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D6.1 – Methodology of characterization of the biowaste management system in the DECISIVE demonstration sites:

Current and new systems simulation for the LYON and CATALONIA cases

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A Decentralised Management Scheme for Innovative Valorization of Urban Biowaste

D6.1 – Report on the system simulation for the LYON and CATALONIA cases

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ABSTRACT

This report gives a preliminary characterization of the two demonstration sites in Lyon and Catalonia, for the implementation of the DECISIVE technologies: micro-Anaerobic Digestion (mAD), biogas local valorization with Stirling Engine (SE) and Solid-State Fermentation (SSF). A methodology of characterization has been developed and applied in the two real cases before and after the implementation of the pilots.

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PREFACE

The present document, one of the deliverables foreseen for the DECISIVE project, is meant to give a preliminary characterization of the two demonstration sites in Lyon and Catalonia, for the implementation of the DECISIVE technologies: micro-Anaerobic Digestion (mAD), biogas local valorization with Stirling Engine (SE) and Solid-State Fermentation (SSF). A methodology of characterization has been developed and applied in the two real cases before and after the implementation of the pilots. This methodology will be refined in deliverable D5.1 where the methodology for planning a decentralized biowaste management supporting the Decision Support Tool (DST) will be further developed. This tool is meant to allow an informed discussion among stakeholders to support the selection of the most appropriate solution (or combination of solutions) for the management of the biowaste in a specific urban area, based on: specific sustainability indicators and model assumptions.

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Abbreviations and Acronyms

AD	Anaerobic Digestion
AMB	Metropolitan Area of Barcelona
ARC	Agència de Residus de Catalunya – Waste Agency of Catalonia
BW	Biowaste
CAPEX	Capital expenditures
CAS	Civic Amenity Site
CHP	Combined Heat and Power
DECISIVE	**DEC**entral**I**zed management **S**cheme for **I**nnovative **V**alorization of urban biowast**E**
DST	Decision Support Tool
FW	Food waste
GA	Grant Agreement
GL	Grand Lyon
ITS	Innovative Technological Systems
mAD	Micro Anaerobic Digestion
MSW	Municipal Solid Waste
OPEX	Operating expenses
SSF	Solid State Fermentation
UAB	Autonomous University of Barcelona
WFD	Waste Framework Directive

Executive Summary

This report is meant to give a preliminary characterization of the two demonstration sites (in Catalonia and Lyon) decided “a priori” to implement the DECISIVE technologies: micro-Anaerobic Digestion (mAD), biogas valorization in a Stirling Engine (SE) and Solid-State Fermentation (SSF) to valorize urban biowaste in decentralized plants.
A methodology for characterizing biowaste management systems is developed to compare the current situation (“baseline scenario”) to the estimated situation with the implementation of the DECISIVE pilot (“alternative scenario”) in both case studies.

The characterization of the baseline scenario in a specific area requires to identify its main characteristics (socio-demographic specifications) and the current biowaste management system (system stages, technical requirements and produced outputs such as energy, valuable products, refuse, and emissions).

Even if the core of the DECISIVE project is municipal biowaste, the analysis has been extended to municipal waste since the existing municipal waste management system is not always provided with specific treatments for the source-separated biowaste. Moreover, a change in biowaste flow management will imply a change in other waste flows as well. This implies that to compare the baseline scenario with the alternative one it is needed to study how the biowaste included in the residual waste is currently treated.

The characterization of the alternative scenario includes an overview of the hypothetical configuration of the alternative system, defining the process units and their technical features (surface, supply of consumables, accessibility) and valuable outputs. A list of criteria based on the feasibility, desirability and potential of the alternative system is presented to guide in the site selection process or to check the adequacy of a specific site for the implementation of the alternative system. Besides site selection criteria, relevant technical, legal and social aspects and local energy and material demands are identified to have further elements to decide if a location is appropriate for implementing DECISIVE technologies.

To preliminarily test the viability of DECISIVE pilots in these two real cases, the developed methodology has been applied to both case studies and three different characterizations are presented: the first at metropolitan area level, where urban waste is generally managed from a single authority such as the Grand Lyon (GL) and the Metropolitan Area of Barcelona (AMB), the second related to the current situation of the study zones (Lyon demonstration zone and the UAB Campus), before the implementation of the pilot (*ex-ante* situation) and the third related to the study zones implementing DECISIVE pilots (*ex-post* situation) in the specific demonstration sites (“Refarmers site” and the “UAB Civic Amenity Site”). The “baseline scenario” and “alternative scenario” for both case studies are also represented by using prospective mass and energy balances.

The Catalonia case includes a description of the selection and confirmation process of the specific demonstration site, which was not decided “a priori”, as for the Lyon case. The UAB Campus has been selected as the Catalan demonstration site after having analysing pros and cons for each proposed location. The Catalan pilot is designed with an annual capacity of 200 t obtained gathering mainly biowaste from restaurants of the UAB Campus.

For the Lyon case, if this site was already decided at the beginning of the project, the study zone “Lyon study zone” is defined only theoretically (at this stage of the project) as a circular area centred in Refarmers site. The identification of the specific restaurants that will feed the pilot has not started yet at this stage of the project, later a campaign looking for partnering restaurants will be done.

The results of the characterizations presented in this report are preliminary since they are based on the knowledge built on the data gathered until now (in this phase of the project) in both case studies. Confirmation or modification of the information presented in this report, and evaluation of missing data in terms of waste production quantification and qualitative characterization will be provided in a later phase of the DECISIVE project.

The three objectives of this report have been achieved: 1. The Catalan site has been selected and confirmed; 2. A methodology of characterization for biowaste management systems has been developed; 3. Both demonstration sites have been characterized.

1. Introduction

The DECISIVE project aims at developing and demonstrating eco-innovative solutions to valorize municipal biowaste, consisting of a Decision Support Tool (DST) to plan, design and assess decentralized biowaste management networks and three eco-designed decentralised technologies micro-scale Anaerobic Digestion (mAD), Stirling Engine (SE) and Solid-State Fermentation (SSF). The project also includes the testing of these eco-innovative solutions in two demonstration sites: Lyon (France) and Catalonia (Spain).

It is important to underline the distinction between "DECISIVE technologies" indicating specifically mAD, SE and SSF and the "alternative system" or "DECISIVE system" which includes DECISIVE technologies and covers a larger range of stages of the biowaste treatment chain such as collection, pre-treatment or digestate post-treatment (such as solid-liquid separation unit, and hygienization).

The term "biowaste" herein used in this document concerns the main part of municipal organic waste and it is defined in the Waste Framework Directive (WFD) as "biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants". The term "commercial biowaste" refers only to commercial waste that is similar to municipal waste according to the definition of waste[1] that regards household waste and similar: commercial, industrial and institutional wastes including fractions separated such as generated in restaurants, hotels, markets, catering, schools, health facilities, etc.

Lyon and Catalonia were the territories selected "a priori" to implement the DECISIVE system. While for Lyon the specific site where to locate the pilot was already defined at the beginning of the project, in the case of Catalonia the specific location needed to be decided and confirmed in the early-stages of the project. Thus, the first activity in Catalonia was to select and confirm the site where to set up the pilot. Afterwards, the biowaste management systems in both demonstration sites were characterized by comparing the current situation with the expected situation with the alternative system. To do that a methodology for characterization needed to be developed and then applied to each demonstration site.

This document presents first the methodology of characterization and then applies it to Lyon and Catalonia in order to understand both the "baseline scenario" (current situation without the DECISIVE pilot) and the "alternative scenario" (alternative situation with the DECISIVE pilot). After having defined the baseline scenario, the proposed methodology assesses the adequacy of the site for the implementation of the DECISIVE system by evaluating the "alternative scenario".

The "alternative scenarios" are also represented by using prospective mass and energy balances. It is important to underline that while the tool whose methodology will be presented in the D5.1, to be submitted in February 2018, will include different alternative scenarios (DECISIVE and others), this deliverable only presents the DECISIVE scenario as an alternative to the current management system.

This characterization methodology is partially based on the existing deliverables D3.5[2] and D4.1[3] and it will be developed further in deliverable D5.1, where the methodology supporting the DST will be completely defined. As a matter of fact, the presented methodology is strictly connected to the first step of the DST methodology, which is to gather useful data for the description of the demonstration sites *ex-ante* (before the implementation of the pilots) and *ex-post* (after the implementation of the pilots).

The characterization methodology includes three levels: the first one relates to larger territories, the "targeted territories", where urban waste are generally managed from a single authority such as the Grand Lyon (GL) and the Metropolitan Area of Barcelona (AMB), the second concerns the "study zones" (within the targeted territories) *ex-ante* and the third one refers to the study zones and the demonstration sites when implementing the DECISIVE pilots (*ex-post*). The characteristics of the targeted territory and the study zone before implementation of the DECISIVE pilots give a picture of the potential/need for the introduction of a decentralized biowaste management system or for improving the existing ones. The developed methodology will also be used for studying and characterizing other areas later in the project.

It is important to underline that the results of these characterizations are preliminary since they are based on the knowledge built on the data gathered until now (in this phase of the project). Confirmation or modification of the

[1] Code 20 in the Commission Decision on the European List of Waste (COM 2000/532/EC)

[2]http://www.decisive2020.eu/wp-content/uploads/2017/09/Survey-on-waste-collection-systems-with-evaluations-for-decentralised-applications.pdf

[3] D.4.1 - Report on pre-defined specification for micro-AD

information presented in this report, and evaluation of missing data in terms of waste production quantification and qualitative characterization will be provided in a later phase of the DECISIVE project.

2. Methodology for characterization of biowaste management systems

This section describes the methodology for characterizing the biowaste management systems. The methodology includes two parts: the first part aims at characterizing the existing biowaste management system for a specific urban area and the second part is meant to assess the suitability of that area for implementing the "alternative system", i.e. the DECISIVE system.

The methodology includes three areas of study: targeted territory, study zone and demonstration site. The proposed methodology can be applied first to have a diagnosis of the baseline scenario both in the targeted territories and the study zones and then for characterizing the "alternative system" in the ex-post scenario in the study zones and at demonstration site level.

2.1 Characterization of the "baseline scenario"

The requirements of a given biowaste management system in terms of treatment capacity, energy, water, fuel, material flows, machineries, surface and labour are needed to define the baseline scenario.

Even if the core of the DECISIVE project is urban biowaste, the analysis is partially extended to municipal solid waste (MSW) since the existing MSW management system does not always provide a dedicated treatment system for the biowaste fraction, i.e. the biowaste remains entirely in the residual waste. Even when biowaste is source-separated and it is treated in ad-hoc system, a large amount of biowaste will remain in the residual bin. The reason for such inclusion lies in the fact that to compare the baseline and alternative scenarios, both should have managed same amounts of biowaste even if biowaste is part of the residual waste.

In this framework a generic biowaste management system is modelled as a box (see *Figure 1*) that modulates the interaction between the generation units of an urban area (including households, hospitals, restaurants, hotels, schools, etc.), which consumes a flow of goods (e.g. food) and generates a flow of biowaste and the environment that receives the outputs produced by this system (valuable products and solid, liquid and gaseous effluents). *Figure 1* illustrates the main elements needed to characterize the system in terms of 1) biowaste input and 2) technical requirements of the biowaste management system in place and 3) the produced valuable outputs (heat, electricity, fertilizer/amendment and biopesticides) and the effluents to the environment (refuse and emissions).

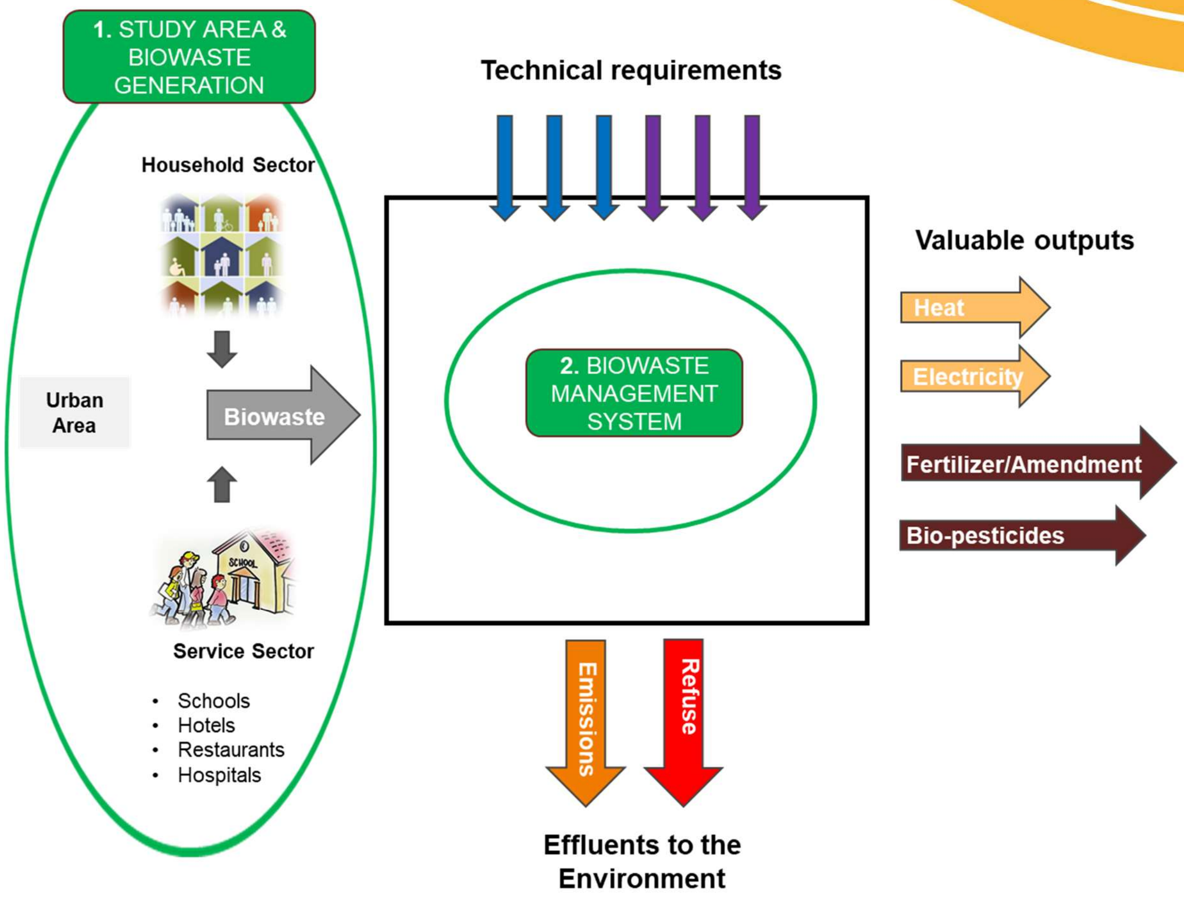


Figure 1 - Location Overview of a generic biowaste management scheme (Source: own elaboration)

2.1.1 Definition of the study area and biowaste generation

The methodology defines three different study areas to be defined in the analysis: "Targeted territory", "Study zone" and "Demonstration site".

- The "targeted territory" is delimited by the administrative area relevant for decisions on waste management. For example, in the Catalonia case study, the Metropolitan Area of Barcelona (AMB) has been selected as the targeted territory because it is the public authority responsible for waste treatment in the area. For the Lyon case, the "target territory" is represented by the Grand Lyon (GL).
- The "study zone" is defined as the catchment area that should potentially feed the mAD in the "alternative scenario". It can be defined based on either the distance from the demonstrations site or quantity of biowaste available. As a matter of fact, even if the amount of biowaste for the alternative system is fixed, it is necessary to examine a wider waste generation catchment area including both source-separated biowaste and non-separated biowaste that is going to residual urban waste (e.g the UAB Campus for the Catalonia case and the Lyon study zone for the Lyon case)
- The "Demonstration site" is defined by the specific location of the alternative system (e.g. Deixalleria of UAB – Civic Amenity Sites of UAB for Catalonia and the Refarmers site for Lyon).

Once the three areas of the study are defined, its characteristics are analyzed first at a territory level, at a study zone level and then a demonstration site level. For the definition of territory and study zone levels different types of data are gathered including: general information, demography data, amount and type of existing biowaste generation sources, as well as composition and generation of MSW, see *Table 1*.

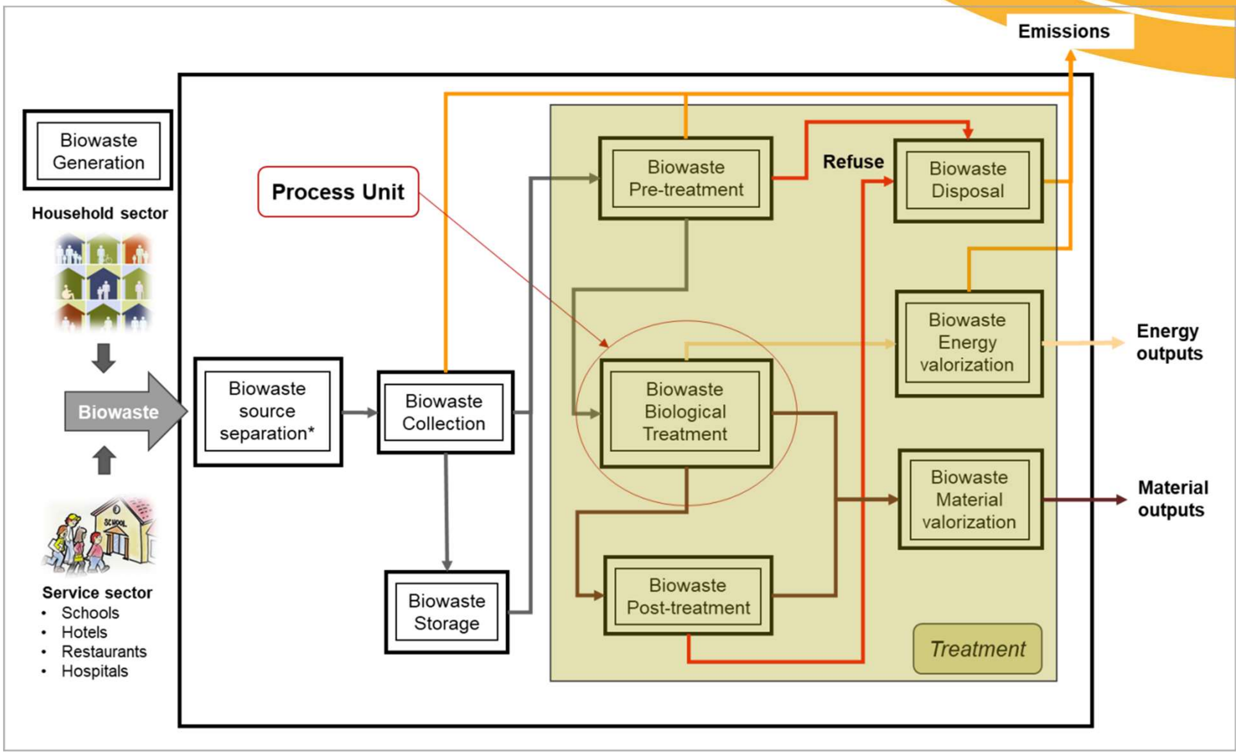
Table 1 - Characterization elements for the area to study: general information and urban biowaste generation

AREA TO STUDY: "targeted territory" and "study zone"		
GENERAL INFORMATION		
ELEMENTS	**PARAMETERS**	**Unit/type**
Demographic characteristics of the area	Population /residents and tourists)	inh
	Population density	inh/km²
Biowaste sources	Type of activities identified in the area to study	agricultural, industrial, commercial, residential
	Household kitchen waste	inh/household (type of households)
		Number of households per type
		% of annual occupation
	Traditional Restaurants and collective catering	clients or menu/year (type of restaurant)
		Number of restaurants per type
		working days/year
	Hotel and hospital	clients or beds/year (type of hotel)
		Number of hotels per type
		% of annual occupation
	School	Students/year (type of school)
		Amount of schools per type
	Urban gardens	Surface (ha)
WASTE GENERATION		
Municipal Solid Waste	Total generated MSW	t/year – kg/inh/year or day
Characterization of generated MSW	Total generated biowaste*	% on generated MSW
		t/year
	Plastic	% on generated MSW
	Glass	% on generated MSW
	Paper & Cardboard	% on generated MSW
	Other	% on generated MSW
	Moisture	% on generated MSW

*Total generated biowaste represents the annual amount of biowaste created as a result of an activity such as food preparation, food consumption, pruning or grass cutting. It includes food waste green and woody waste. The latter being the part of the garden waste that can be digested by anaerobic microorganisms.

