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Scenarios for decentralised bio-waste collection chains with a waste collection database for representative situations

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DECISIVE

A DECENTRALISED MANAGEMENT SCHEME FOR INNOVATIVE VALORISATION OF URBAN BIOWASTE

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A Decentralised Management Scheme for Innovative Valorisation of Urban Biowaste

D3.7 – Scenarios for decentralised bio-waste collection chains with a waste collection database for representative situations

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Executive Summary

This study continues on the topic of bio-waste collection introduced in DECISIVE deliverable 3.5 and aims to add information on how to develop a decentralised collection system by presenting stakeholder opinions, a bio-waste collection database, and bio-waste collection chain scenarios. The study contributes to the development of the DECISIVE decision support tool (DST), which generally aims to assess decentralised bio-waste valorisation schemes and compare them to the common centralised waste management options.

In the first part, *stakeholder interviews* with key players of local areas from the six DECISIVE countries (Belgium, Denmark, France, Germany, Italy, Spain) are described. The results from the interviews provide a good insight into the specifics of local waste management systems. Insider information is received on specific local problems, and on thoughts about solutions. Statements are given considering technical, social, economic and legal information regarding the current waste collection systems. Furthermore opinions of stakeholders on decentralised waste collection systems are documented. Important conclusions were the following: (i) the public waste management sector has to be involved, (ii) initiation projects should consider generators with sufficient food waste amounts (e.g. large food services), and (iii) a new system should have advantages for the generators (citizens, food services), who are also the key for a high bio-waste quality.

In the second part, the DECISIVE *bio-waste collection database* is introduced. The database structure considers the three phases of the collection chain: generation, source-separation, and collection. Each phase includes specific parameters for which data are required. Summaries from the currently available data into the database are provided. Data related to waste focus on food waste from households and from food services and include ranges for each DECISIVE country. Data related to storage and transport is introduced with examples. The issue of data acquisition and data uncertainties is addressed with the example of the EUROSTAT waste database by showing its limitations. To receive data of satisfactory quality, a combination of data collection methods should be applied, combining and comparing different sources for data like statistical surveys, scientific reports and analyses done in municipalities. For a more precise data gathering procedures and information sources are suggested. Since data from common sources are not representative for a specific location, practical investigation within the district where the decentralized system is to be established is suggested. Generally, it can be stated that the risk of failure of a newly implemented process decreases with increasing quality of data used in the conception phase.

Finally, eight *decentralised bio-waste collection chain scenarios* are presented. The core substrate for the scenarios is food waste from households and food services. The scenarios were developed by combining a number of selected parameters. The parameters considered were: the catchment area, the population density, the quantity of source-separated and collected food waste, the quality of source-separated and collected food waste, the collection frequency, the collection system, the transport system, the co-substrate. For each parameter two or four options were provided based on the information previously gathered. In this way the waste collection from the site of the generator to the site of valorisation is described as storyline with illustrative flow sheet extended with mass and energy flow diagrams. The scenarios show the diversity of options. They are compared and each may be useful for a different local situation. In future works, these scenarios will be used to develop precise waste collection processes for specific sites to be included in the DECISIVE DST.

List of abbreviations

ABP	Animal by-products
AD	Anaerobic digestion
BE	Belgium
BP	Bring point
cap	capita
CAS	Civic amenity site
DtD	Door-to-door collection
d	Day
DE	Germany
DK	Denmark
DST	Decision support tool
ES	Spain
EWC	European Waste Catalogue
FR	France
FW	Food waste
IT	Italy
mAD	Micro-scale anaerobic digestion
MSW	Municipal solid waste
PAYT	Pay as you throw
t	metric tonne (1 t = 1 Mg = 1000 kg)
w	Week
y	Year
AUTO	automatic

Stakeholder groups

EAO	NGO/environmental associations/research organisations
FMA	Facility manager/service technicians
HA	Housing association
NHW	Non-household waste generator
PA	Public authorities
UD	Urban developer
WM-pr	Private waste management
WM-pu	Public waste management
WT	Waste treatment
AN-xx	Anonymised stakeholder with country abbreviation inserted for xx

Deliverables mentioned

D3.5	Survey on waste collection systems with evaluations for decentralised applications
D3.6	Report on results for household food waste collection and decentralised shredding in the “Lübeck-case”
D4.1	Report on pre-defined specification for micro-AD
D5.1	Methodology for the planning of decentralised biowaste management
D6.2	State-of-the-art of communication materials and incentive methods and communication materials and incentives proposal (not yet published)
D6.4	Report on the simulation of the implementation of the methodology in different types of locations (not yet published)

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1 Introduction

DECISIVE investigates decentralised bio-waste management schemes including micro-scale anaerobic digestion (mAD) facilities as decentralised valorisation units. The project aims at providing a decision support tool (DST) which includes the possibility of comparing bio-waste management scenarios starting at its generation phase over source-separation, collection, treatment until product use (DECISIVE 2018: http://www.decisive2020.eu/). In order to develop such DST, a collaborative approach including 13 partners from six countries is chosen.

In DECISIVE the term *decentralised* waste collection refers to the proximity of waste management between waste generators and the valorisation units. It does not only refer to already existing door-to-door (DtD) collection in which waste collection may be considered as decentralised. However, such collection system can also be included in a decentralised waste management. It includes collectors only responsible for the neighbourhood which is treating its bio-waste in a decentralised valorisation unit situated in the same neighbourhood.

This study continues on the topic of bio-waste collection which was introduced in Deliverable D3.5[a] including information on bio-waste collection in the DECISIVE countries and selected cities by describing the collection systems (DtD, bring point (BP)), collection frequencies, the status of source-separation and the allowed fractions in the bio-waste bin. The present study aims at adding valuable information on how to develop a decentralised collection system by

- presenting stakeholder opinions from key players of the bio-waste valorisation chain on current and possible decentralised waste collection systems,
- introducing a database including the provision of key parameters, and by giving examples for ways of data acquisition,
- introducing bio-waste collection chain scenarios with the aim of improving bio-waste quality and valorisation on a local scale.

In order to gather knowledge on regional differences concerning bio-waste collection, the opinions of regional stakeholders have to be considered. These were investigated by conducting interviews with key players of local areas from the six DECISIVE countries (chapter 2).
In chapter 3 the challenge of data acquisition is described using the example of the EUROSTAT bio-waste database. As a consequence, a DECISIVE bio-waste collection database is introduced. An important part of the work consisted of finding uniform terminologies, which are easy to understand in the various countries and by the various stakeholder groups. The database includes data from the three different collection phases *generation*, *source-separation* and *collection*, including data on waste-related parameters with a focus on food waste as well as data on transport-related (only until valorisation site) and storage-related parameters. Important parameters are explained and values for the different DECISIVE countries are given. The database has to be in a structure compatible with the DST, in order to be able to use the data to work on the environmental, economic, and social assessment methodologies in other DECISIVE work-packages.
Finally, decentralised bio-waste collection scenarios are presented in chapter 4 using the information gathered in chapter 2 and 3. Parameters describing bio-waste collection are described. Scenarios were developed by combining a number of selected parameters and by using summarised and simplified data from chapter 3 to describe the waste collection from the site of the generator to the site of valorisation. These scenarios were designed to be applied on a decentralised level at a local scale and aim at improving bio-waste quality. Furthermore, they show the diversity of possible options for different local conditions. The storyline with illustrative flow sheets are extended with mass and energy flow diagrams.

Database and collection chain scenarios contribute to the development of the DECISIVE decision support tool (DST), which generally aims to provide data to design and assess decentralised bio-waste valorisation schemes (e.g. mAD with solid state fermentation and composting compared with community composting as valorisation step) and compare them to the common centralised waste management options (e.g.

[a] Report available at: http://www.decisive2020.eu/wp-content/uploads/2018/01/Survey-on-waste-collection-systems-with-evaluations-for-decentralised-applications.pdf

centralised AD, composting, incineration, landfilling).

Figure 1 displays the interactions of this study with other DECISIVE activities.

Figure 1: Conceptual framework of the links between the study of "Scenarios for decentralised bio-waste collection chains with a waste collection database for representative studies" to other activities within the DECISIVE project

2 Regional stakeholder opinions on waste collection systems

In Deliverable D 3.5 current waste collection issues were addressed based on literature studies. An overview of the types of waste collection systems was provided for the DECISIVE countries with the aim of mapping the state of development of source-separated bio-waste collection systems. It can be considered as a basic inventory on the commonly used waste collection systems. Information from different kinds of literature is not always easy to compare due to different definitions of terminologies and a lack of comprehension. Often there are information gaps on the degree of deployment of the separate collection of bio-waste (e.g. fully or partially roll out, pilot test).

This chapter aims at closing information gaps and at obtaining more profound knowledge related to waste collection specifically focusing on local levels. Therefore, a survey based on stakeholder interviews was carried out for six regions of the six DECISIVE countries. Section 2.1 gives a short introduction on the methodology of carrying out the interviews. The results of the interviews are described in two parts: one deals with relevant information on issues of the current collection system including technical, social, economic and legal aspects given by the stakeholders regarding the current waste collection systems and decentralised waste collection (Section 2.2.1). The other section includes opinions of stakeholders on the challenges and potentials of decentralised waste collection systems (Section 2.2.2). The opinions varied among the different regions since waste management is organised differently in these various areas. The chapter is concluded with recommendations for the development of decentralised bio-waste collection systems (section 2.3).

2.1 Interview methodology

The overall interview questions were designed in two sections: i) questions referring to the current system for waste management and its challenges and ii) questions referring to potential barriers which may result from a transition to a new waste management system, the DECISIVE proposal of decentralised bio-waste management. For both, the following question topics were identified:

- General goal of interview
- Quantities and qualities
- Legal framework
- Financial framework
- Behaviour of waste generator
- Behaviour of waste manager
- Infrastructure
- Communication

Six regions within the DECISIVE countries were chosen in which stakeholders had to be selected. Table 1 gives an overview of these regions and the number of conducted interviews. The selected expert groups and an explanation is given in Table 2. The abbreviations of stakeholder groups are used to assign a statement to them in section 2.2.1 and 2.2.2.

The six DECISIVE partners who conducted interviews chose the stakeholders according to their own criteria, e.g. existing contacts, the choice of at least one stakeholder per group or availability of stakeholders. Some of the chosen stakeholders represented two different expert groups. For example, the public or private waste management (Group 1 and 2) is often in combination with waste treatment companies/entities (Group 3).

Interviews were conducted in person in most cases but also via phone/video chat. They were recorded with an audio recorder or by taking notes usually held in the language of the respective country. Subsequently, the interviews were translated into English and transcribed into an excel sheet.

During the interviews, the interviewees were first introduced to the DECISIVE project and then they introduced their own company or organisation. The prepared questions were not necessarily asked in a specific order, but rather how they fitted into the open discussions. This allowed for more detailed ones, which had not been planned. Furthermore, some interviewees were experts in specific issues of waste collection and therefore the interviews focused on their area of expertise, e.g. legal or technical aspects of waste collection. Questions to which the stakeholder had little to contribute were left out.

All interviews belonging to one region were summarised by the regional interviewers following a template, but only focusing on the collection related issues. Based on these six summaries, the most important issues were extracted and related to technical, social, economic, legal and other aspects (section 2.2.1). Furthermore, information on pros and cons of implementing a decentralised waste management system were extracted (section 2.2.2).
For reasons of anonymity, citation is done regarding the letter of consent. If a stakeholder requested full anonymisation, citation is only done regarding the general expert group.

Table 1: Overview on the stakeholder interviews carried out by the DECISIVE-partners

DECISIVE country	**Region**	**Interviews carried out**	**Number of interviewed experts**	**Number of interviews included in this evaluation**
Germany (DE)	Hamburg	12	14	11
Denmark (DK)	Copenhagen	7	8	7
Spain (ES)	Catalonia	8	12	8
Belgium (BE)	Brussels	10	11	10
France (FR)	Mainly Brittany, Rennes	9	11	8
Italy (IT)	Friuli Venezia Giulia	5	5	5

Table 2: Specification of identified expert groups including anticipated area of professional knowledge and number of conducted interviews per stakeholder group

Stakeholder Group	Description of group	Number of interviewed experts*	
1. Public waste management (collection) **WM-pu**	• key expert, carries out the public contract of waste management, mostly not subject to pursuit of profit, expenses covered by fees or taxes, often including waste treatment • can potentially provide insider knowledge to all addressed issues	BE: 1 DK: 1 ES: 2 FR: 2 DE: 2 IT: 3	**11**
2. Private waste management (collection) **WM-pr**	• key expert, carries out the public contract of waste management according to negotiated contract with the responsible authority (budget, price per unit, price per service), subjected to pursuit of profit • can potentially provide insider knowledge to all addressed issues	BE: 0 DK: 1 ES: 1 FR: 1 DE: 2 IT: 0	**5**
3. Waste treatment companies/ entities **WT**	• key expert, all types of waste treatment of the biogenic fraction can be considered - biogas, composting, incineration, landfilling, both public and private owned • can potentially provide insider knowledge to all addressed issues with focus on utilisation/valorisation of bio-waste	BE: 2 DK: 1 ES: 2 FR: 1 DE: 4 IT: 0	**10**
4. Public authorities **PU**	• key expert, set the agenda/legislation for and contracts the waste management, higher level (national, federal/district, regional) department e.g. of energy/environment AND lower level authorities e.g. city/district/ neighbourhood councils or consortium of cities responsible actors for waste management • can potentially provide insider knowledge to all addressed issues	BE: 2 DK: 1 ES: 4 FR: 2 DE: 2 IT: 2	**13**
5. Urban developer **UD**	• urbanists and architects (private district development / public authority of city development) • can potentially provide insider knowledge in particular for implementation possibilities in new city quarters and potentially recent challenges at the interface waste generator – waste collection (e.g. infrastructure)	BE: 0 DK: 1 ES: 0 FR: 1 DE: 1 IT: 0	**3**
6. Housing associations **HA**	• both representation of house owners (e.g. building society, housing cooperative) and representation of rent payer (e.g. tenants unions) • can potentially provide insider knowledge in particular for recent challenges at the interface waste generator – waste collection (i.e. infrastructure, behaviour) and potentially implementation possibilities in households	BE: 0 DK: 1 ES: 0 FR: 0 DE: 1 IT: 0	**2**
7. Non-household waste generator **NHW**	• restaurant/hotel/trade associations, large food services like canteens, urban farmers, local food market management, allotment gardeners (i.e. generator, or their representatives, of big bio-waste quantities) • can potentially provide insider knowledge in particular for implementation possibilities with integration of non-household waste generator and recent challenges at the interface waste generator – waste collection (e.g. infrastructure, behaviour, quantities and qualities)	BE: 2 DK: 1 ES: 0 FR: 2 DE: 0 IT: 0	**5**
8. Facility manager/ service technicians **FMA**	• responsible person/company for general service at the waste generator's place (e.g. care taker at residential multi-story-building) • can potentially provide insider knowledge in particular for recent challenges at the interface waste generator – waste collection (i.e. infrastructure, behaviour)	BE: 0 DK: 1 ES: 0 FR: 0 DE: 1 IT: 0	**2**
9. NGO/ environmental associations/ research **EAO**	• environmental NGOs, associations and research institutions with focus on origin, prevention, behaviour, recycling and valorisation of waste and decentralised citizen based solutions (e.g. energy cooperatives) • can potentially provide insider knowledge to all recent challenges with focus on the waste generator	BE: 4 DK: 0 ES: 3 FR: 2 DE: 1 IT: 0	**10**

**some of the interviewees fit to more than one expert group and were included in both*

2.2 Interview results

2.2.1 Region specific evaluation of information on the current waste collection system

The following tables show the most important statements regarding the technical (Table 3), social (Table 4), economic (Table 5) and legal (Table 6) aspects of waste collection for the different areas in the DECISIVE partner countries.

Table 3: Important region-specific statements by interviewed stakeholders regarding technical aspects of waste collection

DECISIVE region and country	Technical Aspects
Hamburg, Germany	• Waste management of private households in Hamburg is responsibility of the public owned company "Stadtreinigung Hamburg (SRH)" while the waste management food services is in competition with private companies (Lübben[1]). • The routing system for waste trucks is planned to fill them in the shortest time and distance (Lübben[1]). • Macro-impurities in source-separated bio-waste differ from the type of household: around 1% in single/duplex/row houses to 4% in multi-story apartments (Lübben[1]). • Bio-waste of one truck load is incinerated if macro-impurities are higher than 5% (Lübben[1]). • Macro-impurities content in bio-waste from food services depends on the source (Faull[2]): ○ Restaurants, hotels, canteens: 2-3% ○ Percentage increases for food waste from supermarkets (more packaging) and even more for food waste from the food industry (e.g. canned food on pallets). • Bins from food services are cleaned and exchanged each time of collection (Faull[2]). • Collection frequency for bio-waste from food services is 1/w or 2/w (Faull[2]).
Copenhagen, Denmark	• Wet AD (pulping) of bio-waste is considered the most efficient, because it allows for high impurities up to 20% in the fraction without damaging the treatment (AN-DK1[3], AN-DK7[12]). • Garden waste is collected from households 10 times per year and separated into green/leafy and woody waste at the reload facility. Woody waste is incinerated and green waste is composted (AN-DK1[3]). • Many big hotels and restaurants use a shredder to treat their food waste (AN-DK6[8]). • To improve source-separation efficiency, technical solutions are suggested (AN-DK2[4]): Barcodes on bags (container only opens when barcode is correct), adaption of container lid to waste type (letter box type for paper, small and round for bio-waste).
Catalonia, Spain	• The source-separated bio-waste collection rate in DtD is twice as high as in BP (Muñoz[5]). • Only 1/3 of bio-waste is collected in the source-separated fraction, 2/3 in residual waste (Guerrero and Pous[6]). • It is estimated that 2/3 of the collected bio-waste originates from households and 1/3 from food service sector (Guerrero and Pous[6]). • A low collection frequency for residual waste in municipalities with DtD encourages bio-waste source-separation (Guerrero and Pous[6]). • Macro-impurities in the bio-waste depend on the collection system and vary between under 5% (DtD) up to 20% (BP) (Guerrero and Pous[6]). • The bio-waste quality is analysed four times per year for each of the 1600 collection routes in Catalonia (Guerrero and Pous[6]).
Brussels, Belgium	• A DtD collection system of garden waste is in place. Furthermore, two composting units exist in Brussels but problems with the quality exist due to plastic bags (AN-BE1[7]) • Source-separated food waste collection frequency is 1/w and is available for all inhabitants since 2017 but only on voluntary basis (AN-BE1[7]). • Residual waste still consists of around 50% bio-waste (AN-BE2[3]). • No definite plan for optimised treatment of food waste exists but mAD units could be a solution either in green areas within the city centre or on urban farms (AN-BE3[8]). • 150 locations of community composting sites are available. Community and home composting would process about 16,000 t/y of bio-waste (Scherrier[9]).

DECISIVE region and country	Technical Aspects
Brittany, France	• Only around 7-8% of French households have source-separated bio-waste collection (Guastavi[10]). • The municipality of Rennes promotes a proximity composting with 450 shared composting bins run by the NGO *Vert le Jardin*. Quality problems only exist with biodegradable plastic bags which do not decompose (Royer[11]). • A source-separated bio-waste collection pilot project in Rennes is operated for big generators (school canteens, restaurants) (AN-FR1[7]). • Urban planning in Rennes includes the issue of waste collection for the future; until 2025 source-separated bio-waste collection should be accessible to each household (AN-FR1[7]). • Source-separated bio-waste collection is in place in the region *pays de Vilaine*. To avoid coarse garden waste the container has a small volume (35L). Quality is controlled visually and bio-waste with bad quality is not being collected. Macro-impurities are usually around 1.5% (AN-FR2[7,12]). • *La tricyclerie*, an association which is in charge of DtD bio-waste collection of 20 restaurants, collects food waste using cargo bicycles. Macro-impurities are very low (Billon[13]). • Voluntary BP were implemented in the city of *Bruz* to collect recyclables and residual waste. Problems were faced with "hidden" collection points since waste is not disposed inside the collection device but next to it (AN-FR3[4]). • For the example of small municipalities in the region of *Besançon* it was proved that a higher amount of good quality bio-waste can be collected with voluntary BP (AN-FR4[14]).
Friuli Venezia Giulia, Italy	• The coverage of source-separated bio-waste collection increased from around 12% in 1998 to around 66% in 2016 (Sgubin[16]). • The highest source-separation efficiency is obtained in municipality of San Vito di Fagagna (87% of food waste) (Bernes[15]). • Municipalities can choose their waste management company; mainly 5 different companies are active, managing between 1 and 50 municipalities (Bernes[15], AN-IT1[7], AN-IT2[3]). • Most waste management companies have sub-contracts with private companies for waste collection (Sgubin[16]). • Macro-impurities content of bio-waste ranges from 1% (DtD) to 5% (BP) in this region (Sgubin[16]). • It is mandatory to use the garbage bags indicated by the municipalities. Otherwise the collection company do not collect the waste (Bernes[15], AN-IT1[7]). • Green waste is usually collected in "ecological" areas on the street (AN-IT1[7]). • In BP systems bio-waste is collected daily while for DtD systems it is collected twice per week (Bernes[15], AN-IT1[7]). • An advantage of the bins of a BP system is the high technology that can be used which is not feasible for DtD (AN-IT3[7]).

[1]Stefan Lübben, Stadtreinigung Hamburg, WM-pu & WT; [2]Marco Faull, BioCycling GmbH, WT; [3]PA; [4]UD; [5]Silvia Muñoz, Ajuntament de Reus, PA; [6]Teresa Guerrero and Meri Pous, Agència de Residus de Catalunya, PA; [7]WM-pu; [8]NHW; [9]Nicolas Scherrier, Brussels Environment, PA; [10]Raphael Guastavi, Agence de l'environnement et de la maîtrise de l'energie (ADEME), PA; [11]Céline Royer, Vert Le Jardin, EAO; [12]WT; [13]Coline Billon, La Tricyclerie, EAO; [14]WM-pr; [15]Renato Bernes, A&T 2000, WM-pu; [16]Cristina Sgubin, ARPA FVG, PA

The most commented issues of technical aspects (Table 3) are related to source-separation, impurities, collection frequencies and systems. Some stakeholders commented on currently applied decentralised treatment procedures, some of them going in the same direction as stated in D3.5. Regarding impurities the provided ranges vary between 1 and up to 20%. The wastes from food services, from smaller houses and from DtD systems were reported to have the better qualities compared to apartment houses or BP systems. However, there are major regional differences with the proceeding at high macro-impurities. While in Hamburg bio-waste is incinerated at macro-impurities over 5%, the bio-waste treatment in the Copenhagen region allows for macro-impurities up to 20%. Specifically, plastic bags were reported as a problem. Separate garden waste collection systems exist in some cases including DtD, BP and civic amenity sites (CAS) systems. Also decentralised waste valorisation systems are reported, e.g. shredding systems used in food services and private households as well as community composting systems.

Table 4: Important region-specific statements by interviewed stakeholders regarding social aspects of waste collection

DECISIVE region and country	Social Aspects
Hamburg, Germany	• The main problem of macro-impurities in food waste is the behaviour of inhabitants to dispose of plastic in the bio-waste or to use plastic bags. The so-called "biodegradable" plastic bags don't degrade in anaerobic digestion or composting plants and are rather disadvantageous (Gelpke[1], Faull[2]). • Wax coated paper bags were introduced in 2017 by *Stadtreinigung Hamburg* but free supply is limited to 30 bags per year (Lübben[22]). Free supply should be unlimited or costs covered by a taxing system implemented by political resolutions which have to be made to make the system work (Gelpke[1]). • No social acceptance to use buckets without bags since people don't want to invest time for cleaning them (Glowacki[4] and Billig[5], Lübben[22]). • Awareness creation and "make it easy and attractive to collect correctly" are important social solutions to reduce plastic impurities at the point of collection since technology for sieving out plastics at the treatment site is and will always be limited (Gelpke[1]). • Requirements for a good bio-waste collection system are: 1) Facility and comfortability, 2) no nuisances in kitchen bucket and bio-waste bin and 3) short distances to bio-waste bin (Bork[3]). • A better waste sorting can only be achieved with better education (Glowacki[4] and Billig[5]).
Copenhagen, Denmark	• In general, an overwhelming majority of the population supports source-separation and believes they have a personal responsibility to contribute to good separation (AN-DK1[6], AN-DK7[16]). • The best quality of recyclable fractions comes from districts with single-family houses (AN-DK7[16]). • In apartment buildings, caretakers observe some errors. Between 10 and 30% of the residents do not separate at all or make errors in separation (AN-DK1[6], AN-DK3[7], AN-DK4[8]). However, caretakers correct some of the mistakes done by the inhabitants and clean up after them (AN-DK4[8]). • The degree of centralisation or decentralisation of waste treatment is not the determining factor for the residents' waste separation behaviour (AN-DK[8]). • The liveability and orderliness of dwellings, the population's general waste handling ethics, the knowledge and competences of residents and the physical infrastructure are the key social and socio-material factors in achieving high quality source-separation (AN-DK1[6], AN-DK[8]).
Catalonia, Spain	• The increase of accessibility and proximity of collection points in terms of changing from a BP to a DtD system increased the source-separation efficiency. A next step could be a PAYT system (Cruz[9]). • On the other hand, municipalities do not want to bother citizens with changes in waste collection (e.g. from BP to DtD collection) (Muñoz[10]). • Odours are the main impact to keep waste treatment facilities out of urban areas. Odour problems can be overcome with closed unloading areas, tanks and container system for AD plants (Fernandez[11]). • The main reasons for the citizens having bad source-separation behaviour are the lack of knowledge about the environmental consequences and the lack of economic incentives (no consequences for bad source-separation behaviour) (Guerrero and Pous[21]). • The main excuses for not source-separating bio-waste are 1) the myth that waste is mingled by collectors with other fractions, 2) the lack of space, and 3) laziness (Fernandez[11]). • Citizens should be educated in workshops about waste management already at school (Fernandez[11]). • The REVOLTA project[b] increased awareness by offering trainings. There is a prevention potential of 40% for restaurants and 10% for schools was found (Vallès[12]). • "Catastrophic" messages addressed to the waste generator may improve behaviours (Muñoz[10]).
DECISIVE	Social Aspects

[b] http://territori.gencat.cat/es/detalls/Article/ARC_Revolta_Tarpuna

region and country	
Brussels, Belgium	• Issues regarding source-separation are mainly originating from difficulties to understand sorting guidelines (AN-BE1[13]). • Voluntary approaches developed with decentralised composting systems show that people tend to be good in waste sorting (Yves Bertrand[14]). • Contributing to a shared project and meeting local people is very important to many participants of decentralised composting units (AN-BE4[15]).
Brittany, France	• No significant social (and economic) factors seem to differentiate behaviours towards bio-waste collection but the type of house. The quality of bio-waste from collective housings is worse than in other kinds of houses in the city of Rennes (AN-FR1[13]). • Good sorting is obtained when citizens understand well the aim of the project (AN-FR2[13,16]). • Waste sorting in some restaurants was stopped due to lack of acceptance by the kitchen staff. However, restaurant managers are mostly enthusiastic (Billon[17]). • Communication campaigns are the most important incentives for improving bio-waste quality (AN-FR4[18]). • If the sorting is declared incorrect along two weeks and too many macro-impurities impurities are observed visually, the household or food service gets visited by the waste management authority who explains the sorting rules and probably gives a training (AN-FR2[13,16])
Friuli Venezia Giulia, Italy	• As an incentive for better source-separation efficiency the municipalities provide bags and bins for free (Bernes[19], AN-IT1[13]). • Tours at the valorisation sites are offered each year to disprove the common thinking that everything is mixed again at the end (AN-IT2[6], AN-IT3[13]). • Free compost is offered as well (AN-IT1[13]). • Fees are applied for bad source-separation while fewer taxes are applied for reaching objectives (Bernes[19]). • Bio-waste is burned when it ends in the residual waste and it is communicated to citizens that prices are much higher for this treatment (AN-IT2[6], AN-IT3[13]).

[1]Wolfram Gelpke, Buhck GmbH & Co. KG, WT; [2]Marco Faull, BioCycling GmbH, WT; [3]Thomas Bork, SAGA, HA; [4]Romann Glowacki; Deutsches Biomasseforschungszentrum, EAO; [5]Eric Billig, Zentrum für Umweltforschung, EAO; [6]PA; [7]HA; [8]FMA; [9]Montse Cruz, Associació de Municipis Catalans per a la Recollida Selectiva Porta a Porta (Portaaporta), EAO; [10]Silvia Muñoz, Ajuntament de Reus, PA; [11]Belen Fernandez, Institute of Agrifood Research and Technology (IRTA), NHW; [12]Josep Maria Vallès, Tarpuna cooperative, EAO; [13]WM-Pu; [14]Yves Bertrand, La Ferme du Parc Maximilien, EAO; [15]EAO; [16]WT; [17]Coline Billon, La Tricyclerie, EAO; [18]WM-pr; [19]Renato Bernes, A&T 2000, WM-pu; [20]Cristina Sgubin, ARPA FVG, PA; [21]Teresa Guerrero and Meri Pous, Agència de Residus de Catalunya, PA; [22]Stefan Lübben, Stadtreinigung Hamburg, WM-pu & WT

Regarding social aspects (Table 4), stakeholders mostly commented on knowledge, quality, comfort and nuisances' issues, which mainly focused on the household sector. The stakeholders gave important information especially for designing new collection systems. Citizens may prefer plastic bags, because they are afraid of leakage when using paper bags. Buckets without bags may not be used, since frequent cleaning is necessary. A system accepted by citizens shall be easy and comfortable, no nuisance with short transport ways. Contributions to a shared project may be a motivation. Further incentives could be free bags or bins or free compost. Also tours to the valorisation sites are offered in one area. There may be a general support in theory; however, the source-separation quality is often limited. Improvements may be realistic with better education, a general cleanness of the neighbourhood, better information on environmental consequences and easy to understand guidelines. Furthermore, often no consequences are applied if waste separation behaviour is not good. In other cases, fees are applied or citizens get visited by the waste management authorities if their source-separation behaviour is bad for a two-week period. In some cases, caretakers correct separation mistakes.

