents or electromagnetic fields to work properly.

GDP:

Gross domestic product

LCA:

Life cycle assessment

MAVT:

Multi-attribute value theory (an MCDM method)

MCDM:

Multicriteria Decision-Making

PPW:

Packagin and packaging waste (including paper).

PRO:

Producer responsibility organization. Producer responsibility scheme is a system set up by a producer to ensure that they bear some of the responsibility of reducing some of the environmental impacts of the manufacture, placing on the market and disposal of their products.

PROMETHEE:

Preference ranking organization method for enrichment evaluation (an MCDM method)

RWG:

Regional Working Group (meeting with experts external to the project consortium as part of the participatory approach of the COLLECTORS project)

WEEE:

Waste electrical and electronic equipment. Any electrical or electronic equipment, substance or object which is actually, intended to or required to be, discarded.

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