2.1.2 Biowaste management system

The methodology considers an existing biowaste management as a box constituted by different process units, see *Figure 2*. Each process unit refers to different technologies for the different phases of the biowaste management system (e.g. source separation, collection, pre-treatment, treatment and post-treatment) according to the specific system in place. For example, pre-treatment can include grinding or/and sorting or/and mixing phases, the same is valid for the rest of the phases in the entire chain.



* Biowaste source separation unit includes both non-separated and source-separated biowaste

Figure 2 - Overview of the process units of a generic biowaste management system (Source: own elaboration)

A short description of the process units or phases related to the *Figure 2* is reported in Annex A1.

Each process unit (e.g. red circle in *Figure 2*) is represented by a specific technology and it is characterized by a set of technical requirements (type of input, capacity, but also different consumptions such as electricity, heat) needed to treat the input waste entering the unit (*Figure 3*). Depending on the input and the technical requirements, the process unit produces valuable outputs, refuses and emissions.

Zooming in on an individual process unit (*Figure 3*), these technical requirements represent what Georgescu-Roegen defines as flow and fund categories[4]. The "fund categories" are entities or physical structures that transform, consume or produce flows but that preserve their identity over the duration of the representation. They include: 1) human activity[5] (measured in hours) allocated to different activities within the system and measured respectively as direct labour, 2) surface (measured in hectares) allocated to the entire chain of the process, 3) machineries and infrastructures (measured in terms of number, type and power capacity of each installed machinery) allocated to the different units of the process. Contrary, the flow categories refer to elements that are transformed by fund categories and that appear or disappear over the duration of the analysis. They include: 1) input waste; 2) processes residues and emissions; 3) energy (electrical and thermal) demand and/ or surplus; 4) water; 5) fuel, 6) other outputs, and 7) other inputs.

Information on current biowaste treatment and plants such as: number and types of plants, waste amounts treated by plant and other values need to be gathered for the "Targeted territory". More detailed information than the "targeted territory" is required later on for the "Study zone" (e.g. details on plant of destination: process, amounts treated, waste types treated). *Table 1* includes the main technical requirements needed to describe the entire chain of a biowaste management system in place in the study zone.

[4] Georgescu-Roegen, N., 1971. The Entropy Law and the Economic Process. Harvard University Press, Cambridge, Massachusetts.
[5] Concept of human activity as fund: Giampietro, M., Mayumi, K. & Bukkens, S.G. Environment, Development and Sustainability (2001) 3: 275. https://doi.org/10.1023/A:1020864009411

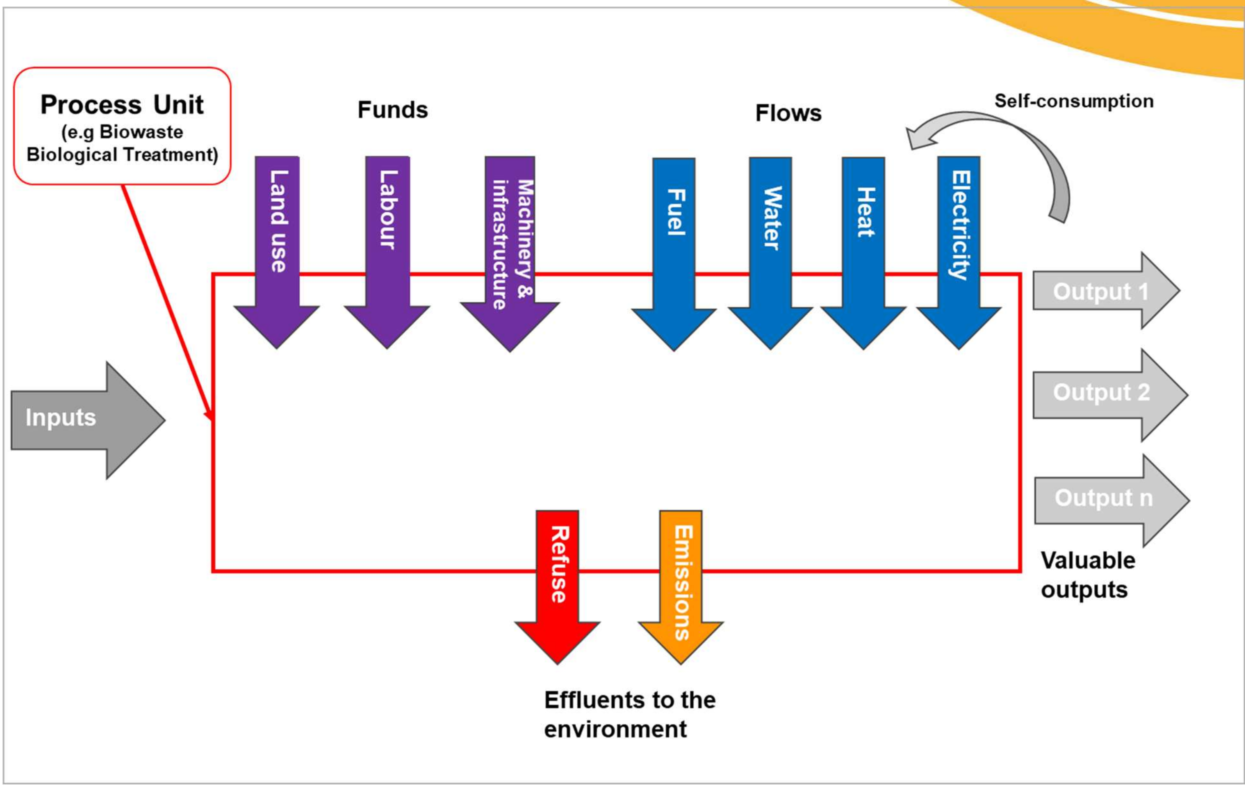


Figure 3 - Overview of technical requirements of each process unit of the biowaste management system (Source: own elaboration)

Table 2 - Technical requirements to define the entire biowaste management system in the study zone

BIOWASTE MANAGEMENT SYSTEM in place in the "study zone"			
ELEMENTS	**PARAMETERS**		**Unit/type**
Biowaste generation	Biowaste from households		t/year
	Biowaste from restaurants		t/year
	Biowaste from collective catering		t/year
	Biowaste from hotel		t/year
	Biowaste from schools		t/year
	Other (for example co-substrates)		t/year
Performance of separate biowaste collection	Source-separated biowaste of total MSW		t/year
			% on MSW
	Non-separated Biowaste included in the residual waste*		% on MSW
	Total Macro-impurities in source-separated biowaste		% on MSW
Composition of biowaste	Composition of macro-impurities	Glass	% on MSW
		Plastic	% on MSW
		Metal	% on MSW
		Paper & cardboard	% on MSW
		Other	% on MSW
	Chemical composition of biowaste including micro-impurities content	Moisture	%
		Total Organic Matter (TOM)	% on DM
		Organic Nitrogen	% on DM
		Nutrients (Na, Fe, K, P…	% on DM
		Pollutants (Cd, Ni, Pb…)	% on DM
SOCIAL AND TECHNICAL ASPECTS OF BIOWASTE COLLECTION			
ELEMENTS	**PARAMETERS**		**Unit/type**
Social	Deployment of previous awareness campaigns		Y/N (short description in case of yes)
	Surveys on perception of the citizens of the area		Y/N (short description in case of yes)
	Implementation of source-separated collection system		Y/N (short description in case of yes)
	Specific collection of biowaste (door to door (DD) or bring point (BP) or other)		Name of the collection system in place
Technical	Frequency of collection		Number of days/week
	Commercial and household biowaste together collected		Y/N

PROCESS UNITS of BIOWASTE MANAGEMENT SYSTEM		
ELEMENTS	**PARAMETERS**	**Unit/type**
Inputs	Input 1	t/year
	Input 2	t/year
	Input 3	t/year
	Input 4 ….	t/year
Outputs	Output 1	t/year
	Output 2	t/year
	Output 3	t/year
	Output 4…	t/year
Consumptions	Fuel for equipment	gasoline, diesel
	Fuel for transport	€/working hour
	Water	L/year
	Thermal energy	kWhth/year(-)
	Electrical energy	kWhel/year (-)
	Labour - Hand work	hours/year
Production	Thermal energy	kWhth/year (+)
	Electrical energy	kWhel/year (+)
	Environmental impact - Emissions	t CO_2eq/year
Infrastructures & machineries	Units needed for each process phase	Number per typology
	Lifetime of the machineries/plant	year
	Space occupied	m^2
Costs	Operational Costs OPEX	€/year
	Investment Costs CAPEX	€

*Biowaste included in the residual waste represents non-separated biowaste collected.
** DM: Dry Matter

In addition to the information listed in *Table 2,* a material flow analysis of the existing biowaste management system can provide a better picture of the baseline scenario (*ex-ante* situation) as well as the amount and type of valuable outputs and the effluents produced.

2.2 Characterization of the “alternative scenario”

Once the baseline scenarios of the “targeted territory” and the “study zone” have been defined, the next step is looking for a suitable site to install the alternative system within the “study zone” and characterize the “alternative scenario”.

There is a strict connection between the criteria for selection of a suitable site for implementing an innovative biowaste treatment system characteristics and knowing how that alternative system works and what it needs. As a matter of fact, the characteristics of a specific area (generated biowaste amount and quality, available space, existing energy and water provisions, etc.) can accept different types of treatment system.

Even if the exact technologies used in the alternative system are being currently developed, assumptions about the potential configuration of the equipment are made (and defined in section *2.2.1*) to develop a preliminary definition of the suitable area for implementing these decentralized technologies (described in Sections *2.2.2*, *2.2.3*, and *2.2.4*).

2.2.1 Alternative system

The DECISIVE technologies are micro-Anaerobic Digestion (mAD) and local valorization of biogas in a Stirling Engine (SE) and Solid-State Fermentation (SSF). However, further process units need to be considered to correctly implement the proposed decentralized systems, see *Figure 4*. As shown in *Figure 4*, the source-separated biowaste is processed to generate valuable outputs such as biogas and digestate. Almost the totality of the produced digestate is hygienized to obtain fertilizer and a part of the digestate is treated in the SSF unit to obtain biopesticides. The biogas is sent to a Stirling engine to produce electricity and heat.

Figure 5 represents more in details the mAD and SE units. In the mAD microorganisms break down biowaste in the absence of oxygen producing two valuable products: i) the digestate that can be used as fertilizer after centrifugation, hygienization or composting and ii) the biogas, consisting of methane, carbon dioxide and traces of other ‘contaminant’ gases. This biogas can be used directly as fuel, in an external combustion Stirling engine generating heat and power. This engine works closed-loop using a gas as thermodynamic fluid (usually air, Nitrogen, Helium or Hydrogen or other particular fluids in high performances versions). When a suitable temperature difference between its hot and cold spot has reached, a cyclic pulsation is caused (at the beginning started properly), normally changed in reciprocating motion of the pistons. The pulsation persists until the temperature difference is kept by giving heat to the hot spot and by subtracting heat to the cold one.

Figure 6 gives a detailed representation of the SSF process. The SSF process consists of the use of Bacillus thuriengensis (Bt) as inoculum to produce the biopesticide. Taking advantage of the ability of Bt to produce spores in adverse conditions, the aim of the SSF is to use the digestate as a substrate for the development of a soil amendment with biopesticide effect and/or a liquid biopesticide. More details are provided in D 4.6[6].

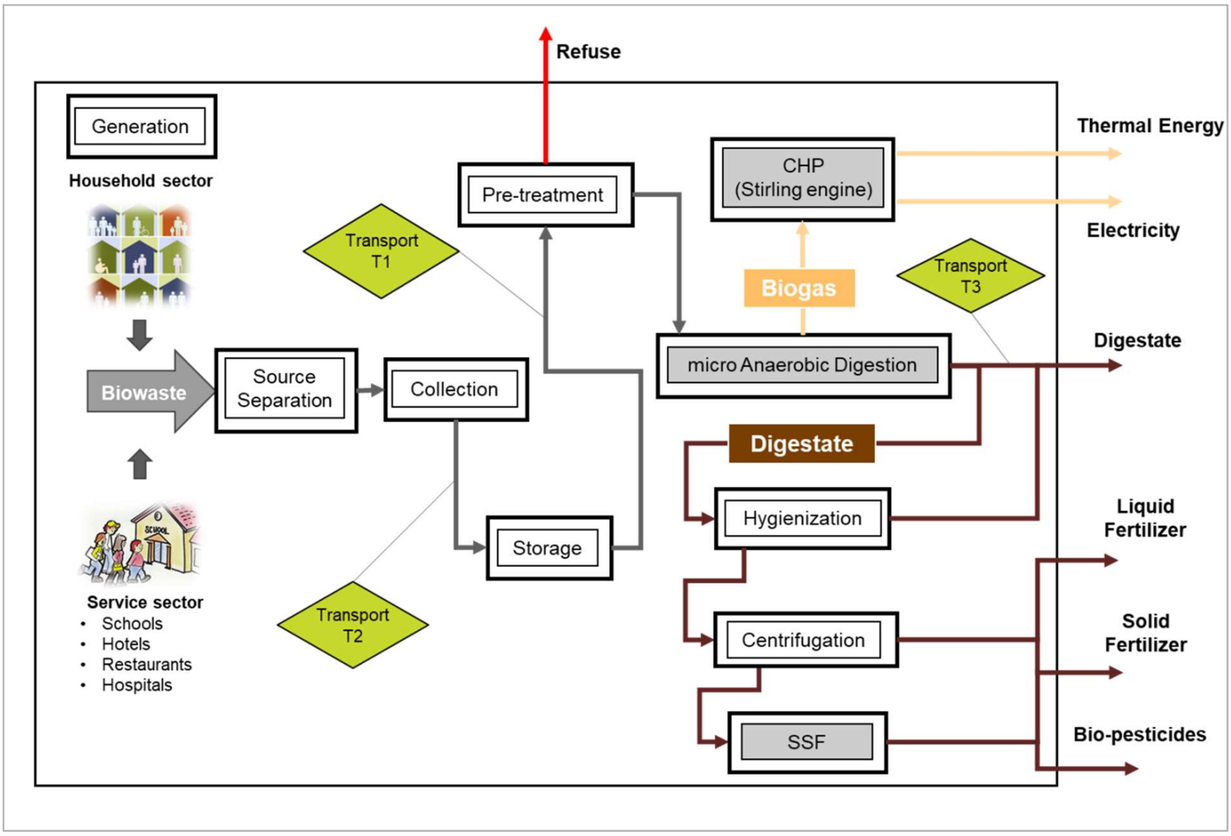


Figure 4 - Representation of process units of the alternative system including in grey the DECISIVE technologies (mAD; CHP and SSF) (Source: own elaboration) - N.B. Hygienization could also be positioned before mAD

[6]http://www.decisive2020.eu/wp-content/uploads/2017/09/Report-on-the-possibilities-of-digestate-use-from-SSF.pdf

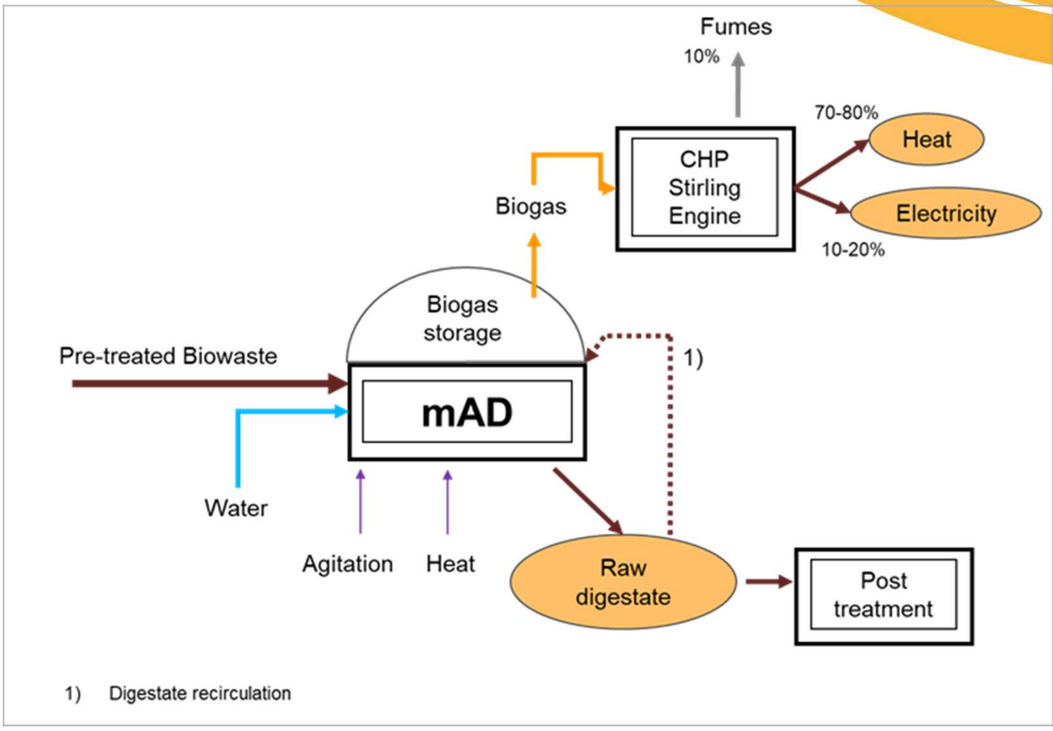


Figure 5 - Representation of the mAD and the Stirling Engine process for the alternative system (Source: own elaboration)

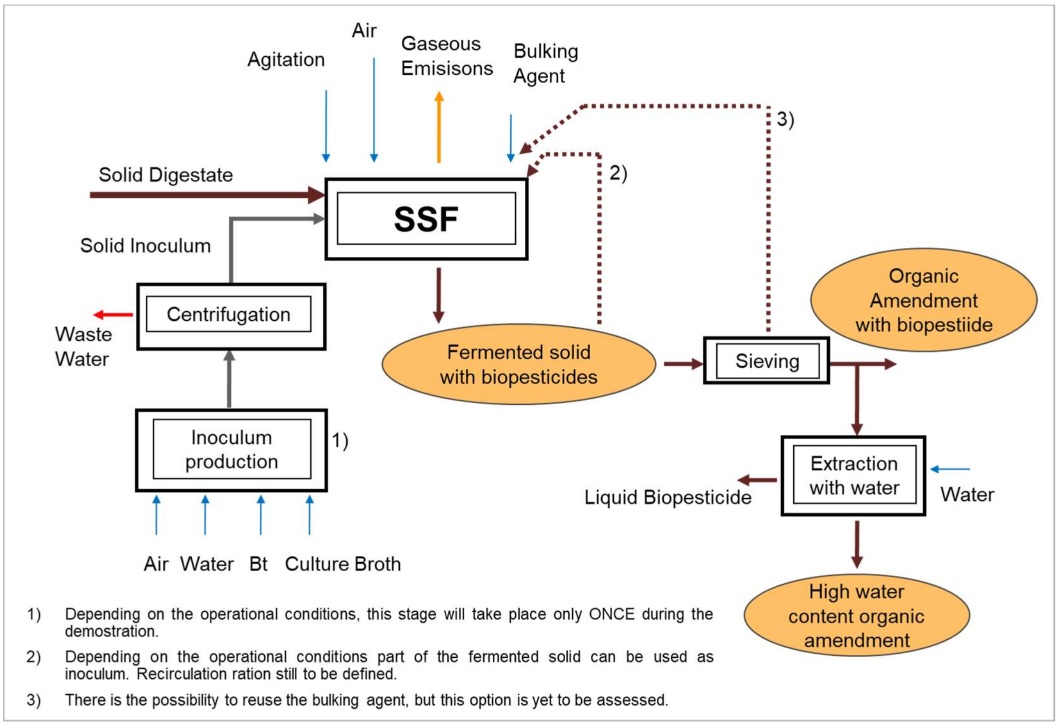


Figure 6 - Representation of the Solid-State Fermentation process for the alternative system (Source: own elaboration on data from D.4.6)

Once the flow chart of the alternative system has been defined, a further step in the characterization of the “alternative scenario” is the elaboration of the related mass and energy balance. The calculation method and the assumptions used for the prospective mass and energy balance of the alternative system have been included in Annex A2.

Table 3 presents the parameters to characterize the alternative system in terms of technical requirements. The indicated parameters are evaluated for the individual process units (storage, pre-treatment, mAD, post-treatment (e.g. hygienization), biogas valorization (CHP with Stirling engine), digestate valorization (e.g. SSF). By integrating the information coming from each unit, an assessment of the technical requirements for the entire alternative system can be carried out to support the site selection.