Table 5: Important region-specific statements by interviewed stakeholders regarding economic aspects of waste collection

DECISIVE region and country	Economic Aspects
Hamburg, Germany	• A better waste sorting would have financial benefits for the people since the bio-waste bin is almost free of fees and residual waste is charged with the size of the bin (Pollmann[1]).
Copenhagen, Denmark	• Waste collection and handling must be non-profit for the municipality (AN-DK1[11]). • The fee for recyclable fractions is smaller than for residual waste (AN-DK1[11]). • All collection from households in the municipality is carried out by private collection companies which compete for a contract every 5-6 years (AN-DK1[11]).
Catalonia, Spain	• The bio-waste collection cost depends on the municipality and varies from 50 to 200 €/t. A tax payback system is applied and depends on the amount of treated waste and macro-impurities content (Cruz[2], Guerrero and Pous[3]). • There is a need for increased control to avoid mixing of bio-waste and residual waste for waste generators from food services since landfill is still cheaper than separate treatment for these generators (Ros[4]). • Municipalities should have a local strategy for source-separation of bio-waste to be charged with a standard tax for landfill. Without such a strategy they will be charged more than double (Guerrero and Pous[3]).
Brussels, Belgium	• Food services are not likely to be ready to pay much for bio-waste and there are little economic incentives for waste generators to source-separate since residual waste collection is cheaper than bio-waste collection (Scherrier[5]). • Citizens do not pay a specific waste tax. The waste management is financed with 2/3 from a regional grant and 1/3 from incomes linked with sales (energy, sorted materials) (AN-BE1[6]). • Gate fees represent an important part of the incomes of an AD plant and are established according the competitive treatment methods (usually incineration) (de la Vega[7]).
Brittany, France	• Waste collection is generally covered by taxes or incentive-based fees (if existing) for households (Guastavi[8]). • There are no financial incentives for source-separated bio-waste collection. However, taxing the residual waste could be a solution to improve source-separated bio-waste collection (AN-FR2[6,9], Royer[10]).
Friuli Venezia Giulia, Italy	• -

[1]Michael Pollmann, Behörde für Umwelt und Energie Hamburg, PA; [2]Montse Cruz, Associació de Municipis Catalans per a la Recollida Selectiva Porta a Porta (Portaaporta), EAO; [3]Teresa Guerrero and Meri Pous, Agència de Residus de Catalunya, PA; [4]Eva Ros, GGR Gelabert, Gestión de Residuos, WM-pr; [5]Nicolas Scherrier, Brussels Environment, PA; [6]WM-pu; [7]Nicolas de la Vega, European Biogas Association, WT; [8]Raphael Guastavi, Agence de l'environnement et de la maîtrise de l'energie (ADEME), PA; [9]WT; [10]Céline Royer, Vert le Jardin, EAO; [11]PA

The statements to economic aspects (Table 5) focused mainly on the pay-back options of waste generators to waste managers. The options are very different between the countries. Partly a fee is collected from citizens, whereas in some cases the fee for source-separated bio-waste is much lower compared to the one for residual waste. In some regions/countries costs for waste collection are included in the taxes, in others citizens do not have to pay at all. Tax pay-back systems are reported depending on the macro-impurity content of the bio-waste. The waste collection costs may vary strongly between the municipalities.

Table 6: Important region-specific statements by interviewed stakeholders regarding legal aspects of waste collection

DECISIVE region and country	Legal Aspects
Hamburg, Germany	• The law on circular economy is a very good tool for a mandatory source-separated collection of bio-waste; however, the challenge is its comprehensive implementation (Pollmann[1]). • It would be good to implement a law which enforces the landlord to provide space for a bio-waste bin (Pollmann[1]).
Copenhagen, Denmark	• At EU level, it is illegal to use food waste from restaurants or even private households as feed. This regulation is an impediment for businesses who want to be innovative and establish circular resource flows (AN-DK1[2]).
Catalonia, Spain	• In 2008 the obligation of bio-waste source-separation (since 1993 in Catalonia) was combined with fiscal benefits (Guerrero and Pous[11]). • Politicians are afraid to lose votes if they implement a fine-system for bad source-separation (Segret[3]).
Brussels, Belgium	• The animal by-products (ABP) regulation is the most challenging one: To avoid the expensive hygienisation, food waste would have to be composed only of unprocessed plant-based waste which is not included in the ABP regulation (Aurélien[4], Scherrier[5]). • There is no obligation for source-separation of bio-waste for households or food services (AN-BE1[6], Scherrier[5]).
Brittany, France	• There is no obligation for source-separation of bio-waste from households but it is mandatory for big generators (AN-FR2[6,7]). • The ABP regulation is very constraining for small local collection systems (AN-FR4[8]). • For safety reasons, bio-waste bins of restaurants have to be equipped with foot controls to avoid hand contact of the staff (Billon[9]). • There are specific regulations for voluntary BP concerning road safety at site, public health and limit of public annoyance (noise and odour) (AN-FR3[10]).
Friuli Venezia Giulia, Italy	• The region has its own legislation for waste treatment (LR n30 from 1987). • Entities involved in waste management must be authorised by the government.

[1]Michael Pollmann, Behörde für Umwelt und Energie Hamburg, PA; [2]PA; [3]Mar Segret, Mancomunitat la Plana, WT & PA; [4]Amaz Aurélien, Roots, NHW; [5]Nicolas Scherrier, Brussels Environment, PA; [6]WM-pu; [7]WT; [8]WM-pr; [9]Coline Billon, La Tricyclerie, EAO; [10]UD; [11]Teresa Guerrero and Meri Pous, Agència de Residus de Catalunya, PA

Regarding legal aspects (Table 6), partly EU regulations were mentioned, whereas the animal-by-product regulation (ABP) was the most concerned one. Furthermore, the national or regional regulations for obligations to source-separation were mentioned. In some cases, politicians explained their concerns or gave suggestions for new policies, e.g. the obligation for landlords to provide space for bio-waste bins.

2.2.2 Stakeholder opinions on decentralised waste collection systems

This section deals with the opinions of the different stakeholder groups regarding the challenge of implementation of decentralised waste collection which is closely connected to the issue of the establishment of a decentralised mAD unit. It aims at finding arguments in favour or against the implementation of a decentralised bio-waste collection system including suggestions on how such system could be realised. Table 7 through to Table 11 include opinions of stakeholders from the different groups from the six DECISIVE countries.

Table 7: Opinions on decentralised waste collection systems of stakeholders of the Hamburg area in Germany

Area Hamburg, Germany		
Pro	**Con**	**Suggestions**
Decentralised valorisation of bio-waste might be economically feasible for a minimum plant size of 1000 t/y (Gelpke[1]). The transport over short distances would save costs (Adwiraah[2]). Under legal aspects bio-waste from food services can possibly be treated in a decentralised system (Pollmann[8]). Bakeries look for smart solutions (Glowacki[3] and Billig[4]). A decentralised system might increase people's awareness for correct bio-waste separation and collection (Siechau[5]).	The majority of people do not want to spend more time, effort and money for bio-waste source-separation in a decentralised system, e.g. for a BP system (Braun[6]) which is too far for them. Urban space is limited and expensive: Many interviewees do not see an improvement with a decentralised system. More space is required for decentralised mAD plants compared to a single central AD plant if the same amount of waste shall be treated. An authorisation process is required for anaerobic digestion plants (Siechau[5], Glowacki[3] and Billig[4]). Instead of having only one for a central unit there would be one process for each single mAD plant (Siechau[5]). A decentralised collection system would be more labour- and therefore cost-intensive (Adwiraah[2]). Higher investment and operating costs are expected for many mAD plants compared to one central unit (Siechau[5]). The collection system for a mAD unit can only be a BP system due to economic feasibility (Lübben[7]).	Financial incentives are essential for a higher motivation of private households to actively participate in a decentralised collection system. The decentralised system should not require more effort and should be more convenient for the generator as the current one and not more expensive for the waste management (Braun[6]). A decentralised system must be without labour-intensive handling (Adwiraah[2]). A BP system to the mAD site could be one solution to safe transport costs (Lübben[7], Gelpke[1]) or the installation of food waste disposers connected with wastewater (Gelpke[1]). According to current legislation, bio-waste from private households belongs to the city's public waste management (Stadtreinigung Hamburg). A decentralised system could only be implemented by them (Pollmann[8]). A decentralised system is feasible if it is comprehensive, meaning all kinds of waste and not only bio-waste have to be collected (Pollmann[8]).
[1]Wolfram Gelpke, Buhck GmbH & Co.KG, WT; [2]Helmut Adwiraah, Averdung Ingenieursgesellschaft mbH, UD; [3]Romann Glowacki, Deutsches Biomasseforschungszentrum, EAO; [4]Eric Billig, Zentrum für Umweltforschung, EAO; [5]Rüdiger Siechau, Stadtreinigung Hamburg, WM-pu and WT; [6]Andre Braun, ProQuartier Hamburg GmbH, HA; [7]Stefan Lübben, Stadtreinigung Hamburg, WM-pu & WT; [8]Michael Pollmann, Behörde für Umwelt und Energie Hamburg, PA		

Table 8: Opinions on decentralised waste collection systems of stakeholders of the Copenhagen area in Denmark

Area Copenhagen, Denmark		
Pro	**Con**	**Suggestions**
A decentralised system for bio-waste management could be relevant in specific circumstances, either in public and private businesses such as hospitals, prisons (AN-DK5[2]) and restaurants (AN-DK6[3]) or in rural areas that are not easily connected to centralised systems (AN-DK7[4]).	A system for decentralised mAD is not perceived as relevant. Centralised wet treatment is considered more effective, more economically viable and also more robust because it allows for more macro-impurities in the bio-waste input (AN-DK1[6], AN-DK7[4]). There is a concern that leakage of gas from many small facilities might lead to a bigger CO_2 footprint than incineration (AN-DK7[4]). Biogas plants are categorised as polluting business and therefore they must be located at least 500 m from urban areas and at least 300 m from inhabited buildings. It is uncertain whether this legislation also applies to mAD (from the Danish *national risks act*) (AN-DK2[5]).	The degree of centralisation or decentralisation of waste management is not a determining factor for residents' waste separation behaviour. The liveability and orderliness of dwellings, the population's general waste handling ethics, the knowledge and competences of residents and the physical infrastructure are the key social and socio-material factors in achieving high quality source separation (all expert groups). It is important that there is enough space for the treatment facilitiy that there are no nuisances for the customers that the transport is minimised, and facilities are well maintained to avoid leakage (AN-DK2[5], AN-DK5[2]). For a DtD collection, the walking distance from the place of waste generation to the bin outside the house must be below 50 m (AN-DK7[4], AN-DK1[6]).
[1]Byens Udvikling, Municipality of Copenhagen, UD; [2]WM-pr; [3]NHW; [4]WT; [5]UD; [6]PA		

Table 9: Opinions on decentralised waste collection systems of stakeholders of the Catalonia region in Spain

Region Catalonia, Spain		
Pro	**Con**	**Suggestions**
The proximity of decentralised system could increase awareness and knowledge about bio-waste management issues (AN-ES1[5], Ros[1], Muñoz[2]). Moving the products of treatment back to the waste generator and personalisation of recovery system could improve waste quality (Guerrero and Pous[3]). Improved bio-waste quality in a decentralised system would also increase quality of other recyclables (Ros[1]).	A lack of space in large cities might pose as a limitation to install a mAD within buildings in the city centre (Ros[1]). An arguable issue is the cost saving for transportation since big trucks might still be required for transportation of digestate (Ros[1]). Previous projects showed that the biggest challenge is to get households engaged (Guerrero and Pous[3]).	Personal incentives, such as financial benefits could help to get bio-waste generators involved in the system (Muñoz[2], Vallès[4]). Communication with people is necessary to show them that risks regarding exposure to vermin, diseases and odour do not exist for a mAD in their neighbourhood (AN-ES1[5], Muñoz[2]).
[1]Eva Ros, GGR Gelabert Gestión de Residuos, WM-pr; [2]Silvia Muñoz, Ajuntament de Reus, PA; [3]Teresa Guerrero and Meri Pous, Agència de Residus de Catalunya, PA; [4]Josep Maria Vallès, Tarpuna cooperative, EAO; [5]WM-pu		

Table 10: Opinions on decentralised waste collection systems of stakeholders of the Brussels area in Belgium

Area Brussels, Belgium		
Pro	**Con**	**Suggestions**
A decentralised composting strategy has already been implemented for several years for both home-composting and decentralised compost units in zones with public access. It shows a general potential interest from the citizen (Aurélien[1]). Urban farms could be interested in mAD units as most of them do not require a constant supply of energy (AN-BE4[5]). Waste generators would be willing to participate in the decentralised bio-waste collection system if it is convenient to use, with low nuisances and low costs (Scherrier[2]). The fact that there is currently no regional treatment unit to process bio-waste, limit the competition of the centralised system with a potential decentralised system (Scherrier[2]).	Waste generators currently pay little or nothing for waste management, meaning that there is little intention to apply a selective collection (Bertrand[3]). AD in general does not appear to be profitable without subsidies (AN-BE1[6]). Urban farms are not capable to invest in such system nor do they have enough manpower (AN-BE3[7]). Implementation of hygienisation units in a mAD plant is expensive and energy consuming (de la Vega[4]). Household bio-waste and its DtD collection are under the monopoly of Bruxelles Propreté. Therefore, a decentralised waste collection organised by others than Bruxelles Propreté can only be a BP system (Bertrand[3]).	A decentralised system should focus on similar waste generators (e.g. restaurants, canteens etc.) (de la Vega[4], Bertrand[3]). A network of technicians being able to maintain several decentralised plants could be feasible (AN-BE4[5]). If placed on urban farms, the farmers might be able to operate the plant on a technical side (AN-BE4[5]). Local solutions could be the way for implementing decentralised waste collection (AN-BE1[6]).
[1]Amaz Aurélien, Roots, NHW; [2]Nicolas Scherrier, Brussels Environment, PA; [3]Yves Bertrand, La Ferme du Parc Maximilien, EAO; [4]Nicolas de la Vega, European Biogas Association, WT; [5]EAO; [6]WM-pu; [7]NHW		

Table 11: Opinions on decentralised waste collection systems of stakeholders of the Brittany region in France

Region Brittany, France		
Pro	**Con**	**Suggestions**
Social housing could be a good occasion to investigate a decentralised waste management system (AN-FR3[4]). Voluntary BP are a good option to receive a good bio-waste quality (Guastavi[1]).	From an urbanistic point of view, changing the existing system of waste collection and management could be difficult in a very dense urban area because of the issue of available space for the waste storage (AN-FR3[4]). The decentralised system is understood to decrease the collection costs but increase the cost for technical equipment (AN-FR2[5,6]). In an area with collective housing, a decentralised system would face issues regarding the lack of space and bad bio-waste quality (AN-FR4[7]).	Specific means of collection could be bicycles and horses and voluntary bring points (Guastavi[1]). The distance to bring points should be not more than 150 m (AN-FR5[8]). The focus should be laid on the waste from big generators (restaurant, schools, etc.) (AN-FR5[8]). Households should be supported by financial incentives (Royer[2]). The collection flat rate for residual waste (MSW) should be increased to promote a better sorting (Billon[3]).
[1]Raphael Guastavi, Agence de l'environnement et de la maîtrise de l'energie (ADEME), PA; [2]Céline Royer, Vert Le Jardin, EAO; [3]Coline Billon, La Tricyclerie, EAO; [4]UD; [5]WM-pu; [6]WT; [7]WM-pr; [8]PA		

Table 12: Opinions on decentralised waste collection systems of stakeholders of the Friuli Venezia Giulia region in Italy

Region Friuli Venezia Giulia, Italy		
Pro	**Con**	**Suggestions**
There is a simplification on legislation regarding organic waste treatment in small communities for plants that manage less than 130 t/y (Regulation: DM Ambiente 266, 2016).	-	Small towns in the mountains, where trucks cannot access easily could implement a decentralised waste collection (and treatment) system (Sgubin[1]).
[1]Cristina Sgubin, ARPA FVG, PA		

The variety of nine different stakeholder groups from six regions ensured that a variety of different opinions could be gathered. Numerous arguments were provided in the “pro” as well as in the “con” section. In addition, some suggestions for implementing a decentralised collection system were made. Comparing the arguments, there is not a big difference regarding the issues addressed within the different regions; however, within the local-specific direction of the statements. Doubts to implement a decentralised waste collection system appear to have a higher weight than the benefits such system could bring so far.

- *Pro’s*: Regardless the stakeholder group, most arguments in favour with a decentralised waste collection system would be that costs could be saved in terms of transport and that the awareness of the citizens could be increased since they would know what happens with their waste and which benefits they could receive. Furthermore, it seems possible that the bio-waste quality could be improved due to the decentralisation and that there might be a principal interest on the participation of a decentralised scheme.
- *Con’s*: A major argument against the implementation of decentralised collection is the concern that citizens do not want to spend more time and money for source-separation (and treatment) of waste. The argument of limited space is often mentioned, too. It is expected that a new collection system will require more time for sorting and more space. The “pro” argument of saving costs was also doubted since it might not become true if the overall process is considered including the disposal of digestates. Big trucks might still be required to bring the digestate out of the city.

Even more concerns are seen with the implementation of mAD facilities as valorisation unit of the collected bio-waste in a decentralised approach. Therefore, the cost issue, the authorisation processes as well as leakages from gas and odours are concerned. However, certain sources of bio-waste are mentioned, which could be used for implementation of a decentralised bio-waste management system. Following suggestions for waste origins with potential for mAD were made:

- Restaurants, canteens, bakeries
- Schools, hospitals, prisons
- Small towns with areas where trucks do not have access (e.g. in mountains)
- Rural areas, which are not easy to connect to central systems

The existing waste collection and management system as well as the authorisation issue was of concern. Some argued that the responsibility for a decentralised collection can only be at the authority which collects the waste in the current centralised bio-waste management system. Otherwise, legal ways to implement a parallel system have to be found. On the other hand, (private) urban farms appear promising; however, only with a bring system. Another issue is the decentralised collection system: on the one hand BP waste collection may be considered more promising since it seems cheaper but on the other hand a DtD system seems better since waste collection more convenient for the citizens and the distance for transport is usually shorter (not longer than 50 m). It has to be considered that macro-impurities are usually higher in BP collection systems compared to DtD collection systems. However, the current used collection system should not be modified.

For the implementation of a decentralised waste collection system, suggestions were made. A major one is that financial incentives have to be made for the citizens and that they should benefit from a good bio-waste source-separation with a very low macro-impurities’ content. Furthermore, it is suggested to intensify the communication and to demonstrate to the citizens that there are no risks (e.g. vermin, diseases, odours) but benefits with modern treatment systems.

Finally, some information was gathered regarding the sizes of decentralised locations. For one expert it appears feasible to run mADs with a capacity of 1000 t bio-waste/y. Others stated that for facilities managing less than 130 t/y simplified legislation is foreseen. Furthermore, the distance between mAD and inhabited zones should be above 200 m. All factors are important for the determination of the area where to implement decentralised bio-waste management.

2.3 Recommendations for the development of decentralised collection systems

From the information gained by the stakeholder interviews and the evaluation done in section 2.2.1 and 2.2.2 some conclusions were drawn for the development of decentralised collection systems. Generally, it can be said that the interviews provided a good insight into the local waste management system, to receive insider information, to be informed on specific recent local issues and on ideas for solutions. In addition, knowing opinions on the suggested new systems is valuable and critic helps to develop solutions which have a chance for implementation. Following, some recommendations that have to be considered in the development process of decentralised collection system are summarised:

- The participatory involvement of the public waste management sector into the preparation and operation of a decentralised system is mandatory.
- For testing sites or initiation projects, generators with sufficient bio-waste amounts should be selected (e.g. from certain food services) and citizens involvement should be a priority.
- A new system should have advantages for the citizens. This would be the case if for example the system is more convenient and demand adapted, space saving, and nuisance reducing than the current system. Furthermore, citizens should get benefits from the system, e.g. valorisation products for free or reduced fees for good source-separation.
- The recent waste collection system, either DtD or BP, should be kept. On the other hand, voluntary BP, either one at the decentralised valorisation unit or several in one neighbourhood, can be offered and people can use them if they are willing to.
- Devices or bags for waste collection should be distributed to the citizens for free.
- The key for high bio-waste quality is the generator (citizen, food service staff). A successful source-separation may be achieved if the goal of the waste collection is well defined and communicated and the instructions for the sorting are clear and easy to understand.
- There are concerns regarding the fact that mAD does not seem possible to be implemented. In any case, a decentralised bio-waste collection system can be implemented serving another decentralised valorisation unit such as composting.

A part of the recommendations is considered in the development of bio-waste collection chain scenarios for decentralised collection, which are presented in chapter 4. Further arguments will be considered in future work packages, e.g. for the implementation of pilot collection systems.

3 DECISIVE bio-waste collection database

The *bio-waste collection database* will be part of the DECISIVE-DST. An outline of the database structure including a summary of the relevant collection parameters is provided in section 3.1. In section 3.2, the issue of data acquisition and data uncertainties is explained with the example of the EUROSTAT waste database for food wastes (FW) from European and DECISIVE countries. In section 3.3 the general structure of the DECISIVE *bio-waste collection database* is described followed by the description of the bio-waste collection phases and its parameters. Finally, the DECISIVE *bio-waste collection database* will be introduced in section 3.4 with a specific focus on food waste and its collection, focussing on data originating from small areas until a maximum of a regional level. The DECISIVE *bio-waste collection database* includes ranges of the gathered data of each DECISIVE country. The whole database will be the basis to describe waste collection chains and processes.

3.1 General overview

For the design of decentralised collection systems, it is important to have a detailed understanding of various systems and differences that may occur between them. Having a profound knowledge of bio-waste generation and of the collection system is also necessary. This report builds on the general bio-waste collection chain which was developed in D 3.5. It includes data related to waste generators and collectors who are the two main stakeholder groups of bio-waste collection chains. Table 13 shows a summary of the structure and content of the DECISIVE *bio-waste collection database* which will be explained in more detail in section 3.3.

Table 13: General set-up of the DECISIVE bio-waste collection database

Database structure includes	Database content includes
the principal structure (connectable to the DST), with subdivision to • the waste management *phases* (generation, source-separation and collection) • the *stakeholders* (generators, collectors) • the *parameters* directly connected to the waste management phases (divided into waste related, collection system set-up related storage related, and transport related parameters)	a multitude of documented raw data provided by the DECISIVE partners including • name of parameter (with related information) • waste management phase • type of waste source (e.g. household, restaurant, canteens) • time and location reference (year, city, region) • data quality types (single, mean, minimum and maximum values with units) • reference with link and information on type of reference (e.g. scientific study, reports, statistics) • own calculations with assumptions to fit data to the database parameters and units

The assignment of data to the *bio-waste collection database* and the summarising interpretation is a key aspect for the successful use of the DST. Data in general are available from manifold sources. However, they may be different in significance and validity and could therefore be misinterpreted which would lead to incorrect conclusions. Waste data varies widely depending on the specific situation. Furthermore, waste heterogeneity is an issue which makes accurate data generation very challenging starting with the sampling of waste. These are, among others, critical issues for the *bio-waste collection database*. This issue is addressed in section 3.2 for data on bio-waste amounts released by EUROSTAT for all EU-28 countries. Bio-waste amounts were chosen, since they are the starting point of each concept development of waste collection. Using unsuitable values may easily lead to over- or under-estimation for the suitable scale of technical facilities (e.g. collection devices, mAD units).

3.2 The challenge of data acquisition

3.2.1 The example of the European reference database EUROSTAT

The availability of accurate and reliable food waste data is highly important when implementing the DECISIVE DST. Acquiring this kind of data is known to be challenging, for example certain key parameters are simply unavailable, whereby on other occasions there may be too much data and/or conflicting definitions when comparing different sets of data. The source of a dataset can also be of concern, even if the source is reliable and the information is well prepared. Misinterpretations can easily occur and this could lead to incorrect conclusions. These issues shall be explained with help of the database for food waste amounts provided by EUROSTAT in order to provide basics for the correct data acquisition and interpretation regarding the design of food waste collection chains.

Databases provided by EUROSTAT are one of the easiest accessible databases at the European level. EUROSTAT is a Directorate-General of the European Commission with the main responsibility of providing statistical information and to promote the harmonisation of statistical methods across its member states (EUROSTAT 2018c). Among others, it provides an overview on Europe-wide available bio-waste data including various waste classes and sources. It is updated on an annual basis.
The evaluation of EUROSTAT data carried out in section 3.2.2 is focused on the waste categories which contain food waste. Furthermore, the methods of data acquisition are presented to be transparent regarding the working hypothesis. The knowledge on food waste amounts as one bio-waste fraction is the precondition, if waste collection chains shall be designed. In section 3.2.3 national data collection methods are described. In section 3.2.4 uncertainties data from official statistics such as EUROSTAT are described followed by a conclusion and a potential alternative strategy for data acquisition.

3.2.2 Food waste amounts in the EUROSTAT database

EUROSTAT (2018a) provides a statistical overview of waste data across Europe according to the strategy: *"Data on the generation and treatment of waste is collected from the Member States. The information on waste generation has a breakdown in sources […] and in waste categories."* (EUROSTAT 2018d). Data are collected biannually from European countries based on the waste statistics regulation (EC 2150/2002) (EUROSTAT 2017) where they are clustered and harmonised (EUROSTAT 2010) to support the following database structure:

- GEO (European country),
- HAZARD (hazard class),
- NACE (origin based on classification of economic activities and households),
- TIME (period of time),
- UNITS (t, kg/cap), and
- WASTE (waste category).

The EUROSTAT waste data sets are sub-classified into 51 waste categories (items) according to the *Guidance on EWC-Stat*[c] *Waste Categories* (EPA 2002). It is mainly a substance oriented classification and is listed in different types of agricultural, municipal, and industrial wastes in the EWC using a six-digit code. The EWC contains 20 chapters describing the source of the waste with further subdivisions and includes more than 80 waste types that are biogenic or contain biogenic fractions in significant amounts.

Data for food waste from private households and from food services are required for the DECISIVE bio-waste collection database. In EUROSTAT *households* are a considered class of waste source. According to EUROSTAT, possible amounts of food waste can be found in three EUROSTAT categories: *animal- and mixed food waste* (W09.1), *vegetal waste* (W09.2), and *household and similar waste* (W10.1) (EUROSTAT 2017), which are all considered as non-hazardous. In Table 14 they are summarised and assigned to the

[c] European Waste Catalogue

EWC classification following the (EPA 2002) guidance.

According to EUROSTAT (2010) pre- and post-consumer food wastes belong to the following EWC-chapters:

- Chapter 02 - Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing → According to EUROSTAT, *vegetal wastes* are accounted for entirely within this chapter (with the exception of *biodegradable green waste*) and also some *animal and mixed food wastes*;
- Chapter 20 - Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions → According to EUROSTAT, *household and similar wastes* fall entirely within this chapter, while *animal and mixed food wastes* only partly.

Table 14: EUROSTAT categories with food waste shares and their assignments to the EWC sub-classifications containing food waste from private households and food services

	EUROSTAT			**EWC**		
Name	Code	Item	Definition	Chapter	Sub-fraction containing food waste	
					Name	Code
Animal- and mixed food waste	W09.1	31	animal and mixed food waste of food preparation and products from food preparation and agriculture as well as separate collection	20 (2/10)*	Biodegradable kitchen and canteen waste	20 01 08
					Edible oil and fat	20 01 25
Vegetal waste	W09.2	32	vegetal waste from food preparation and products from food preparation and agriculture as well as separate collection	2 (2/11)*	-	-
Household and similar wastes	W10.1	34	mixed municipal waste, bulky waste, street cleaning waste, kitchen waste and household equipment except separately collected fractions with main amounts from households and similar wastes from all other commercial and administrative branches	20 (2/5)*	Mixed municipal waste	20 03 01
					Municipal wastes not otherwise specified	20 03 99

*number of categories / sub-fractions; considered from EUROSTAT for the categories which contain food waste

The EUROSTAT waste categories W09.1 and W09.2 are supposed to include information on source-separated food waste generated in different sectors. However, W09.2 only considers the wastes from chapter 2 of the EWC, which are assigned to the pre-consumer stages, and do not include private households and food services. Therefore, W09.2 is not considered in the further evaluation of this report. For W09.1, only two sub-fractions refer to food waste from the considered waste sources. The amounts provided for *animal- and mixed food wastes* by EUROSTAT could include source-separated food waste from food services, and potentially from private households if source-separated and collected without garden waste.