Table 3 - Technical requirements of the alternative system to support the site selection

PARAMETERS for all equipment	Unit
Biowaste input (capacity of the mAD)	t/year
Space occupied, overall dimensions	m^2
Water consumption	m^3/year
Thermal energy consumption	MJ/year
Electricity energy consumption	kWhe/year
CHP Power Capacity nominal	kW
Electrical	kWe
Thermal	KWth
Biogas production	Nm^3/year
Thermal energy production	$kWht_h$/year
Electricity production	kWh_e/year
Digestate production	t/year
Solid Fertilizer	t/year
Liquid Fertilizer	t/year
Maintenance cost	€/year
Total cost	€
Operating personnel requirements	working hours/year

2.2.2 Demonstration site selection criteria

When dealing with the delicate issue of selecting a place where to install an innovative system it is needed to take into consideration the bilateral connection between the criteria to select the specific technologies and the site selection criteria.

Site selection criteria is subdivided into three concepts: viability, desirability and potential:

- *Viability:* criteria of technical and economic and legal viability concerning the compatibility with processes related to technologic and economic constraints. They reply to the questions: Is the amount of input biowaste enough to feed the mAD? Do we have the appropriate technology? Do we have enough space? Do we have water and energy connection? Are the costs affordable? Is it in line with legislation?
- *Desirability:* criteria of social compatibility linked to the consistency of the project with institutional strategies, legislation and social values and reply to questions such as: Will the population accept the project? Are there any cultural barriers?
- *Potential:* criteria of demonstration potential linked to the replicability and transferability of the project replying to questions such as: Will the initiative be easily replicable in another place with the same characteristics? Will the project be repeatable in another place even under different conditions?

In *Table 4* a list of criteria to support the decision on the site for the implementation of DECISIVE systems has been proposed together with relevant comments and reflections.

Table 4 - List of viability, desirability and potential criteria to select the demonstration site for the alternative system

Viability Criteria			Comments/reflections
BIOWASTE INPUT		Type of generation sources (households/commercials)	It is important to check the quality (impurities content) of biowaste input for the alternative system.
		Available amount of biowaste in the selected area	This criterion determines the scale and type of the alternative system.
		Agreements of biowaste supply	Biowaste input (quantity and quality) to the plant needs to be guaranteed.
LOGISTIC - TRANSPORTATION		Proximity to waste generators	Biowaste treated where it is produced can both reduce transportation costs and incentivize biowaste reduction in the area by increasing people awareness about waste generation.
		Proximity to peri-farms area (to avoid cost of digestate use)	If the alternative system is to be implemented in peri-urban areas, location will probably be far from waste generators but at least close to the areas where to spread digestate.
		Logistic of routes and morphology of territory	Optimization of transportation is needed.
TECHNOLOGY		Maximum amount and quality of biowaste input	Analysis of mAD technologies available on the market is needed. Storage unit needs to be considered for buffering reasons. Biowaste pre-treatment and digestate post-treatment units are needed especially if the biowaste quality is low (high macro-impurities content).
		Biophysical requirements	The analysis of Flows and Funds (see *Figure 3)* is needed.
		Costs (fixed and operational)	The choice of technology is constrained by the available budget.
		Efficiency of Biogas production	In mAD it is quite difficult to maintain constant biogas production.
OUTPUTS	DIGESTATE	Treatment Cost Responsibility	The responsibility of paying for the treatment of digestate needs to be considered.
		Quality	Without pre-treatment of biowaste, impurities can be present and influence the fertilizer quality.
		Availability (budget and space) to treat digestate	Need to consider the requirements for the post-treatment of the digestate (composting, hygienization, or another valorization)
	BIOGAS	Delivery of Electricity Surplus	If there is electricity surplus, self-consumption by the responsible of the mAD can be considered.
		Surplus of thermal energy	Proximity to existing heat demands needs to be checked.
LEGISLATION		Regulation limitations & permits	Compliance with European regulations (Landfill Directive, Recycling targets of the WFD, requirements of the bio-based products to be sold as fertilizers (e.g. limit concentrations of micro-pollutants) need to be checked. Analysis of local regulations (maybe much stricter than EU regulations) needs to be take into account. Each area has specific legislation limitations for implementing the alternative system that need to be explored before to start any further analysis. Time for achieving authorizations needs to be considered.
Desirability Criteria			**Comments/reflections**
INSTITUTIONAL CONSTRAINTS and INCENTIVES		Availability of incentives	The existence of subsidies for green energy production or recycling can support the implementation.
		Acceptance of population	Population can disagree regarding the installation of the alternative system. Allowing for participatory processes in relation to the implementation of the alternative system could be useful.
		Sensibility to waste management issue	The introduction of the alternative system could be easier in areas where good practises of waste management are already in place. Contrary, the percentage of improvement of the system could be higher in an area with lower current performance.

Potential Criteria		Comments/reflections
DEMONSTRATION POTENTIAL	Replicability	The conception and results of the alternative system should be reproducible in other sites with similar characteristics. If the host of the alternative system is a public entity with orientation to investigation this can facilitate dissemination and then the replicability of the initiative.
	Transferability	The result of the alternative system should be applicable in other sites even under different conditions.

2.2.3 Needed characteristics for the study zone and the demonstration site

To analyze the site where the DECISIVE system will be located, the information to gather includes technical and legal requirements and social aspects (*Table 5*).

The technical elements to be checked in the chosen location are: 1) surface available to implement the DECISIVE scheme taking into account not only the required area for the entire equipment but also the space needed for trucks' manoeuvring; 2) accessibility to the area and logistic of the routes from biowaste collection to the final delivery to the DECISIVE plant and 3) status of the energy and water provisions. For point 2) a GIS map or simply a description of the entire area (according to the availability of the data) needs to be provided to support the logistic optimization of the waste transportation.

Concerning the legal requirements, compulsory permits (land use, building, etc.) and time required to achieve them need to be checked to comply with the local regulation before the implementation of the DECISIVE plant.

The presence of the DECISIVE system can be accepted by people living in the surrounding area but can also create the so-called NIMBY (Not in my Back Yard) effect. Qualitative parameters such as visual impact, odours or noise generation have been proposed to measure this social aspect. The distance between the DECISIVE equipment and the closest residential premises has also been proposed among the parameters to evaluate the social impact of the DECISIVE scheme. In some cases, a minimum distance between mAD plants and houses is compulsory, so in these cases this element belongs to regulatory & legislation compliance. French law, for example obliges a distance of 50 or 100m between AD plants and houses. The last social parameter proposed is the concern about sustainable biowaste management that can be measured (more in details later in the project) comparing the share and the quality (content of macro-impurities) of the source-separated biowaste *ex-ante* and *ex-post* (before and after the implementation).

Table 5 - Relevant information about the study zone and the demonstration site to develop the alternative system

Territorial level	ELEMENTS	PARAMETERS	Unit
Demonstration site	Technical requirements	Available surface to place the equipment	m^2
		Existing energy and water provisions	Y/N
		Logistic of routes and morphology of territory	Description
			Maps
Study zone	Legal requirements	Local permits' limitations	Building and environmental permits and local regulations
	Social aspects	Labour	working hours/year
			Qualification levels
		Space required to handle waste	m^2 needed in private houses, urban areas, and industrial areas
		Acceptance (NIMBY effect)	Y/N (odours, noises, visual effect)
		Proximity to urban areas	m
		Concern about sustainable biowaste management	Y/N % of source-separated biowaste on total MSW
			Macro-impurities (% of plastic, paper etc.) in source-separated biowaste

2.2.4 Analysis of demand for valuable outputs

Table 6 summarizes all the parameters that could be used to analyze alternatives for the valorization of outputs (biogas and digestate) in relation to the specific conditions of the sites, and their heat, power and material demands. Among such parameters, the available land to spread fertilizer, the characteristics of digestate to spread, and the heat demand of surrounding areas have higher priority than the fertilizers and biopesticides market demand due to the availability of the data.

An analysis of local heat demands from existing infrastructures such as industries, schools, hospitals and swimming pools can be done to evaluate potential uses for the thermal energy produced from the DECISIVE systems once the heat demand of the process itself has been covered.

The potential for nearby use of digestate/fertilizers/biopesticides can be also evaluated in terms of available land for spreading the digestate locally and local and national market demand for fertilizers and biopesticides. Regarding the use of digestate as fertilizer, the limitations in content of micro-pollutants is key to matching the limits established by regulation defining if the fertilizer is marketable

Table 6 - Analysis of demand for valuable outputs from the alternative system

DECISIVE SYSTEMS' VALUABLE OUPUTS DEMAND		
ELEMENTS	**PARAMETERS**	**Unit**
MATERIAL valorization	Available land to spread digestate/fertilizer	ha
	Distance of the demonstration site to the land where to spread digestate	m
	Fertilizer/soil improver market demand	t/year
	Bio pesticides market demand	t/year
ENERGY valorization	Existing local thermal energy demand	Y/N
	Thermal energy demand	kWh/year

3. Application of the methodology to the demonstration sites

To preliminarily test the viability of implementing the DECISIVE decentralized innovative valorization of biowaste in Lyon and Catalonia demonstration sites, the methodology of characterization developed in the previous chapter is here applied. This chapter describes such application for Lyon (*3.1*) and Catalonia (*3.3*). Both sections have the same structure that includes first the characterization of the three types of areas, i.e. targeted territory, study zone and demonstration site, and then a description of the critical points for implementing the pilot. However, there is an additional subsection for Catalonia (*3.3.1*) that describes the selection and confirmation process of the specific demonstration site, which was not decided before the project started as done for the Lyon case.

3.1 General considerations for both demonstration sites

In both demonstration projects, urban commercial biowaste will be the main feedstock for the mAD units. Energy produced will be used both for self-consumption of the pilot and for eventual local energy demands and the produced organic fertilizers will be likely used in nearby areas together with the bio-pesticides generated by SSF processes.

It is important to underline that, while two mAD systems with different treatment capacities for each site (50 t/year for Lyon and 200 t/year for Catalonia) will be bought from commercial suppliers, in the case of SSF, only one unit will be assembled at pilot scale. In principle, this unit will be used on the Catalonia site during the first year of the demonstration and then it will be transferred to the Lyon site during the following year. The SSF pilot will not be able to valorize the entire amount of digestate generated in the mAD, but it has been estimated that it will be dimensioned for around 10% of the produced digestate in the mAD pilot with the highest treatment capacity (Catalan pilot).

The boundaries of the "study zones" have been defined taking into account the treatment capacities of both pilots and the amount of biowaste generated in the area including not only the source-separated biowaste but also the non-separated biowaste that is currently thrown away in the residual bin. For the GL 100% of biowaste is still in residual waste since no biowaste separation at source is actually made, while for the AMB around 68%[7] of generated biowaste is still in the residual waste.

Since the specific mAD technologies to use in both demonstration sites are not decided yet and also the real characteristics of biowaste inputs are not yet available, assumptions have been considered to make preliminary calculations for elaborating preliminary mass and energy balances. It has been assumed to use the same type of technology equipment for both demonstration sites but sizing them according to the annual biowaste input for Lyon and Catalonia. Calculation details are included in Annex A2. Further information related to mAD can be found in D3.5[8] and D4.1.

The SSF process at a pilot scale is also not defined yet, because it depends greatly on the AD technology and the digestate characteristics. Quantitative indications related to material flow analysis and energy balance and technical requirements of the SSF process are not included in this report, but they will be evaluated during the demonstration phase of the project. Further information related to SSF are reported in D 4.6[9].

Biogas generated during the anaerobic digestion process will be valorized by using Stirling Engines provided by ITS (a partner of DECISIVE project). A SE for each demonstration site will be built ad-hoc according to the biogas production which depends from the biowaste input to the mAD.

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[7] Own calculation on ARC,2016 and PRECAT20 2015 – assuming that the share of biowaste in generated MSW in Catalonia (39,9%) is the same of the AMB, and that 12,5% is the percentage of source-separated biowaste collected in the AMB, the biowaste remaining in residual urban waste is around 68% out of the generated biowaste in MSW.

[8] http://www.decisive2020.eu/wp-content/uploads/2017/09/Survey-on-waste-collection-systems-with-evaluations-for-decentralised-applications.pdf

[9] http://www.decisive2020.eu/wp-content/uploads/2017/09/Report-on-the-possibilities-of-digestate-use-from-SSF.pdf

3.2 Lyon case study: current knowledge

3.2.1 Characterization of targeted territory

The "Grand Lyon" (GL) is a local authority gathering 59 municipalities around Lyon. The city developed around 2 rivers: the Saône and the Rhône, the latter flowing from Lake Geneva down to the Mediterranean Sea. The GL covers 534 km² and in 2014, its population was 1.3 million inhabitants[10], which represent about 600,000 households[11]. It is located within a greater urban area of 2.2 million inhabitants, the second largest in France. The GL density is 2,383 inh/km², with central city Lyon having a density of 10,583 inh//km².

The GL is in the Rhône Department, which is itself part of the Auvergne-Rhône-Alpes region, a very dynamic region with a strong industrial past. The economy is mainly organized around the industrial and commercial sectors. The GL is the most important urban area in France for industry. Pharmaceuticals, chemistry, petrochemistry, automotive, glass and food industries are the most prominent. In terms of services, banking and finance as well as logistics are the stronger sectors (see *Table 7*).

The GL also prides itself in being the French capital of gastronomy: it has 4,418 restaurants, including 19 Michelin-star ones. The agricultural area covers about 10,000 ha, corresponding to 20% of the GL surface area. Most agricultural sectors are represented: cereal crops, stock rearing, arboriculture, horticulture and vegetables.

Figure 7 - Location of GL in France (Source: Forthcoming D3.8 to be published in April 2018)

Table 7 – Employee jobs in the GL (source: "CHIFFRES CLÉS 2017"

Number of employee per sector	
Sector	***Values***
Industry	75,524
Health	58,770
Digital	40,610
Security & cybersecurity	26,300
Logistics	15,317
Insurance	10,092
Other	421,242
Total	**647,855**

[10] INSEE 2014 cited by Grand Lyon, in "Direction de la Propreté", Rapport annuel 2014
[11] Grand Lyon 2014 - "Direction de la Propreté", Rapport annuel 2014
https://www.grandlyon.com/fileadmin/user_upload/media/pdf/proprete/rapports/20151216_gl_proprete_rapportannuel_2014.pdf

3.2.1.1 Waste management system in the GL

The Grand Lyon separately collects the following types of household waste:

- Recyclables (paper, cardboard, plastics), in containers for each individual house or buildings
- Glass, in bring-points
- Bulky and hazardous waste, at Civic Amenity Sites (CAS)
- The remaining is collected as residual waste, in containers for each individual household or building.

In addition to waste from households, the GL also collects waste from private companies and public organisations (service sector) of the same type and in the same quantities as households' waste, i.e. up to 840 litres per week and per organisation (this number includes recyclables and residual waste). Municipal waste from service sector is aggregated in the GL statistics under the category "waste from household and equivalent" that corresponds to MSW from households and the service sector (see *Table 8*). Biowaste is not separately collected as other waste fractions such as glass, plastic, metal, paper & cardboard those reach 42% of the total MSW generated in the GL (*Table 9*). Thus, all the biowaste is found in the residual waste bin.

Table 8 - Municipal Solid Waste collection from household and service sector in the GL, mass by source (source: Grand Lyon 2014)

WASTE COLLECTION in the GL in 2014	t/year	Percentage
Residual waste home/building containers	308,776	58%
Recyclable waste home/building containers	63,927	12%
Glass bring points	26,734	5%
One-off collections (paper, asbestos, Christmas trees…)	236	0%
Bulky and hazardous waste, at Civic Amenity Sites (CAS)	133,296	25%
	532,969	**100%**

Table 9 - Key data for Waste source-separated collection in the Grand Lyon (source: Grand Lyon 2014)

SOURCE-SEPARATED WASTE COLLECTION in the GL in 2014				
ELEMENTS	**PARAMETERS**	**Unit/type**	**Values**	**Sources**
Performance of source-separated waste collection				Grand Lyon (2014)
	% of source-separated fractions on the MSW generation	%on total generated MSW	42%	
	Source-separated biowaste of total MSW	%on total generated MSW	0%	
	Paper & Cardboard	%on source-separated MSW*	21%	
	Plastic	% on source-separated MSW	1.5%	
	Glass	% on source-separated MSW	12%	
	Metal	% on source-separated MSW	3.4%	
	Other	% on source-separated MSW	64%	

*Source-separated MSW represents the MSW generation discounting residual waste

The French Environmental Agency (ADEME) published a methodology to assess biowaste generation based on the various types of sources. The methodology considered a ratio to reflect the fraction of biowaste that could potentially be collected, the rest being still mixed with residual waste. This methodology was used to estimate the biowaste sources and amounts shown in *Figure 8* and *Table 10.*

Table 10 - Biowaste sources and quantities generated in the Grand Lyon

Targeted territory: The Grand Lyon				
GENERAL INFORMATION				
ELEMENTS	**PARAMETERS**	**Unit/type**	**Values**	**Sources**
Biowaste sources	Type of activities identified in the area to study	Agricultural, industrial, commercial, residential	The DECISIVE demonstration will focus on restaurants	
	Household sector	Number of inh.	1,351,078	Eurostat (2014)
	School canteen	Type (meals/year)	7.8 million for primary (144,945 students) 12.9 for secondary (129,986 students)	Survey + estimation based on ADEME values
		N of restaurants per type	543 primary, 166 secondary	Governmental data (www.data.gouv.fr)
	Health facilities	Type (meals/year)	15.7 million for hospitals 15.4 million for other facilities	Estimation based on ADEME values
		N of health facilities	40 hospitals, 874 other facilities	Base FINESS
	Collective catering	Type (meals/year)	40 million	Estimation based on ADEME values
		N of restaurant per type	515 but 347 included for the study (to avoid double counting with hospitals and schools)	SIREN (2016)
	Traditional restaurants	Type (meals/year)	42 million	Estimation based on ADEME values
		N of restaurant per type	3103	SIREN (2016)
	Total Restaurants	N of restaurant per type	4,418 all together	Chiffres-clés 2017, Grand Lyon, 2017
	Hotel	Type (N of clients or beds/year)	4.7 million hotel nights	Chiffres-clés 2017, Grand Lyon, 2017
		N of hotel per type	266 all together	Chiffres-clés 2017, Grand Lyon, 2017
	Lawn cutting	Surface of lawn (ha)	8,299	IGN BD ORtho
BIOWASTE GENERATION				
Amount of biowaste flows generated	Total Amount	t/year	102,023	Estimation from the methodology developed in D3.8 to be published in April 2018
	Biowaste from Households	t/year	67,173	Estimation from the methodology developed in D3.8 to be published in April 2018
	Biowaste from Restaurants	t/year	School canteens: 3,542 Health facilities: 4,043 Collective catering: 5,163 Traditional restaurant: 5,503	Estimation from the methodology developed in D3.8 to be published in April 2018
	Other (co-substrates: Grass)	t/year	16,599	Estimation from the methodology developed in D3.8 to be published in April 2018

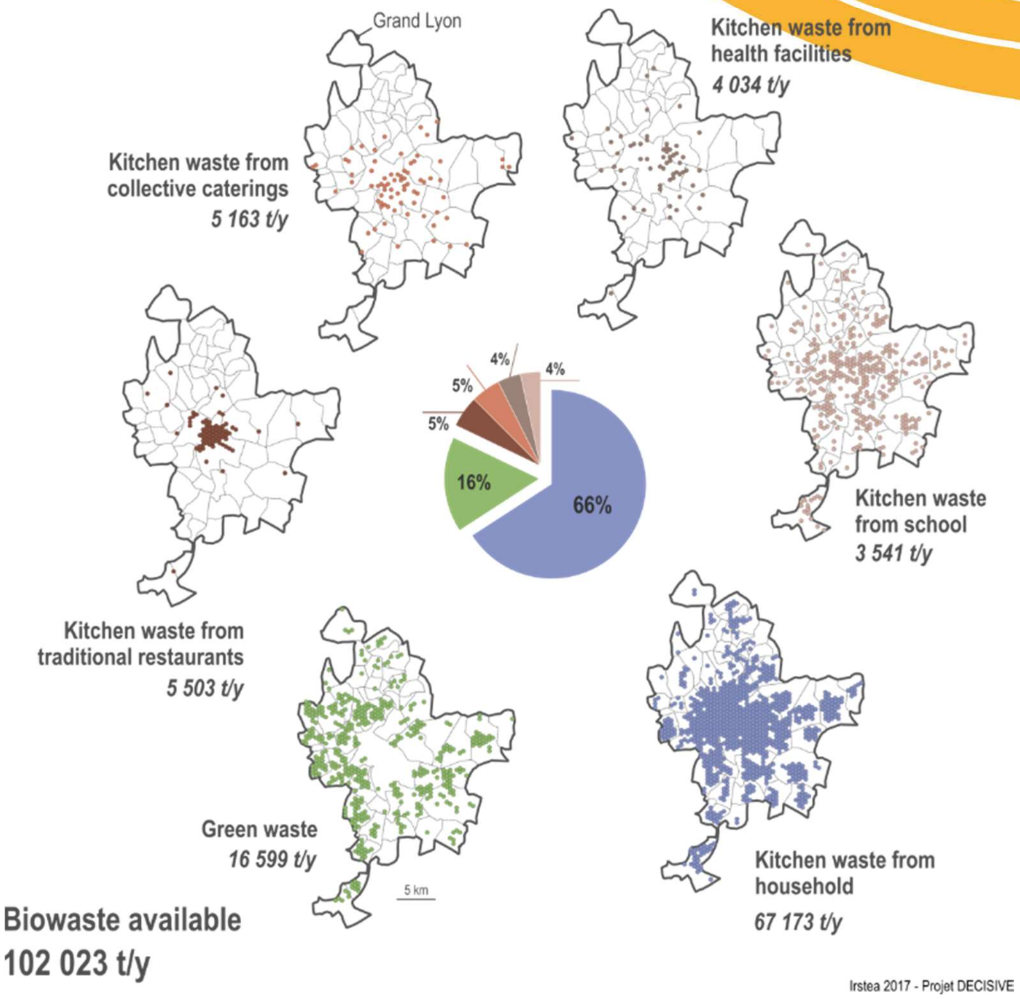


Figure 8 - Biowaste sources and quantities generated in the Grand Lyon (Source: Forthcoming D3.8 to be published in April 2018)

Main figures on waste treatment in the GL are inserted in *Table 11*. Collected recyclables are sorted in specific units and 69% is eventually recycled. The rest goes to incineration (27%) or landfill (3%).