Figure 2 displays the amount of *animal and mixed food waste* (W09.1) and *vegetal waste* (W09.2) provided by EUROSTAT for the sector of *households*. Although not relevant for the DECISIVE frame, W09.2 is also displayed, since data could mistakenly be considered due to the term *vegetal waste* (section 3.2.4). European countries are sorted in decreasing order regarding the W09.1 amount with the displayed amounts potentially containing food waste amounts belonging to the EWC sub-fractions *biodegradable kitchen and canteen waste* and *edible oil and fat*.

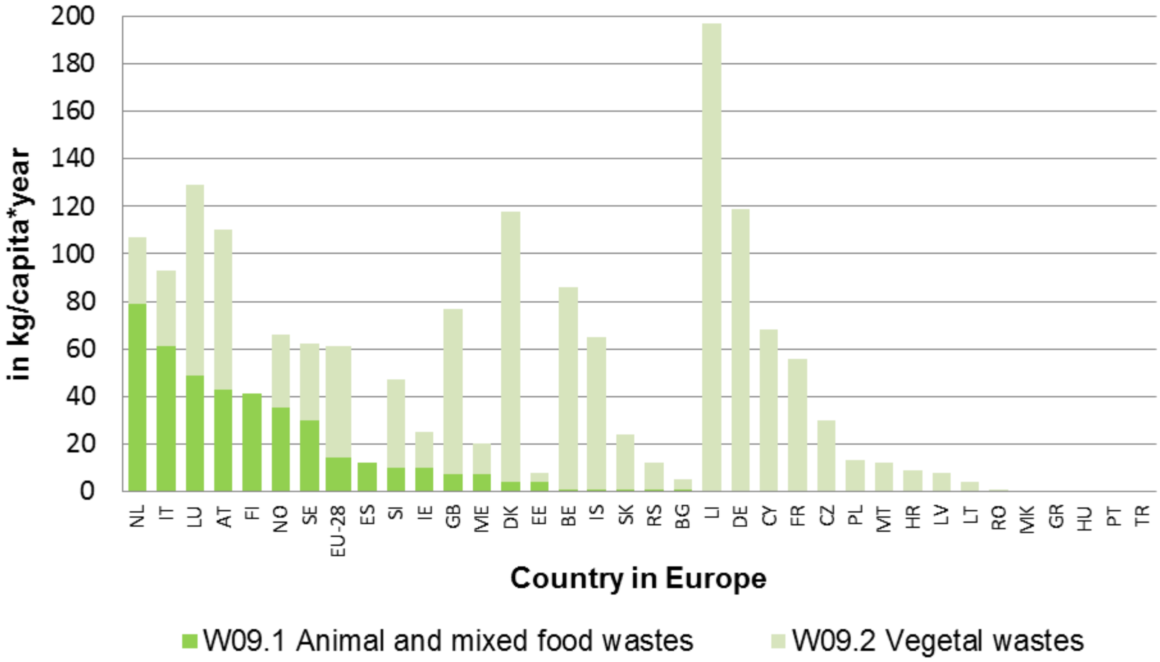
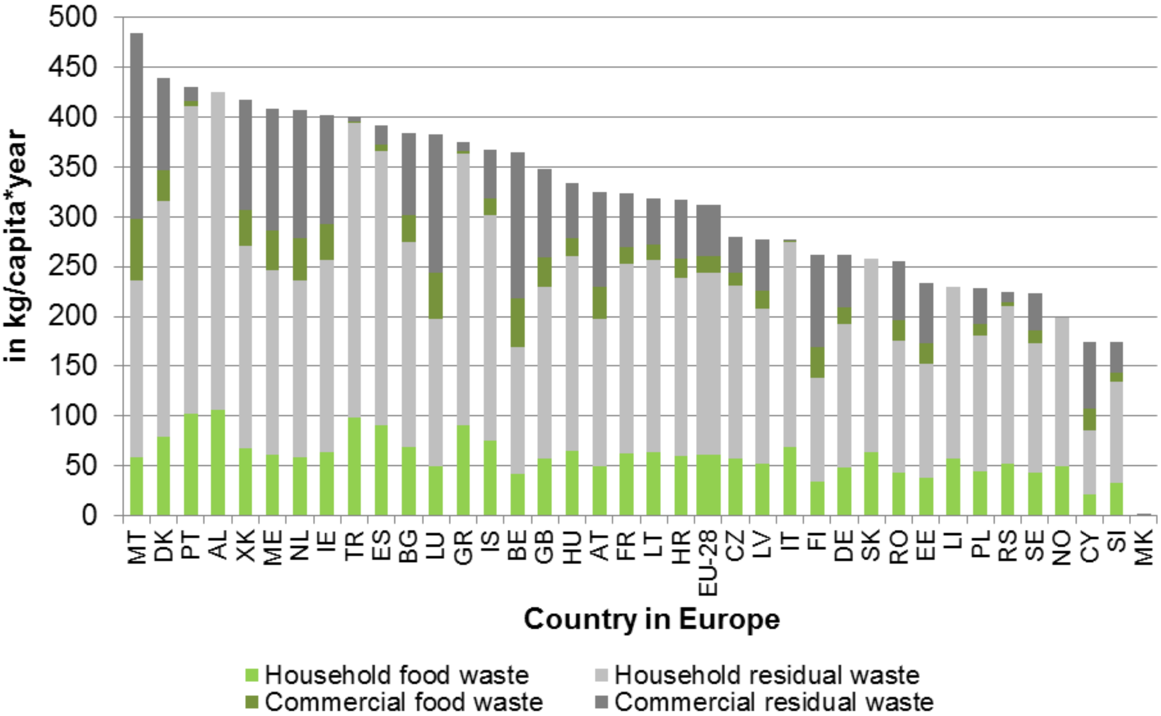


Figure 2: Amounts of the categories "animal- and mixed food waste" (W09.1) and "vegetal waste" (W09.2) from households provided by EUROSTAT for the European countries in 2014 (EUROSTAT 2018a)

Animal and mixed food waste amounts (W09.1) from households range between 0 and 80 kg/capita*y, with the Netherlands and Italy producing the greatest amounts (Figure 2). Italy, the only DECISIVE country above the EU average, collects source-separated food waste from households while woody wastes, leaves and grass are collected separately (D3.5[d]). Additionally, containers for source-separated oil and fat collection are distributed in some parts of Italy. Almost half of the countries are assigned to a value of 0 kg/capita*y, including two DECISIVE countries (Germany, France). Food waste is indeed being produced by households in these countries but the data might not be assigned to W09.1.
Some DECISIVE countries with source-separation of bio-waste in place collect food waste and garden waste together (Germany, Belgium; D3.5[e]) while some others have a separate collection for garden waste (Denmark, Spanish region of Catalonia, Italy; D3.5[f]). Countries without food waste source-separation dispose of their food waste with the residual waste (France, many regions of Spain; D3.5[g]). In all cases, the food waste amounts are contained in the W10.1 category of *household and similar waste*.

Figure 8 displays the food waste amounts contained in the EUROSTAT category W10.1. The figure was subdivided for the sector of *households* and for all other sectors covered by W10.1. The food waste share was calculated with an estimate of 25% of the total waste based on a survey undertaken with 13 member states (EUROSTAT 2017).

[d] p. 26
[e] p. 22 and 25
[f] p. 23, 26 and 27
[g] p. 22-27



A share of 25% of food waste is estimated by EUROSTAT for the category of "household and similar waste" (W10.1).

Figure 3: Amounts of the category "household and similar waste" (W10.1) provided by EUROSTAT for the European countries in 2014 (EUROSTAT 2018a)

The highest share of *household and similar waste* is assigned to the sector of *households* for all countries (Figure 3). In conclusion, amounts of food waste are also higher for the household sector compared to the amounts of food waste from food services. Figure 3 displays that some countries reach food waste estimates slightly above 100 kg/capita*y: Malta, Denmark, Portugal, Albania, Kosovo, and the Netherlands. From the DECISIVE countries Denmark (110 kg/capita*y) and Spain (98 kg/capita*y) share the highest values. However, a clear difference between the distribution of food waste based on household sector and on the food service sector can be observed. Italy (69 kg/capita*y) and Germany (65 kg/capita*y) showed the lowest values, but also with a clear difference when comparing each sector. In the case of Italy almost 100% of the total food waste amounts are assigned to the household sector. The Former Yugoslav Republic of Macedonia as well as Bosnia and Herzegovina were seen to be last place in their waste production (1 and 0 kg/capita*y). The low amounts appear to be unreliable and may be explained due to the lack of data. To explain the differences and the highly variable values, the EUROSTAT data are evaluated in more detail in Table 15.

Food services:

Food waste from food services fall into the NACE-category[h] *I-56* (*Accomodation and food service activities* including the three sub-sections *Restaurants and mobile food service activities*, *event catering and other food services*, and *beverage serving activities*). However, these sections are unified with the NACE-section G-U in EUROSTAT. It is assumed that only section I includes food waste from food services, since the other sections cover wastes without connections to food waste. Furthermore, food wastes from food services could also be assigned to the category *waste collection, treatment and disposal activities; materials recovery* (NACE_R2 E-38).

Private households:

The households are not covered via the NACE_R2 classification. The food waste from private households could be assigned to the category *household waste* (W10.1) or to the category of *animal- and mixed food waste* (W09.1); to the latter only belongs source-separated food waste which is collected without garden waste. Table 15 shows the amounts of W10.1 and W09.1 and the estimated food waste amounts.

Table 15: Overview of 2014 EUROSTAT-data for wastes with food waste shares including calculated estimations of total food waste amounts from households

	Household and similar wastes (W10.1)						**Animal and mixed food waste (W09.1)**				**Food waste from private households and food services**		
	EUROSTAT category				*Food waste share[1]*		*EUROSTAT category*				*Calculated amounts[3]*		
Unit	*kg/capita*y*												
Region	ALL[2a]	HH[2b]	WC[2c]	SE[2d]	ALL[2a]	HH[2b]	ALL[2a]	HH[2b]	WC[2c]	SE[2d]	HH	SE	HH + SE
BE	364	169	30	103	91	42	100	1	10	19	42	78	120
DK	439	316	1	85	110	79	24	4	0	6	83	37	120
FR	323	252	0	60	81	63	61	0	0	22	63	40	103
DE	261	192	1	51	65	48	22	0	0	15	48	32	80
IT	275	275	1	0	69	69	66	61	1	0	130	1	131
ES	391	365	0	20	98	91	39	12	0	3	103	10	113
EU-28	**312**	**243**	**6**	**50**	**78**	**61**	**46**	**14**	**1**	**10**	75	28	103

HH: Households; SE: Food service; WC: Waste collection; All: all sectors

1: calculated from the respective EUROSTAT category and the food waste share estimate of 25% (EUROSTAT 2017)
2a: EUROSTAT-category: All NACE_R2 activities plus households (EUROSTAT 2018a, 2018b)
2b: EUROSTAT-category: Households (EUROSTAT 2018c)
2c: EUROSTAT-category: Waste collection, treatment and disposal activities; materials recovery (E38 in NACE_R2 classification) (EUROSTAT 2018a)
2d: EUROSTAT-category: Services (except wholesale of waste and scrap) (G to U in NACE_R2) (EUROSTAT 2018a)
3: see section "Calculation of estimates for food waste from private households and from food services"

A suggestive procedure for providing the best possible estimate for food waste amounts from private households and food services based on EUROSTAT data[h] is explained in the following.

Calculation of estimates for food waste from private households and from food services:

The estimates of food waste amounts from private households were calculated with equation (1):

$$\sum W10.1_{HH} * 0.25 + W09.1_{HH} = FW_{total,HH} \tag{1}$$

The estimates of food waste amounts from the food service sector were calculated with equation (2):

$$\sum W10.1_{All} * 0.25 - W10.1_{HH} * 0.25 + W09.1_{WC} + W09.1_{SE} = FW_{total,SE} \tag{2}$$

[h]The metadata of EUROSTAT (2019) is either assigned to production or consumption activities. For production activities a further breakdown is supplied in 18 economic activities according to the NACE rev. 2 (R2) classification (EUROSTAT 2018a).

In summary of the various pathways in Table 15, the DECISIVE countries resulted in food waste estimates from food services ranging between 1 kg/capita*y (Italy) and 78 kg/capita*y (Belgium), and from private households between 42 kg/capita*y (Belgium) and 130 kg/capita*y (Italy). These ranges still contain many uncertainties, beginning with the random estimation of 25% food waste share in W10.1 and the issue of assigning of food waste was unachievable. Furthermore, the application of this estimation of food waste in W10.1 for households and food services is also uncertain. The provided values for amounts of food waste from private households and food services based on EUROSTAT data can therefore only be a very rough estimate.

3.2.3 National data collection methods

Although the DECISIVE countries use the EWC classification for their statistical analysis and linkages between EWC and EUROSTAT are documented, the transformation to the EUROSTAT categories is not conducted in the same way.

International differences in data collection methods might occur and also within a single country the procedure may vary. This issue is clearly highlighted by analyzing methodologies in the countries Germany, Italy and the Spanish region of Catalonia.

Germany
Each Federal state of Germany provides an annual municipal waste balance on municipal waste (Destatis 2018; LLUR 2018). The acquisition of basic data takes place based on the EWC code, whereas for certain waste types additional subdivisions are used. For the waste considered here this refers to *mixed municipal waste* (EWC code 20 03 01) which is subdivided into: *Indifferentiable mixed municipal wastes* (20 03 01 00), *household waste and similar commercial wastes, mutually collected by public waste collection services* (20 03 01 01), *commercial wastes similar to household wastes, not collected with household waste* (20 03 01 02) and *biobin wastes* (20 03 01 04).
The procedure is similar in all Federal states on the basis of the regulation on environmental statistics (UStatG) in connection with the German regulation on statistics (BStatG). Statistics are generated on the basis of the data obtained from public waste collection companies (örE), which are responsible for the collection of wastes from private households. The Federal state data are submitted to the German statistical office for compilation to the German waste statistics, which is the basis for the EUROSTAT data. The results are considered as high quality for the reported amounts, since it is a complete evaluation. The most recent data from German statistics are available from 2016. In Table 16, data from 2014 are displayed (Destatis 2018) and compared with the EUROSTAT data (EUROSTAT 2018a).

Table 16: Comparison of German food waste data from EUROSTAT (2018a, 2018b, 2018c) and Destatis (2018) for the year 2014

Source	**Waste type**	**Amount in 10^3 t/y**
EUROSTAT	Household and similar waste (W10.1): all sectors except households	5,573
	Household and similar waste (W10.1): households	15,534
	Sum of previous	**21,107**
DESTATIS	Household waste and similar commercial wastes (200301 00, 01, 02)	13,171
	Biobin waste (200301 04)	4,603
	Mixed municipal waste (200301, calculated from, DESTATIS sub-groups)	17,773
	Sum of previous	**35,547**

It can be seen that the values are not directly transferable to EUROSTAT groups, but that they are in similar ranges. It should be noted that the values provided by DESTATIS are comprehensive for the wastes collected from the private households and that they contain some undefined waste amounts collected from food services since commercial food waste generators are not obliged to deliver their waste to the public waste collection companies (Destatis 2016). Therefore, the municipal waste balance includes the waste from private households, and limited amounts from food services. This is due to the organisation of the collection system with responsibility for households in the public sector and the freedom of choice for the food services. This may explain the relatively low calculated food waste amounts reported in Table 15 (80 kg/capita*y). The ratio between private households and food services is unknown. Furthermore, it has to be mentioned that the data summarised in EUROSTAT W10.1 include source-separated as well as non-separated bio-wastes.

Italy

The explanation on the method of data acquisition is taken from the Italian Report of urban waste (ISPRA 2017). Data originates from different sources but mostly directly from a municipal level. Data were collected from regional or provincial governments and agencies, e.g. *Agency for Environmental Protection of the region of Friuli Venezia Giulia*[i]. The *National Institute for environmental protection and research Via Vitaliano Brancati*, ISPRA[j] presents a nationwide urban waste report each year with the most recent report from 2017. The *Ministry of Environment and Protection of the territory and the sea*[k] gives the guidelines for the calculation of amounts and quality of source-separate collection. Opposed to the German system, waste originating from households and food service sector is collected together. The highest calculated food waste amounts in Table 15 were reported for Italy (131 kg/capita*y). The reason might be the joint collection of food waste from households and food service sector. The different possible assignments for private households and food services based on EUROSTAT groupings displayed in Table 15 have been proven to be not very useful when considering the national collection strategies.

Catalonia, Spain

In the case of Spain, bio-waste management has very recently become the focus of attention of the Autonomous Communities as well as of the *Ministry of the Environment* and is undergoing substantial changes at the present. The competence of waste management lies with the Autonomous Communities which have different approaches and levels of record keeping. Therefore, country data originate from a compilation and aggregation of regional data of considerably different quality and robustness. Therefore, available data for the previous years are still heterogeneous. Data on the DECISIVE case study region of Catalonia, Spain will be introduced in more detail since it has been conduction bio-waste management and its monitoring for a long time and therefore data availability is high and very detailed (section 3.4.1).

In Catalonia, average municipal waste composition analysis is usually carried out in the context of the waste management programs, in order to supply basic information for the planning scenarios. The most recent analysis dates from 2013 and is published in the Annex 11 of the *Catalan Waste and Resources Management Program* PRECAT20 (ARC 2018b). The amounts of total generated food waste are calculated based on the percentage of food waste contained in the total municipal waste according to this composition analysis. The amount of source-separated food waste corresponds to the entry data from weighing or volumetric estimates of waste truck loads, compiled from all biological treatment facilities for separately collected bio-waste in Catalonia. They are therefore more accurate than the calculated amounts of food waste generation based on averages, especially when broken down to the municipal level. The collected source-separated bio-waste is characterised every trimester for each collection circuit. With this characterisation and the weighting, the amounts of source-separated bio-waste and its macro-impurities can be displayed in detail.

[i] Agenzia regionale per la protezione dell'ambiente del Friuli Venezia Giulia

[j] Intituto Superiore per la Protezione e la Ricerca Ambientale Via Vitaliano Brancati

[k] Ministero dell'Ambiente e della Tutela del Territorio e del Mare

3.2.4 Reasons for data uncertainties

Three examples of issues that may occur from the misinterpretation of terminologies in statistical databases are provided based on experiences with the interpretation of EUROSTAT data:

- **Waste generation:** Within DECISIVE, the collection chain has been elaborated in detail considering *generation, source-separation* and *collection* of waste separately (section 3.3, Figure 4). EUROSTAT termed *generated wastes* data; however, only considers the collected wastes when compared with the DECISIVE terminology. This may well lead to underestimations in waste generation, due to the neglect of certain important pathways of food waste (e.g. home composting or pet feeding).
- **Food waste:** FAO provides data from importance for the food supply chain (Gustavsson et al. 2011). FAO subdivides into *food losses* (occurring before consumption) and *food wastes* (occurring in private households and the food service sector). EUROSTAT uses the term food waste for both and considers three groups (W09.1, W09.2, W10.1) containing food waste. In the context of DECISIVE, food losses (represented by W09.2) that occur in the food chain before consumption (e.g. agriculture, industrial food preparation and processing) are not relevant. Since EUROSTAT does not distinguish between food losses and food waste, this could easily lead to an overestimation of food waste amounts.
- **Vegetal waste:** Food waste can be subdivided into waste from mainly animal-based origin or mainly plant-based origin (D3.6). The term v*egetal waste* may imply a specific fraction of food waste originated from vegetation. Using EUROSTAT data may again lead to overestimation as only food losses are covered and therefore not considered in the scope of DECISIVE.

Concluding from the previous, it is important to understand the exact meanings of terms used and the conditions that define a value, e.g. the kind of bio-waste included in it, the types of waste generators included, the data acquisition method applied, the timely and local frame. Data on food waste quantities, but also on other parameters, may be unreliable due to the following factors, which are explained with an example related to DECISIVE:

- **Inconsistency of definitions:** Definitions might be missing or too complicated. Commonly used terms such as *bio-waste*, *organic waste*, *food waste* and *kitchen waste* do not explain which individual types of biomass are actually included. These terms can lead to different individual interpretations if no definition is given. Thus, the considered waste fraction (e.g. total, avoidable and non-avoidable food waste, inedible and edible parts, animal-based or plant-based) is difficult to estimate, if at all, correctly (Stenmarck et al. 2016; Kranert et al. 2012). The bio-waste categories considered in DECISIVE are displayed in Figure 5.
- **Issue of waste sources included:** The source-separated food waste is not always collected separately from households and food services, e.g. in the case of Italy (D 3.5 2017; ISPRA 2017). Furthermore, food waste is often collected mixed with garden waste. Therefore, assumptions made for one country may not be valid for another one and could lead to misinterpretations.
- **Different calculation methods:** Different methods for the calculation of food waste amounts reduce the comparability of data. Several authors suggest a harmonisation of the calculation methods and its parameters in order to improve data quality, completeness and transparency (Brosowski et al. 2015; Parfitt et al. 2010; Kranert et al. 2012; Körner et al. 2009; EUROSTAT 2019). Calculations may be done due to self-given scopes and different assumptions. Therefore, the methodology for calculations of food waste data can differ among different reports. The methodology might change within the same statistical office which might lead to incomparability of data from different years.
- **Lack of accuracy:** Various detection methods are applied as well as rough estimations including different data backgrounds. There are important differences in food waste amounts among EU-countries probably originating from differences in the quality of data collection methodologies. A lack of studies and data of sufficient quality available was also stated for instance by Stenmarck et al. (2016) for studies on the food waste sector. This is the case for the rough estimation in the EUROSTAT data, that 25% of bio-waste is contained in the category W10.1 *household and similar wastes* which also includes *similar wastes from food services*. It can be expected that the share of bio-waste from households differes from the share of bio-waste from food services.
- **Non-standardised physical units:** Results may refer to non-standardised physical units (e.g. inch, Tsd. T) or unclear assignments of waste (e.g. wet or dry mass; % without relations). Therefore, only SI-units should be used and if possible data should be converted.

EUROSTAT data and EWC codes are not useful if food waste amounts from private households and from food services are required, as it is the case for the development of decentralised waste management concepts. The EUROSTAT categories containing food waste from private households and food services (W09.1, W10.1) do not provide a specific sub-sector allowing for a separation of the waste source. The common classifications are oriented on the “classic” waste management goal “*to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use*” (European Union 11/19/2008). Considering this aspect, the introduction of additional waste categories for annual statistical evaluations would be useful since data on food waste from private households and food services are not collected separately. However, since they are not yet available at the moment, other strategies for improved data acquisition for food waste from households and from food services are suggested in section 3.5.

3.3 Description of the DECISIVE bio-waste collection database

3.3.1 General structure of the database

To introduce a decentralised waste management system it is important to have a good understanding but also a broad range of detailed waste collection data for the parameters introduced in this section.

The development of the database is separated into two parts:

1) In the *raw database* data is gathered for the six DECISIVE countries. The general structure of the bio-waste collection chain database follows its phases *bio-waste generation*, *bio-waste source-separation* and *bio-waste collection* (red boxes, Figure 4). The subdivision into three phases was firstly introduced in D3.5 and further improved and adapted to fit to the general structure of the DECISIVE *bio-waste collection database* and the general structure of the DST. Figure 4 gives an overview of the applied terminologies within the three phases. The structure can be applied for different bio-waste types (blue, Figure 4) which mainly relate to the bio-wastes’ source. The three phases include parameters related to waste, storage, transport and collection system in general (yellow, Figure 4) and the stakeholder groups *generators* and *collectors* (green, Figure 4). Furthermore, the data are related to a time reference and the location of source. Furthermore, the raw database contains assumptions as well as short calculations to relate a value to the defined unit (appendix 1), e.g. food waste related to capita (households) or meal (food services) etc. Storage and transport related data are given depending on the storage devices (e.g. bag, bucket, container, tanks) and on the transport devices (vehicles). The DECISIVE *bio-waste collection database* includes data on a national but also on a regional, municipal level and local level including a case study scale. The data quality is validated only by using data of proper references. These references are
    - scientific studies,
    - scientific summaries,
    - information from waste management agencies,
    - information from companies producing equipments,
    - DECISIVE evaluation provided in reports.
2) In section 3.4.1 and 3.4.2 the results from the data gathering in the raw database are summarised by *extracting and compiling* the data in order to display ranges of minimum and maximum values for the DECISIVE countries. For the evaluation, all entries originate from regional, municipal or local levels. By clustering and summarising the data of these levels to national ranges, the degree of detail increases in comparison to a single national value which fails to display differences at a small scale.
   For the *waste* database the Spanish region of Catalonia was taken as a case study region since 1) the data availability is very high compared to other Spanish regions, 2) the waste management system is different compared to other Spanish regions, and 3) the data originate from the Catalan waste agency (ARC), one of the DECISIVE partners, assuring a high quality data.
   Regarding the storage and transport related parameters, data was more limited. However, many

parameters are rather connected with the companies producing equipments and not to a specific country. The list of references considered in the sections 3.4.1 and 3.4.2 is provided in appendix 2 including assignments to the specific stakeholder group.

The data can be used to build precise waste collection processes to be included in the DST. Those processes will be available in the DST documentation and in deliverable D6.4.

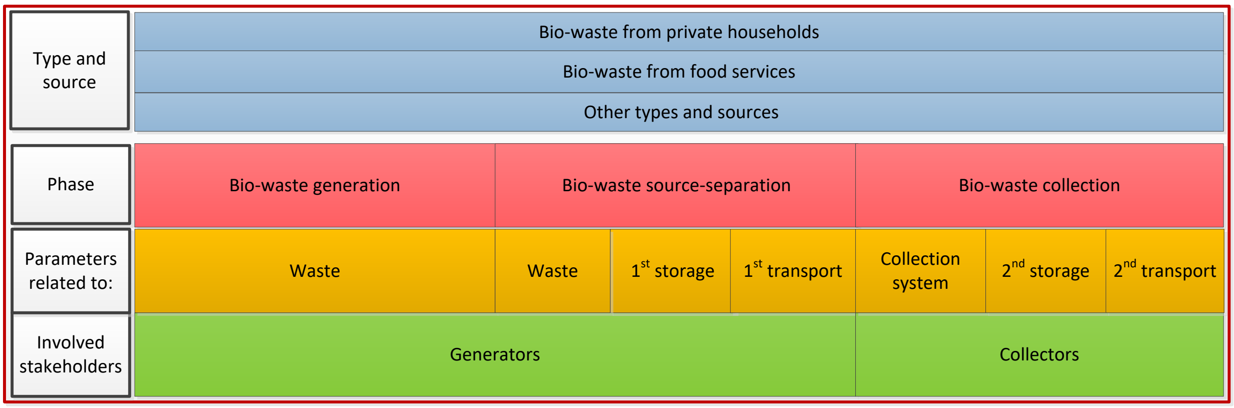


Figure 4: Connection between the collection chain phases of the bio-waste collection chain database and their related parameters and involved stakeholders

A general description of the content of waste related, storage related, transport related and collection system related parameters as well as on the involved stakeholders is given in section 3.3.2. A detailed description of the parameters of the different bio-waste collection chain phases is given section 3.3.3.

3.3.2 General definition of the different parameter sections and stakeholders

The involved *stakeholders* of the *bio-waste collection chain database* include two types:

- ***Generator*** - *Actor that generates bio-waste and is responsible for its source-separation:* In terms of food waste, the *generator* can be a person of a household or of the food service sector. In both cases, the waste can originate from the kitchen (preparation residues) or the consumer (leftovers). Generators of garden waste can be either a person from a household, professional gardeners or or persons that are professionally responsible to clean public green areas. A definition of *bio-waste generation* is provided in the glossary of D5.1[l].
- ***Collector*** - *Actor responsible for the collection of bio-waste generated by the generator:* This can be for example a janitor or a person working for a waste management company.

The four different categories of *parameters* of the *bio-waste collection database* are briefly explained as follows:

- ***Waste related parameters*** - *Mainly refer to the amount of total generated bio-waste or amount referred to source-separated, non-source-separated, and collected waste:* The total municipal solid waste, bio-waste, food waste and its various components as well as green and woody waste are considered in the *bio-waste generation phase*. For the *bio-waste source-separation phase*, the type of waste is related to the bin in which it is disposed, e.g. food waste in bio-waste bin. *Other disposal routes* are considered as well. Additionally, the quality of the waste is given, by including the amount of macro-impurities in the different bio-waste types[m].

[l] Report available at: http://www.decisive2020.eu/wp-content/uploads/2018/03/DECISIVE_WP5_D5-1_release-01.pdf
[m] The chemical (and physical) properties of the waste are excluded from in the process of bio-waste collection since they are only important for the subsequent valorisation process. Therefore, they are not in the scope of this report.

- ***Storage related parameters*** - *Refer to type and place of storage.*
  - *1^{st} storage:* In terms of food waste, the place of the 1^{st} storage is usually inside the household or more specifically at the place of generation (e.g. kitchen of households or restaurants). The parameters refer to the storage devices (bucket, bag) and its specific properties.
  - *2^{nd} storage[n]:* In terms of food waste, the place of the 2^{nd} storage is usually outside the house or the restaurant or in the basement. The 2^{nd} storage lies in the responsibility of the collector, who picks up the waste and transports it to the site for further processing. The parameters refer to the storage device (bin, tank, container) and its specific properties.
- ***Collection related system parameters*** - *Describes all parameters which relate to the collection system:* They refer to the type of collection scheme applied (DtD, BP, CAS, AUTOMATIC (AUTO)), its specifics (shares of one scheme in the whole system, number of collection points, collection frequency) and details of the collection area (house types, population density, population connection rate to the collection scheme).
- ***Transport related parameters*** - *Refer to different types of transport and vehicles.*
  - *1^{st} transport* includes the transfer of waste from the place of generation (1^{st} storage) to the place of pick-up by the collector (2^{nd} storage). It is usually carried out by the waste generator. The parameters refer to the time and distance of transport.
  - *2^{nd} transport* includes the transfer from the 2^{nd} storage to the valorisation or disposal site. The parameters cover the distance or time required for a collection and transport route. Furthermore, specifics regarding the transport vehicle are included such as type of vehicle (cargo e-bike, e-vehicle, conventional truck) and related specific parameters, e.g. loading capacities, fuel demand or labour demand. Food waste disposers and their related parameters are included in this section as well.