Table 11 - Treatment of MSW from household and service sector in the GL, mass (source: Grand Lyon 2014)

WASTE TREATMENT	t in 2014	% on Total MSW
Total waste incinerated with energy production	314,326	59%
Residual MSW incinerated	297,363	56%
Refuse from recyclables incinerated	16,963	3%
Waste sent to material valorization through recycling	118,149	22%
Waste sent to material valorization other than recycling (backfill)	32,359	6%
Total waste to Landfill	32,395	6%
Residual MSW landfilled	11,414	2%
Refuse from recyclables landfilled	19,325	4%
Waste sent to Composting	32,589	6%
	529,818	**100%**

The GL has two incineration units (Lyon South and Lyon North), which treat waste from the GL (84% of total capacity) but also from other territories. A fire at the Lyon North unit in 2013 disturbed its operations in 2013 and 2014. *Table 11* summarizes the amounts treated in 2012 and the energy performances of both incinerations units.

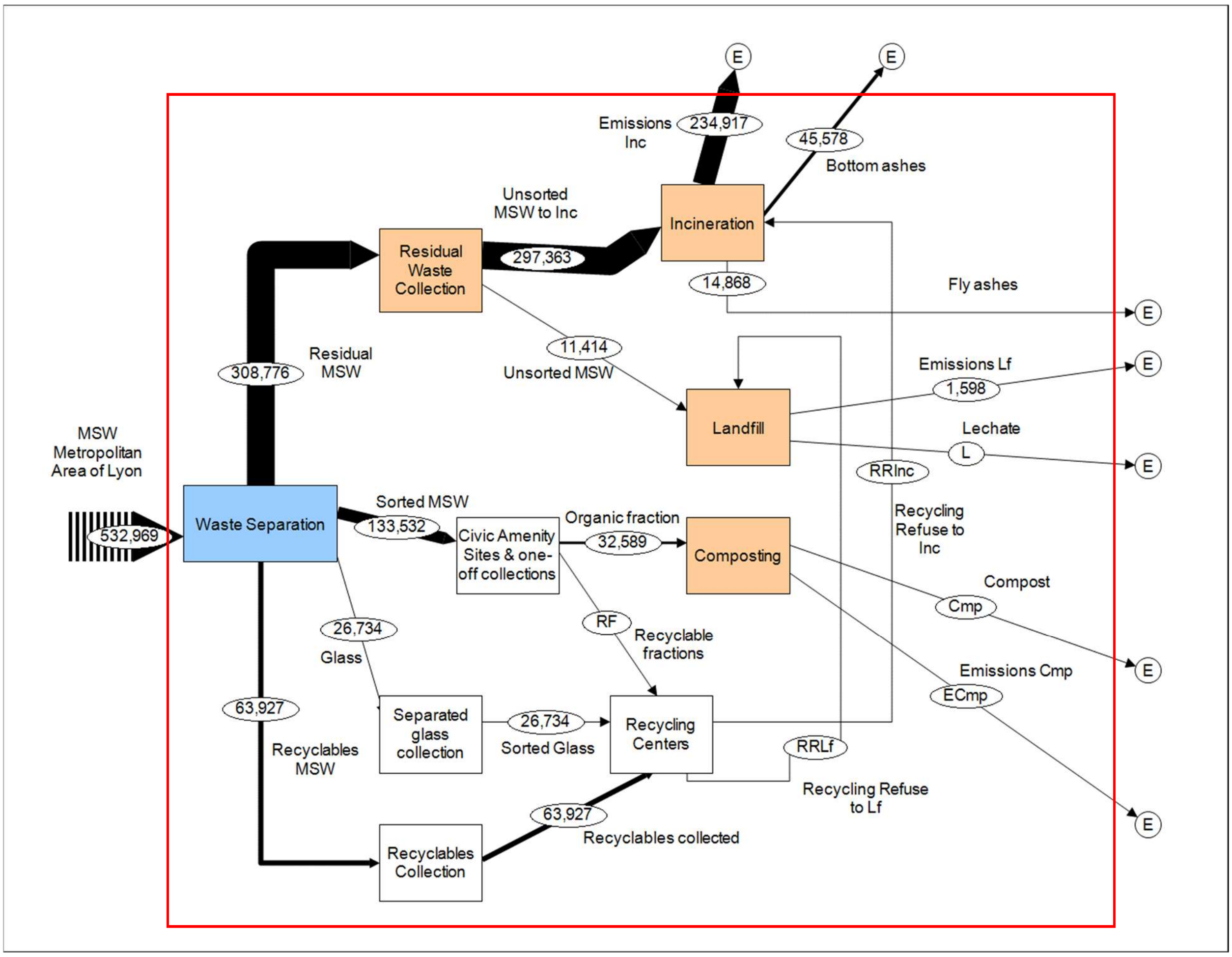
Table 12 - Amount of treated waste and energy performance of local incineration units (source: Grand Lyon 2014)

INCINERATION	t in 2012*		Energy performance**
Lyon Sud	239,917	64%	70%
Lyon Nord	132,644	35%	50%
External Units	2,623	1%	*60%****
	375,184	**100%**	

**2012 numbers as a fire in 2013 disturbed one of the units in 2013 & 2014*
*** energy performance: this indicator based on a formula specified in the French official memorandum (circulaire 09-030 du 30 mars 2009 publié au Bulletin officiel des douanes le 30 mars 2009) represents a ratio between produced and consumed energy by the incineration unit*
**** assumption*

Using all the information summarized above, the mass-flow diagram of the MSW generated in the Grand Lyon was developed (*Figure 9*).

The red frame represents the boundaries of the system and the acronym E indicates the mass flows going outside the boundaries.



BW: Biowaste; Lf: Landfill; Inc: Incineration; Cmp: Composting; RF: Recyclable Fractions; RR: Recycling Refuse; E: external mass flows (going outside the boundaries' system)

Figure 9 – Mass-flow diagram of the waste management system of the Grand Lyon in 2014. Values in t/year (2014). (Source: own elaboration)

3.2.2 Characterization of the study zone

The Lyon DECISIVE pilot will be installed at CFPH (*Centre de Formation et de Promotion Horticole*), a public horticulture training and promotional centre. CFPH is based on a 10-hectare piece of land in the city of Ecully, right on the outskirts of Lyon, about 1 km from the nearest metro station and about 200 m from the limit of the city of Lyon (see *Figure 10*). The demonstration site is therefore surrounded by a dense urban area, but is quite unique as these 10 hectares are not built, but dedicated to landscape, horticulture & farming. CFPH is part of a local public institute, which also includes a high school, a commercial nursery & horticulture farm (1,000 m²) that is used for vocational purposes and the regional centre for apprenticeship.

This public institute (EPLEFPA – *établissement public local d'enseignement et de formation professionnelle agricoles*), under the Ministry of Agriculture, focuses on horticulture, landscape & agriculture and prepares for the jobs of tomorrow in urban farming and urban bio-waste management. It has a population of 300 students following a conventional curriculum (16-20 years old), 250 apprentices (14-20 years old), as well as adult students: 50 of them on long-term programmes and 1,000 on short-term programmes.

In addition to its primary educational mission, the public institute is also concerned with socio-economic inclusion, animation of the rural territory, experimentation / innovation and international cooperation. These missions are conducted in particular through the CFPH, which developed partnerships with several urban agriculture projects that are based on their site:

- Api Environnement, bee-keeping
- La Ferme de l'Abbé Rozier: a social inclusion organic farming project
- Refarmers (member of the DECISIVE consortium): vertical hydroponics

Figure 10 - Location of the Refarmers site (Lyon demonstration site) (Source: Google Maps)

3.2.2.1 Definition of the boundaries

The "study zone" for the Lyon case (called "Lyon study zone") has been defined as a theoretical area centred around the demonstration site whose position was already defined from the beginning of the project in the "Refarmers site" that should provide 50 t of biowaste per year collected from restaurants. A radius of less than 2 km has been fixed in order to define this zone to characterize the baseline scenario.
It is important to underline that at this preliminary stage of the project, the delimitation of the study zone has been made first looking generally at the sources located in proximity of the demonstration site and then focusing only on the biowaste sources targeted by the project. The real boundaries of Lyon study zone will be defined in a more accurate way, considering the area where restaurants willing to take part in the demonstration are located.
As mentioned above, source-separation of biowaste is not compulsory in the Grand Lyon so the restaurants that will be involved in the project will be the ones to which Refarmers and/or the CFPH deliver fresh produce – testing a circular model – and that will agree to take part in the demonstration and voluntarily source-separating their biowaste.

It was estimated that 41 restaurants located in this area (the 2-km theoretical area), generate a total of 57 t/year of source-separated biowaste that discounting the macro-impurities can feed the mAD. *Figure 11* and *Table 13* reports all the biowaste sources around the Refarmers site. It is possible that in a later stage of the project, some of the 41 restaurants needed to get the 50 t/year of biowaste will be located outside of the 2-km theoretical area. The campaign to identify partnering restaurants has not started yet at this stage of the project. Adding co-substrates such as lawn cuttings to the biowaste generated restaurants as input for the mAD could be also a possibility to investigate. It is important to underline that the maps in *Figure 9* and *Figure 11* are designed in 2017 but they are based on the most recent data available (oldest data are related to 2013) since the method implies the use of various databases that have not been created at the same time.

Table 13 - General information in the Lyon study zone

General information & biowaste generation – Lyon study zone				
ELEMENTS	**PARAMETERS**	**Unit/type**	**Values**	**Sources**
Demographic characteristics of the area	Population	N inh	36,240	Forthcoming D3.8 to be published in April 2018
	Area	Km^2	± 6	
	Urban density	inh/km²	± 6,000	
	Residential area	Type (N of inh/households)	36,240	
		N of household per type	td*	
	Commercial restaurants	Type (meals/year)	440,150	
		N of restaurants	41	
	School canteen	Type (meals/year)	117,529 for primary schools (3,711 students) 458,605 for secondary schools (4,862 students)	
		N of restaurant per type	21 primary, 8 secondary	
	Health facilities	Type (meals/year)	265,930 for hospitals 1,104,064 for other facilities	
		N of restaurant per type	1 hospitals, 32 other facilities	
	Collective catering	Type (meals/year)	952,381	

*td: to define later in the project

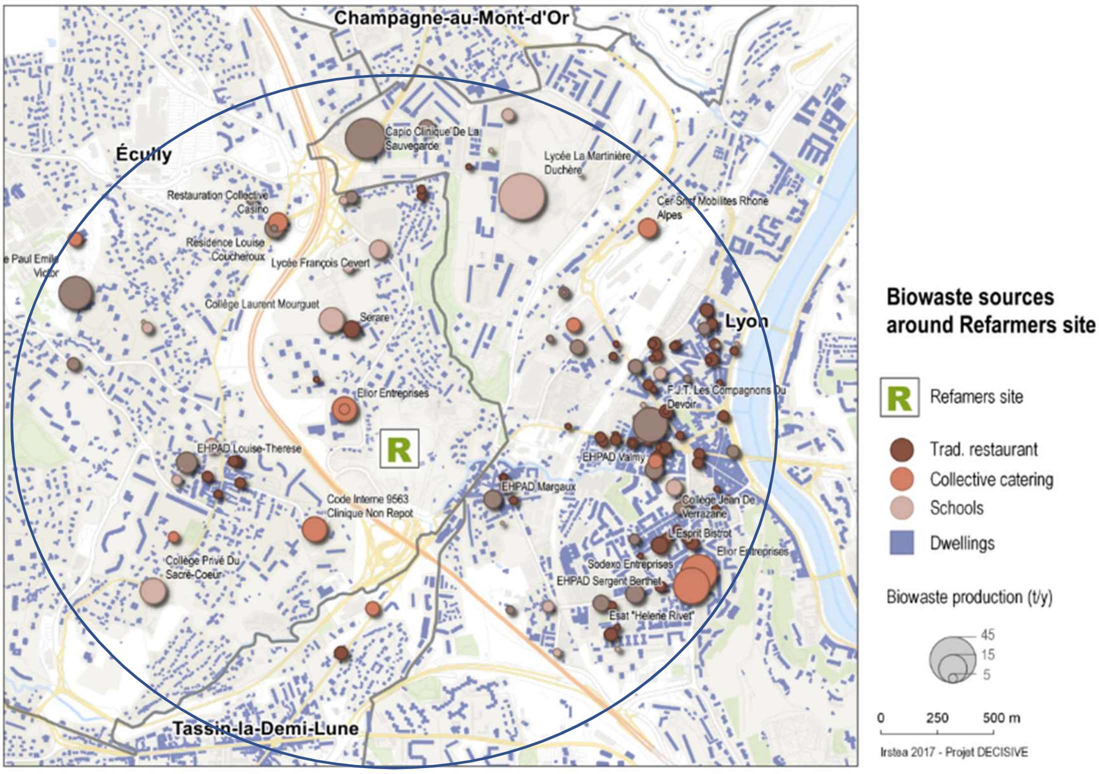
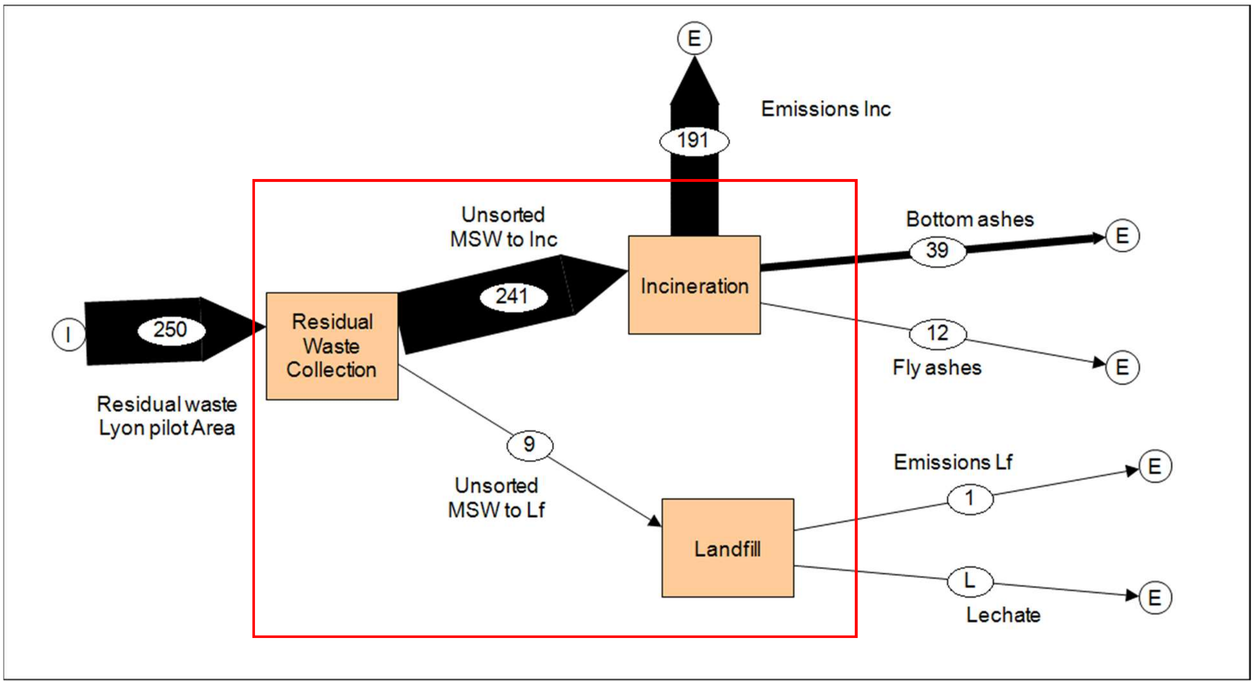


Figure 11 - Map of biowaste sources and quantity estimates in the targeted area based on the most recent data available. (Source: Forthcoming D3.9 to be published in August 2018)

3.2.2.2 Waste management system

The current waste management system in the "Lyon study zone" is the same as in the GL. MSW and consequently the biowaste included in the residual waste is mainly incinerated. In the Lyon pilot the mAD will be dimensioned with a capacity of 50 t/year, but to reach this amount of biowaste it will be needed to analyze a yearly amount of 250 t of MSW to compare baseline and alternative scenario (considering a recovery rate for biowaste of 70%[12] and that biowaste represents around 30%[13] of total MSW). *Figure 12* shows the mass flow of the study zone.



Lf: Landfill; Inc: Incineration; E: external mass flows (going outside the boundaries' system)

Figure 12 – Mass-flow diagram of the waste management system of the Lyon demonstration zone related to baseline scenario. Values in t/year (2014) (Source: own elaboration)

3.2.3 Characterization of the "alternative scenario"

3.2.3.1 Checking the adequacy of the Lyon demonstration site

The assessment methodology presented in *2.2.2* is applied to the Lyon demonstration site, which was however chosen at the outset of the DECISIVE project. The criteria presented to select the site are used here to confirm the adequacy of the site itself (see *Table 14*).

Table 14 - List of viability, desirability and potential criteria to select the site for the alternative system applied to Lyon demonstration site

Viability Criteria		Considerations on Lyon site
INSTITUTIONAL CONSTRAINTS	Regulation limitations & permits	Local authorities have expressed great interest in the alternative system and have been supportive of the demonstration implementation, because it is highly innovative, Limitations foreseen from the applicable regulations need to be respected.
INPUT BIOWASTE	Type of generation sources	The nature of the site does not affect the quality or quantity of collected biowaste, which comes from selected external sources, i.e. restaurants.
	Available amount of biowaste	

[12] RÉDUIRE, TRIER ET VALORISER LES BIODÉCHETS DES GROS PRODUCTEURS
Guide pratique, Novembre 2013, Étude réalisée pour le compte de l'ADEME par IDE Environnement Contrat n°1206C0033

[13] Estimation on data from French environmental agency (ADEME); MSW has 31% of "putrescible" waste, which includes food waste (23%).