While all parameters of the phases *bio-waste generation* and *bio-waste source-separation* are connected with the *generator* responsible for *1^{st} storage* and *1^{st} transport,* all parameters of the phase *bio-waste collection* are connected with the *collector.* The *collector* is responsible for all collection related processes of the *2^{nd} storage* and *2^{nd} transport* to the valorisation, treatment or disposal site. In a collection system with a civic amenity site (CAS), the generator is also responsible for the 2^{nd} storage and the 2^{nd} transport to the CAS.

3.3.3 The bio-waste collection chain phases and its parameters

3.3.3.1 Waste types included in the bio-waste collection chain

In order to avoid misinterpretations, the terminologies have to be clear and assigned to the specific phase in the collection chain. Figure 5 displays on the one hand the connections between the three bio-waste collection phases *generation, source-separation* and *collection*. Definitions of these phases can be found in D5.1. They are further described in this section. On the other hand, waste sub-types have been introduced and grouped to their superior waste type highlighted by the box with black frame (Figure 5). For example, total bio-waste generated includes food waste and garden waste. The latter is composed of green waste and woody waste. While green boxes refer to bio-waste, the red boxes refer to the non-organic fractions. The non-organic fractions are described as *other waste* in the residual waste bin while they are defined as *macro-impurities* in the bio-waste bin. However, the composition of *other waste* and *macro-impurities* could theoretically be the same, i.e. consisting of plastics, metals or others.
Figure 5 also demonstrates the fractions desired for mAD (thin black arrows). However, *macro-impurities* will still be part of source-separated bio-waste (thin dotted black arrow, Figure 5). Woody waste is indeed an organic component but due to its high lignocellulosic content it is unsuitable for anaerobic digestion. However, it is a valuable component for other biological treatments, e.g. composting.
The bio-waste fractions found in the residual bin are also a desired fraction for mAD however, they are only able to be effectively used if they are shifted to the bio-waste bin due to better source-separation efficiency.

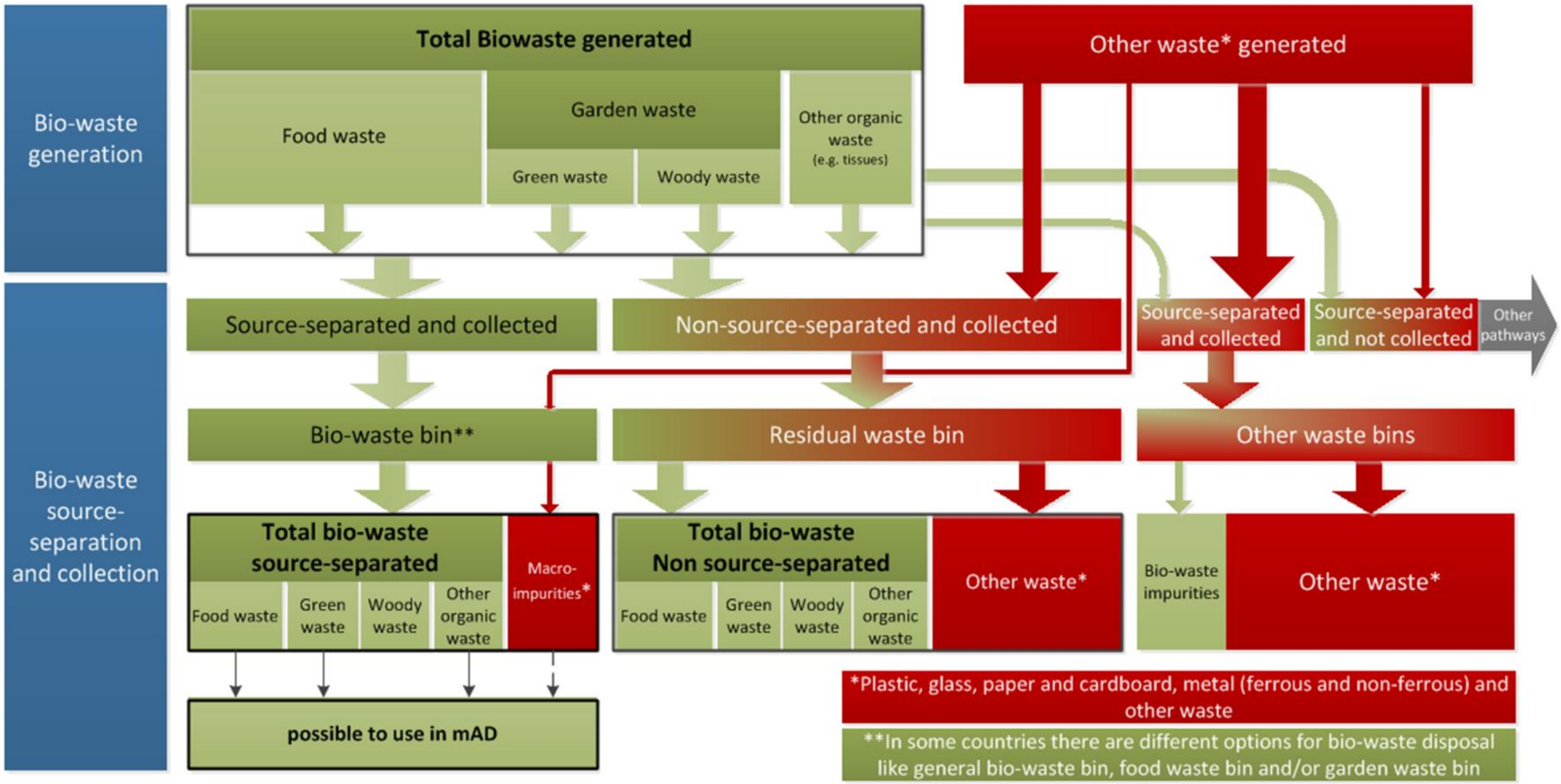


Figure 5: Types of waste in municipal solid waste, their regarding collection chain phase as well as bins and feasible fractions for mAD

3.3.3.2 Bio-waste generation phase

The *bio-waste generation* includes *bio-waste* which is contained in the bio-waste bin as well as the residual waste bin and also bio-waste which goes other pathways, e.g. home composting, pet feeding or disposal into the toilet. The amount of *generated food waste* is often an estimate since data for disposal pathways other than the bin are scarce (see appendix 1 for units of the parameters).. Generated bio-waste includes the following fractions[o]:

- total *bio-waste* and its sub-fractions
  - *Food waste*
  - *Garden waste*
    - *Green waste* (e.g. grass, flowers and leaves)
    - *Woody waste* (e.g. branches, stems and roots)
  - *Other organic waste* (e.g. tissues and kitchen papers).

DECISIVE's core substrate *food waste* is further divided into the following parameters:

- *Mainly animal-based food waste*: Part that consists exclusively or mainly of animal products (e.g. meat, bones, dairy products)
- *Mainly plant-based food waste*: Part that consists exclusively or mainly of plant products (e.g. vegetables, fruits or cereals)

Processed food products often consist of animal- and plant-based compounds (e.g. doughs composed of milk and flour, prepared meals with noodles and meat-based sauce). In these cases, the assignments are made with regard to the fraction with the major quantity, either animal- or plant-based. Information on the animal-based compounds is for instance important to consider for the animal by-products regulation (European Union 2009) which makes a hygienisation process mandatory for animal-based food waste.

Furthermore, *food waste* can be subdivided into avoidable and non-avoidable fractions:

- *Avoidable food waste*: Part that was once able to be consumed and has not been consumed. This includes e.g. expired food (e.g. rotten food, food from oversized portions).
- *Non-avoidable food waste*: Part that is generally unable to be consumed, occurring mainly during preparation or consumption (e.g. tea bags, banana skin, coffee, bones or egg shells)

In most literature, the previously introduced food waste sub-fractions are usually mentioned together as a cumulative value of bio-waste. However, the sub-fractions have different properties and therefore need to be assessed separately to allow for a suitable valorisation.

3.3.3.3 Bio-waste source-separation phase

This phase focuses on the source-separation behaviour of the waste generator and includes *waste parameters* as well as *1st storage* and *1st transport parameters*. The bio-waste amounts are distinguished regarding the waste bin in which it is disposed of, e.g. source-separated bio-waste bin, residual waste bin and other waste bins (Figure 5).
Furthermore, this phase provides information on the quality of the source-separated bio-waste by relating the bio-waste to the total amount of waste hold by the specific bin. The quality of the bio-waste is important for the purpose of bio-waste valorisation. Data on source-separated bio-waste often refers to the amount which is as well collected later on. However, also the bio-waste which is being source-separated and used for home composting is integrated in this phase but difficult to assess.
For the *1st storage* and *1st transport parameters*, this phase includes i) consumables and devices requiredto carry out the bio-waste storage at the source of generation (e.g. bins for the kitchen, bags, water to clean the bins), ii) space required for bio-waste storage at the source of bio-waste generation, iii) time and distance required to reach the next storage place (e.g. outside the house).

[o] Definitions for those fractions are given in the glossary in D5.1

Waste related parameters

The three important waste streams involved in this phase include a major part of the total generated bio-waste and are classified as *source-separated bio-waste*, *source-separated garden waste* (green and woody waste) and *residual waste*. The amount of *food waste*, *green waste*, *woody waste*, *other organics* but also the *non-organic waste* can be related to the designated bins or *other disposal routes* (Figure 5). Depending on the bin these wastes are either classified as source-separated or non-source-separated:

- *Source-separated bio-waste*: Refers to the bio-waste fractions found in bio-waste bin
- *Non source-separated bio-waste*: Refers to the bio-waste found in the residual waste bin

The quality of bio-waste can be quantified by including the concentration of macro-impurities[p]. Woody components are a special case as they are no macro-impurity per definition because of their organic origin. Therefore, it has to be removed just as macro-impurities if a mAD is the chosen valorisation process. Woody waste is not suitable for this treatment, due to its difficult to digest lignin. All non-organic fractions in bio-waste are described as macro-impurities. In the residual waste, any non-organic waste is defined as *other waste*. In the following the non-organic fractions are described:

- *Total macro-impurities*: Refers to the total amount of inorganic or non-anaerobically degradable material found in the different waste streams of source-separated bio-waste
- *Macro-impurity fractions*: Plastic, glass, paper and cardboard, ferrous and non-ferrous metal and others.
- *Other waste*: Non-organic waste fraction in residual waste

Where source-separated collection of bio-waste is in place, there will be at least two collectible waste streams. All kinds of bio-waste can theoretically be found in the bio-waste bin but commonly they can also be found in the residual waste bin or other disposal routes. It has to be considered that in places where no source-separation is offered, all collected bio-waste is found in the residual waste bin or other disposal routes.

1st storage related parameters

An important 1st storage parameter is the time of storage inside the house until the transfer to the 2nd storage outside the house. Furthermore, technical data on the devices of storage are included. The commonly used devices today are:

- *Buckets* are small rigid container with an either round or rectangular surface area for indoor storage which are often placed below the sink. To avoid misinterpretation, when compared with a bin (section 3.3.3.4), a bucket should be easy to carry by one person when fully loaded. It is used as a support for pre-separation before disposal into the bin outside the house.
- *Bags* are flexible devices for indoor storage. They can be fitted into a bucket or stand alone and come in different materials (Table 17). They are used as a support for pre-separation before disposal into the 2nd storage device.

Figure 6 shows different kinds of the previously mentioned devices. Table 17 shows the different parameters related to 1st storage devices.

[p] Chemical micro-impurities are not considered for the bio-waste collection in this report but are important for the subsequent treatment.

[1] ventilated bucket

[2] bucket with paper bag

[3] wax coated paper bag

[4] biodegradable plastic bag

Figure 6: Examples for devices for in-house storage (1st storage) (References: [1] biobagusa.com, [2] & [3] Stadtreinigung Hamburg, [4] Amazon.com)

Table 17: Materials and parameters of 1st storage devices

Device	Common Material	Parameters
Bag	Fossil based plastic, bio-based compostable/non-compostable plastic, uncoated paper, waxed paper	• Volume: Volumetric size for bio-waste in the device • Consumption: Specific number of devices, e.g. required for one tonne of bio-waste • Life time: Time of use of a device until a new one has to be purchased • Type: Design of the device, e.g. stackable or aired bucket • Cost: Price to purchase one device, usually referred to its volume • Water demand cleaning: Amount of water required to clean or flush the device • Energy demand: How much energy is required to grind the bio-waste (only for food waste disposer) or for production of device • Base area: Necessary area to install/place the device
Bucket	Plastic, metal	

1st transport related parameters

They include data on the distance from the in-house storage (1st storage) to the next storage (outside the house, 2nd storage) and the time required for the transfer of waste.

3.3.3.4 Bio-waste collection phase

The different bio-waste collection parameters are related to the type of collection system which includes information on data specific for the collection area. Furthermore, the types and properties of equipment (e.g. electric or diesel run vehicles, fuel demand) or labour required are important parameters. For the DECISIVE-DST these parameters will be related to the amount of waste collected in the specific area (see appendix 1 for units of the parameters). In the following, important parameters of the bio-waste collection phase are described.

Collection system related parameters

These parameters refer to the applied waste collection system in a region or municipality:

- *Type of collection system*: It is distinguished between DtD, BP or CAS. These terms were briefly introduced in D3.5 and in more detail in the following. They are generally defined by the distance to its attached houses or households.
  - *Door-to-door (DtD)* collection is defined by its proximity to the households between the door and the 2nd storage. Different stakeholders stated a maximum walking distance of 50 m (section 2.2.2) Furthermore, the bins can only be used by one or several defined households. The number of

households connected to one bin has to be considered since the responsibility for a good source-separation might decrease with an increasing number of households. Therefore, it has to be distinguished between two types of DtD systems:

- *DtD* bin(s) attached to one household
- *DtD* bin(s) attached to more than one household

○ *Bring points (BP)* are public accessible and not exclusively attached to specific households. They are designed to serve an area including several households. Usually, the walking distance between the door and the bin is longer than for DtD collection. In the case of Catalonia, the bins are placed within a 500m-radius around the houses.

○ *Civic amenity sites* are collection points which are operated by qualified staff. The citizens bring the waste to those sites (D3.5). The distance from the point of waste generation to this site can be up to a few kilometres.

Further parameters are to describe the bio-waste collection system:

- *Share of collection system types*: Different types of collection systems may be used in parallel in one area. Therefore, the share of e.g. DtD and BP occurring in a specific area can be provided.
- *Collection points*: It represents the number of collection points in the collection system of a specific area.
- *Population connection rate per bin or collection system*: It includes the number of households/inhabitants connected to a bin or a type of collection system (DtD, BP, CAS).
- *Population density in collection area*: The parameter describes the number of inhabitants living in the specific area.
- *Bio-waste collection frequencies*: It describes the frequencies in which bio-waste in total, food waste or garden waste are collected.
- *Residual waste collection frequency*: It describes the frequency in which residual waste is collected.

2nd storage related parameters

The 2nd storage related parameters include data on the storage devices. The most common devices are:

- *Bins* are usually situated outside the house and configured for a small number of inhabitants attached to it, e.g. single-houses. They are supposed to be transportable by one person.
- *Containers* are usually situated outside the house and configured for a bigger number of inhabitants attached to it, e.g. apartment building. They can only be transported with technical support. They can be placed at ground level or underground.
- *Tanks* can be placed at ground level or underground. They are supposed to store bio-waste which is suitable for pumping (oils, fats).

Figure 7 displays different devices for the 2nd storage: a typical door-to-door bio-waste bin in Germany [1], an underground bio-waste tank in Germany [2], and typical bring-point containers for bio-waste (brown lid) and residual waste (grey lid) in Barcelona [3]. The parameters are equivalent to the ones explained in Table 17 for 1st storage.

[1] 120 L bin [2] Underground container [3] BP container at ground level

Figure 7: Devices for kerbside waste storage (2nd storage) (References: [1] & [2] Stadtreinigung Hamburg, [3] Ajuntament de Barcelona)

2nd transport related parameters

The 2nd transport parameters include data on the distance and time for one collection round as well as data on the collection vehicles or devices. A common conventional collection vehicle is a fuel driven truck with large transport capacities (around 14 – 22 m^3). For decentralised waste management systems, smaller devices as well as different forms of power are taken into consideration. This includes electric driven vehicles, such as e-bikes, e-buggies or small e-trucks can be used more flexible and sustainable in small collection areas. Furthermore, food waste disposer can be considered as food waste collection devices. Figure 8 shows different examples of electric waste vehicles: a cargo e-bike in Hamburg [1] a typical e-vehicle from Piaggio in Barcelona [2] and an e-vehicle from Alkè [3].

[1] Cargo e-bike [2] Piaggio E-Vehicle [3] Alke e-vehicle

Figure 8: Examples for electric driven waste collection vehicles, (References: [1] DLR/V.Ehrler, [2] Vespa Balart, [3] Alkè)

Following, important parameters of the waste collection vehicles are described:

- *Loading volume*: The volumetric size for bio-waste in the collection unit of the vehicle.
- *Loading weight/occupation*: The maximum weight that can be loaded in the collection unit of the vehicle.
- *Consumption*: The number of collection vehicles required to transport one tonne of bio-waste.
- *Vehicle life time:* Time of use of a collection vehicle until a new one is purchased.
- *Vehicle cost*: Cost to purchase one collection vehicle.
- *Cruising range:* Distance possible to drive with one tankful.
- *Energy demand:* This parameter is subdivided into the different types of energy such as fuel or electricity consumption per kilometre. Furthermore, the demand can be subdivided into the transport phase of driving empty, the phase of the loading (energy consumption for lifting bins and stop-and-go) and the phase of driving loaded related to the distance and amount of collected waste.
- *Specific labour demand*: The number of workers that are required to operate the collection vehicle (driver, waste collector etc.) related to the amount of collected waste.
- *Specific labour salary*: Salary per month related to the amount of collected waste.

A *food waste disposer* is usually installed next to the sink and grinds the food waste into a pulp. By adding water, it can automatically transfer the waste into a pipe system which either leads to a tank or is connected to the wastewater system. Important parameters for the food waste disposer are the costs, the water demand and the energy consumption.

3.4 Results of the DECISIVE bio-waste collection database

3.4.1 Results for waste related data

3.4.1.1 The example of food waste

According to Gustavsson et al. (2011) the food supply chain consists of several stages: agricultural production; postharvest handling and storage, processing and packaging and the later stage which is food distribution and consumption. The food waste data considered in this study only includes waste generated in the last stage of the food supply chain, namely distribution and consumptions. For the evaluation, the food waste amounts are divided into 1) *generated*, 2) *source-separated and collected* (bio-waste bin), and 3) *non-source separated and collected* (residual waste bin) amounts (section 3.3.3). Furthermore, data on *macro-impurities* are included as a quality characteristic of the source-separated food waste. *Avoidable* and *non-avoidable* food waste amounts are described separately as well to demonstrate the potential for food waste reduction.

3.4.1.2 Food waste from households

The summary of food waste amounts of the household sector of the six DECISIVE countries is shown in Table 18. For the case of Catalonia, the data on source-separated food waste correspond to the organic fraction of municipal solid waste and contains food waste and very small quantities of green waste. However, garden waste is collected separately. For the fraction of non-source-separated food waste, only a percentage as a regional average exists whereby 32.28% of the residual waste is estimated to consist of food waste. However, this average was used to calculate a rough estimation of the food waste quantities in the residual waste on a municipal level in Catalonia.

Food waste amounts

In DECISIVE, the amounts of generated food waste refer to the cumulative food waste amounts found in the residual waste bin, in the bio-waste bin as well as in some other pathways (e.g.home-composting, pet feed, wastewater system) together. This definition was also used by some authors (e.g. reference 3: (Kranert et al. 2012)). Others analysed the collected waste and defined it as generated food waste (reference 15: Edjabou et al. (2016)). In some cases, the amounts of generated food waste are lower than the amount of source-separated and collected food waste (Denmark, Italy). An explanation might be the different methods for calculations or that generated food waste is generally only estimated as a regional (or national) average but source-separated waste is measured frequently at collection as it is the case of Catalonia. In the case of data of Catalonia, the generated food waste amounts were calculated adding up the amount of the non-source-separated and source-separated bio-waste. The amount of non-source-separated bio-waste was estimated with an average for Catalonia, being 32.28% of the residual waste (ARC 2018b). The range of Catalonian food waste amounts in Table 18 excludes data from touristic areas. Those data are included in Table 20 which gives more detailed information on food waste from different Catalonian municipalities.

Not only the generated and source-separated food waste amounts are difficult to compare but also the source-separated food waste amounts between the countries, since different collections strategies are used within the countries (D3.5). Partly the values provided refer to national or regional averages; partly they are just focused on a case study level. The wide ranges of *source-separated and collected food waste* detected within one country or region (e.g. in Italy and in the Spanish region of Catalonia) demonstrate that there are big differences in the waste collection systems within the country or region.

Food waste qualities

The share of macro-impurities is provided by a few authors and investigated by a few waste management agencies. In the case of Italy, where data mostly originates from municipalities of the region Friuli-Venezia Giulia, the range of macro-impurities is very small while the range of Catalan municipalities is broad. This is due to the more common BP collection system in which usually a higher share of macro-impurities occurs.

Table 18: Comparison of food waste data of the household sector including data on the six DECISIVE countries

Parameter	Country							Unit	References
	Belgium	Denmark	France	Germany	Italy	Spain (country)	Catalonia (region)		
Food waste generated	65 - 78	62 - 91	100	73 - 92	18 – 155[f]	76	86 – 302[f]	kg/capita*y	BE: 18,19,20; DK: 12,13[d]; FR: 12 DE: 2,3,4,17; IT: 1,17[c],25,29,31 ES: 22; CAT: 23
Food waste source-separated and collected	40 - 43	76 - 102	17 - 161	19 - 32	6 - 200[b]	NA	<1 - 285	kg/capita*y	BE: 18,19; DK: 15[d]; FR: 14,21,32; DE: 3,7,8; IT: 1, 29,31,36[a] CAT: 24
Macro-impurities	NA	NA	1.5 - 2	1 - 5	2.8 - 8.5	NA	0.3 - 33	% of source-separated food waste	DE: 3, 37 CAT: 24 IT: 25,36
Food waste non-source-separated and collected	24 - 65	82	104	42 - 55	2 - 80[b,g]	NA	9 – 126[e]	kg/capita*y	BE: 18,19,20 DK: 15; FR: 21; DE: 2,3,7,8; IT: 1,25; CAT: 23

References in Appendix 2

BE: Belgium, DK: Denmark, FR: France, DE: Germany, IT: Italy, CAT: Catalonia
NA: not available (data which was not available until submission of D3.7 or has not been found)

[a]Amounts of source-separated and collected food waste of this reference (6 – 105 kg/capita*y) were calculated with an average share of 66% of food waste in source-separated bio-waste (34% garden waste).

[b]Includes also food waste from food services.

[c]Value is assumed to be generated food waste, but no clear definition was given in the reference.

[d]Value based on waste sorting in single- and multi-family houses.

[e]The non-source-separated food waste was calculated using the amount of residual waste and the average share of food waste of 32.28% (ARC 2018b). The touristic municipalities are excluded.

[f]It is assumed that the amount of generated food waste is the sum of the source-separated and non-source-separated food waste.

[g]Based on a calculation including the range of 4 - 26% of organic waste in the residual waste. The minimum amount was calculated with the minimum amount of residual waste (38.6 kg/capita*y) and a food waste share of 4% and the maximum amount with the maximum amount of residual waste (307 kg/capita*y, excluding touristic municipalities) and a food waste share of 26%.

Amounts of avoidable and non-avoidable food waste

In Table 19 the data regarding the shares of avoidable waste and non-avoidable food wastes are compiled, respectively. The data focusses on the household sector, but also information on food services or food industry might be included. Kranert et al. (2012) additionally includes a *partly avoidable* fraction. In some studies related to food waste from the food service sector, it is not clearly defined which food waste items belong to the avoidable and unavoidable fraction.

A high amount of avoidable food waste is usually related to less organised food purchasing management in both, the household and food service sector. In general, it can be stated that the ratio of avoidable to non-avoidable fractions depends on the source of bio-waste. At the example of a study of the Belgian region of Flanders, the avoidable fraction of food waste from households is around 45% while the food service sector has a wide range between 10% accounting for the food industry and 95% for the catering sector. In the cases of households, avoidable amounts are to be found in both, the source-separated and collected as well as the non-separated and collected pathways.

Table 19: Comparison of avoidable and non-avoidable food waste amounts of the household sector including data on the six DECISIVE countries

Parameter	Country						Unit	References
	Belgium, Region Flanders	Denmark	France	Germany	Italy	Spain, Region Catalonia		
Food waste avoidable generated	45 / 10 – 95*	23	22.9	47 - 59	NA	NA	% of food waste	BE: 35 DK: 26 FR: 21 DE: 3,4
Food waste non-avoidable generated	55 / 5 – 90*	NA	39.5	35 - 26	NA	NA	% of food waste	BE: 35 FR: 21 DE: 3,4
Food waste avoidable source-separated & collected	NA	56.5	NA	47 - 60	NA	7.4	% of food waste	DK: 15 DE: 5,22 CAT: 11
Food waste non-avoidable source-separated & collected	NA	43.6	NA	35 -40	NA	65	% of food waste	DK: 15 DE: 3,22 CAT: 11
Food waste avoidable non-source-separated & collected	42	NA	NA	NA	NA	NA	% of food waste	BE: 33

References in Appendix 2

*Including food services

The case study region of Catalonia

The data provided by waste management agencies allows for a more detailed description of local situations which can be used as starting point for the development of decentralised concepts. The statistics of Catalonia which are displayed in Table 20 include data from municipalities with different ranges of inhabitants (size of cities). The table shows data on the amount of *source-separated food waste* including its *macro-impurities*, the amount of *residual waste* and the amount of *non-source-separated food waste* which was calculated as mentioned in the section “Food waste amounts” of this section. Therefore, the amount of *non-source-separated food waste* should be considered with caution since it is only based on an estimated share of the residual waste. The information on the procedure for the data generation of source-separated bio-waste and macro-impurities in Catalonia is explained in section 3.2.3.

Table 20 includes municipalities with a bad performance of source-separated bio-waste collection, e.g. Castelldefels (7.3 kg FW/capita*y, 15.5% macro-impurities), and data on municipalities with good performances, e.g. Viladrau (223.0 kg FW/capita*y, 0.72% macro-impurities). For each municipality group, the lowest and the highest value are marked for each parameter.
Furthermore, the influence of tourists is highlighted for the respective municipalities. The municipality of Salou is characterised by a considerable number of tourists during the summer time. This is being quantified by a full time person equivalent of 188% based on the registered inhabitants (Idescat 2016). The municipality, but also Roses, Castell Platja d’Aro, Tossa de Mar, Sta. Susana and Setcases have a high share of residual waste. Especially in those cities it is difficult to apply the regional share of food waste in the residual waste which is why they were excluded in Table 18. There is no data on the share of waste produced by the inhabitants and produced by the tourists. The high amount of *source-separated food waste* of these municipalities could be rather originated from the food service sectors related to tourism (hotels, restaurants etc.) than from the inhabitants.

Table 20: Amounts of source-separated food waste including macro-impurities and amounts of non-source-separated food waste for selected municipalities in the Spanish region of Catalonia

Number of inhabitants	Municipality	Population density [cap/km²] (2017)*	Food waste source-separated [kg/cap*y]	Macro-impurities [%]	Residual waste [kg/cap*y]	Food waste non-source-separated [kg/cap*y]	Observation
>250,000	Hospitalet de Llobregat	20,753	13.1	11.8	290.5	93.8	
	Barcelona	16,000	67.6	15.9	301.2	97.2	
100,001 – 250,000	Reus	1,953	12.0	19.7	308.5	99.6	
	Mataró	5,606	42.0	9.5	292.0	94.2	
	Lleida	647	34.8	6.6	301.2	97.2	
	Badalona	10,182	20.8	22.8	292.2	94.3	
	Terrassa	3,083	35.0	12.8	234.4	75.7	
	Tarragona	2,271	26.6	14.5	332.4	107.3	
50,001 – 100,000	Castelldefels	5,113	7.3	15.5	389.3	125.7	Touristic summer
	Girona	2,532	84.9	19.2	223.2	72.0	
	Manresa	1,807	35.4	6.3	265.1	85.6	
	Cornellà de Llobregat	12,391	17.4	19.3	283.8	91.6	
	Sant Cugat del Vallès	1,857	66.5	18.0	222.7	71.9	
10,001 – 50,000	Figueres	2,381	5.6	3.7	349.4	112.8	
	Salou	1,737	161.0	21.3	685.3	221.2	Touristic summer; 188% of inhabitants equivalent per year*
	Roses	419	11.5	3.1	605.7	195.5	Touristic summer; 122% of inhabitants equivalent per year*
	Amposta	149	74.4	31.5	249.5	80.5	Touristic summer
	Sant Sadurní d'Anoia	671	121.6	10.5	89.5	28.9	
	Castell-Platja d'Aro	486	66.0	8.7	938.2	302.9	Touristic summer; 155% of inhabitants equivalent per year*
5,001 – 10,000	Puigcerdà	468	7.3	5.1	476.6	153.8	Touristic winter
	Cabrils	1,042	177.0	4.8	288.3	93.1	
	Centelles	488	28.4	0.3	303.0	97.8	
	Ulldecona	50	73.9	27.4	182.9	59.1	
	Artés	312	114.8	7.1	74.4	24.0	
	Tossa de Mar	144	134.3	7.3	883.3	285.1	Touristic summer; 187% of inhabitants equivalent per year*
501 – 5,000	Montagut i Oix	10	0.5	7.2	385.1	124.3	
	Viladrau	20	223.0	0.7	197.7	63.8	
	Sta. Susana	266	310.0	5.7	1,343.9	433.8	Touristic summer; 275% of inhabitants equivalent per year*
	Folgueroles	219	125.8	0.5	46.4	15.0	
	Tivenys	16	81.5	33.0	209.1	67.5	
	Vilablareix	434	108.9	2.4	27.1	8.8	
≤ 500	Soriguera	4	7.3	3.0	245.1	79.1	
	Tavèrnoles	17	285.8	6.1	53.0	17.1	
	Malla	24	92.1	0.6	61.0	19.7	
	Freginals	23	82.2	25.6	166.7	53.8	
	Setcases	4	60.0	4.4	806.7	260.4	Touristic winter

Minimum value | Maximum value | *(Idescat 2016)

Reference for waste amounts: (ARC 2016)
Reference for population density: Catalan wikipedia

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Figure 9 shows the quantile distribution of the data on source-separated food waste collection in Catalonia provided in Table 20. It demonstrates that the outliers are scarce and values of source-separated food waste are evenly distributed around the median value.

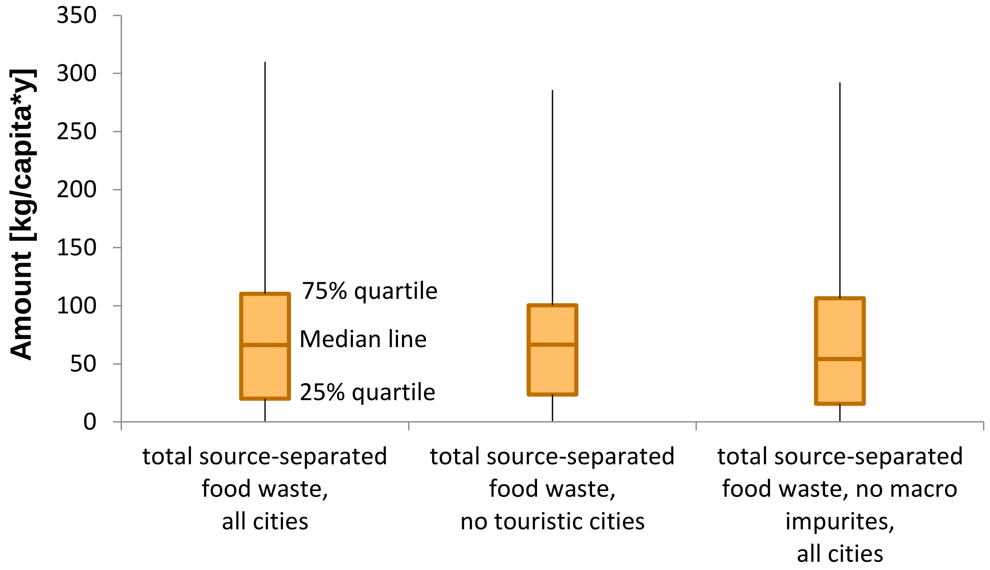


Figure 9: Comparison of amounts of source-separated food waste from all cities of Catalonia with amounts excluding touristic cities and amounts excluding the share of macro-impurities

Figure 10 shows the range of regional, municipal and local data for amounts of source-separated and non-source-separated collected food waste per capita in the DECISIVE countries (orange, yellow: from Table 18) in comparison to the national data of EUROSTAT (black: from Table 15). It is apparent that there is a very large difference between the ranges, especially of *source-separated food waste*. This can be mainly explained by the context of the data in the different countries. While in Belgium, for example, separate food waste collection was only introduced in 2017 and, therefore, there is very little data available, Spain has a very broad database of several years of source-separated food waste collection and different collection systems (BP, DtD).

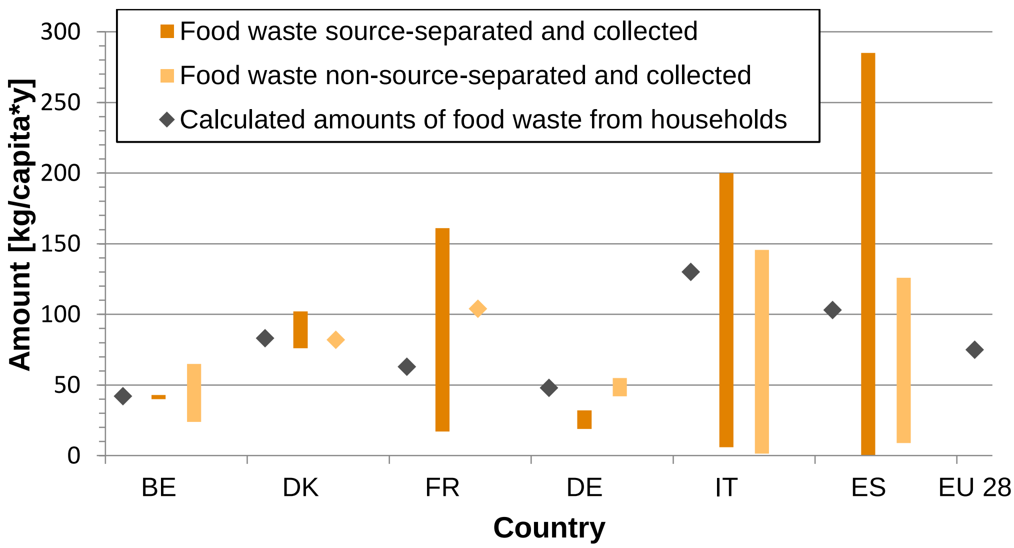


Figure 10: Comparison of amounts of source-separated and non-source-separated food waste from households from various sources with calculated amounts for both kinds of waste from EUROSTAT

It is obvious that the EUROSTAT averages can lead to bad estimations as they only demonstrate one average value. Furthermore, EUROSTAT combines source-separated and non-source-separated food waste, which can lead to an overestimation of source-separated food waste if this information is not known.

3.4.1.3 Food waste from food services

Scientific and local studies related to the food service sector are scarce. Table 21 shows the compiled food waste amounts of the food service sector of the different DECISIVE countries. It includes food waste originating from hotels, restaurants, canteens, schools, hospitals, commercial catering, bars and cafes. When only specific food services are included, it is mentioned below the table. The amount of food waste is related to the meal. In the case of Italy, it is not distinguished between food waste from households or the food service sector since those waste streams are collected together (ISPRA 2017).

Table 21: Comparison of food waste data of the food service sector including data on the six DECISIVE countries

Parameter	Country						Unit	References
	Belgium**	Denmark	France	Germany	Italy[a]	Spain**		
Food waste generated	NA	NA	11 – 500	28 - 350	80 – 200[c]	120	g/meal	FR: 21, 32 DE: 3,6,10 IT: 34 ES: 30
Food waste source-separated & collected	NA	27	NA	8 – 109[b]	NA	NA	g/meal	DK: 12* DE: 6
Macro-impurities	NA	NA	NA	NA	NA	4	% of food waste	ES: 30
Food waste non-source-separated & collected	NA	NA	NA	20-342[b]	NA	NA	g/meal	DE: 6

References in Appendix 2.

* Values are based on an assumption and do not underlay real measurements
** Data is available but not for the required unit.
[a] Same values as in Table 18, since food waste from households and food services are collected together.
[b] Calculation based on the reference giving an average of 31% of source-separated food waste
[c] Only school canteen; Calculation based on the reference giving total weight of food waste and served dishes for entrée, main and side dishes.

In many cases, food waste originated from food services is collected by private companies which might not investigate the amount or composition of waste in detail. Furthermore, food waste from the food service sector is collected together with the household food waste in some cases and a separate investigation is not possible. In some municipalities there are separate collection circuits for the food service sector.

The data of generated food waste varies among the different types of food services. As the example of France demonstrates, the amount of food waste per meal can be as high as 500 g/meal, in some cases even more. So called central kitchens have a very low amount of waste per dish. One reason could be that the food gets already delivered cut and ready to cook. Schools have a higher amount of waste, 100 – 200 g/meal than central kitchens. Food waste from regular restaurants varies between 180 and 380 g/meal, while the food waste from fast food restaurants vary between 43 and 175 g/meal (ADEME 2013, 2015). Kranert et al. (2012) summarises data for restaurants, canteens, hotels and schools in Germany and gives an average value of 175 g/meal.

Further references (BE: 12, 18; FR: 14; IT: 12; appendix 2) were available with other units, but they were not considered as useful for the issue of planning a decentralised bio-waste collection concept.

3.4.2 Results for storage and transport related data

The following section introduces data on the parameters related to the *collection system, 1st* and *2nd storage* and *1st* and *2nd transport*. Data is scarce for many of these aspects especially when it comes to specifications inside the countries. Waste generation data was available from all six DECISIVE countries, but data related to the *collection system*, *storage* and *transport* was mainly available from Germany, Italy and Spain/Catalonia. Consequently, almost only data related to these countries are listed in Table 22, Table 23, Table 24 and Table 25. However, data on storage devices (bins, buckets, containers) and transport (vehicles) are more producer-specific than country-specific.

Table 22 displays data related to 1st storage devices. Buckets and bags are often purchased by the citizens. In most of the cases the waste generator purchases its own 1st storage equipment. The suppliers are usually supermarkets. Price ranges are wide since options range from cheap plastic boxes to designer objects with integrated bucket systems. Regarding functionality, there are different options such as stackable buckets or aired buckets. Bags differ as well in size but also in material: They can be made of plastic (fossil-based or bio-based) or paper (uncoated or wax-coated). Some of the material is supposed to be biodegradable. In the case of Italy, the waste management authorities are responsibility for the supply of 1st storage equipment. Therefore, the devices are standardised and provided for free.
For the introduction of decentralised systems it is recommendable to use standardised options and, at lease for the introductionary phases, provide the devices for free.

Table 22: Data related to first storage devices

Parameter	Country			Unit	Reference
	Germany	Italy, Region FVW	Spain, Region CAT		
Bucket: Volume	5 - 30	7	7 - 40	L/device	DE: 3 IT: 25 CAT: 28
Bucket: Cost	3 – 30; <500*	free	2.3 - 8.03	€/device	DE: 2,3 IT: 25 CAT: 28
Bucket: Base area	NA	NA	0.03 - 0.07	m^2/device	ES: 4
Bucket: Waste storage time	7 - 30	NA	NA	days	DE: 2
Bag: Volume	7.4 - 240	7	7 - 240	L/device	DE: 3 IT: 25 CAT: 28
Bag: Cost	0.05 - 0.55	free	0.05 - 0.69	€/device	DE: 2,3 IT: 25 ES: 4

FVG: Friuli Venezia Giulia; CAT: Catalonia
*combined and integrated bucket system
NA: Not available

References in Appendix 2

Table 23 displays data on the bio-waste collection-system in general. Further data for the collection frequency was available for bio-waste collection frequencies for Belgium (1/w – 2/m), Denmark (1/w – 1/m) and France (3/w – 1/w). The collection frequency is very region-specific and is defined by the waste management organisation, usually in close connection with the applied type of waste collection system. In Germany DtD is the only applied system for bio-waste collection, in Italy it is the dominating system and in Catalonia BP is the dominating system. For the introduction of a decentralised bio-waste management, the existing system should be considered. Data for current connection rates of inhabitants to source-separated bio-waste collection can be purchased from the waste management authorities. These data could give information on areas in which a decentralised bio-waste management can possibly be introduced.

Table 23: Data related to the bio-waste collection system

Parameter	Country			Unit	Reference
	Germany	Italy	Spain, Region CAT		
Bio-waste collection frequency[c]	1/w – 2/m	1/d – 2/w	1/d – 1/w	per d, w or m	All: 5
Share of DtD collection	100	65.3[a]	11.6	% of inhabitants	IT: 31 CAT: 24
Share of BP collection	0	20.2[a]	88.4	% of inhabitants	IT: 31 CAT: 24
Inhabitants connection rate to source-separated bio-waste collection	NA	NA	95	% of inhabitants	CAT: 24
Inhabitants connected per collection point	NA	NA	2.78 – 247.5	capita/coll. Point	CAT: 24
Restaurant connection rate to source-separated bio-waste collection	NA	NA	100[b]	% of restaurants	CAT: 24

CAT: Catalonia; m: month, w: week, d: day, References in Appendix 2

[a]The missing share appears since the collection system of some communities is still unspecified

[b]Only includes the municipalities of Barcelona, Girona, Tiana, Matadepera, La Seu d'Urgell, Cerdanyola del Vallès, Celrà and Vilablareix

[c] The biowaste collection frequencies for Belgium are 1/w – 2/m, for Denmark 1/w – 1/m and for France 3/w – 1/w.

NA: Not available

In Table 24 data refer to 2nd storage devices. The waste management authorities have the responsibility for the provision of bins and containers. The size of these devices is closely connected with the type of collection system and the collection frequency. Opposed to the purchase of 1st storage systems by the citizens, the costs for 2nd storage are currently considered in waste management fees. Space limitations for 2nd storage devices are specifically relevant in densely populated cities and therefore should be also considered in the planning of a decentralised bio-waste management.

Table 24: Data related to second storage devices

Parameter	Country			Unit	Reference
	Germany	Italy	Spain		
Bin: Volume	60-1,100	NA	20-1,100	L/device	CAT: 28 DE: 40,43
Bin: cost	15-189	NA	8,23-175	€/device	CAT: 28 DE: 40, 41,43
Container: Volume	1,100– 6,500	NA	2,200-15,000	L/device	CAT: 28 DE: 42
Container: Cost	168	NA	NA	€/device	DE: 43
Container: Base area	NA	NA	7.4 - 13	m^2/device	ES: 24

*Costs for the container with a volume of 1,100 litres References in Appendix 2

1st transport related parameters are basically the time and distance the generators have to walk to bring their waste to the 2nd storage. These parameters depend on each household and therefore vary extremely. Thus, no data for 1st transport is included in this report. Table 25 displays data on 2nd transport. It is subdivided into data on the different transport vehicles *e-bike, e-vehicle,* and *conventional fuel driven trucks*. In a decentralised system, energy-saving vehicles such as e-bikes or e-vehicles may be the prefered ones. However, small conventional diesel driven trucks may be an option as well. Information for large conventional trucks is also required to compare centralised and decentralised options.

Table 25: Data related to second transport

Parameter	E-bike	E-vehicle	Truck	Unit	Reference
Tank capacity	317.5	400 - 650	NA	kg	39,45
Tank volume	NA	2	7-41	m^3	28,38
Charge time	2.5	1.5 - 11	-	h	39,45
Cruising range	64 – 128	75 - 150	NA	km	39,45
Electricity demand	0.02 – 0.04	0.13 – 0.18	-	kWh/km	39,45
Cost	4,720 (5,499$)	20,000 – 27,000	190,000 - 220,000	€/vehicle	39.43,45
Fuel demand	-	-	0,45-0,9	L/km	43,44
Life time	NA	NA	8	Years	43
Labour salary	NA	NA	45,300 – 49,100*	€/y (load and driver)	43

*Germany

References in Appendix 2

3.5 Recommendations for data acquisition to design decentralised bio-waste collection scenarios

The recommendations for data acquisition to design decentralised collection chains are focused on the amounts on food waste from households and food services as well as additional data required to characterise a bio-waste or food waste collection chain. In the household sector the consumers (citizens) and their individual consumption habits are significant drivers of food waste generation, and can be very different on several local levels. In the food service sector locally generated amounts depend mostly on the kind of food services present and on the number of served meals and their respective unit size. In to centralised systems, working with average data is feasible, since local differences in patterns are negligible. In decentralised systems however, using averages could easily lead to over- or under dimensioning of technical equipment and therefore holds a rist of failure. It is therefore important to obtain more specific data for optimum design of decentralised systems. For the design of decentralised concepts following aspects have to be considered for data acquisition:

- Amounts of generated bio-waste fractions are generally more difficult to assess compared to collected amounts. They are based on estimations in many cases. Thus, data on collected amounts are more reliable.
- Data providing sources use different terminologies and methods for data provisions. No standards exist for the food waste sector. Therefore, different terminologies have to be interpreted, and if possible, standardised.

To receive data of satisfactory quality for the DECISIVE-DST, a combination of data collection methods have to be applied, combining and comparing different sources for data such as statistical surveys, scientific reports and municipal reports. Bio-waste fractions have to be addressed with clear definitions and not only under the general term *bio-waste*. A combination of different collecting methods, which combines surveys with statistical estimations and literature sources, is suggested. In the following some issues regarding the information sources are provided:

- For data acquisition, a study of official databases is useful to obtain an initial impression on food waste amounts. The EUROSTAT waste database is useful however, the interpretation of food waste amounts from households and food services is a challenge and contains uncertainties. It is advisable to use regional statistical data to get a background on data for the respective region. Statistical offices may also be contacted to receive background data of the published statistics for more specified local information.

- It can be difficult to compare scientific studies. The data provided are based on varying procedures of measure to basic inventories with many assumptions being made. The considered scales of investigations vary between a national level and local pilot-scale. Some scientific studies provide many details about the issues of data gathering and describe methods for calculations very comprehensively. It appears to be useful to have a wide understanding of the studies from the respective country or region, and the ones which provide many details on data gathering.
- Waste management companies carry out waste composition analyses at different frequencies and intensities. In most cases, the amounts represent the collected quantities. Generated amounts are sometimes estimated including the share of bio-waste in the residual waste (non-source separated bio-waste) without further specification. Furthermore, food waste and garden waste from households are collected together in some cases. In other cases, food waste from households is collected separately from garden waste but is collected together with food waste from food services.

Concluding from the previous, it is recommended to gather data specific for the area where a decentralised bio-waste management is intended to be implemented. While the interpretation of EUROSTAT data is difficult, scientific studies from other regions might be too specific and can not be applied easily to the area of interest. Using data from waste management companies depends on its quality and if single collection circuits are analysed separately to obtain data on a local scale. The data included in section 3.4.1 and 3.4.2 can be used for initial estimations in the conceptual phase of the implementation of a decentralised waste management system. In a second step, the gathering of more precise data are required with the inclusion of practical investigations in the specific area. For the gathering of more precise data, the following procedures and information sources are suggested:
For the amounts of food waste from households:

- Information on population (numbers, density etc.) from official statistics
- Information on waste quantities and composition from the local public and private waste management companies
- Specific information on procedures, issues and concerns with food waste from interviews with citizens from the specific area
- Results from extended waste sortings carried out in the specific area[q]

For the amounts of food waste from food services:

- Information on waste quantities and composition from the local public and private waste management companies
- Information from the food services regarding the type of food service, the number of guests, the number of prepared meals and the amount of food waste

For data on food waste storage and transport:

- Information from the waste management companies on the existing collection system
- Specific information from stakeholder interviews (with groups introduced in chapter 2 expanded by citizens and food service staff) on devices, procedures and concerns
- Information from suppliers of technical equipment

Actions that can be undertaken to receive high quality local data will depend on the available contacts, the time frame and budget. It can be stated that the risk of failure for the design of a new collection process is reduced with high quality data. A repetition of the practical investigation is recommended after a new system is implemented to evaluate the impact.

[q] Strategy described in D 3.6

4 Scenarios for bio-waste collection chains supporting decentralised valorisation

This chapter introduces to bio-waste collection chain scenarios. The bio-waste collection chain scenarios refer to decentralised approaches. The core substrate for the scenarios is food waste (FW) from households and food services. The possibility of adding green waste originating from private gardens is also given as an option. First the parameters selected for the scenario development are introduced (section 4.1). The scenario options are determined by general regional conditions such as population density or the quantity of source-separated food waste. Different options were related to the critical parameters used for the development of the scenarios (section 4.1) and summarised in section 4.2. Those options were combined in different ways to create 8 collection chain scenarios which are explained in section 4.3. The bio-waste collection chain scenarios are described by visualised flow sheets and by mass and energy balances (section 4.3). Regarding the energy balance, a general assumption is that the consumption for driving empty and fully loaded is the same for any vehicle.

4.1 Critical parameters for the development of bio-waste collection chains

In D3.5 many different ambient, social and technical aspects were defined as critical parameters of waste collection. Those were narrowed down in this chapter to the most important parameters which influence bio-waste collection. Most of the social aspects were excluded since they are hard to assess but can possibly be described with a technical value.
For example, the amount of source-separated bio-waste compared to the amount of non-source-separated bio-waste in the residual waste bin is one of the most important parameters for waste management to identify, outlining the motivation of inhabitants. The general possibilities for a setting of a waste collection scenario were already demonstrated in D3.5. Furthermore, the information gathered in chapter 2 was used for setting up the bio-waste collection scenarios.
The different scenario options (values) are based on simplifications based on the results of the evaluation of the database in order to have rounded values (section 3.4).

- **Catchment area:** It defines the area in which bio-waste is collected exclusively to be transferred to the decentralised treatment plant. Among others it may define the size of the valorisation unit. It is defined by the quantity of source-separated bio-/food waste per inhabitant, the population density. If co-substrates (e.g. green waste) are planned to be used in the mAD as well, a smaller catchment area can be chosen compared to using food waste only.

Scenario options: VERY SMALL: 0.1 km^2, SMALL: 0.5 km^2 MEDIUM: 1.5 km^2, LARGE: 3 km^2

- **Population density:** Relates to the registered absolute population including the total surface area as well as the settlement surface expressed as inhabitants per square kilometre (inh./km^2). Describes directly the urban/settlement structure. Sparsely populated areas usually consist mainly of single-family or row houses, e.g. in the peripheries of a city, and densely populated areas rather consist of apartment houses with many floors, e.g. in central areas of a city. Population density therefore is a determinant of the amount of bio-waste generated and collected in a specific area. For the development of the bio-waste collection scenarios the population density is related to case study areas such as the very densely populated city of Barcelona, the densely populated city of Lyon, the medium densely populated city of Lübeck and sparsely populated Spanish towns, e.g. Matadepera (362 inh./km^2) or Artés (312 inh./km^2) in Catalonia.

Scenario options: VERY HIGH: 16,000 inh./km^2 (Barcelona, Spain), HIGH: 10,000 inh./km^2 (Lyon, France), MEDIUM: 1,000 inh./km^2 (Lübeck, Germany), LOW: 350 inh./km^2 (Matadepera, Artés)

- **Quantity of source-separated food waste:** Represents the amount of source-separated bio-waste. It can depend from the motivation of the inhabitants and the incentives given by local authorities. A low quantity of source-separated food waste with a high quantity of total generated food waste demonstrates a failure of the source-separated food waste collection system. In such a scenario, the food waste is partly (or fully) disposed in the residual waste bin, possibly due to no source-separated bio-waste collection being in place. A high share of source-separated food waste results from a high motivation of inhabitants and good incentives. However, source-separated food waste can still contain macro-impurities. The quantity of source-separated food waste can only be increased by introducing an easy to understand source-separation and collection system. For the development of the scenarios it is assumed that incentives are given. The amounts of source-separated bio-waste are rounded and simplified from Table 18 (section 3.4) including all DECISIVE countries.

Scenario options: LOW: 20 kg/capita*y, MEDIUM: 50 kg/capita*y, HIGH: 100 kg/capita*y, VERY HIGH: 150 kg/capita*y

- **Quality of source-separated food waste:** The share of macro-impurities such as plastics, metals and other non-organic material define the quality of source-separated bio-waste. A good quality can be achieved with a high motivation of the inhabitants by giving good incentives and by implementing a separation system which is easy to understand. The quality is especially important for a decentralised system, in which equipment for separation of waste fractions, i.e. pre-treatment technology, should be avoided to reduce costs. As displayed in Table 18 and in more detail in Table 20 for the case of Catalonia, macro-impurities range from 0.3% up to 33% in the source-separated bio-waste. From chapter 2 it was concluded that macro-impurities are higher within a BP collection system than in a DtD collection system. The scenarios are developed including the assumption of given incentives and a good controlling system. Therefore, the scenario options for bio-waste quality will not range up to 33%, since this can be assumed as a very bad quality and a low motivation of the inhabitants originating from a badly organised waste management system. The scenario options display the share of macro-impurities in the source-separated food waste.

Scenario options: LOW: 10%, MEDIUM: 5%, HIGH: 2%, VERY HIGH: 0.3%

- **Collection frequency:** The main driver for the frequency of collection is the amount of source-separated bio-waste stored in the bin. It affects the collected quantities and quality of source-separated bio-waste. For instance, if residual waste collection frequency is higher than bio-waste collection, people will be tempted to get rid of their food waste by discarding it in the residual waste bin to limit nuisances. Retrospectively, a reduced collection frequency for residual waste could be a driving force for better source separation. A further driver of collection frequency is the climate. In warmer countries, such as Spain or Italy, the collection frequency is usually higher than in countries such as Germany or Denmark, which experience a temperate climate. This is due to the fact that the fermentation processes run faster at higher temperatures and lead to unpleasant odour development. Furthermore, seasonal variations can alter the types of bio-waste generated and therefore the collection frequency. This is the case of green waste, whose generation is high especially at the end of summer and autumn, but low in winter and spring. Commonly applied collection frequencies in the DECISIVE countries are for example daily, three times a week, once a week or two times a month showing also a tendency for increased collection frequency with increasing population density (D3.5).

Scenario options: LOW: 2/month, MEDIUM: 1/week, HIGH: 3/week, VERY HIGH: daily

- **Collection system:** Options for waste collection systems are door-to-door (DtD), bring-points (BP) or civic amenity sites (CAS). In the case of DtD and BP, the bio-waste is picked-up by a collector from the collection point and transported to the biological treatment site. A bring point in a decentralised system could also be a waste vehicle which alternates its position each day. This could increase waste quality when compared to a generic bring point since professional staff can visually screen the waste. In terms of CAS, waste is brought by the inhabitant and managed by professional staff. In decentralised systems, a typical CAS could be at the site of the mAD facility or another decentralised valorisation unit. The configuration of a neighbourhood might have an impact on the choice of collection system in the decentralised system as well, especially in old towns where space is limited. When planning new neighbourhoods, the implementation of kitchen waste shredders could be considered. This is defined as an automatic (in-door) waste collection system.

Scenario options: DtD, BP, CAS, AUTO

- **Transport systems:** The previous aspects have a large impact on the type of transport systems. In centralised systems, often big waste collection trucks designed for large bio-waste amounts, are applied. However, also the use of smaller vehicles is possible in centralised systems, e.g. in old parts of cities with narrow streets. Large trucks do not appear to be suitable for decentralised options where low amounts of total waste have to be collected in the respective collection area. Smaller transport vehicles are considered to be suitable. In decentralised systems the transport could be carried out e.g. with human powered cargo tricycles, buggy-like devices or small electric waste-trucks. For the planning of new neighbourhoods, automatic transport systems such as vacuum pipelines are an alternative and are usually combined with in-door collection, using a food waste disposer.

  Scenario options: HUMAN POWERED VEHICLE, E-VEHICLE, CONVENTIONAL TRUCK, PIPELINE

- **Co-Substrates:** Co-substrates can be applied for example in areas with seasonal demographic changes (e.g. student towns) or as an integral concept to use all bio-resources of the collection area. The main co-substrate is green waste from private gardens or public areas.

  Scenario options: YES, NO

- **Type of source:** The most common sources of bio-waste of a municipality are households and the food service sector (e.g. restaurants). If the type of source is the food service sector, the parameter “population density” should be adapted to “food service density”. All other parameters remain as for the household sector. In a mixed form it is also possible that both household and food service bio-waste are collected together, as it is the case in Italy.

  Scenario options: HOUSEHOLDS, HOUSEHOLDS & FOOD SERVICE, FOOD SERVICE

The following parameters are also of a high importance for collection scenarios but will not be considered for the development of the different scenarios to simplify the concept. Some of these parameters related to waste collection schemes cannot be quantified easily and are rather subjective. One is the motivation of the population shaped by giving incentives which has to be investigated separately (see section “incentives”). However, some have an influence on the parameters described before (e.g. climate defines the collection frequency).