	Agreements of biowaste supply		Refarmers and the CFPH already have commercial relationships with a number of restaurants and plan to reach out to more, so as to collect the needed quantity of biowaste.
	Quality of biowaste		Biowaste collected from restaurants is expected to have a low content of macro-impurities.
TECHNOLOGY	Maximum amount and quality of biowaste input		Technological pilot is being designed based on an annual capacity of 50 t of biowaste.
LOGISTIC - TRANSPORTATION	Proximity to waste generators (to avoid logistic of transportation)		The aim is to collect biowaste from restaurants that are customers of Refarmers and CFPH to optimize logistics.
	Proximity to peri-farms area (to avoid cost of digestate disposal)		CFPH site is 10 hectares and the institute has another site (of 16 hectares) at 5 km from CFPH. GL has 10,000 hectares of agricultural land, most of which are located on the outskirts of the territory, up to 20 km from the pilot site.
OUTPUTS	DIGESTATE	Treatment Cost for digestate	Answering these questions is part of the demonstration objectives.
		Quality of digestate	Availability (budget and space) to treat digestate
		Proximity of areas to spread digestate/compost	Despite being within a 10 hectare-horticulture and farming site, the Lyon pilot site is surrounded by a dense urban area. It is therefore close to waste generators, and further away from areas to potentially spread digestate.
	BIOGAS	Delivery of electricity surplus	The Lyon pilot is located just outside a hydroponic greenhouse that can use the electricity surplus.
		Surplus of thermal energy to meet local heat demands	The greenhouse and a residential house are within a few dozen metres from the pilot and have thermal needs, which however vary with seasons. A hotel and conference centre are located about 250 m from the pilot with significant needs for thermal energy.
Desirability Criteria			**Considerations on Lyon site**
NORMATIVE CONSTRAINTS	Acceptance of population		Answering these questions is part of the demonstration objectives.
	Sensibility to waste management issue		There is no biowaste source separation in the GL so the DECISIVE demonstration has a potential to highly improve the environmental performance of the treatment of the collected biowaste, with a great potential for duplication if the demonstration is successful.
Potential Criteria			**Considerations on Lyon site**
DEMONSTRATION POTENTIAL	Replicability		As of today, there does not seem to be any constraints to duplicate the demonstration in other sites with similar characteristics.
	Transferability		The location and nature of the pilot site are quite unique: it has a large piece of land with farming and composting within a dense metropolitan area, and managed by a public institute with strong relationships with the farming and landscape sectors. These very specific conditions question the demonstration transferability which will have to be assessed during the project.

3.2.3.2 Technical description of the Lyon pilot

The pilot will be installed close to the Refarmers' greenhouse. Any electricity surplus - i.e. once the auto consumption of the pilot is discounted - produced by the Stirling engine will be stored on batteries and used to power pumps, lighting and ventilation. Any heat surplus will be used to heat the greenhouse, and potentially the nearby house and hotel. The DECISIVE pilot will be also near the main track going through the site, to allow easy vehicle access, see *Figure 13*. The pilot will be located more than 50 m away from the nearest building of the neighbour (hotel and conference centre Valpré) as it is foreseen by the local law[14] that fixes criteria and distance thresholds related to AD installations[15].

A centrifuge will be used to separate liquid from solid digestates. Part of the liquid digestate will be used as fertilisation by Refarmers. In the first demonstration phase, solid digestate and the rest of the liquid digestate will be spread on farm land as fertilizers. In the second demonstration phase, when the SSF unit has been moved from the Catalonia pilot to Lyon, part of the solid digestate will go through a SSF process to produce biopesticides. Technical requirements needed for the pilot to implement in the Refarmers site are evaluated in *Table 15*.

Table 15 - Technical requirements for the DECISIVE pilot in Lyon (own elaboration)

Technical requirements for the pilot in Lyon	**Unit**	**Values**
Biowaste input	t/year	50
Water consumption	m^3/year	22.9
Thermal energy consumption	kWhth/year	4,200
Heat demand in digester	kWhth/year	4,800
Electricity consumption	kWhe/year	5,200
Electricity demand in digester	kWhe/year	4,800
Fuel requirements	Liter/year	no need for extra fuel
Maintenance cost for the Stirling engine	€/year	300
Space occupied, overall dimensions	m^2	12
CHP Power Capacity nominal	kW	10
Electrical	kWe	1
Thermal	KWth	8
Operating personnel requirements	Working hours/year	1,638
Biogas production	Nm^3/year	3,400
Net Thermal energy production	kWhth/year	17,000
Net Electricity production	kWhe/year	20
Digestate production	t/year	61.6
Solid Fertilizer	t/year	4.2
Liquid Fertilizer	t/year	57.4

Figure 13 - View of the future DECISIVE pilot location with Refarmers greenhouse in the background marked as a yellow square

Lyon demonstration sites has an available surface of around 100 m^2 and is provided with energy connections. Further investigation is needed to check if roadworks are necessary between the entrance of the site (city street) and the

[14] Ministerial Order of the 26 November 2009 (Official Journal n°0274, the 26 of November 2009, p. 20312, text n ° 5).
[15] The pilot has been classified as AD installation according to Installation Classified for the Protection of the Environment (ICPE) heading 2781

demonstration site since this area is currently dirt. The needed permits and regulations to take into account for implementing this pilot are listed in *3.2.4*. The closest housing (CFPH employee, within CFPH site) is about 30 m away from the Lyon demonstration site while the closest urban area is 62 m far. Population acceptance for implementing the pilot is not yet investigated and concern about sustainable biowaste management can be considered basic since biowaste is mixed in the residual bin.

Analysis of local energy material demands

An analysis of thermal (heating or cooling) energy demands (schools, hospitals, companies, swimming pools) should be done to evaluate the possibility of using the heat produced from the pilot (net value discounting process heat demand (digester and hygienization). The final position of the hygienization in the chain will be most probably before digestion. The potentiality for nearby use of digestate/fertilizers should be also evaluated in terms of available land for spreading and local and national market demand but, at this phase of the project it is difficult to evaluate. Technical specifications of the sites will be defined in the future deliverable D4.1 and the assessment of these choices will be part of deliverable D7.3 by the end of the project.

A detailed theoretical mass & energy balance is given in *Figure 14*. In terms of energy, it shows that the pilot will use almost all the electricity it generates for its own process but that it will generate net heat (80% of total produced heat). In terms of mass, it shows that 90% of mass put in the system (2/3 biowaste and 1/3 water) comes out as digestate with fertilizing potential.

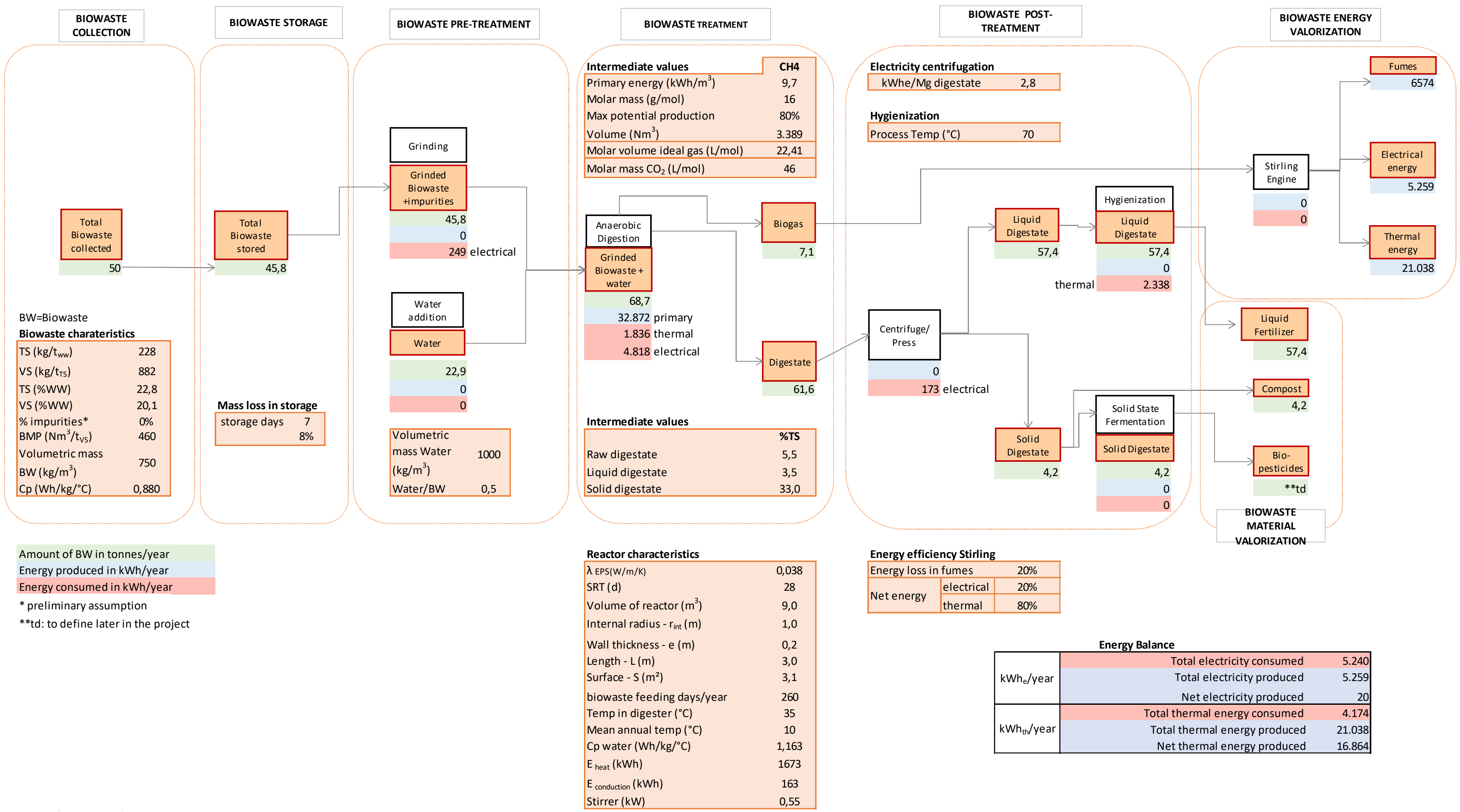


Figure 14 - Prospective mass and energy balance for the Lyon DECISIVE pilot in the Refarmers' site (Source: own elaboration)

3.2.4 Critical points before the implementation in the Lyon site

This part presents the potential problems related to biowaste sources and collection and critical points forecast for the implementation of the pilot in Lyon.

Source of biowaste input for the mAD: There is no biowaste separation in the Lyon region and the major part of waste from companies is collected for publicly financed. Since Refarmers does not manage the entire needed amount of waste, it was decided to focus on biowaste generated from restaurants for the Lyon demonstration site. The critical issue could be the difficulty in convincing a number of restaurants to separate their biowaste and maybe pay a fee for collection. Maybe the introduction of new legislations pushing for a better waste management could shape the actual situation. CFPH (through La Ferme de l'Abbé Rozier) already has such a deal with 2 restaurants, which shows it is possible. A first estimate shows we will have to collect from approximately 41 restaurants.

mAD technology requirements and constraints: Connections to infrastructure networks (water, grey water, electricity) need to be provided to treat a yearly amount of biowaste of around 50 t.

Budget constraints: The maximum cost for the alternative system will allow to decide about the affordability of the plant implementation. Training an operator at Lyon will be necessary so the relative cost needs to be taken into account among the operational costs to run the mAD

Use of energy production: During winter time, thermal energy can be used for the Refarmers Greenhouse and for heating the digester hygienizing digestate. The use of thermal energy production during summer is yet to be investigated. The potential electricity surplus may supply the water pump in the Greenhouse

Adaptation of the existing biowaste collection: As biowaste is not source-separated in the Lyon region, a specific collection of food waste in restaurants will have to be set up to gather the biowaste to feed the mAD. The amount of food waste currently collected is not enough to cover the needs of the DECISIVE pilot. FW collection from restaurants therefore has to be extended to other co-substrates such as lawn cuttings or if possible, households biowaste.

Permits needed for implementing the pilot: Building permit is needed[16]. Pilot falls under the 2nd tier of the legislation for "Sites Registered for Environmental Protection Installations[17]" Assessment of the environmental impact is required. This requirement can be waived on a case by case basis upon application.

Digestate management: Digestate application might fall under the legislation for spreading on agricultural land[18] that is under discussion with the relevant local and national authorities (Grand Lyon, Direction Départementale de la Protection des Populations, Direction Départementale des Territoires).

Implementation of SSF: The operation of the SSF is not critical for the required space but it could be critical because no experts will be constantly present on site. Training an operator will be needed.

Use of digestate and product from SSF: Raw digestate cannot be entirely spread on the CFPH site. However, among the permits needed, a plan for spreading is mandatory. The main solution could be the transportation of the digestate to nearby agricultural lands after its composting. The SSF products use is not a critical issue since the quantities will be very small and could be handled on site.

[16] Code de l'urbanisme: articles L421-1 à L421-9 - Opérations soumises à permis de construire; Code de l'urbanisme: articles R423-1 et R423-2 - Demande de permis de construire

[17] Classées pour la Protection de l'Environnement (ICPE)

[18] i) directive 91/676/CEE du Conseil du 12 décembre 1991 concernant la protection des eaux contre la pollution par les nitrates à partir des sources agricoles; ii) règlement 1257/1999/CEE du Conseil du 17 mai 1999 concernant le soutien au développement rural par le Fonds européen d'orientation et de garantie agricole (FEOGA) et pris en exécution des articles modifiant et abrogeant certains règlements; iii) code de l'environnement, notamment les articles L. 211-1 à L. 211-3, L. 214-1 à L. 214-7, L. 216-3, L. 512-5 et L. 517-2 des livres II et V; iv) décret n° 93-1038 du 27 août 1993 relatif à la protection des eaux contre la pollution par les nitrates d'origine agricole; v) décret n° 2001-34 du 10 janvier 2001 relatif aux programmes d'action à mettre en œuvre en vue de la protection des eaux par les nitrates d'origine Agricole; vi) arrêtés du 29 février 1992 et du 13 juin 1994 modifiés relatifs aux installations classées pour la protection de l'environnement; vii)arrêté du 22 novembre 1993 relatif au code des bonnes pratiques agricoles.

3.3 Catalonia case study: current knowledge

3.3.1 Selection and confirmation of the Catalan site

This section describes the ad-hoc process used to select the location and type of the Catalonia demonstration site. The draft list of criteria in *Table 4,* and the scheme in *Figure 4*, have been used to support the decision about the choice of the more suitable demonstration site. The critical points encountered during the process of selection and how these critical points have been solved has been reported. Pros and Cons for each location proposed to host the Catalan pilot have been analyzed and the site choice has been justified in *3.3.1.3*.

3.3.1.1 Critical points in the process of site selection in Catalonia

Several meetings with partners of the consortium have been carried out to identify and solve these critical points. For each criticality, proposed options have been presented to facilitate the final decision in the selection of the location of the pilot.

Source of biowaste input for the mAD

Anaerobic Digestion technology requires as input a very high quality biowaste (food waste, green waste excluding woody waste) with reduced presence of impurities otherwise an intensive pre-treatment system would need to be introduced. Since the equipment required for the DECISIVE project is microscale, an intensive pre-treatment would not be economically feasible.

The results regarding the source-separated collection of biowaste in Catalonia, after 20 years of experience, indicate that high levels of quality are only achieved in rural areas (<10,000 inhabitants) with the introduction of a door-to-door collection system and in commercial activities with a door to door collection in general.

According to the project proposal the site in Catalonia intended to treat mainly biowaste (food waste) from households but, different bottlenecks have been recognized in considering this type of input for the mAD: 1) to get 200 t/year of biowaste around 3,000 households (about 6,000 inhabitants) would need to be involved (considering the currently percentage of source-separated collection of biowaste and demographic composition per household in Catalonia), 2) the diversity of households puts at risk the control of quality of input biowaste demanding high supervision increasing operational costs, 3) to find an area available to place the pilot in a public area has shown to be difficult and 4) sensitizing a large number of citizens to improve the biowaste separation in terms of quantity and quality seems more difficult than sensitizing a commercial activity manager.

To overcome those limitations it has been decided to combine two decisions: 1) treat only “commercial biowaste” from activities such as restaurants or markets that are similar to urban waste according the definition of municipal waste and 2) measuring the indirect impact on the population living close to the demonstration site by estimating the changes in the habits of this population (e.g. biowaste generation and sorting) as a result of: a) Pilot implementation and b) Communication and awareness campaigns.

The Catalan demonstration site will start treating only commercial biowaste and then, if considered possible, biowaste from a few households could be added. Involving a small sample of citizens in the assessment of waste prevention effect in the households, could be a good compromise.

The possible involvement of a small sample of population mentioned in point 2 is desirable since the DECISIVE project aims to impact on the population to achieve a change in habits related to prevention in waste generation and to the improvement of the source-separated biowaste collection, the involvement of the population located in a delimited area close to the demonstration site would be considered as an important factor. The impact of the initiative would be measured in an indirect way comparing the amount of total waste generation and of source-separated biowaste and other fraction (and its level of impurities) before and after the implementation and running of the pilot.

It should be noted that in Catalonia the source-separated biowaste collection is implemented throughout the territory and currently all collection circuits are quantitatively and qualitatively monitored for centralized plants and from some composting decentralised plants. This implies that it would be feasible to check the indirect impact on the selected households in waste prevention and waste separation even if their biowaste would still be collected and treated in the same centralized facilities as currently.

Technological constraints regarding equipment requirements and site conditions

Each phase/process unit of the entire biowaste management chain that will be implemented on the Catalonia demonstration site has been analyzed to evidence the related requirements and constraints.

- ***Need for a pre-treatment unit:*** In principle it is preferable to avoid on-site pre-treatments to reduce costs and the surface requirement for the equipment. However, such a unit seems to be particularly important for the well-functioning AD to sort, store, shred and mix the biowaste before its anaerobic digestion (even if commercial biowaste will be used as input for the digestor and its quality in terms of macro-impurities should be better compared to household biowaste which is more difficult to control). As a matter of fact, one of the mAD technologies available on the market (SeAB) is facing problems due to the lack of enough pre-treatment before the anaerobic digestion: large particles, such as animal bones or fruit stones tend to block the system for pumping biowaste into the digester. To better prepare the input for the digestion and easing the biowaste degradation a further pre-treatment unit has been foreseen. The need for a pre-treatment should be considered when selecting the commercial mAD equipment for the demonstration site.
- ***DRY or WET Anaerobic Digestion:*** Neither relevant advantages nor disadvantages have been identified in selecting a DRY or WET process for the Catalan site. However, it has been evidenced that DRY AD technology is mainly used in centralized plants and it has shown to be difficult to find commercial options for microscale. Moreover, since part of the digestate produced in the Catalonia pilot will be used as input for SSF pilot managed by UAB, a solid/liquid separation unit is foreseen to properly prepare the digestate for the SSF. This post-treatment for the part of digestate that will be sent to the SSF will be especially needed if the final mAD is WET, the water content being a criticality for the SSF.
- ***Batch or Continuous Anaerobic Digestion:*** For “batch” or “continuous” solutions neither obvious advantages nor disadvantages have been identified. For instance, batch technologies do not need daily feeding and continuous technologies do not require several units. However, that should be checked with the technology provider.
- ***Combined Heat and Power:*** Since ITS will provide a Stirling Engine for the Catalonia site, this unit will not be ordered from the technology provider (reduction in investment costs). Even thought, heat demand has to be analyzed in order to evaluate the potential use of heat generated. The advantages of the Stirling engine are the capability of working properly even if composition of CH_4 changes and the fact that the external combustion does not require biogas desulfurization if the content of H_2S is less than 1%. The nominal power capacity of the engine will be about 10kW, considering 200 t/year of biowaste as input, which corresponds to 1kWe and 8 kWth respectively of electricity and thermal power. Efficiency values are due to the size of the engine (different values compared to 1MW engine) and are estimative since they will depend on the biogas quality. This will influence the real electricity production that, if biogas production is continuous, has been estimated at around 8,000-8,500 kWhe/year. Since the thermal energy efficiency is around 80%, the selection of the site needs to consider the potential heat demands existing in the area in order to properly use heat generation from mAD.
- ***Need for a Biogas purification unit:*** The biogas produced from the mAD needs to be at least desulfurized before being burned in the Stirling engine if H_2S content exceeds 1.0%. In this case technology providers will need to ensure desulfurization and establishing agreements related to this issue. In case H_2S content respects the maximum value allowed for ITS, the produced biogas will be directly burned in the engine. However, a measurement unit for H_2S content needs to be included in the equipment.
- ***Need for a post-treatment unit:*** The final destination of the digestate produced in the pilot needs to be defined. Anyway, post-treatments of digestate (hygienization and separation/concentration units) should be included in the pilot or alternatively digestate management should be assumed in terms of external treatment cost (to add among operational costs). This choice can change the size requirement in the selection of the demonstration site. Digestate needs to be composted or hygienized before or after the anaerobic digestion, otherwise it cannot be used as fertilizer.
- ***Commercial or manufactured mAD technology:*** a commercial solution for a capacity of 200 t/year will be selected for the Catalonia site (according to D4.1s). However, a rough market analysis showed that commercial technologies for micro AD matching the specific conditions of the project seemingly are not easy to find especially for dry processes (see first market analysis in deliverable D4.1). Moreover, the most sophisticated technologies are expensive.