- **Capture rate of food waste:** For the estimation of the total potential of food waste amounts it is important to know how much food waste ends up in the residual waste bin or is disposed via other pathways. If the capture rate is e.g. 70% in the bio-waste bin, there is still the potential for a further increase of capture (30%). Furthermore, the potential capture rate has to be considered in the planning of the collection equipment and the treatment plant. Based on the data gathered, the scenario options were developed representing the difference between generated and source-separated food waste including a theoretical complete collection of generated food waste as source-separated food waste.
- **Neighbourhood management:** In established areas the already existing infrastructure has to be taken into consideration and waste collection possibilities have to be found easy to integrate. Changing an existing system is commonly challenging and requires triggering factors which may induce a transition (e.g. if a regional government has problem to reach the renewable energy goals, new suggestions in this direction may be welcome and therefore mAD could be supported), which may vary from region to region (chapter 2). For newly constructed city quarters the collection options are greater than for existing systems. In general, it is easier to implement an adequate collection system when city planning and waste management planning go hand in hand.
- **Seasonal demographic changes:** Variations in terms of area-related food waste generation can occur under certain circumstances. In touristic areas the food waste amount generated by the food service sector varies with high and low season and/or weekends. Furthermore, both the amounts of food waste generated by households and the food service sector decrease in typical university cities during summer or winter break.
- **Climate:** The climate, which is e.g. Oceanic or Mediterranean in the DECISIVE countries (D3.5), does not have an influence on the waste sorting performance of the waste generator. However, the climate influences the bio-waste degradation rate and the subsequent generation of unpleasant odours. To overcome this issue, the waste storage times of 1st and 2nd storage have to be adjusted via the increase or decrease of the collection frequency. A further parameter of influence is the size of

collection vessels. Not only regional but also seasonal temperature variations have to be taken into account.

- **Incentives for the bio-waste generator to increase the bio-waste quality:** Incentives include approaches like an easy to use pre-collection equipment, a well organised collection service, frequent quality controls, information campaigns or economic instruments such as recycling subsidies.These incentives aim to improve the source-separated bio-waste quality by improving the behaviour of the population. Furthermore, they should aim at increasing the motivation by demonstrating reliable reasons for the need of waste source-separation, and for social responsibility. For the development of the bio-waste collection scenarios, it is assumed that any of these incentives are already applied. A detailed description on methods of incentives will be given in D6.2.

All the mentioned parameters support the choice of **size of the mAD plant**. The necessary capacity of biological treatment is directly related to the number of inhabitants and/or food services that are connected to it (catchment area x population density x quantity of source-separated food/bio-waste). In the case of the two DECISIVE case studies mAD capacities of 50 and 100 t/y of fresh weight were defined (D4.1), respectively.

4.2 From parameters to scenarios

Table 26 shows the parameters which were chosen for the development of the bio-waste collection chain scenarios and their options. All combinations of parameters would make a total of 32,768 options. However, some scenario options for one parameter exclude options of another parameter and therefore there are actually less viable options. For example, a high quantity of source-separated food waste would require a high collection frequency, at least in countries with a warm climate where nuisances develop fast. Furthermore, the transport system can be defined by the total amount of source-separated food/bio-waste as well as the catchment area. The collection frequency is also defined by the quantity of source-separated food waste per inhabitant or area as well as the region (climate). Finally, eight scenarios were selected for this report (chapter 4.3.1 to 4.3.8) by combining different options of the different parameters given in Table 26 in order to present a broad variety of scenarios.

Table 26: Options to combine for the development of bio-waste collection chain scenarios

Option	Catchment area	Population density	Quantity of source-separated food waste	Quality of source-separated food waste	Collection frequency	Collection system	Transport system	Co-substrate
1	VERY SMALL	LOW	LOW	LOW	LOW	DtD	HUMAN POWERED VEHICLE	YES
2	SMALL	MEDIUM	MEDIUM	MEDIUM	MEDIUM	BP	E-VEHICLE	NO
3	MEDIUM	HIGH	HIGH	HIGH	HIGH	CAS	CONV. TRUCK	-
4	LARGE	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH	AUTO	PIPELINE	-

The bio-waste collection chain scenarios form the basis for identification of suitable decentralised bio-waste collection settings for a specific situation. They

- can be used to confirm a hypothesis on bio-waste collection regarding selected bio-waste collection design and system parameters (assessment activities via DST)
- are suggestions for decision support towards new implementations or transitions from common to new collection systems
- are developed on the basis of the scenario options in Table 26 with feature-combinations and on the general bio-waste collection chain provided in D3.5, and
- "tell a story" how the waste is being transferred from its source to biological treatment.

Several scenarios are required since different local situations will demand different schemes for bio-waste collection from households and other sectors. The scenarios developed for this report include food waste from households (typically including small amounts of green waste) and also one for food waste from the food service sector. All scenarios are based on storage and transport activities, which are carried out by the two different stakeholder groups “generators” and “collectors”.

The set-up for each theoretic scenario is introduced in section 4.3.1 to 4.3.8 including the selected parameters and an additional illustrative scheme for the collection from the household to the valorisation site. The figure includes the type of source, the devices for storage and transport and the waste collection system. Furthermore, the mass and energy balance is displayed for each scenario. The mass balance includes amounts of source-separated food waste and its macro-impurities. The procedure of calculating the energy balance is explained in the following:

The energy balance for the collection of food waste is based on the total distance covered within one collection day and the properties and number of vehicles required for collecting the waste. The energy consumption of the vehicles is given in kWh per km and kg of food waste. For simplification, the catchment areas are arranged in squares and the streets are aligned in order to form smaller quarters (Figure 11). It is assumed that there are no one-way roads and that vehicles can turn around in order to reduce the total driving distance. The distance between each cross-way differs for each scenario and is in a range between 105m and 350m, mainly influenced by the population density. The distances are displayed for each scenario in appendix 3. The mAD plant is placed 200m outside the catchment area since legislative regulations may require a certain minimum distance from inhabited areas[r]. The total distance for the arrival of the empty collection vehicle at the catchment area and the return of the loaded vehicle at the mAD site of 400m is therefore considered when planning the collection route of the collection vehicle(s). Furthermore, total distances mentioned in the energy balances are related to one collection day.
The previously mentioned simplifications are applied for each size of catchment area in order to allow for a comparison of the different scenarios. Furthermore, the routing concept for DtD scenarios was developed in the same style for different sized catchment areas and the different vehicles. Exceptions are applied for BP scenarios and if more than one vehicle is necessary for the collection of waste.
As an example, a very small catchment area (0.1 km^2) is displayed in Figure 11 including the setting for a very high population density. The routing concepts of each scenario (chapter 4.3.1 to 4.3.8) are displayed in appendix 3. Scenario 8 includes only the energy consumption of the food waste disposer since no transport vehicle is necessary.

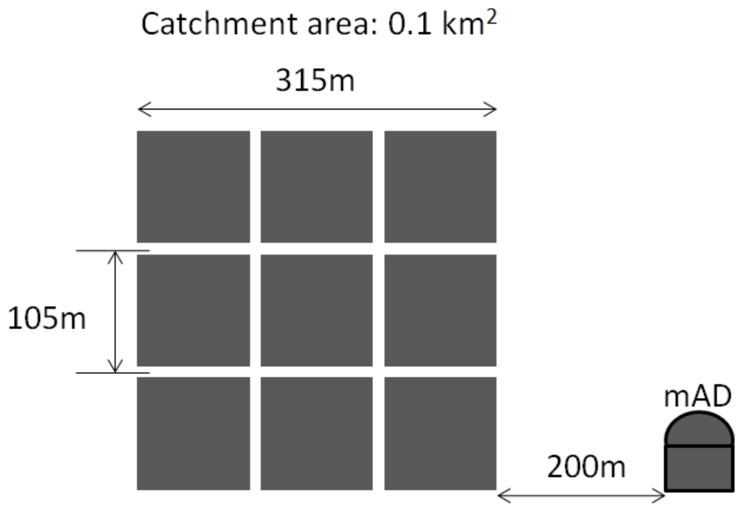


Figure 11: Example for the theoretical setting of the very small catchment area and a high population density in order to calculate the collection distances

[r] See annex of D4.1

4.3 Bio-waste collection chain scenarios

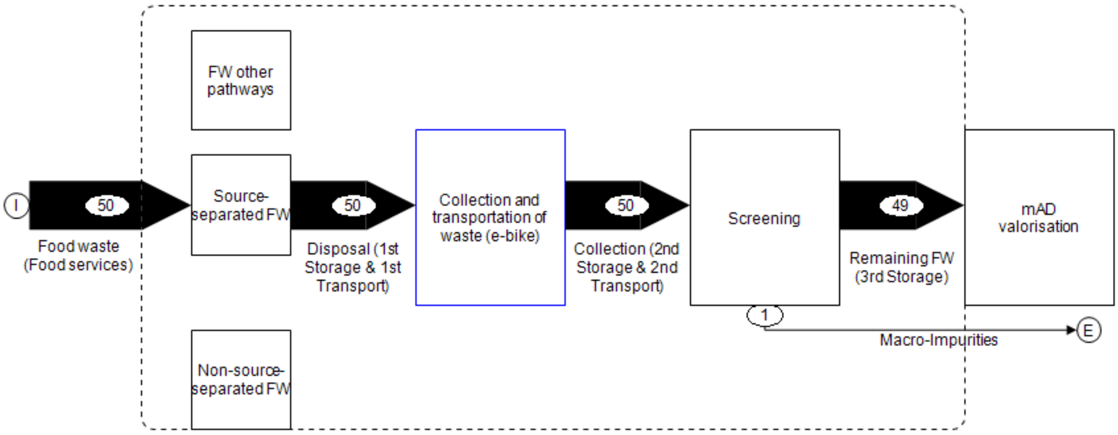
4.3.1 Scenario 1: E-bike door-to-door

A medium quantity of source-separated food waste per inhabitant from households is collected in a very small area with a high population density. The total amount of source-separated food waste is 50 t/y. The generator stores the waste in a small 5 – 7 litre bucket in which an equal sized wax coated paper bag is placed. Since the collection system is door-to-door, the generator transfers his waste to his own 20 - 30 L waste bin outside the house whenever necessary. The small volume allows the waste collector to transfer the waste to the bike container by hand. The quality of the source-separated food waste is high due to the given incentives, the system set-up of a door-to-door pick-up and due to visual controls made by the waste collector. If the quality deteriorates, the waste is not collected. However, the potential for a higher quantity of source-separated food waste is still given since a part is still disposed in the residual waste bin. The high collection frequency of the food waste bin compared to a lower one of the residual waste should encourage the inhabitants to dispose of more of their food waste in the bio-waste bin. An increase of source-separated waste amount will have to be considered for the dimensioning of the treatment plant. To allow for this, the plant could be fed with co-substrates (e.g. green waste) and the amount can be decreased with increasing amount of source-separated food waste.

The collection vehicle for the food waste is an electric cargo-bike with a loading capacity of 320 kg (Radburro 2018). The small volume of the 2nd storage devices allows the waste collector to transfer the waste to the cargo-bike container with human power. The waste collection frequency is 3 times per week due to a Mediterranean climate and the consequent fast degradation. Furthermore, it is due to the limited amount of waste which can be transported by the collector. For a collection frequency of 3 times per week, the collector has to carry around 320 kg per collection day which can be done in 2 collection rounds or by adding a second collector and cargo bike to the collection system.

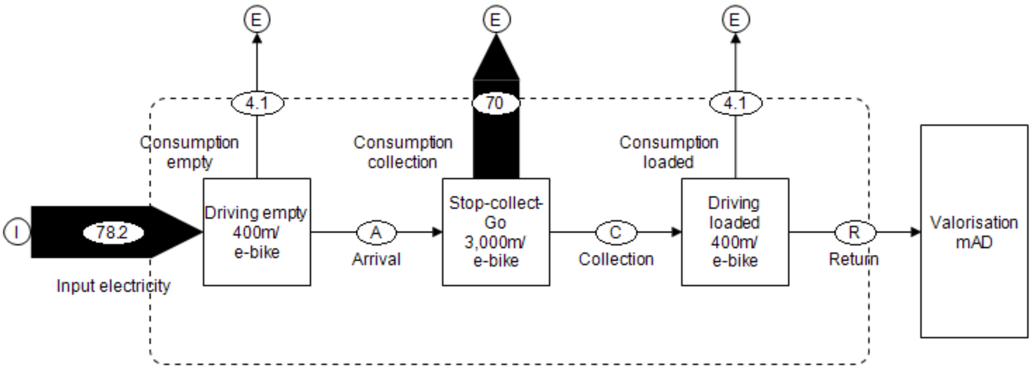
Figure 12 displays the storyline of scenario 1 while Figure 13 and Figure 14 display its mass and energy balance, respectively.

Figure 12: Scheme of collection scenario 1



Unit: t/y

Figure 13: Mass balance of scenario 1



*Unit: 10^{-3} kWh/km*t FW*

Figure 14: Energy balance of scenario 1

4.3.2 Scenario 2: Flexible bring point e-vehicle

A very high quantity of source-separated food waste per inhabitant from households is collected in a large area with a low population density. The total amount of source-separated food waste is approximately 160 t/y. The generator stores the waste in a small 5 - 10 litre bucket in which a bag can be placed to avoid cleaning. The collection is carried out with a flexible bring point system and a high collection frequency. The flexible bring points are placed at the crosses of the streets between the quarters. The catchment area is divided into two parts which are collected separately three times per week (e.g. part is collected on Monday, Wednesday and Friday, part two is collected on Tuesday, Thursday and Saturday). With this separation, a total food waste amount of 505 kg per area and collection day can be collected with a single e-vehicle with a tank capacity of around 620 kg (e-vehicle by (Alkè 2018), model ATXN1, type WA5). To any of these points the waste generator can bring their food waste. For each of the collection days, the time schedule of the collector at a specific collection point is around half an hour and is at a different time each collection day to enable each household to bring their waste at least once per week. The bring points are located less than 300 meters from any inhabitant in order to limit distance of transport for the generator. The waste collector visually screens the waste and adds it directly to the container of the vehicle while removing the bag. The generator can also bring the bucket without any bag. This enables for a very high quality food waste since good incentives are a driver for a high motivation of the citizens.
The very low collection frequency of the residual waste bin is assured almost all food waste is collected with high quality and the highest possible quantity in the bio-waste bin. One of the main incentives is that the inhabitants pay for the collection system as a community but also get rewarded by the products of waste valorisation.
Green waste as a co-substrate is collected on demand at the same bring points on the days where no food waste collection is taking place.
Figure 15 displays the storyline of scenario 2 while Figure 16 and Figure 17 display its mass and energy balance, respectively.

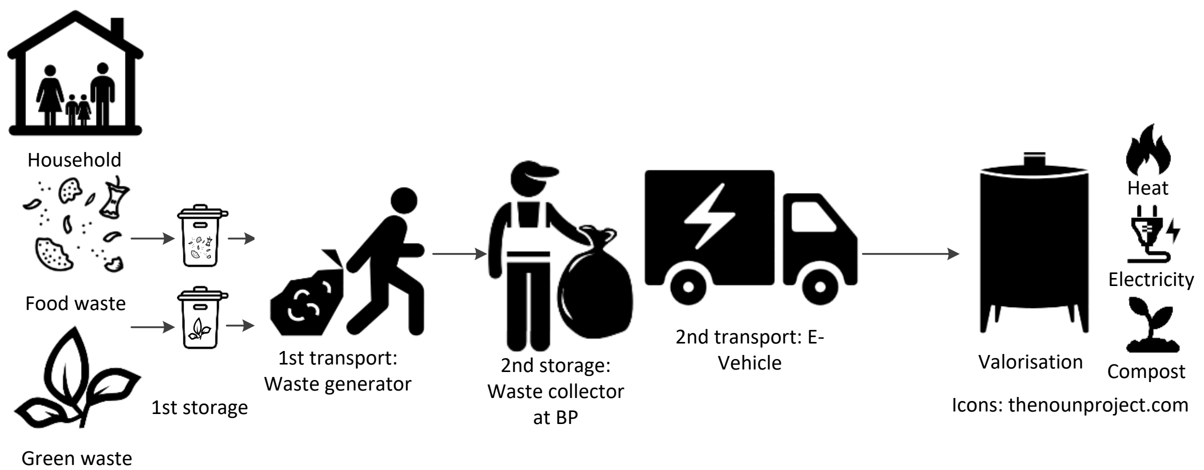


Figure 15: Scheme of collection scenario 2

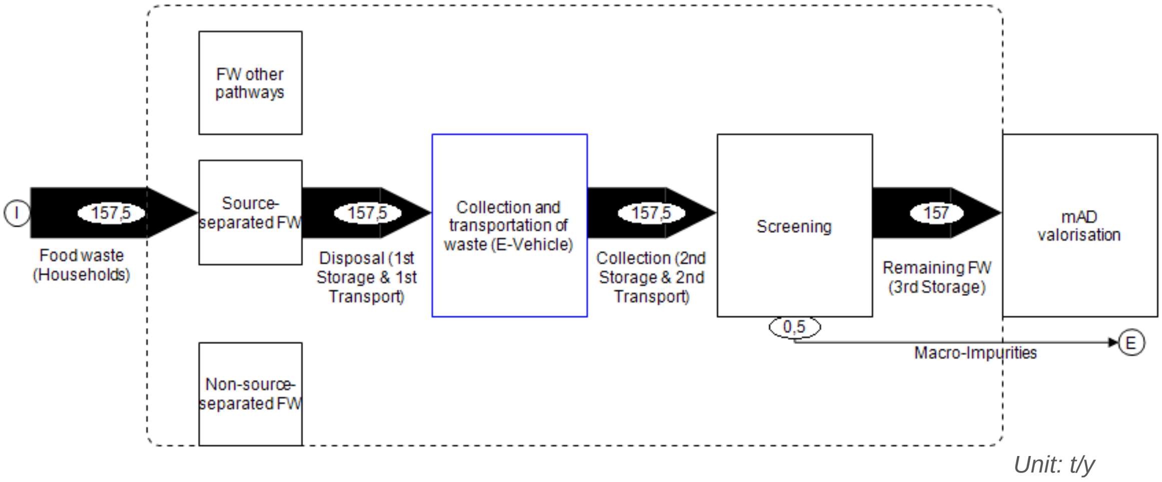


Figure 16: Mass balance of scenario 2

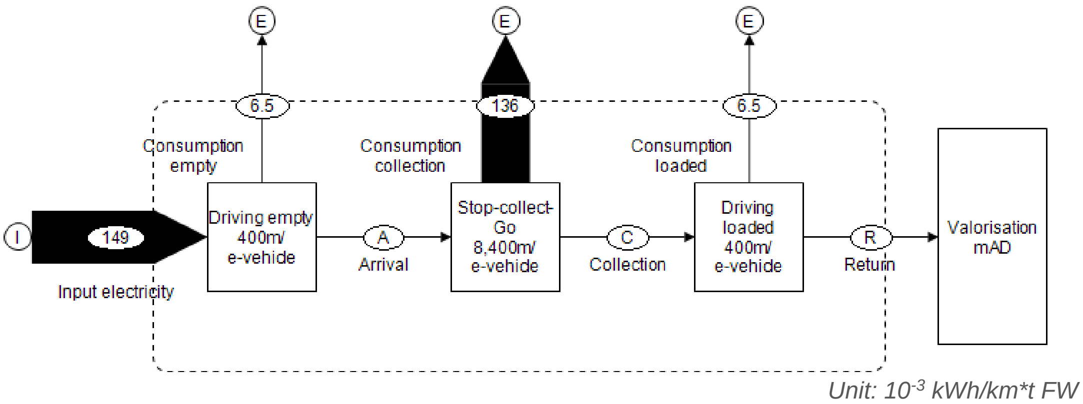


Figure 17: Energy balance of scenario 2

4.3.3 Scenario 3: E-vehicle door-to-door

A medium quantity of source-separated food waste per inhabitant from households is collected in a medium size area with a medium population density. The total amount of source-separated food waste is around 75 t/y. The waste generator stores the food waste in a small 5-7 litre bucket. The collection is carried out door-to-door three times per week due to Mediterranean climate, the waste amounts of around 480 kg per collection day. The total storage capacity of the electric vehicle is 620 kg, which is an electric vehicle. The collection can be carried out with two teams (each with two bikes) in order to be able to collect all waste amounts in one round. A specific feature of this system is that the generator places the bucket outside his house and no big bin is necessary. This is especially important for example in old towns with narrow alleys where space is limited. Furthermore, dirty buckets can be exchanged by clean ones or can be cleaned in place if the e-vehicle is equipped with a small water tank (e.g e-vehicle by Alkè, model ATXN1, type WA5). The quality of the source-separated food waste is high due to the high collection frequency and the visual control of the waste collector. If the quality is bad, the waste is not collected. However, the potential for a higher quantity of source-separated food waste is still given since a part is still disposed in the residual waste bin. The high collection frequency of the food waste bin compared to a lower one of the residual waste should encourage the inhabitants to dispose of more of their food waste in the bio-waste bin. Furthermore, almost no nuisances occur, since the waste is collected daily.
Figure 18 displays the storyline of scenario 3 while Figure 19 and Figure 20 display its mass and energy balance, respectively.

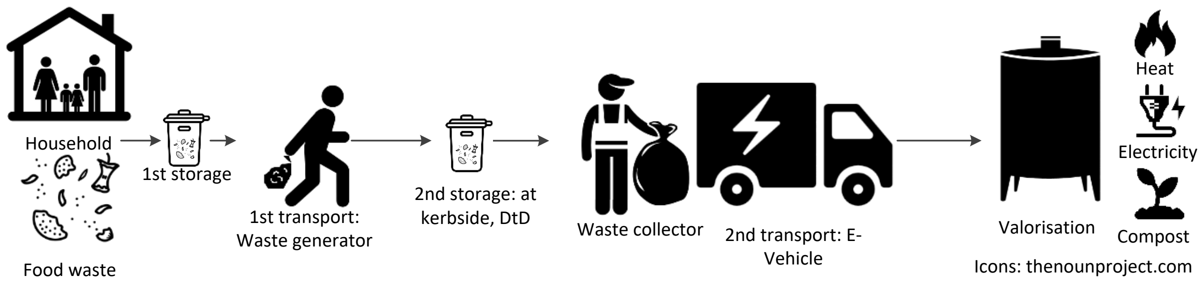


Figure 18: Scheme of collection scenario 3

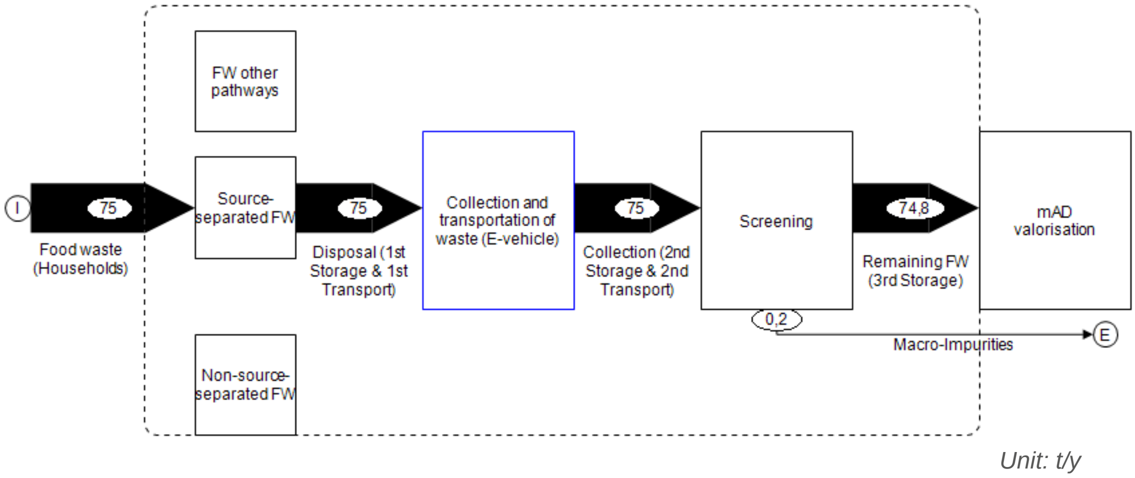


Figure 19: Mass balance of scenario 3

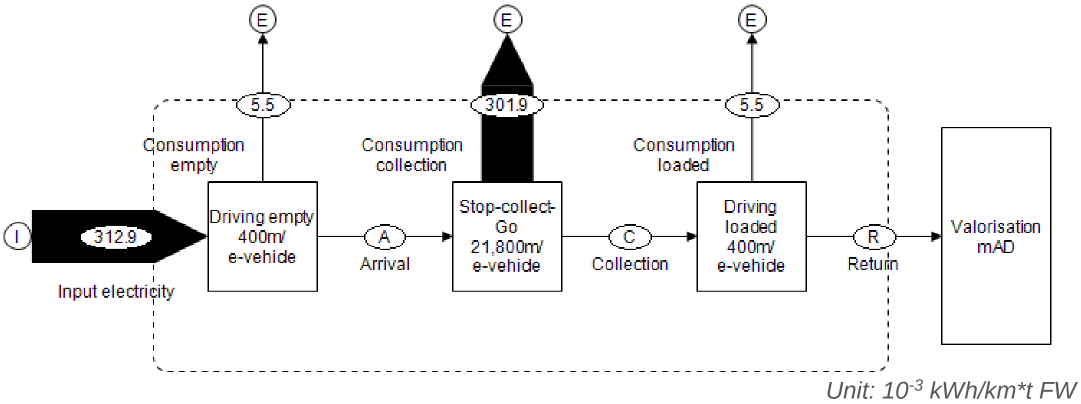


Figure 20: Energy balance of scenario 3

4.3.4 Scenario 4: Conventional truck

A very high quantity of source-separated food waste per inhabitant from households is collected in a large area with a low population density. The total amount of source-separated food waste is around 160 t/y. The waste generator stores the waste in a small 5-7 litre bucket in which an equal sized wax coated paper bag is placed. Outside the house there is bin with a volume of 60-80 litres to which the waste generator transfers the bag. The collection is carried out door-to-door with a biweekly frequency due to temperate climate conditions. The collection is carried out with a small fossil fuel driven conventional waste truck. The truck needs a tank capacity of around 6 tonnes in order to collect the amount of 6058 kg food waste per collection day. The quality is high since the population attached to the system gets rewarded with the valorisation products made from their waste, e.g. compost.
Figure 21 displays the storyline of scenario 4 while Figure 22 and Figure 23 display its mass and energy balance, respectively.

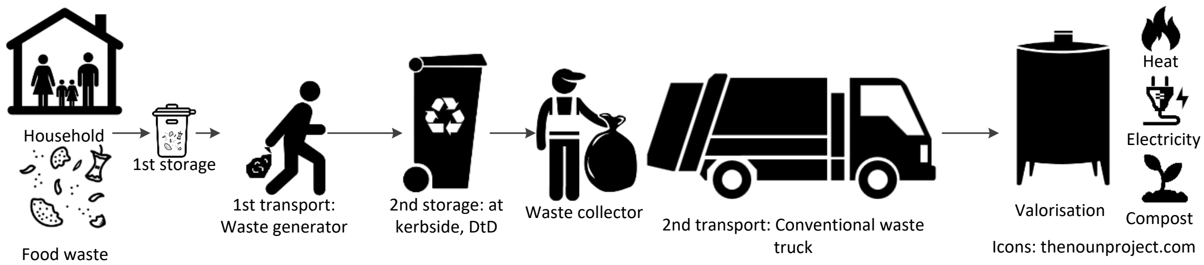


Figure 21: Scheme of collection scenario 4

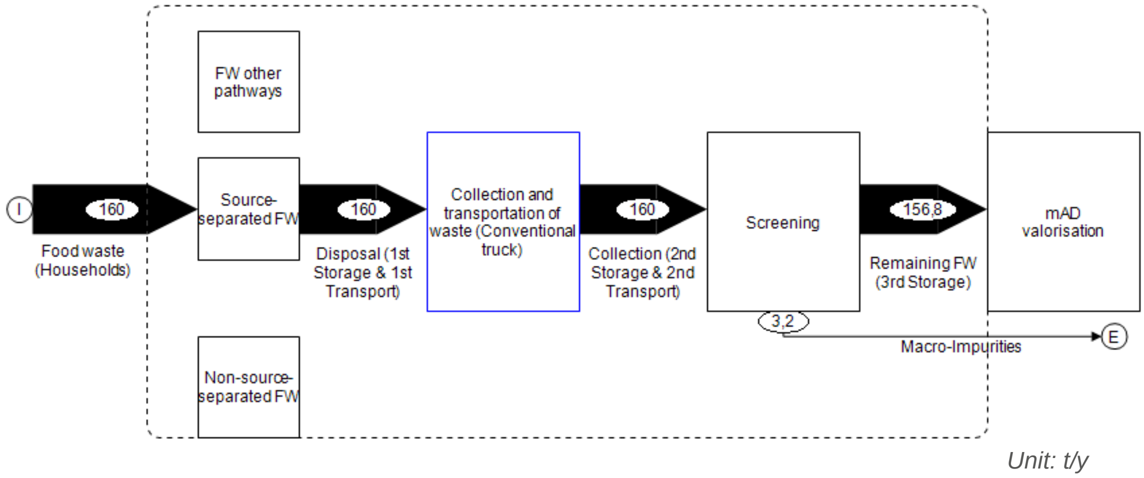


Figure 22: Mass balance of scenario 4

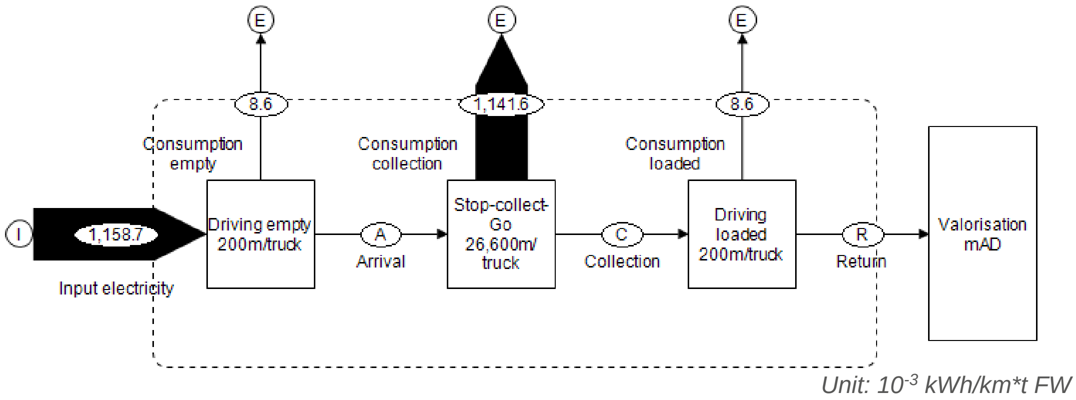


Figure 23: Energy balance of scenario 4

4.3.5 Scenario 5: Community urban farm as civic amenity site

A high quantity of source-separated food waste per inhabitant from households is collected in a very small area with a medium population density. The total amount of source-separated food waste is around 50 t/y. The waste generator stores the food waste in small 5-7 litres buckets. The collection system includes a civic amenity site (CAS) to which the generator has to bring the food waste whenever it is suitable. It is possible to bring the waste daily up to once a week. All kinds of waste have to be brought to the site. The CAS is combined with an urban farm which uses the food waste and green waste to produce compost. The waste generators attached to the system can buy fresh fruits and vegetables from the urban farm. The waste has a high quality due to the reward of purchasing high quality products and visual screening by the staff working at the CAS. The waste is rejected if the quality is bad. Since the area is small, and the CAS is in the centre of the area, the longest distance for a generator is 350m. It is assumed that they bring their waste by foot or by bike. The food waste is brought 200m outside of the area if a mAD plant is the valorisation unit once per week in two collection circuits to transport the weekly waste amount of 961 kg.
Figure 24 displays the storyline of scenario 5 while Figure 25 and Figure 26 display its mass and energy balance, respectively.

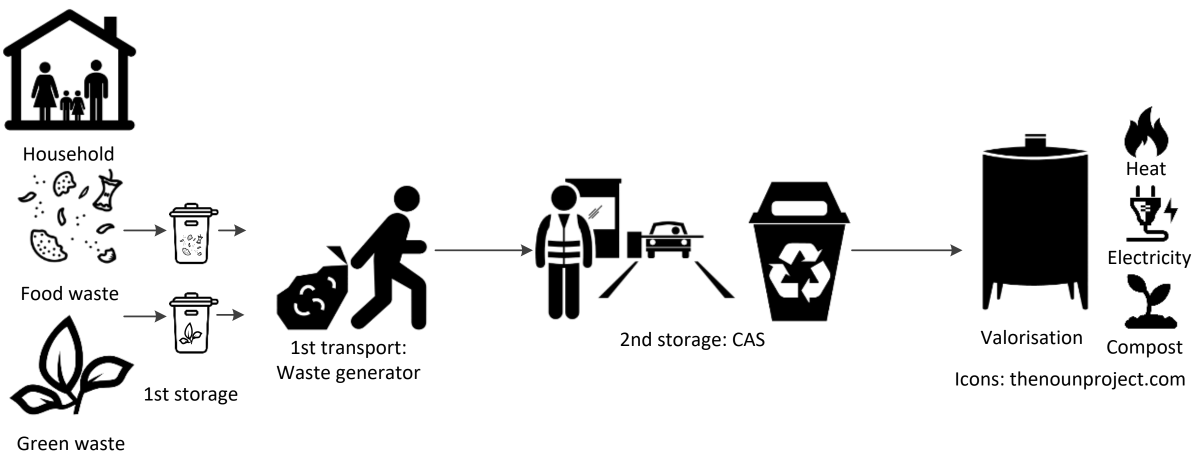


Figure 24: Scheme of collection scenario 5

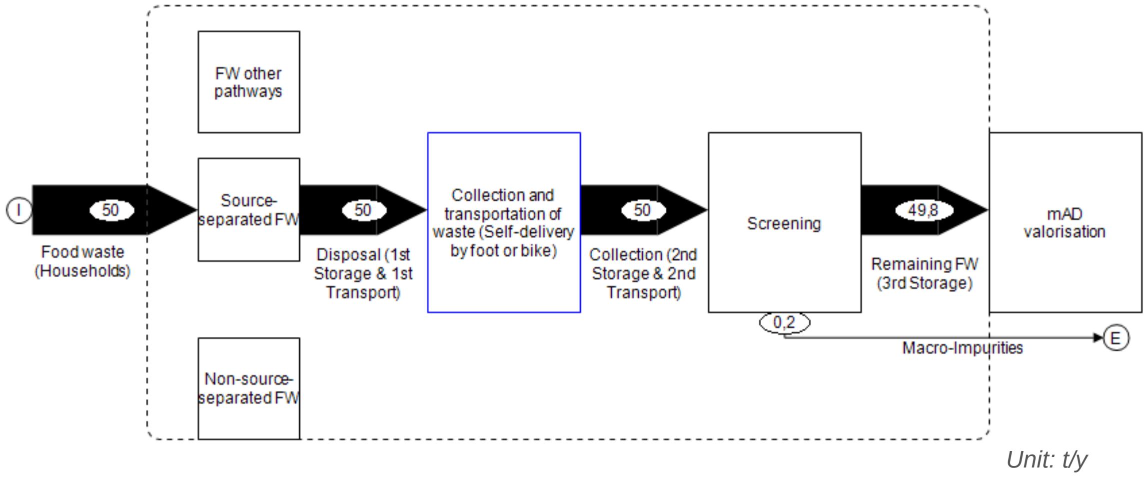


Figure 25: Mass balance of scenario 5

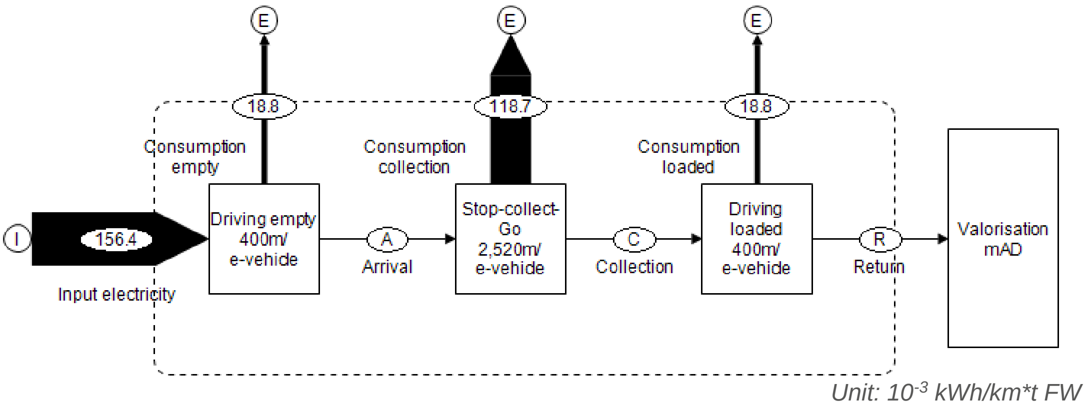


Figure 26: Energy balance of scenario 5

4.3.6 Scenario 6: Old town e-bike with bucket cleaning

A very high quantity of source-separated food waste per inhabitant from households is collected in a small area, an old town with a medium population density. The total amount of source-separated food waste is around 75 t/y. The waste generator stores the food waste in small 5 - 7 litre buckets. Food waste collection is carried out door-to-door on a daily basis. A specific feature of this system is that the generator places the bucket outside his house and no big bin is necessary. This is especially important in old towns with narrow alleys where space is limited. It is placed outside the house by the generator when it is full or it is convenient. The waste is collected with a team of two collectors, one collecting the waste and the other collecting the dirty and emptied buckets and exchanging it by a clean one. For a very small catchment area, the bucket cleaning and waste collection can possibly be done by only one person.
Within the collection area, four e-bikes are used for the collection, separated into two collection routes. Its container has a loading capacity of 320 kg which allows for the collection of the average daily amount of food waste of 200 kg. The quality of food waste is high due to visual screening and the high collection frequency leading to no nuisances. The waste is not collected when the quality is lower.
Figure 27 displays the storyline of scenario 6 while Figure 28 and Figure 29 display its mass and energy balance, respectively.

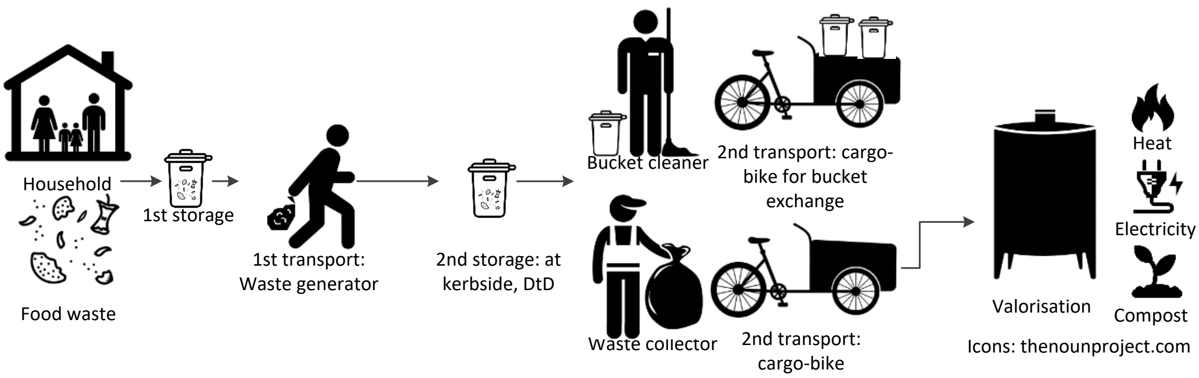


Figure 27: Scheme of collection scenario 6

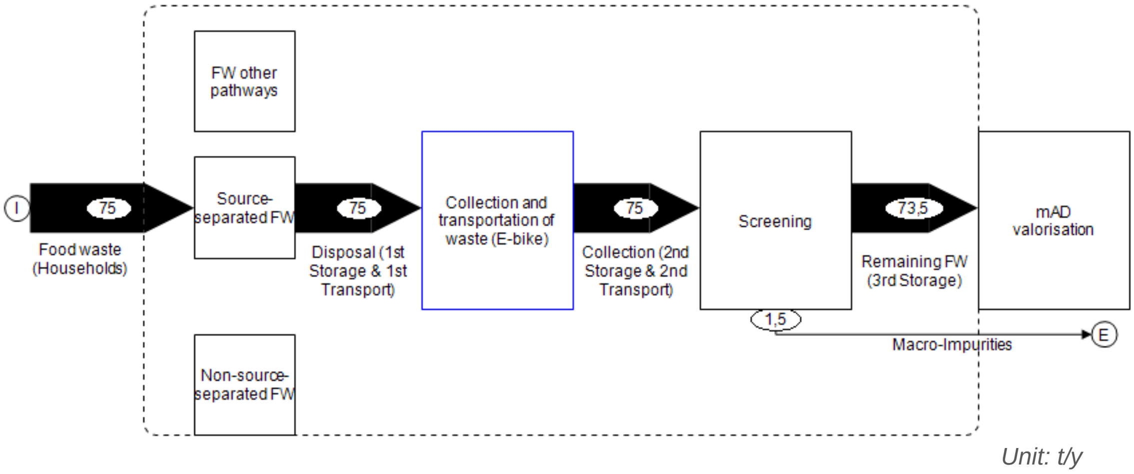


Figure 28: Mass balance of scenario 6

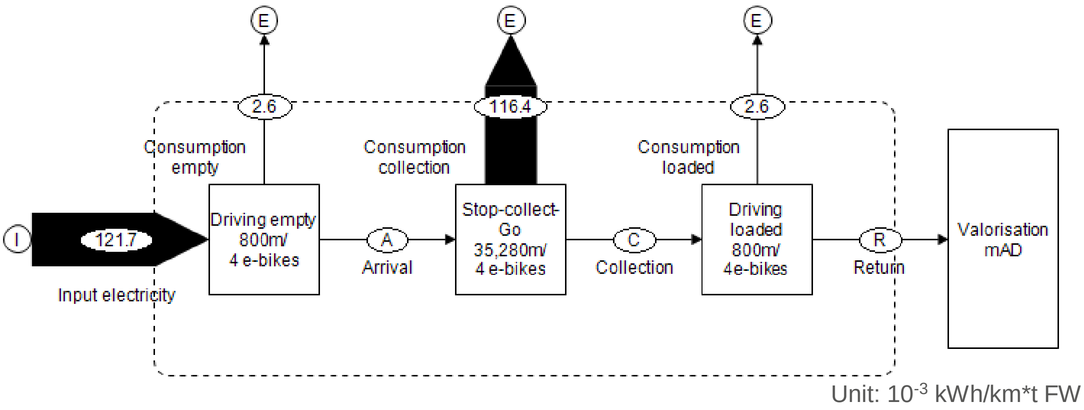


Figure 29: Energy balance of scenario 6

4.3.7 Scenario 7: Food court

A very high quantity of source-separated food waste per food service (restaurant, bakery etc.) from the food service sector is collected in a small area. The amounts of waste generated by the food services are equivalent to a very high population density since it is a touristic area with many restaurants. The total amount of source-separated food waste is 800 t/y. The waste is stored in 40-80 litre bins at the food service and brings the waste to a bring point with a maximum distance of 50 metres and a maximum of 5 food services attached. Furthermore, only the food service sector has access. The bins at the bring points work with a chip-system that scans the bag which is disposed. Thereby it can be traced back to the generator if the waste quality is bad. Waste collection from the bring points is carried out on a daily basis. The collection vehicle is an electric vehicle with a container capacity of around 620 kg (e.g e-vehicle by Alkè, model ATXN1, type WA5). This enables to collect the whole food waste quantity of 2192 kg per collection day with two vehicles in two rounds. The quality of the food waste is very high due to the tracing of the waste generator in the collection system and the social pressure between the food service owners. Another incentive for the high quality is the relation to the urban farm at which the food waste is being valorised. The restaurants receive salads and herbs produced at the farm using the high quality compost produced from the food waste.
Figure 30 displays the storyline of scenario 7 while Figure 31 and Figure 32 display its mass and energy balance, respectively.

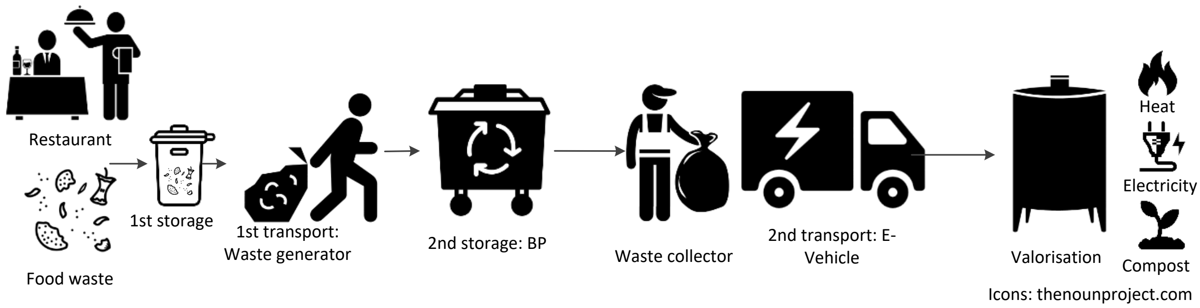
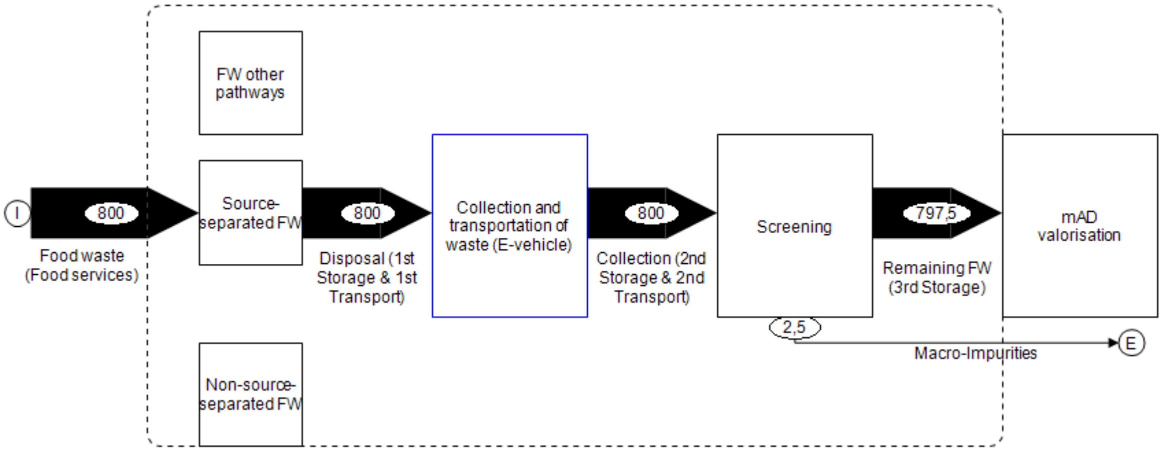
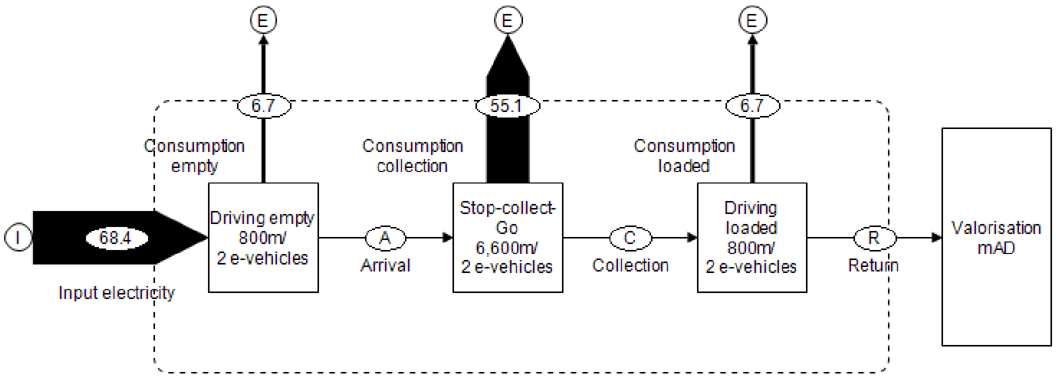


Figure 30: Scheme of collection scenario 7



Unit: t/y

Figure 31: Mass balance of scenario 7



Unit: 10^{-3} kWh/km*t FW

Figure 32: Energy balance scenario 7

4.3.8 Scenario 8: One multi-storey house with food waste disposer

A high quantity of source-separated food waste per inhabitant from a 500 inhabitant's multi-storey house is collected. The total amount of source-separated food waste is 50 t/y. The waste generator does not have to store the waste in-house. It can be disposed directly with a food waste disposer next to the kitchen sink. The food waste is then transferred to the basement driven by gravity and a little water for flushing. There the waste is stored in a tank until it is valorised at site. The quality and quantity is high due to the system set-up since the food waste disposer only allows sludgy material and blocks when plastic or metals are introduced.

Figure 33 displays the storyline of scenario 8 while Figure 34 and Figure 35 display its mass and energy balance, respectively. Figure 35 cannot be compared with the specific consumption in the other scenarios since no vehicle is used and therefore the energy consumption can not be related to the collection distance. However, total consumption per year and per tonne of food waste will be compared in chapter 4.4.

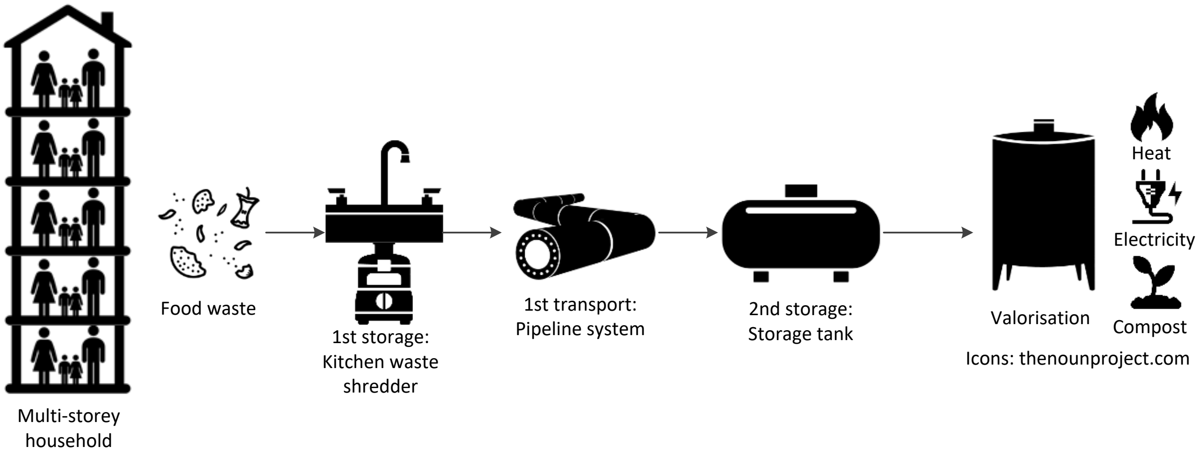


Figure 33: Scheme of collection scenario 8

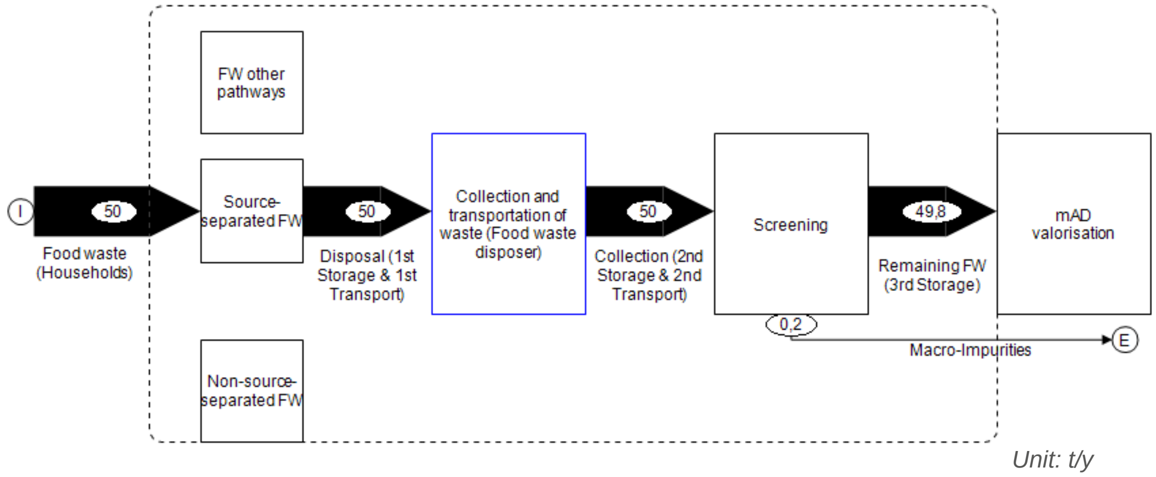


Figure 34: Mass balance of scenario 8

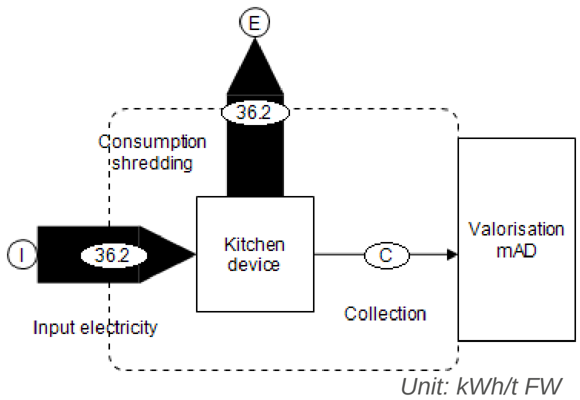


Figure 35: Energy balance of scenario 8

4.4 Comparison of scenarios

This chapter compares the eight different scenarios including the results of the mass- and energy balances. Table 27 displays the different parameter options chosen for each scenario.

Table 27: Parameter options used for the set-up of the different bio-waste collection scenarios

Catchment area (km^2)	Population density (capita/km^2)	Quantity of collected source-separated FW (kg/capita*y)	Quality of collected source-separated FW (% of macro-impurities in FW)	Collection frequency	Collection system	Transport system	Co-substrate
Scenario 1: E-bike door-to-door							
Very small: 0.1	High: 10,000	Medium: 50	High: 2	High: 3/w	DtD	Human powered	No
Scenario 2: E-vehicle flexible bring point							
Large: 3	Low: 350	Very high: 150	Very high: 0.3	High: 3/w	BP	E-Vehicle	Yes
Scenario 3: E-vehicle door-to-door							
Medium: 1.5	Medium: 1,000	Medium: 50	Very high: 0.3	High: 3/w	DtD	E-vehicle	No
Scenario 4: Conventional truck							
Large: 3	Low: 350	Very high: 150	High: 2	Low: 2/m	DtD	Convent. Truck	No
Scenario 5: Community urban farm as civic amenity cite							
Small: 0.5	Medium: 1,000	High: 100	Very high: 0.3	Medium: 1/w	CAS	E-vehicle	Yes
Scenario 6: Old town e-bike with bucket cleaning							
Small: 0.5	Medium: 1,000	Very high: 150	High: 2	Very high: d	DtD	Human powered	No
Scenario 7: Food court							
Small: 0.5	Very high: 16,000	High: 100	Very high: 0.3	Very high: d	BP	E-Vehicle	No
Scenario 8: One multi-storey house							
One multi-storey house	500 inhabitants	High: 100	Very high: 0.3	Very high: d	AUTO	Pipeline	No

FW – Food waste; mi – macro-impurities, m – month, w – week, d – day

The mass balances display the quantity of source-separated waste including the macro-impurities. However, for further elaboration of the scenarios the amount of non-source-separated food waste as well as the amount of food waste which is going other pathways such as home composting have to be included to evaluate the potential of bio-waste collection. This can only be done with specific data from specific sites and was therefore not included in the theoretical scenarios.

To calculate energy balances for the different theoretical scenarios (description in chapter 4.2), specific data as well as assumptions are necessary. These are compiled in Table 28.

Table 28: Assumptions for the calculations of the energy balances of the different bio-waste collection scenarios

Vehicle	Battery/ energy (kWh)	Collection days (days/y)[a]	Total distance for collection (m/collection-day)[b]	Spec. energy consumption vehicle (kWh/km)	FW produced per year (t/y)	FW collected per collection day (kg/collection day)
Scenario 1: E-bike door-to-door						
1 e-bike	2.5	156	3,800	0.025	50	320
Scenario 2: E-vehicle flexible bring point						
1 e-vehicle	10	156	9,200	0.15	157.5	1010
Scenario 3: E-vehicle door-to-door						
1 e-vehicle	10	156	22,600	0.15	75	480
Scenario 4: Conventional truck						
1 truck	2000[c]	26	27,000	7[d]	157.5	6,058
Scenario 5: Community urban farm as civic amenity cite						
1 e-vehicle	10	52	3,220	0.15	50	961
Scenario 6: Old town E-bike with bucket cleaning						
4 e-bikes	2.5	365	36,880	0.025	75	205
Scenario 7: Food court						
2 e-vehicles	10	365	8,200	0.15	800	2,192
Scenario 8: One multi-storey house with food waste disposer						
200 food waste disposer	NA	-	-	-	50	137

[a]The number of collection days refers to the times the waste is collected in different collection circuits (or in a single household or bring point) per year.
[b]The total distance for collection includes the total distance driven by all vehicles of one scenario at one collection day.
[c]Calculated with an energy equivalent of 200l fuel per tank and 10 kWh/l diesel.
[d]Calculated with the equivalent of 0,7l diesel/km and 10 kWh/l diesel.

Data on the different vehicles is taken from Table 25 and further technical specifications from the equipment or data supplying companies ((Radburro 2018), (Alkè 2018), (Stadtreinigung Hamburg 2017a)). Data on the food waste disposer is taken from (Klauke 2011).

For the calculation of the energy balances, a routing concept was developed and applied to each scenario in order to allow for a comparison (appendix 3). The routing concept was designed in order to use as much loading capacity as possible of the vehicles for each collection circuit and collection day. However, the collection frequency is predefined with the reasons explained in the scenarios. As can be seen in Table 28, the total amount to collect per year varies between 50t and 800t and the amount of food waste to collect per collection day varies between 137 kg and 6,058 kg. This is not only due to the different collection frequencies in each scenario but also due to the size of the catchment area and the food waste generated in it. The total distance for collection includes the number of vehicles used and the number of collection circuits driven per collection day. The distances vary between 3,220m and 36,880m per collection day. For scenario 8, the total number of 200 food waste disposer for the building was implemented using the assumption of 2.5 inhabitants per household.

With these assumptions, the energy balance was calculated. A comparison is displayed in Table 29.