The ideal commercial mAD technology to select for the demonstration site should have: 1) Processing capacity: 200 t/year (amount to treat in the Catalan pilot according to the decisions taken during the GA of April 2017), 2) Real references functioning with biowaste (several micro ADs work with waste water instead of solid waste), 3) Besides digester, pre-treatment and biogas desulfurization (if needed) units included and 4) Post-treatment included or post-treatment done elsewhere, requiring decision on who will pay for it. A rough overview about the characteristics of potential mAD technologies available on the market identifying the main technical requirements and constraints needed to support the selection of the Catalan site has been carried out using the form in *Table 3*. ARC organized a public market consultation to define the better technology and at this stage of the project the final decision is not yet available.

Budget constraint:

ARC's budget for the pilot equipment is 150,000 €. This value should include at least the digester, the pre-treatment unit and the biogas purification (if needed). The engine will be provided by ITS so the economic offers from technology providers will exclude this unit and warrantee the compatibility with the rest of the equipment. Post-treatment of digestate needs to be included in the pilot costs otherwise the related treatment cost needs to be considered. This is a constraint in order to select the site given that most of the potential hosts of the pilot want to know the total cost.

Budget allocation for operational costs and personnel for operating the mAD in Catalonia needs to be considered/assigned/planned. The need for personnel could be reduced by selecting a "batch (no-continuous feeding) AD" instead of a "continuous" AD. Although this option would slightly reduce the personal dedication, labour for running the pilot before and after the project would still be necessary, so it needs to be carefully taken into consideration for the next steps. In any case, there will be some personal support necessary from the site and the uncertainty is a constraint in this aspect as well.

3.3.1.2 Pros & cons of different sites proposed for Catalonia

Pros & Cons have been analyzed for the different sites proposed as demonstration locations in Catalonia. This assessment is based on the draft list of selection criteria reported in *Table 4,* the outcomes and decisions taken regarding the critical issues (*3.3.1.1*) and the available information about the technology providers already contacted. Sites proposed as potential locations for the pilot in Catalonia have been categorized in three different typologies: 1) sites focused on waste generation (location where the biowaste is generated); 2) sites focused on waste treatment (location where biowaste is currently treated: centralized plants) and 3) sites focused on the use of products (locations where the digestate will be used, for example on the land as fertilizer).

In order to analyze the pros & cons, some potential sites have been visited. For instance, among the sites localized where the biowaste is generated, 4 options have been analyzed. In each case there is a general case and a specific one analyzed: option 1 refers to the case of the public hospitals in Barcelona and the specific case of the Vall d'Hebron Hospital, option 2 concerns the Autonomous University of Barcelona (UAB), the third option concerns the city markets in Barcelona with the specific case of the market hall "El Ninot" and the forth option refers to a general group of households. The analysis of pros & cons for the sites located close to a centralized plant have been done considering the case of the bio-treatment plant in Granollers (option 5) while for the sites located in the proximity of the areas where to spread the produced digestate the three peri-urban farms of Camp agrari Baix Llobregat, Gallecs and Maresme (option 6) have been considered.

Table 16 – Pros and cons for different sites in Catalonia

Sites located where biowaste is generated		
Option 1: Vall d'Hebron Hospital		
Pros	• Very high quality and sufficient quantity of biowaste input as manual and mechanical pre-treatment is already installed at the site • High dissemination impact due to constant and elevated flow of citizens that can be informed • Proximity to residential area to which dissemination and awareness creation can be spread at a second stage and where impacts on biowaste collection can be measured	• The site is at present under renovation which allows for redesigning under environmental aspects • Site is associated with the UAB (project partner) belonging to the same University Centre, which eases collaboration • Public hospital and therefore of interest with respect to transferability to other hospital sites • Existence of a nearby public market hall, which could lead to synergies

Cons	• Less impact on quality improvement of biowaste separation (it is already very high) • Outcomes not easily reproducible (difficult to find a hospital with a similar quality of source-separated biowaste)	• Limited space for installation of the mAD unit • Due to site characteristics, the technology proposal has to be precisely defined and technically specified in the short term
Option 2: Autonomous University of Barcelona		
Pros	• UAB lab and offices really close • Interest shown by the UAB managment • Existence of a hotel, restaurants, and students' residences at the Campus assures different kinds of biowaste input • High potential for impact on resident and non-resident students and staff regarding waste separation behaviour and biowaste quality • No administrational problems in transferring the mAD from ARC to UAB, as UAB is one of the Partners • Several possible areas for mAD placement are available	• Existence of agricultural areas on the campus where to potentially spread produced digestate • Improvement of quality of biowaste input easier to get sensitizing a small number of people (restaurant servers) managing a huge amount of waste • Possibility of future introduction of household biowaste from students' residences after assessment of positive effect of awareness campaign • Probably the only site sufficiently flexible regarding mAD technology, especially considering that technology is yet to be decided • Proximity to the SSF unit
Cons	• Even if the project in this site is transferable (it easy to apply in another place) it is not readily reproducible (it is difficult to find a campus with the same characteristics)	• Peri-urban Campus (biowaste should be urban and the interaction with peri-urban should be only related to the provision of fertilizer) • Possible decrease of input quantities in summer
Option 3: "El Ninot" Market hall		
Pros	• Close relation to farmers (potential users of digestate) Possible synergies by use of thermal energy generated by mAD for melting of excess ice used e.g. in fish-stalls	• Placement in urban areas • High dissemination impact on visitors and buyers • Easily reproducible in towns with market halls • Biowaste input of high quality and sufficient quantity
Cons	• Space problems for mAD placement • Not applicable for periodical not permanently installed markets as frequent in northern countries	• No technical staff available on site • mAD accessible to untrained people not involved in the project, high potential for inadequate manipulation
Option 4: Group of households		
Pros	• Impact on biowaste from households (estimated 2/3 of municipal biowaste) • High awareness creation potential • Direct implication of citizens in treatment of their biowaste	• Impact on citizens is directly measurable • Possible impact of waste prevention • Eliminates long routes for biowaste transportation (limited trucks) • High transferability
Cons	• Diversity of sources puts at risk control of input quality • High supervision demand (quality of biowaste needs to be checked before entering into digester) • Elevated number of stakeholders (to get 200 t/year around 1,000 households need to be contacted)	• Difficulties in obtaining permits for mAD placed in public areas compared with commercial areas • Regional diversity of biowaste composition, consumer patterns, societal factors etc. seems higher in households than in commercial activities, this would reduce reproducibility
Sites location where biowaste is currently treated: centralized plants		
Option 5: In proximity of a centralized plant *(Bio-treatment plant). The case of Granollers AD plant*		
Pros	• Input material from a wide range of origins available (different collection systems, commercial sources), which influences quality • Authorized plant for biowaste management (no problems for pilot's permits)	• Digestate from mAD can be treated together with the digestate from the centralized plant • Energetic valorization of biogas from mAD assured • Adequate space available • Specialized staff already available at the plant
Cons	• Not in line with the overall scope of the project in terms of decentralisation, awareness creation and closed loop approach	• Impact of transportation of biowaste from generation to the centralized plant • Impact on citizens reduced, due to lack of visibility
Sites where the digestate will be used		
Option 6: Peri-urban farms. Camp agrari Baix Llobregat, Gallecs and Maresme		
Pros	• Involvement of users (farms) of the digestate produced • Adequate space available	• Sufficient space available • Completely closed circle within a small decentralised area

Cons	• Not located in urban area therefore not within the scope of the project • Impact of transportation of biowaste from generation to pilot located in peri-urban area	• Reduced impact on citizens' awareness and implication • Staff not technically trained • Energy use not guaranteed

3.3.1.3 Confirmation of the Catalan demonstration site

The UAB Campus (option 2) has been selected as the Catalan demonstration site after having analysing Pros and Cons for each other proposed locations. And here the main reasons are summarized:

- The commitment of the Vice-Rector for Innovation and Strategic projects, the agreement of the Vice-Rector for Economics and the support of the Waste Manager of UAB have been reached.
- Several potential areas are available for placing the mAD
- The existence of agricultural areas with research activities where to potentially spread produced digestate.
- The presence of a hotel, 10 restaurants and students' residences at the Campus assures different kind of biowaste input. Despite the fact that currently only around 19% of generated biowaste is selectively collected, there is a commitment from the managers of the catering companies so that the selective collection can reach at least 100 t in one year.
- Even if the mAD will start treating only commercial biowaste it seems possible to add biowaste from the students' residences (considering a small sample) and it will allow to measure the indirect impact on the population living close to the campus (students' residence) by estimating the changes in the habits of this population (e.g. biowaste generation and sorting) due to: pilot implementation and communication and awareness campaigns.
- Due to the huge amount of people (30,000 resident and non-resident students, 8,000 postgraduates and 6,000 employees) passing through the Campus, the effect of sensitivity and communication actions will probably lead to a high impact on waste separation behaviour and biowaste quality.
- An improvement of quality of "commercial biowaste" is estimated to be easier to achieve sensitizing a reduced number of people (restaurant servers) managing a huge amount of biowaste. This is a relevant favourable point since the quality of biowaste is a criticality for the proper functioning of the mAD.
- Experts and students of the UAB could be involved in the stage of operation and management of the pilot project. For example, the laboratories of GICOM group can realize analysis on biowaste and digestate.
- It will facilitate the technical support needed transferring ownership of the mAD from ARC to UAB because the SSF demonstration plant is developed in the campus.

The UAB campus is located in the AMB so this area has been selected as targeted territory for the Catalan demonstration site and the corresponding characterization is presented in the next paragraph.

3.3.2 Characterization of the targeted territory: the metropolitan area of Barcelona

The AMB is located in southern Europe, in Catalonia, in the middle of the Mediterranean corridor that connects Spain with the rest of the continent. Its territory includes the agricultural areas of the Llobregat Delta, the fully urbanised areas of the Barcelona, and the large green areas of the massifs of Garraf and Collserola and the Marina mountain range.

The AMB is one of the largest and most populated metropolitan areas in Europe. The metropolitan area occupies 2 % of total area of Catalonia (2,464,38 Km^2).[19] Its population represents 42.8 % of the total population (3,226,600 N inhabitants),[20] see *Figure 15*. The AMB is composed of 36 municipalities, with high population density with respect to the rest of Catalonia. The average population density is slightly over 5,000 inh/km^2, but can reach over 20,000 inh/km^2 in the biggest municipalities.[21] Around 48 % of the territory is occupied, mainly by residential areas, while 52 % corresponds to non-occupied land; the distribution for all activities are shown in *Figure 16*.

[19] Idescat, 2016
[20] Idescat, 2016
[21] Idescat, 2016

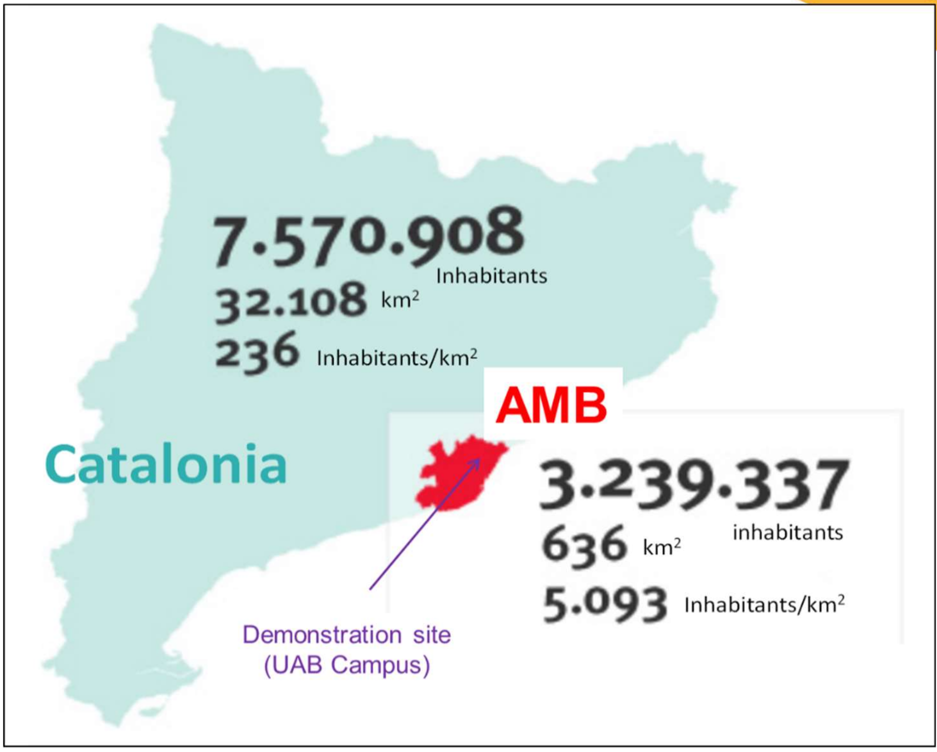


Figure 15 - Location of AMB and the UAB Campus in Catalonia and main demographical data (Source: www.amb.cat)

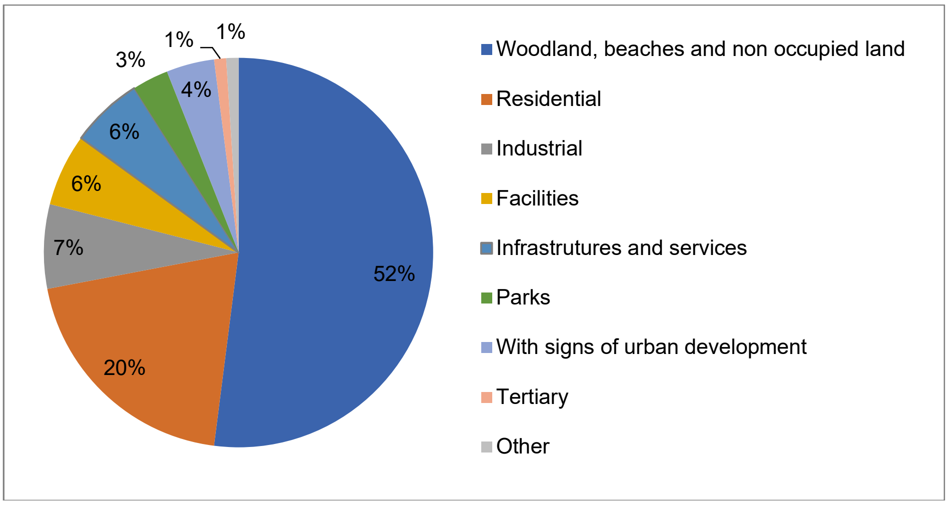


Figure 16 - Territory occupancy in the AMB (Source: www.amb.cat)

3.3.2.1 Waste management system

The waste management in AMB is outlined in the Metropolitan Program of municipal Waste Management (PMGRM) 2009-2016. The objectives are the reduction of waste generation through prevention and waste separation at origin, including awareness campaigns as well as economic incentives.

Since the peak year of 2007, when it reached 528 kg/inh/year or 1.45 kg/inh/day, Municipal Solid Waste (MSW) generation has decreased constantly, even in absolute figures. In 2016 each inhabitant of the AMB generated 441 kg of MSW, which corresponds to 1.21 kg/inh a day and 1.4 Mio t in absolute terms (source: ARC, 2016). This reduction can be attributed to the economic crisis that took place in Spain during these years. However, a slight increase can be observed since 2013 (*Figure 17*). According to the most recent composition analyzes in the AMB biowaste (including biowaste from households and commercial activities plus green waste) represents 39.9 % of the MSW *Table 17*.

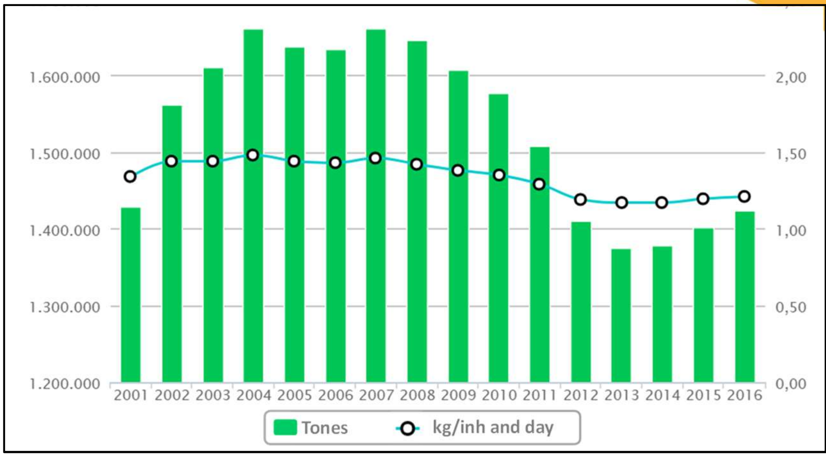


Figure 17 - Evolution of waste generation in the AMB (Source: www.amb.cat)

Table 17 - Waste generation in the AMB and fraction distribution (Source: ARC, 2016; PRECAT20, 2015)

ELEMENTS	PARAMETERS	Unit/type	Values	Source
Municipal Solid Waste generation	Total Amount MSW	t/year	1,423,696	ARC, 2016
Characterization MSW	Biowaste incl. green waste	% on total generated MSW	39.9	PRECAT20
		t/year	568,055	
	Plastic	% on total generated MSW	9.27	
	Glass	% on total generated MSW	5.48	
	Paper & Cardboard	% on total generated MSW	9.57	
	Other*	% on total generated MSW	29.52	
	Moisture	% on total generated MSW	6.26	

*Other corresponds to any other material defined as MSW according to the Catalan waste legislation (i.e. bulky waste, textile, WEEE, waste streams collected in Civic Amenity sites (CAS), etc.).

The most common collection scheme for MSW in the AMB is the kerbside Bring Bank system, where the citizens bring the waste to publicly accessible container banks. Two municipalities of the municipal area Tiana and Torrelles de Llobregat, have a Door-to-Door collection system fully rolled out, whereas 3 more municipalities have implemented a system that combines the bring bank system with areas of Door-to Door collection. Most commonly in the AMB 5 fractions are collected separately: glass, paper and cardboard, packaging, organic and residual fraction. Nevertheless, there are at present 4 municipalities that sort waste into 4 fractions: glass, paper and cardboard, biowaste and inorganic fraction. The latter is a comingled stream of packaging and residual fraction.

The evolution of source-separated waste collection for the 4 above mentioned fractions is shown in *Figure 18*. It can be observed that source-separated biowaste (including both domestic biowaste and green waste) is increasing constantly since 2002. Specifically, the increase in the biowaste collection of 2010 is due to the implementation of a source-separated biowaste collection in the city of Barcelona.

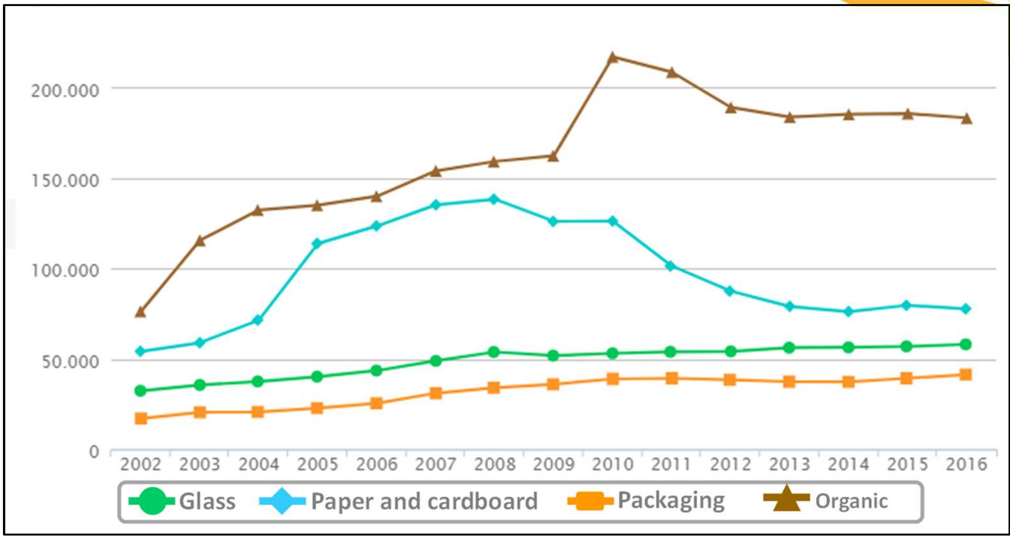


Figure 18 - Evolution of source-separated waste collection in the AMB. Values in t (Source: www.amb.cat)

The source-separated waste collection in relation to total MSW generation in the AMB ranged in 2016 with 34 % slightly below the Catalan average of 39 %. The quantity of biowaste including green waste separated at source and collected separately makes 12.48 % of the total MSW generation. 10.85 % is biowaste from households and commercial activities and 1.63 % is green waste (*Table 18*).