Table 29: Results of the energy balances for the different bio-waste collection scenarios

Total energy consumption (kWh/collection day)	**Total energy consumption (kWh/t FW)**	**Total energy consumption (kWh/y)**	**Total spec. energy consumption (10^{-3} kWh/km*t FW)**
Scenario 1: E-bike door-to-door			
0.1	0.29	14.9	78.2
Scenario 2: E-vehicle flexible bring point			
1.4	1.37	216	149
Scenario 3: E-vehicle door-to-door			
3.4	7.07	530	313
Scenario 4: Conventional truck			
189.0	30.8	4885	1159
Scenario 5: Community urban farm as civic amenity cite			
0.2	0.26	13	156
Scenario 6: Old town E-bike with bucket cleaning			
0.9	4.49	337	122
Scenario 7: Food court			
1.2	0.56	449	68
Scenario 8: One multi-storey house			
-	36.2	1811[a]	-

[a]Calculated with 9.1 kWh/flat*y adapted from (Klauke 2011).

To allow for a broad comparison, 4 different (specific) total energy consumptions were calculated: the consumption per collection day (including all circuits), the consumption per tonne of food waste, the total consumption per year and the specific consumption per kilometre and tonne of food waste. The latter allows for a comparison disregarding the total distance and amount of food waste in each scenario. Scenario 8 is an exception however, due to the fact that no vehicle is considered for the transport of the food waste. Thus, this scenario can only be compared by the total annual energy consumption and the consumption per tonne food waste.
Scenario 7 has the lowest specific energy consumption of $68*10^{-3}$ kWh/km*t, since a high amount of food waste can be collected per collection circuit. Furthermore, the e-vehicle is an energy saving option compared to a conventional truck. Scenario 4 displays the highest total specific energy consumption since the conventional truck has a high consumption compared to the other vehicles. Scenario 1 includes the lowest consumption per collection since the vehicle is a bike and the collection circuit is short due to the very small catchment area. Therefore, the total specific consumption is one of the lowest of all scenarios. Scenario 3 includes the highest total energy consumption for all scenarios including electric vehicles. This is due to the very long collection distances of the area including a medium amount of food waste which requires two collection circuits per collection day. When comparing the total energy consumption per tonne of food waste, the food waste disposers (scenario 8) consume the most. It includes also the second highest energy consumption per year. Scenario 5 on the other hand has the lowest energy consumption per tonne of food waste, since the vehicles are loaded at a very high capacity. This scenario also includes a very short collection distance from the CAS to the valorisation site outside the catchment area. Energy is not consumed for the transport from the household to the CAS since inhabitants bring their waste by foot or bike. Therefore, the annual consumption is very low as well. The same is true for the two bring point-scenarios (scenarios 2 and 7) in which the waste is brought by the inhabitants to the bring point and therefore this distance does not have to be covered by the collector with the collection vehicle.

It can be concluded that scenario 4 is the least suitable for decentralised approaches, since the use of the capacity of a big waste collection truck is not an ideal option. In a small area, small vehicles with a relatively low loading capacity are favourable. On the other hand, more staff is required if waste is collected with e-bikes and e-vehicles because of the lower loading capacity and the time required for collection.

Based on the evaluation of the scenarios, the following assumptions can be made for the use of different vehicles:

- The use of e-bikes for the waste collection is feasible for small catchment areas (up to 0.5 km^2). Otherwise the distances within one collection circuit will become too far to be driven in one collection day due to the required time for collection.
- E-bikes are very flexible and can therefore be used in places with narrow streets and paths such as old towns where access is limited for bigger vehicles
- E-vehicles are a good option in general but the total amount of generated and source-separated waste is important in order to reach the maximum loading capacity. The limiting battery charge time of up to 8 hours is also important to keep in mind.
- Conventional diesel driven trucks only appear to be a good option if they are used with a very high work load due to their high price compared to e-bikes and e-vehicles.

The following assumptions can be made for the type of collection system:

- DtD can generally be applied in each scenario. However, it might be not applicable in old towns where space is limited.
- For a BP system, two scenarios appear to be advantageous. One, in which the bring point is an e-vehicle with flexible stops (scenario 2) and a collector who is always present in order to observe the waste quality and advise the citizens otherwise if they fail to meet a certain standard. The second scenario includes restaurants which are attached to a specific bring point.
- A CAS as a BP is only favourable in very small or small areas, in which the inhabitants would not have to walk more than 350m. However, a rewarding system, e.g. by offering compost for free, could motivate the inhabitants to bring their waste to such site.

5 Conclusion

In this report, a stakeholder interview analysis regarding bio-waste collection as well as a bio-waste collection database for the three phases of bio-waste generation, bio-waste source-separation and bio-waste collection has been provided. Specific recommendations for the development of decentralised bio-waste collection systems were provided in sections 2.3 and 3.5. All of this information was used to develop bio-waste collection chain scenarios focusing on their implementation in a decentralised bio-waste management system. In the following, general conclusions for the development and implementation of decentralised bio-waste collection systems are made.

Local stakeholder involvement

Local stakeholders provided information on important factors which have to be considered in the planning of a decentralised bio-waste management including the fact that many shared their concerns regarding time, money and space for the implementation of a decentralised bio-waste collection system. Therefore, information campaigns for the citizens but also for the stakeholders may help to dispel them.
However, benefits of decentralised bio-waste collection system were addressed as well by the interviewed stakeholders. A decentralised bio-waste management system could increase the awareness of the citizens which in the end may bring an improved bio-waste quality and a reduction of transport costs. It was highlighted that a decentralised bio-waste management system should include benefits and good incentives for better source-separation behaviour of the citizens. Flyers including specific information on the performance of source-separation and waste collection and the proximity of the decentralised bio-waste collection system make the citizens aware of what happens with their waste.
To conclude, the involvement of local stakeholders including citizens is essential for a successful development of a decentralised bio-waste collection and management system.

Data gathering for the concept development of a decentralised bio-waste collection

Concluding from the description of the national data presented by EUROSTAT in section 3.2.1 and 3.2.2, this data is too general to be used for the assessment of feasibility of a local decentralised bio-waste management system. The data is not only very imprecise, since each national statistics office assigns data differently to the various sections, but it is also not clearly defined which sections include food waste from households or food services.
For the implementation of a decentralised bio-waste management system, specific data for the respective area is necessary. However, for the planning phase data from comparable areas, municipalities or regions can be used. An important parameter is the amount of generated, source-separated and non-source-separated bio-waste including its quality. Furthermore, data on parameters regarding the storage and transport have to be gathered.
The DECISIVE database includes precise data on local, municipal and regional level of the six DECISIVE countries. Data is included for the bio-waste collection phases of *generation, source-separation* and *collection* by giving minimum to maximum ranges. This database will be expanded throughout the DECISIVE project phase but still faces the issue of proper definition of terminologies. In many researched references definitions were not clearly defined or distinguished. In some cases, bio-waste was defined as *generated* but it appeared that the *source-separated* and *collected* bio-waste (DECISIVE definition) has been investigated. Even on a local level, the amount of *generated* bio-waste is difficult to determine. In some cases, it is done by estimations or by summing up the amounts of *source-separated* and *non-source-separated* bio-waste. Furthermore, the bio-waste source differs from one DECISIVE country to another. While in Catalonia, bio-waste collection is conducted separately for households and food services, the bio-waste of both sources is collected together in Italy.

The development of bio-waste collection chains suitable for a specific location

Considering the previously mentioned uncertainties, the data provided in the DECISIVE bio-waste collection database can be used to make first estimates for the development of a decentralised bio-waste collection chain. In this report the bio-waste collection chain is defined by eight parameters including two or four options for each: the catchment area, the population density, the quantity of source-separated food waste, the food waste quality including the macro-impurities content, the collection frequency, the collection system, the transport system and the option for co-substrates (section 4.1). From more than 32,000 possible scenarios eight were developed representing a broad variety of decentralised bio-waste collection chains. These scenarios can be used to select the best option for the area where to implement a decentralised bio-waste management. Advantages and disadvantages for the various options can be evaluated. The waste collection scenarios will be further elaborated for the DECISIVE-DST to allow for an improved evaluation of the different options.

Data gathering for detailed development of a decentralised bio-waste collection

After the selection of a suitable bio-waste collection chain, the second phase of the planning of such system can be started including specific investigations in the respective area. For example, food waste amounts from households or food services have to be determined as well as specific storage and transport related parameters or the choice for the site of the valorisation unit.

6 Outlook

This study provides the initiation for the development of decentralised bio-waste management concepts which may include mADs as core units for decentralised bio-waste valorisation. Each of the three parts of the study, the stakeholder analysis, the bio-waste collection database as well as the bio-waste collection chain scenarios will be used and extended in future DECISIVE work packages.

Stakeholder analyses

This report includes only stakeholder information regarding waste collection. However, the interviews include information on issues regarding waste prevention, decentralised mAD and digestate handling. Those will be included in the next steps of the DECISIVE deliverables. For the German case studies Hamburg and Lübeck (-Flintenbreite) more interviews with local stakeholders including citizens will be carried out. In Lübeck-Flintenbreite interviews with selected inhabitants of the neighbourhood will be carried out and simplified questionnaires will be distributed to all citizens. The interview methodology and questions may be linked with the interview methodology which will be applied in the case study of Catalonia to allow for a comparison of results. In general, the interview methodology could as well be applied to other case studies in other DECISIVE countries.

Bio-waste collection database

To obtain specific bio-waste collection related data on a local level, it is planned to assess the food waste generation and collection within the investigations of the case study of Lübeck-Flintenbreite in detail. This includes practical investigations on the quality and quantity of source-separated bio-waste and residual waste. One focus will be also the avoidable food waste fraction. Further analysis may be done in other DECISIVE case studies (Lyon, Catalonia) to allow for a comparison of waste related data with the case of Lübeck-Flintenbreite. All results will be implemented in the database which is continuously elaborated and therefore shall include more specific data for local areas in the future. Data gathering will continue to develop waste processes for specific sites required to fill the database of the DST.

Bio-waste collection chains

The provided bio-waste collection chain scenarios from this study will be the further elaborated to build precise waste collection processes at specific sites that can be introduced into the DECISIVE DST. They are the basis for the development and testing of new decentralised bio-waste collection systems and cover a broad range of local situations. However, a specific case may require a different approach. One specific bio-waste collection chain scenario (e.g. scenario 6) will be adapted and investigated in detail in the case study of Lübeck-Flintenbreite to determine the important interdependencies between stakeholders. The investigation will focus on an improved system for food waste collection from households. The bio-waste collection within the case studies in Catalonia and Lyon may contain further elements for food wastes from households and food services.

7 Appendix

Appendix 1: List of parameters of the bio-waste collection database including units

BIOWASTE TYPE AND SOURCE	FOOD WASTE FROM PRIVATE HOUSEHOLDS		FOOD WASTE FROM FOOD SERVICES	
Phase: Bio-waste generation				
Generator				
Waste related parameters				
Municipal solid waste total generated	kg/capita*y		kg/meal*y	
Bio-waste total generated	kg/capita*y	% of MSW generated	kg/meal*y	% of MSW generated
Food waste total generated	kg/capita*y	% of bio-waste generated	kg/meal*y	% of bio-waste generated
Food waste mainly animal-based generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste mainly plant-based generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste avoidable generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste consumption generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste unopened original packaged generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste opened original packaged generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste original unpackaged generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste non-avoidable generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Food waste preparation generated	kg/capita*y	% of FW generated	kg/meal*y	% of FW generated
Garden waste generated	kg/capita*y	% of bio-waste generated		
Woody waste generated	kg/capita*y	% of bio-waste generated	kg/restaurant*y	% of bio-waste generated
Green waste generated	kg/capita*y	% of bio-waste generated	kg/restaurant*y	% of bio-waste generated
Other organic waste generated	kg/capita*y	% of bio-waste generated	kg/restaurant*y	% of bio-waste generated
Phase: Bio-waste source-separation				
Generator				
Waste related parameters				
Bio-waste time for sorting	h/t (FW/bio-waste)			
Bio-waste source-separated	kg/capita*y	% of bio-waste generated	kg/capita*y	% of bio-waste generated
Food waste in bio-waste source-separated	kg/capita*y	% of bio-waste source-separated	kg/capita*y	% of bio-waste source-separated

Green waste in bio-waste source-separated	kg/capita*y	% of bio-waste source-separated	kg/capita*y	% of bio-waste source-separated
Woody waste in bio-waste source-separated	kg/capita*y	% of bio-waste source-separated	kg/capita*y	% of bio-waste source-separated
Other organics in bio-waste source-separated	kg/capita*y	% of bio-waste source-separated	kg/capita*y	% of bio-waste source-separated
Garden waste source-separated	kg/capita*y	% of bio-waste generated	kg/capita*y	% of bio-waste generated
Food waste in garden waste source-separated	kg/capita*y	% of garden waste source-separated	kg/capita*y	% of garden waste source-separated
Green waste in garden waste source-separated	kg/capita*y	% of garden waste source-separated	kg/capita*y	% of garden waste source-separated
Woody waste in garden waste source-separated	kg/capita*y	% of garden waste source-separated	kg/capita*y	% of garden waste source-separated
Other organics in garden waste source-separated	kg/capita*y	% of garden waste source-separated	kg/capita*y	% of garden waste source-separated
Other disposal routes	kg/capita*y	% of bio-waste generated	kg/capita*y	% of bio-waste generated
Bio-waste other disposal routes	kg/capita*y			
Food waste other disposal routes	kg/capita*y			
Green waste other disposal routes	kg/capita*y			
woody waste other disposal routes	kg/capita*y			
Macro-impurities total in bio-waste source-separated	kg/capita*y	% of bio-waste source-separated	kg/capita*y	% of bio-waste source-separated
Macro-impurities total in food waste source-separated	kg/capita*y	% of FW source-separated	kg/capita*y	% of FW source-separated
Macro-impurities total in garden waste source-separated	kg/capita*y	% of GW source-separated	kg/capita*y	% of GW source-separated
Macro-impurities plastic	% of food/bio-waste	% of total macro-impurities	% of food/bio-waste	% of total macro-impurities
Macro-impurities woody	% of food/bio-waste	% of total macro-impurities	% of food/bio-waste	% of total macro-impurities
Macro-impurities glass	% of food/bio-waste	% of total macro-impurities	% of food/bio-waste	% of total macro-impurities
Macro-impurities paper and cardboard	% of food/bio-waste	% of total macro-impurities	% of food/bio-waste	% of total macro-impurities
Macro-impurities Fe	% of food/bio-waste	% of total macro-impurities	% of food/bio-waste	% of total macro-impurities
Macro-impurities Nfe	% of food/bio-waste	% of total macro-impurities	% of food/bio-waste	% of total macro-impurities
Macro-impurities other	% of food/bio-waste	% of total macro-impurities	% of food/bio-waste	% of total macro-impurities
Residual waste	kg/capita*y			
Bio-waste non source-separated	kg/capita*y	% of residual waste/% of biowaste generated	kg/capita*y	% of residual waste/% of biowaste generated
Food waste in bio-waste non source-separated	kg/capita*y	% of residual waste	kg/capita*y	% of residual waste
Green waste in bio-waste non source-separated	kg/capita*y	% of residual waste	kg/capita*y	% of residual waste
Woody waste in bio-waste non source-separated	kg/capita*y	% of residual waste	kg/capita*y	% of residual waste

Other organics in bio-waste non source-separated	kg/capita*y	% of residual waste	kg/capita*y	% of residual waste
other waste (non-organic)	kg/capita*y	% of residual waste	kg/capita*y	% of residual waste
1st storage related parameters				
Storage time until transport to 2nd storage	days			
Bucket				
Bucket volume	L/bucket			
Bucket consumption	buckets/t (FW/biowaste)			
Bucket occupation	% of total volume			
Bucket life time	years			
Bucket type	standard bucket, stackable bucket, aired bucket		standard bucket, stackable bucket, aired bucket	
Bucket cost	€/bucket	€/ L bucket	€/bucket	€/ L bucket
Bucket water demand cleaning	L/t (FW/biowaste)	L/bucket	L/t (FW/biowaste)	L/bucket
Bucket base area	cm²/device	m²/device	cm²/device	m²/device
Bucket density of bio-waste	kg/L			
Bag				
Bag volume	L/bag			
Bag consumption	bags/t (FW/biowaste)			
Bag occupation	% of total volume			
Bag cost (plastic)	€/bag			
Bag cost (compostable)	€/bag			
Bag cost (uncoated paper)	€/bag			
Bag cost (wax coated paper)	€/bag			
Bag base area	cm²/device	m²/device	cm²/device	m²/device
Bag density of bio-waste	kg/L			
1st transport related parameters				
Distance from 1st storage to 2nd storage	meter / transport*kg FW	meter/transport	meter / transport*kg FW	meter/transport
Time for transport from 1st storage to 2nd storage	min/transport			
Phase: Bio-waste collection				
Collector				
Collection related parameters				
Collection system	DD/BP/CAS/AUTO			
Source type	House type: Single-family house,		restaurant, canteen	

	apartments			
DD scheme share of total collection scheme	% of total collection systems			
BP scheme share of total collection scheme	% of total collection systems			
Automatic scheme share of total collection scheme (food waste disposer)	% of total collection systems			
Connection rate to bio-waste collection	% of households	% of inhabitants	% of restaurants	
Connection rate per collection point	inh./collection point		inh./collection point	
Density in collection area	inh./km²		Restaurants/km²	
Number of collection routes in collection area	number/collection area		unit/collection area	
Collection points	collection points / km²	Number	collection points / km²	Number
Bio-waste collection frequency	days/week			
Collector				
Storage related parameters				
Waste density	kg/L			
Tank				
Tank volume	L/unit			
Tank consumption	tanks/t (FW/biowaste)			
Tank occupation	% of total volume			
Tank life time	years			
Tank cost	€/tank			
Tank water demand cleaning	L/t (FW/biowaste)	L/tank	L/t (FW/biowaste)	L/tank
Tank density of bio-waste	kg/L			
Tank base area over ground	m²/device			
Tank base area under ground	m²/device			
Bin				
Bin volume	L/unit			
Bin consumption	bins/t (FW/biowaste)			
Bin occupation	% of total volume			
Bin life time	years			
Bin cost	€/bin			
Bin water demand cleaning	L/t (FW/biowaste)	L/bin	L/t (FW/biowaste)	L/bin
Bin density of bio-waste	kg/L			
Bin base area over ground	m²/device			
Container				
Container volume	L/unit			
Container consumption	container/t (FW/biowaste)			

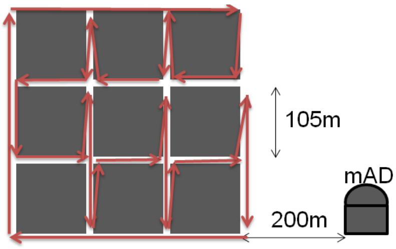
Container occupation	% of total volume			
Container life time	years			
Container cost	€/container			
Container water demand cleaning	L/t (FW/biowaste)	L/container	L/t (FW/biowaste)	L/container
Container density of bio-waste	kg/L			
Container base area over ground	m²/device			
Transport related parameters				
Distance per collection routine	meter/collection routine*t FW	meter/collection routine	meter/collection routine*t FW	meter/collection routine
Distance from 2nd storage to 3rd storage	meter/t FW	meter/collection routine	meter/t FW	meter/collection routine
Time for collection	min/collection routine*t FW	min/transport	min/collection routine*t FW	min/transport
Food waste disposer				
Food waste disposer energy demand	kWh/t (FW/biowaste)			
Food waste disposer water demand	L/t FW			
Food waste disposer cost	€/FW disposer			
Transport vehicle: Truck, Bike, E-Buggy				
Vehicle tank volume	m^3			
Vehicle maximum loading capacity	kg			
Vehicle density of bio-waste in truck tank	kg/L			
Vehicle tank occupation per collection routine	% of total volume			
Vehicle fuel demand	L/t FW*km	L/km	L/t FW*km	L/km
Vehicle cruising range	km			
Vehicle consumption	truck/t*km			
Vehicle life time	years			
Vehicle labour	workerhours/t FW*km			
Vehicle labour salary	€/personmonth*t FW	€/workerhours*t FW*km	€/personmonth*t FW	€/workerhours*t FW*km
Vehicle electricity demand	kWh / km*kg FW			
Vehicle cost	€/vehicle			
Vehicle time for charging	h			

Appendix 2: References of the database used for the ranges given in section 3.4.1 and 3.4.2.

Reference number	Reference	Type of source
1	(ARPA 2017)	Scientific summary
2	Richter et al. (2017)	Scientific summary
3	Kranert et al. (2012)	Scientific study
4	Rosenbauer (2011)	Scientific study
5	(D 3.5 2017)	DECISIVE evaluation provided in reports
6	(Ercolano 2011)	Scientific study
7	Adwiraah (2015)	Scientific study
8	INFA (2018)	Scientific summary
9	Müller (1998)	Scientific study
10	Hilger (2000)	Scientific study
11	Internal document from 2014 based on characterisations of separately collected biowaste (ARC 2014)	Information from waste management agencies
12	Monier (2010)	Scientific summary
13	Danish Environmental Ministry cited by Monier et al. 2010,	Scientific summary
14	Agence de l'Environnement et da la Maîtrise de l'Energie (ADEME), GECO Food Service (2017)	Information from waste management agencies
15	Edjabou et al. (2016)	Scientific study
16	Buchner et al. (2012)	Scientific summary
17	Jörissen et al. (2015)	Scientific study
18	OVAM (2016, 2017)	Information from waste management agencies
19	Bortolotti et al. (2018)	?
20	Service Public de Wallonie (2017)	Information from waste management agencies
21	ADEME (2015)	Information from waste management agencies
22	Spanish Ministry of Agriculture, Food and the Environment (2013)	Scientific summary
23	(ARC 2018c)	Information from waste management agencies
24	ARC (2016)	Information from waste management agencies
25	Interview with stakeholders from the Italian region Friuli Venezia Giulia (2017)	DECISIVE evaluation provided in reports
26	Xue et al. (2017)	Scientific summary
27	(D 3.6 2018)	DECISIVE evaluation provided in reports
28	(ARC 2018a)	Information from waste management agencies
29	Centemero et al. (2017)	Scientific summary
30	Lladó Cilimingras and Pujol Troncoso (2013)	Scientific summary
31	ISPRA (2017)	Scientific summary
32	ADEME (2013)	Information from waste management agencies
33	Roels and Gijseghem (2011)	Scientific summary
34	Falasconi et al. (2015)	Scientific study
35	Flemish Food Supply Chain Platform for Food Loss (2017)	Scientific study
36	Giavini (2017)	Scientific summary
37	Interview with stakeholders from the German federal state of Hamburg (2017)	DECISIVE evaluation provided in reports
38	(FAUN 2018)	Information from companies producing equipment
39	(Alkè 2018)	Information from companies producing equipment

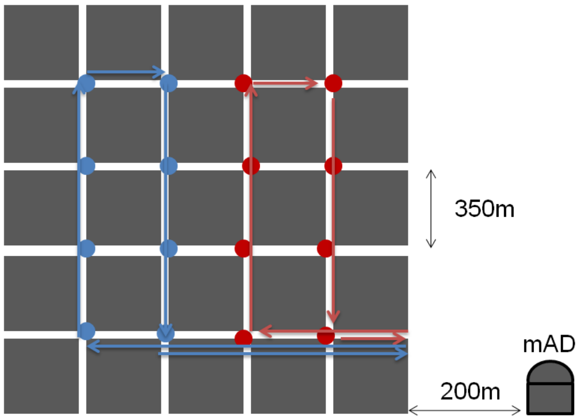
40	(HORNBACH 2018)	Information from companies producing equipment
41	(GLASDON 2018)	Information from companies producing equipment
42	(Stadtreinigung Hamburg 2017b)	Information from waste management agencies
43	(Stadtreinigung Hamburg 2017a)	Information from waste management agencies
44	(Hillmer 2005)	Article
45	(Radburro 2018)	Information from companies producing equipment
46	(Klauke 2011)	Scientific study

Appendix 3: Routes for the bio-waste collection scenarios of chapter 4



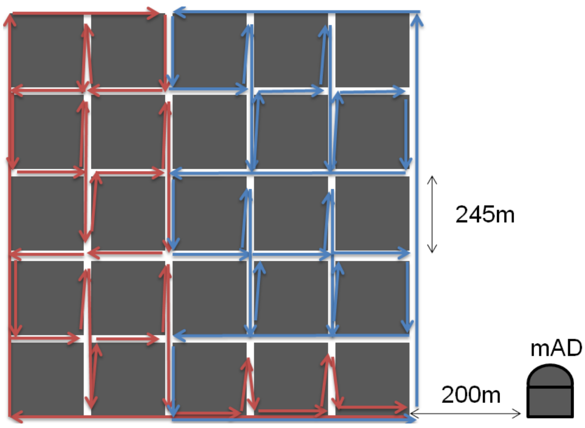
Scenario 1: DtD, 1 e-bike, very small area, high population density

Distance 1 (red): 3,360+400m = 3,760m for 320 kg waste



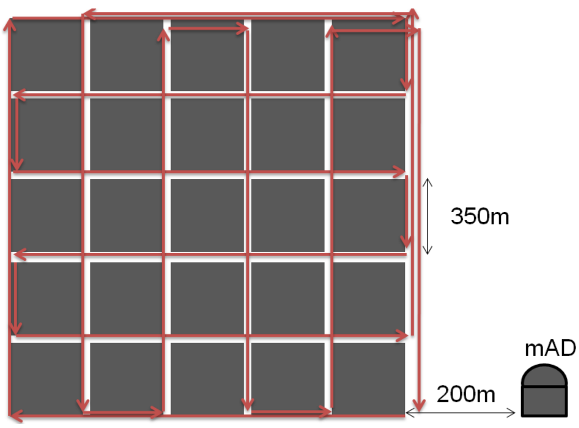
Scenario 2: BP, 1 e-vehicle, large arge, low population density

Distance 1 (red): 3,500+400m = 3,900m; Distance 2 (blue): 4,900+400m = 5,300m; Total distance: 9,200m for 1,026 kg waste



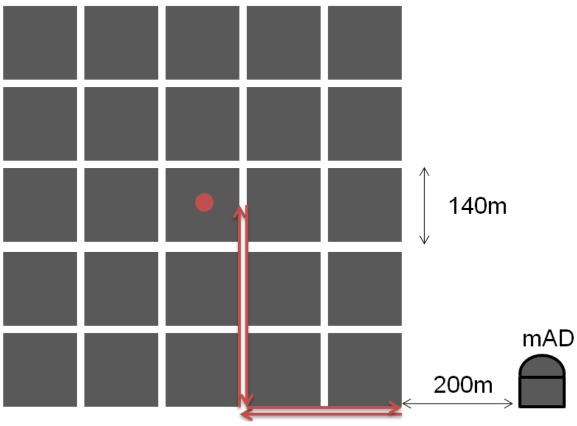
Scenario 3: DtD, 1 e-vehicle, medium area, medium population density

Distance 1 (red): 11,025+400m = 11,425m; Distance 2 (blue): 10,780+400m = 11,180m; Total distance: 22,605m for 480 kg waste



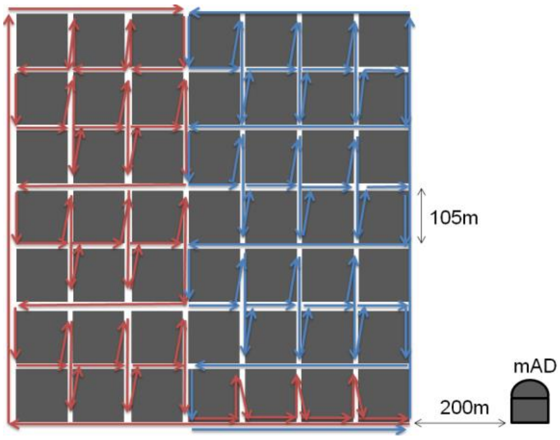
Scenario 4: DtD, 1 truck, large area, low population density

Distance 1 (red): 26,600+400m = 27,000m for 6,150 kg waste



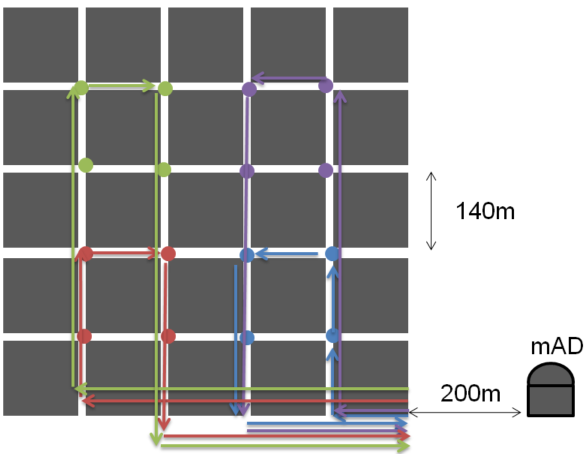
Scenario 5: CAS, 1 e-vehicle, small area, medium population density

Distance 1 (red): (1,260+400)m*2 = 3,320m for 961 kg waste



Scenario 6: DtD, 4 e-bikes, small area, medium population density

Distance 1 (red): (9,030+400)m*2 = 18,860m; Distance 2 (blue): (8,610+400)m*2 = 18,020m; Total distance: 36,880m for 205 kg waste; Average distance per bike: 9,220m



Scenario 7: BP, 2 e-vehicles, small area, very high density

Distance 1 (red): 1,680+400m = 2,080m; Distance 2 (blue): 1,120+400m = 1,520m; Distance 3 (green): 2,100+400m = 2,500m; Distance 4 (violet): 1,680+400m = 2,080m;
Total distance: 8,180m for 2,100 kg waste; Average distance per vehicle: 2,045m

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