Biowaste from households and commercial activities is periodically characterised at the biological treatment facilities and records of the impurities are kept. In 2016 the average impurity rate in biowaste in the AMB was 16 %. Impurities are non-biodegradable materials included in the waste stream (e.g. plastic, glass, etc.).

Considering the previously mentioned waste composition with a biowaste content of 39.9 %, and subtracting from this figure the 12.85 % of source-separated biowaste, results that 27% of total MSW is biowaste that is still included in the residual waste. Both, the impurity rate and the potential biowaste in the residual waste are indicators of the citizens' performance regarding separation at source and the potential for improvement.

Table 18 – Source-separated collection of MWS in the AMB (Source: ARC, 2016, 2017)

ELEMENTS	PARAMETERS	Unit/type	Values	Source
Performance of source-separated biowaste collection	Source-separated biowaste incl. green waste	t/year	177,674	ARC, 2016, 2017
		% of total generated MSW	12.48	
	Biowaste from households and restaurants (FORM)	t/year	154,473	
		% of total generated MSW	10.85	
	Green waste (co-substrates)	t/year	23,201	
		% of total generated MSW	1.63	
	Biowaste included in the residual waste	% of total generated MSW included in residual*	27.42	
	Impurities in source-separated biowaste	% of biowaste FORM collected	16.09	
Other source-separated fractions	Total source-separated fractions/ MSW	% of total generated MSW	33.93	
	Paper & Cardboard	% of total generated MSW	5.35	
	Packaging	% on total generated MSW	2.9	
	Glass	% of total generated MSW	4.08	

	Metal (non-packaging)	% of total MSW	0.10	
	Plastic (non-packaging)	% of total generated MSW	0.07	
	Other	% on total generated MSW	9.05	

*own calculation

In the last years, due to the promotion of biological treatment landfilling and energetic valorization have decreased while composting and MBT treatment have increased (*Figure 19*). In figures, primary disposals to landfill and energetic valorization have decreased 95 % and 75 % respectively since 2002, which is due to the installation of new MBT and Composting facilities in the following years. It must be kept in mind that composting plants treat only source-separated biowaste from households and commercial activities and green waste.

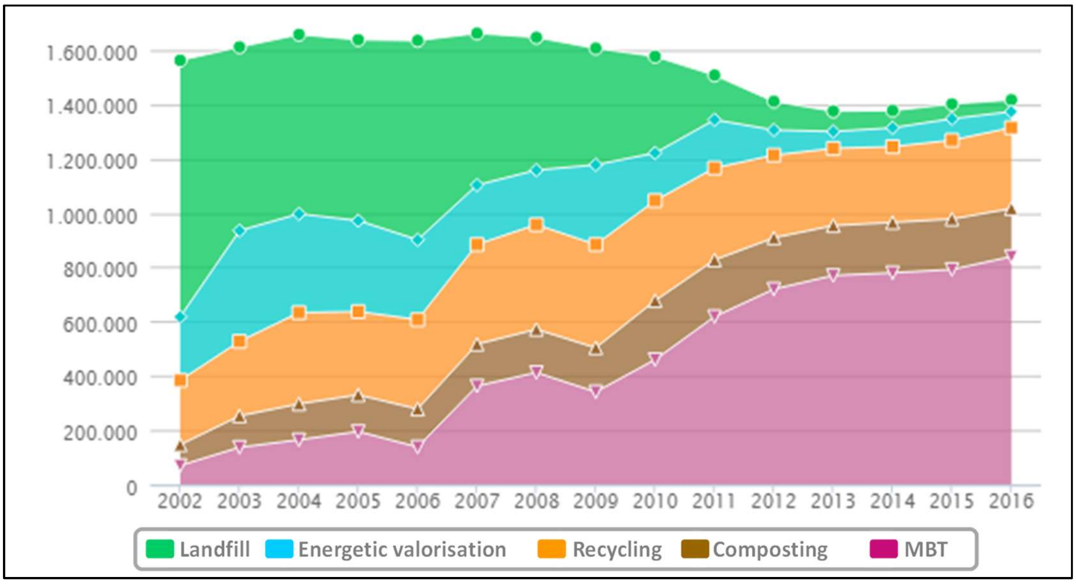


Figure 19 - Evolution of management of municipal waste in the AMB. Values in t. (Source: www.amb.cat)

In the AMB there are several waste management facilities: 2 composting plants, 4 Ecoparcs, 1 Waste-to-Energy plant, 3 sorting plants for packaging, 1 sorting plant for bulky waste and 1 transfer plant (*Figure 20*). Ecoparcs are waste treatment installations that include basically two different lines of treatment: one for the source-separated biowaste and another for the residual waste (where there might still be organic material).

Apart from that there are also 68 Civic Amenity Sites (CAS) and 35 Mobile CAS units. The 2 composting plants exclusively treat biowaste separated at source and subject to source-separated collection. They obtain compost as a final product. *Table 19* summarises the technical features of the biological treatment plants of the AMB. 4 facilities treat the separately collected biowaste. Two of them (Ecoparc 1 and Ecoparc 2) by anaerobic digestion followed by a composting step to obtain compost. In a separate biological treatment line, they stabilise the organic output from the mechanical treatment of residual waste. The resulting material cannot be used as compost, as it does not meet the requirements for application in agriculture. Another 2 facilities treating biowaste from source-separated collection are composting plants (Sant Cugat and Torrelles) The total capacity of these plants is 272,500 t/year of biowaste and 995,000 t/year of residual waste.

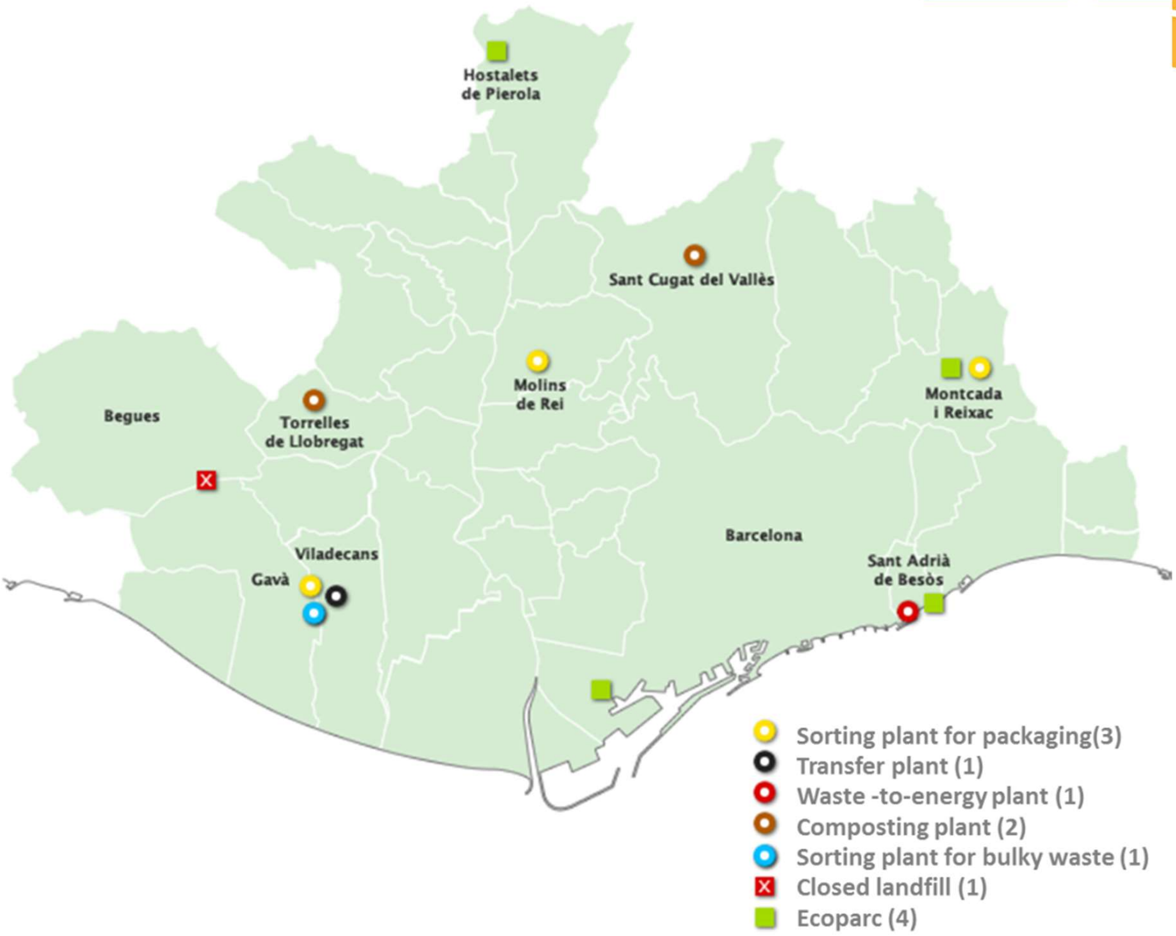


Figure 20 - Facilities and current equipment in AMB (Source: www.amb.cat)

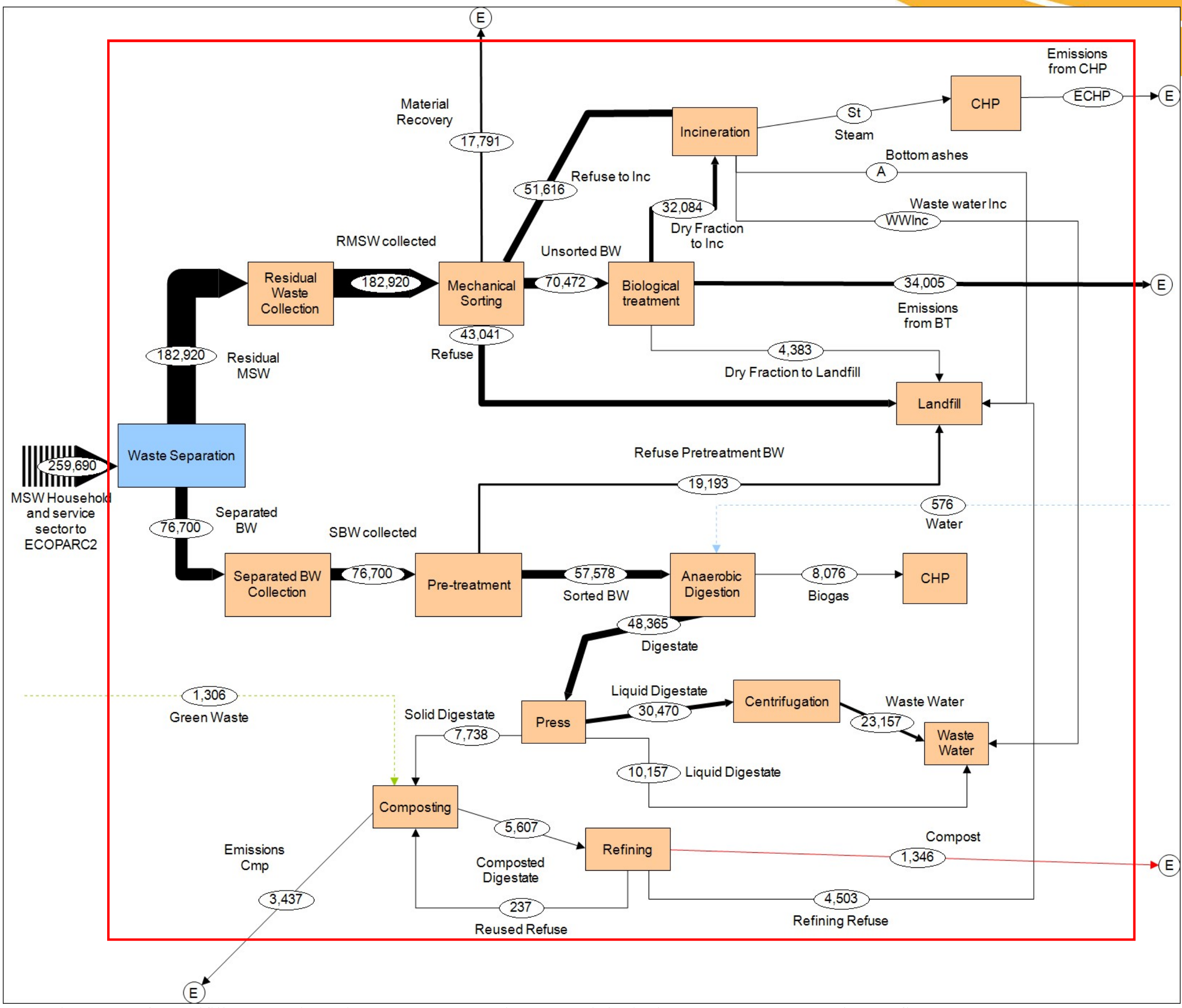
Table 19 - Features of AMB facilities for biological treatment (Source: www.amb.cat)

Plant	**Ecoparc 1**		**Ecoparc 2**		**Ecoparc 3**	**Ecoparc 4**	**Sant Adrià**	**Sant Cugat del Vallès**	**Torrelles de Llobregat**
Data Year	2016		2016		2016	2016	2016	2015*	2015*
Plant type and waste input	MBT plant residual waste	Biological Treatment Plant Biowaste	MBT plant residual waste	Biological Treatment Plant Biowaste	MBT plant residual waste	MBT plant residual waste	Waste to Energy	Composting plant Biowaste	Composting plant Biowaste
Biowaste (t/year)	-	72,132	-	76,770	-	-	-	6,718	4,599
Biogas generation (mio m^3/year)	-	7,272,364	-	10,310,172	2,787,501	-	-	-	-
Electricity generation (MWh/year)	-	13,759	-	20,999	6,314	-	15,650	-	-
Compost production (t/year)	-	3,123	-	3,784	-	-	-	1,804	932

Digestate production from Biowaste (t/year)	-	-	-	15,365	-	-	-	-	-
Residual Waste (t/year)	165,855	-	182,920	-	191,931	340,230	59,195	-	-
Bioestabilized residual waste production (t/year)	28,778	-	36,468	-	-	67,990	-	-	-
Digestate production from residual waste (t/year)	-	-	-	-	3,556	-	-	-	-
Recovered materials (t/year)	14,874	-	18,142	-	16,944	33,884	128	-	-
RDF (Residue Derived Fuel) (t/year)	n.a.	-	n.a.	-	n.a.	n.a.	n.a.	n.a.	n.a.

*Data for 2016 are not representative due to a maintenance shut-down of several months
** n.a. = not available

Among the different facilities included in the AMB, Ecoparc 2 deserves special attention, being the current destination (distance: about 10 km) of waste produced in the UAB Campus (the study zone). Ecoparc 2 presents two different lines of treatment, one for biowaste and one for residual waste. Biowaste is first mechanically separated; in this process some recyclable materials are recovered. After that, the organic material is anaerobically digested, producing biogas and digestate. The biogas is transformed into electricity and the digestate is composted along with green waste. The residual waste also undergoes a previous sorting stage in order to both separate organic fraction and recover recyclable materials. The organic fraction is composted in order to obtain bioestabilized material. The source-separated biowaste collected in the UAB Campus is currently treated by the anaerobic digestion line. *Figure 21* presents the mass-flow diagram for the MSW generated in the AMB going to Ecoparc 2.



BW: Biowaste; Lf: Landfill; Inc: Incineration; Cmp: Composting; BT: Biological Treatment; E: external mass flows

Figure 21 – Mass-flow diagram for Ecoparc 2. Values in t/year (2016). (Source: own calculation on data provided by ARC)

3.3.3 Characterization of the study zone: the UAB Campus

The Campus of the Universitat Autònoma de Barcelona (UAB) includes several academic faculties. The population of the campus consists of students and staff (teachers, researchers, administrative and general services). A floating population of around 35,000 students and 8,000 staff develop daily activities in the campus. Also, the Vila Universitaria accommodates over 1,200 people nearly all year long.

The campus is located in the municipality of Cerdanyola del Vallès (Barcelona), 20km to the North-West of Barcelona, in the Metropolitan Area (*Figure 22*). Cerdanyola del Vallès is the municipality with a population of 57,543 spread over an area of 30.56 km^2 that includes the UAB Campus (called also Bellaterra Campus), and currently the municipal waste generated is all treated in Ecoparc 2, to a methanisation process. The digestate produced is composted along with green waste before it is applied to soil. See the plant description in section *3.3.2*.

The campus of the UAB has a total of 260 ha, of which 90 ha are built; 60 % of total area is composed of forest and agricultural fields (*Figure 23*). The campus is delimited by highways C-58 (SE) and AP-7 (NE), and Bellaterra village (W). *Figure 23* presents the location of the residential area on the campus. Apart from specific building of the university (Vila and Blanc), the Sert area includes private housing of the Bellaterra village within the campus limits.

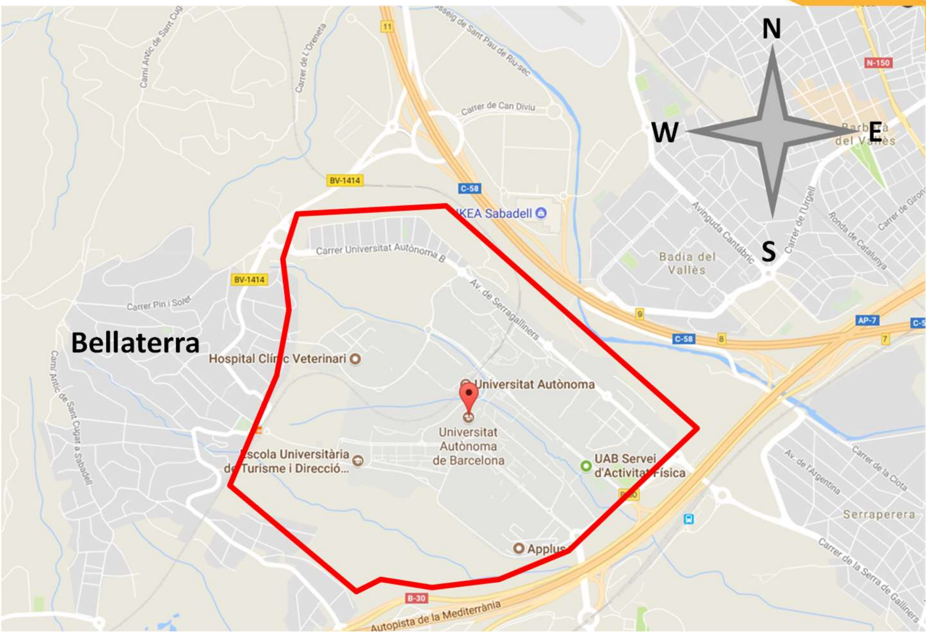


Figure 22 - Location of Campus UAB and approximation to the total surface (Source: Google Maps)

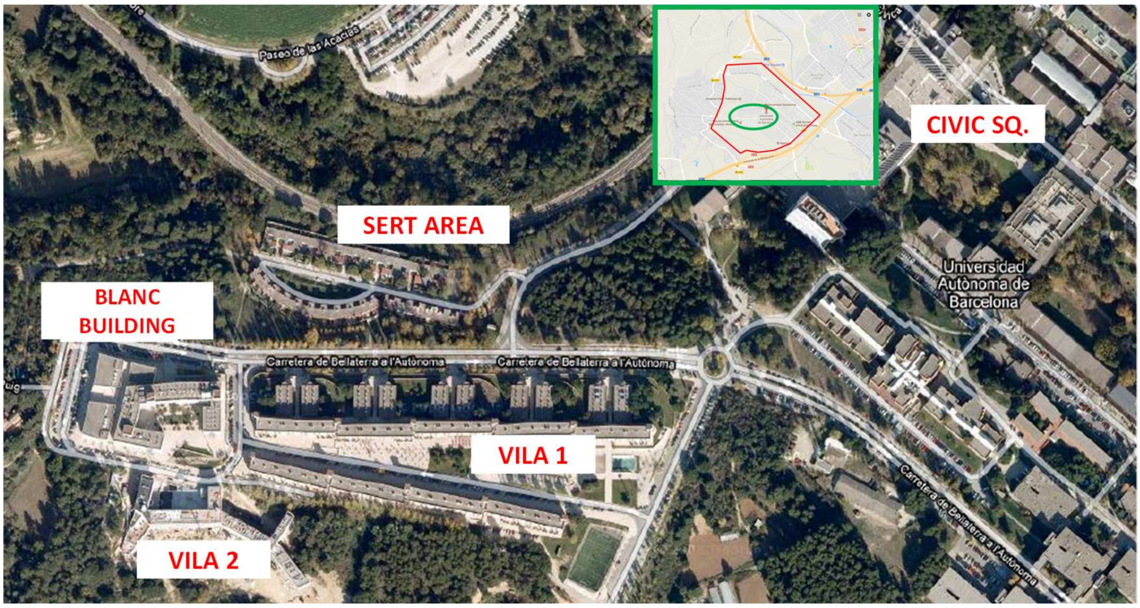


Figure 23 - Detail of accommodation (Vila and private buildings) (Source: Google Maps and UAB)

The number of inhabitants of the campus areas indicated in *Figure 23* are given in *Table 20*. Also, the population of the hotel is not included in this inventory. The total maximum capacity of population (Vila 1, Vila 2 and SERT housing) is 2,280 inhabitants (without the hotel). The hotel (208 beds, meeting rooms, cafeteria and restaurant) is located in the commercial area, along with other commercial activities (2 restaurants and 1 supermarket, among others). The number of inhabitants of the campus areas in the period for courses (1 Sept – 30 June) are given in *Table 20*, while summer occupation is shown in *Table 21*.

Table 20 - Description of occupation in accommodation areas on UAB Campus from September to June (Source: UAB)

Period	AREA OF ACCOMODATION						Total residents	Total maximum capacity
	VILA 1		VILA 2		SERT Housing			
	% of occupation	Inh	% of occupation	Inh	% of occupation	Inh	Inh	Inh
2013-2014	90.92%	1,538	61.45%	257	100.00%	172	**1,967**	**2,280**

2014-2015	84.50%	1,429	68.29%	285	100.00%	172	**1,886**	
2015-2016	91.57%	1,549	86.11%	360	100.00%	172	**2,081**	
2016-2017	91.57%	1,549	87.43%	365	95.60%	165	**2,079**	

Table 21 - Description of occupation in accommodation areas on UAB Campus in summer (July and August) (Source: UAB)

Period	**VILA 1**	**VILA 2**	**SERT Housing**	**Total residents**
(Summer season)	Inh	Inh	Inh	Inh
Jul-Aug 2014	307	194	172	672
Jul-Aug 2015	310	271	172	753
Jul-Aug 2016	483	287	172	942
Jul-Aug 2017	406	307	172	885

It is important to observe the decrease in population during the summer, of around 80 % in Vila 1 in the first period and 75 % in the last. In Vila 2 the decrease in occupation was 25 % while in the last stayed at nearly 50 %. The area of Sert Housing consists of attached private houses, and its occupation remains the same in summer as during the course. The main economic activities developed on the campus include 3 large restaurants, 3 medium restaurants and 3 cafeterias, which are shown in *Figure 24*.

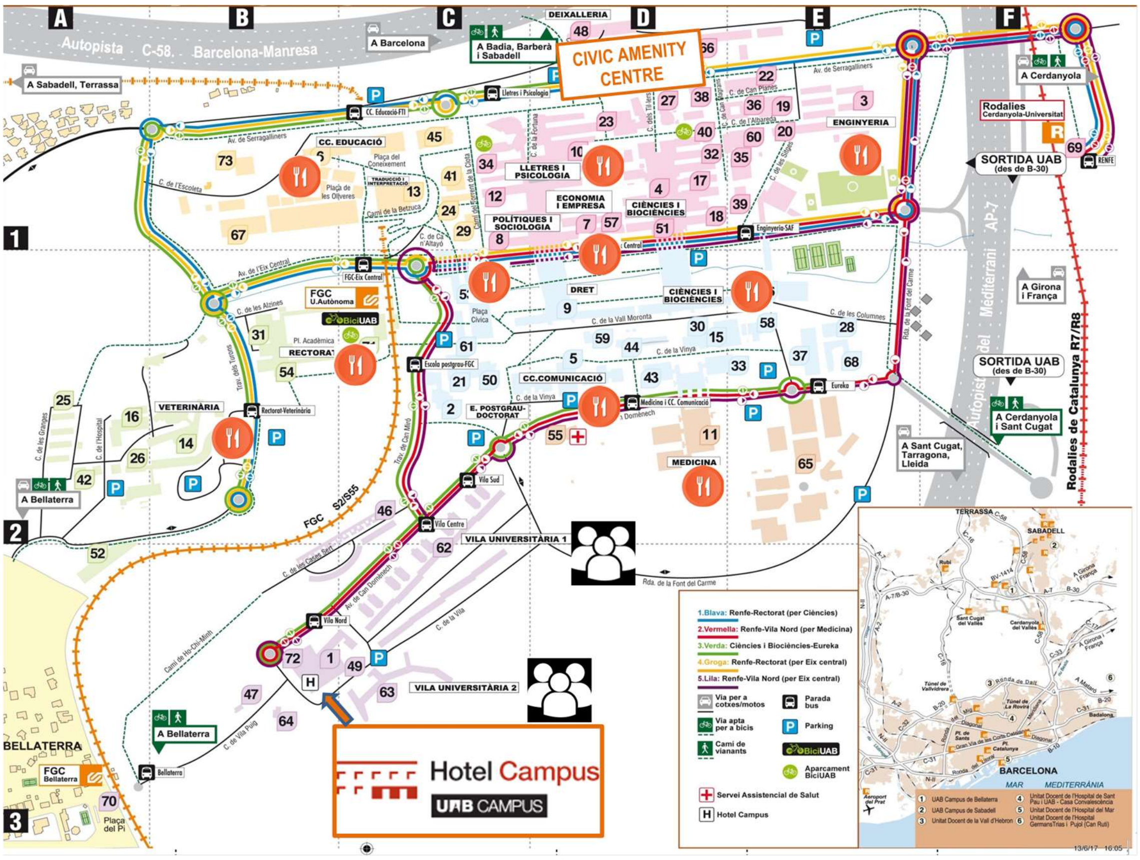


Figure 24 - Distribution of restaurant and cafeterias and other equipment in the campus (Source: Google Maps and UAB)

3.3.3.1 Waste management system

On the UAB campus a great variety of activities generate wastes, from municipal waste and similar to specific wastes arising from research activities (agricultural waste, hazardous and non-hazardous laboratory waste, etc.). For the pilot study the main concern lies with the general municipal waste and particularly the biowaste. The biowaste in the area is generated at different sources. Several restaurants and cafeterias on campus generate kitchen- and food-waste

(*Figure 24*). The area of the Vila is also a potential source of biowaste because it is composed of flats provided with kitchens. Nevertheless, the pilot study mainly focuses on the restaurants, considering that their biowaste generation and handling will be easier to control.

The total amount of municipal solid waste generated in the campus is 1,600 t/year (*Table 24*), which represents 6.5 % of the total waste of Cerdanyola and 0.1 % of the AMB. It is estimated that 300 t/year or 19 % of the total MSW generated in the UAB Campus corresponds to biowaste from households and restaurants. Currently, only around 6% of the total is separately collected, the rest still in the residual bin. To estimate the overall biowaste generation in the restaurants, the number of menus served in each restaurant (*Table 22*) is taken into account. Lladó and Pujol (2013), established a ratio of 0.17 kg of biowaste generated per person/meal during preparation and after consumption (kitchen, backoffice, restaurant). Considering a total of 1,890 menus served on an average of 220 workdays per year, a total biowaste production of about 70 t per year can be expected. In Annex A3, also i a proposal of methodology is also shown to estimate the generation of waste.

Table 22 - Number of average daily menus served in restaurants of the campus (Source: UAB, 2017)

Bar restaurant	**number of meals/day (2017)**
Rectorat	120
Veterinària	200
ETSE	55
Lletres i Psicologia	350
CC Comunicació	45
P. Cívica	450
Ciències i Biociènces	320
Medicina	150
CC. Socials	50
CC. Educació FTI	150
Total	**1890**

At present there is no comparable data on waste composition for the UAB Campus available. *Table 23* presents the characteristics of the source-separated organic fraction collected in the restaurant of the Campus of the Baix Llobregat (Universitat Politècnica de Catalunya-UPC), obtained from the research of two student projects (Lladó and Pujol, 2013; Andreu, 2014). These values allow an approximation to real figures of a source-separated collection of the biowaste. The content in moisture is quite high but variable, while the organic matter is very high in both cases, which is due to the good quality of the selection. Heavy metal content was only determined by Lladó and Pujol (2013), it was very low.

Table 23 - Composition of the organic fraction from a restaurant in the Campus of the Baix Llobregat (UPC) (Source: Lladó and Pujol, 2013; Andreu, 2014)

	Lladó and Pujol, 2013	**Andreu, 2014**
% Moisture	67,46	71,59
% Total organic matter (dwb)	94,19	92,62
% org N (dwb)	4,02	3,64
% P (dwb)	0,30	n.d.
% K (dwb)	1,27	n.d.

n.d.: non determined; dwb:dry weight basis

The collection system on the campus consists of containers for the five main fractions of municipal waste (biowaste, paper and cardboard, packaging, glass and residual waste). The containers are distributed all over the campus, but those for biowaste are only present near restaurants, which are the main source of this waste. Biowaste is source-separated in the restaurants in 120 L bins and afterwards emptied into the biowaste containers (1,800 L) located in the street outside the buildings. These street containers are collected by a truck, bringing the waste to the Ecoparc 2, facility located 7.7 km from the campus centre. However, the biowaste containers are openly accessible and not of exclusive use for the restaurants. This has a negative impact on the quality of the biowaste, which contains a considerable amount of impurities. Data on green waste is not available.

Table 24 - Waste generation and source-separated collection of the area UAB Campus in comparison to AMB and Cerdanyola del Vallès (Sources: ARC, 2016; UAB, 2017)

ELEMENTS	PARAMETERS	AMB	Cerdanyola del Vallès	UAB
MSW	Total amount (t/year)	1,423,696	24,618	1,600
Amount of biowaste flows source-separated	Total amount (t/year)	177,674	3,765	300
	Biowaste from Households and Restaurants (t/year)	154,473	3,265	300
	Green waste (co-substrates) (t/year)	23,201	500	-
Performance of source-separated waste collection	% Source-separated biowaste of total MSW	12.48	15.29	19
	% Source-separated biowaste from households and restaurants of total MSW	10.85	13.26	19
	% biowaste included in the residual waste	27.42	nd	29.7
	% of source-separated fractions	33.93	36.29	-
	% Paper & Cardboard	5.35	6.08	13
	% Packaging	2.90	3.11	6
	% Plastic (non-packaging)	0.07	0.05	
	% Metal (non-packaging)	0.1	0.2	-
	% Glass	4.08	3.85	3
	% Other	9.05	7.96	-
Quality of source-separated biowaste	% Impurities	16.09	10.28	11

All percentages are related to total generated MSW

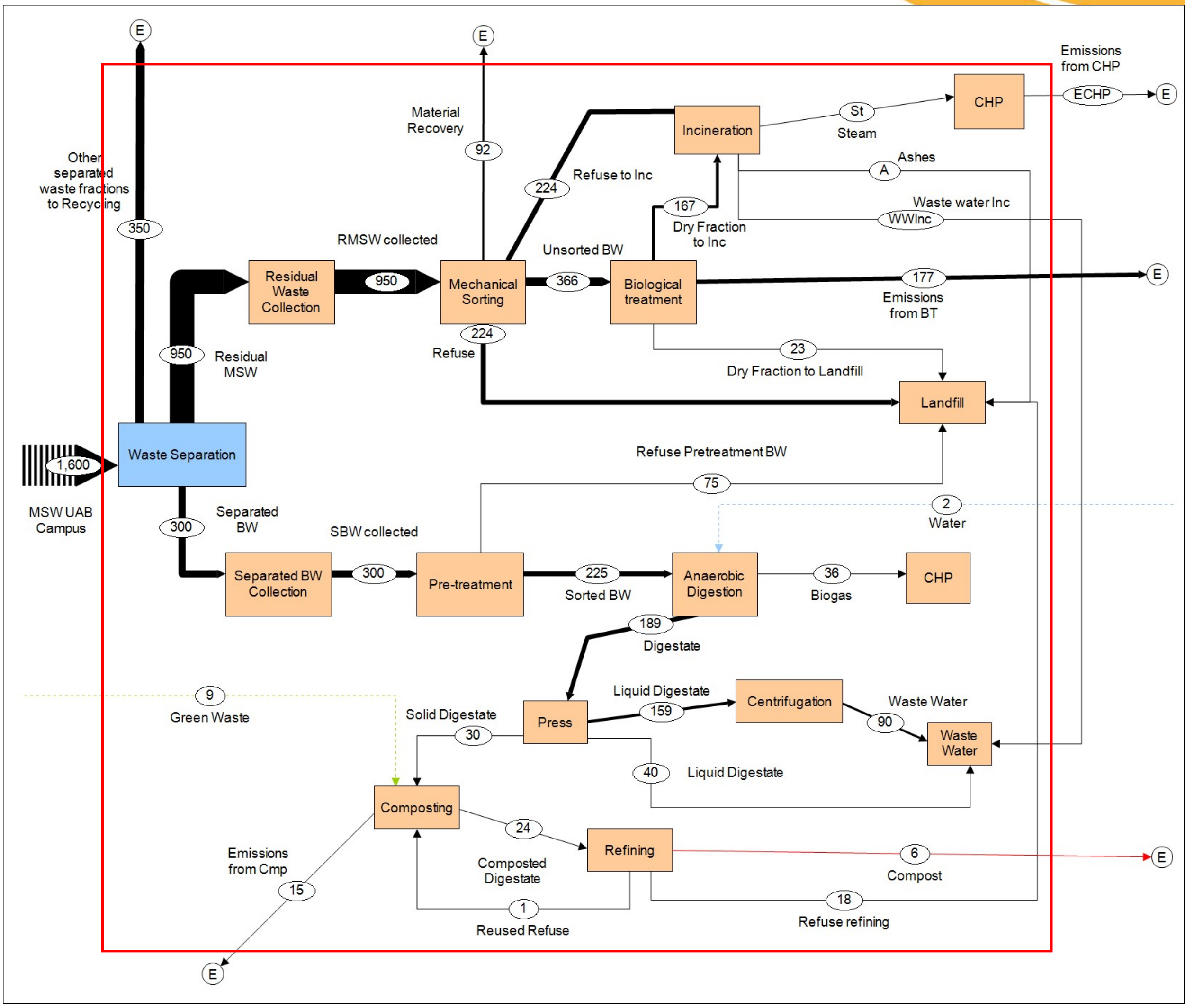
Table 25 gives an overview of the quantities of source-separated biowaste and residual waste collected in the Vila as sum of both Vila 1 and Vila 2. A total of 414 t of these two waste streams were collected in 2016, of which only 18 t are source-separated biowaste collected, while the rest is residual waste (396 t). It is important to note the high percentage of 50 % of biowaste in the residual waste stream. 89 % in the biowaste is organic material, which indicates the presence of 11 % of impurities.

Table 25 - Generation of municipal waste and separation of biowaste and residual waste in the Vila (Source: UAB, 2017)

Municipal waste in the Vila (Vila 1+Vila 2)	Total waste generation	Residual waste	Source-separated biowaste collection
kg/day	1,133	1,085	48
t/year	414	396	18
% of organic fraction*	51%	50%	89%

*% of organic fraction included in the related waste fractions. Example: 51% of organic fraction in included in the total waste generation; 89% of organic fraction is included in the source-separated biowaste, being the rest macro-impurities.

The residual waste and the source-separated biowaste collected in the UAB Campus are sent to Ecoparc2. The first fraction is going to mechanical biological treatment line while the second is treated by the anaerobic digestion line. In order to evaluate the mass-flow diagram for the UAB Campus the ratio coefficients used for Ecoparc2 mass-flow have been also used for this case as is represented in *Figure 25*.



BW: Biowaste; Lf: Landfill; Inc: Incineration; Cmp: Composting; BT: Biological Treatment; WW: Waste Water; E: external mass flows

Figure 25 – Mass-flow diagram of the current management system in UAB Campus (Source: own elaboration)

3.3.4 Characterization of the "alternative scenario"

Biowaste produced in the UAB Campus will be collected to feed the micro-AD unit. Considering the figures in *Table 24* and assuming a maximum collection rate of biowaste, a total amount of 214[22] t of biowaste per year could be collected. During the development of the project it is expected to increase the collection of biowaste, mainly due to the deployment of awareness campaigns in all the campus (restaurants and Vila).

The energy produced from the pilot will be used to heat the maintenance area that is located close to the area to develop the pilot in case there will be energy surplus once the auto consumption of the pilot is discounted. The digestate produced for the mAD will be used in a SSF process to produce bio-pesticides or will be treated, whether solid or liquid, to produce organic fertilizers. Both bio-based products will be used in the veterinarian area as soil amendment or fertiliser or biopesticide in the crops for farm animal feeding.

The treatment technology chosen for the biowaste produced in the UAB campus has been anaerobic digestion in a microdigester-mDA (i.e. small capacity under max 200 t/year). The advantages of this technology are its reduced space demand in comparison to other systems such as composting, as well as the fact that the material can be confined inside a device. This also allows to control gases and liquids, and consequently the production of odours.

[22] 214 t of biowaste/year represents the potential biowaste that is obtained as a sum of 50% of 396 t/year of residual waste (198 t of biowaste/year) and 89% of the 18 t/year of source-separated biowaste collected (16 t of biowaste/year)

Table 26 summarises a first revision of the available technologies that seem suitable for the trial. Some of them are meant for the same objective (SEaB, Homebiogas, BioFerm, etc.), but some others propose a grinding unit (e.g. Rendisk, Envac, Grind2energy), previous to the anaerobic digestion unit where energy is obtained. The latter systems are suggested for large capacity kitchens, as those of restaurants, hospitals, etc. The capacity, cost and complexity of the different options vary widely. The proximity of the provider and cost for transport and installation should be considered, as well as other factors such as warranty services. According to the values calculated from *Table 22*, for the period in which only the implementation for restaurants is considered, the required system should be able to process about 100 t/year of biowaste. This is a first approximation that can be used to select the unit, because the majority of the equipment available on the market does not meet the capacity requirements. Those selected in *Table 26* meet the requirements of size. Nevertheless, other factors might also be taken into account.

Table 26 - Summary of different available technologies for the proposed mDA

Brand	**Model**	**Capacity**	**Country**
SEaB	Flexibuster FB24 FB48	500-1,200 kg/day	UK
Rendisk	Vacuum Disposal System Wet Waste	From 5,000 L	NL
Homebiogas	Homebiogas	-	USA
Bioferm	Eucolino	1,000-6,500 t/year	USA
Envac	MiniVac	180 L/h	SW
Grind 2 Energy	Grind 2 energy	-	USA
Impact bio energy	HORSE AD25	440-3,000 kg/week	USA
QuBE	BioQUBE/QuickQUBE	150 t/year per unit	UK
Tryon	Tricube	500 t/year	FR
Puxin	PX-ABS-66M3	612 kg/day	RC

By locally treating the biowaste generated in the campus through anaerobic digestion would allow to remove the biowaste generated from the current circuit (from UAB to Ecoparc 2), as well as to obtain a product (digestate) to be used in the campus premises directly or after a treatment like composting. The location for the pilot equipment is expected to be on the premises of the civic amenity site (CAS) of the UAB campus (see *Figure 24*). This area is already designated for waste management activities, the basic resources (water, electricity) are available. It is protected by a metallic fence and a person in charge of the CAS is present every day. The specific location proposed for the pilot inside the CAS area (*Figure 26*) is near the main entrance, covering a surface of approximately 200 m^2. This area is considered enough to install all equipment parts. This area needs a small modification of the territory, mainly paving and covering of the specific area, similar to the rest of the CAS, which is already paved and covered. The cost of this intervention could be included in the preparation works for the installation of the pilot.

Figure 26 - Location for the pilot inside the Civic Amenity Site (green line) marked in orange (Source: Google Maps)

Alternatives for the valorization of products (biogas and digestate) and energy (heat and power) from the pilot in relation to the specific conditions of the sites will be analyzed later in the project. The thermal energy (net value discounting DECISIVE processes heat demand) could be used to heat water in a nearby maintenance building. The use of digestate/fertilizers on the agricultural fields of the veterinary faculty, where feedstock for the animals is grown, is considered. Prospective mass-flow and energy flow diagram for the Catalonia pilot has been evaluated according to the assumptions explained in Annex A2. The result of this elaboration has been presented in *Figure 27*.

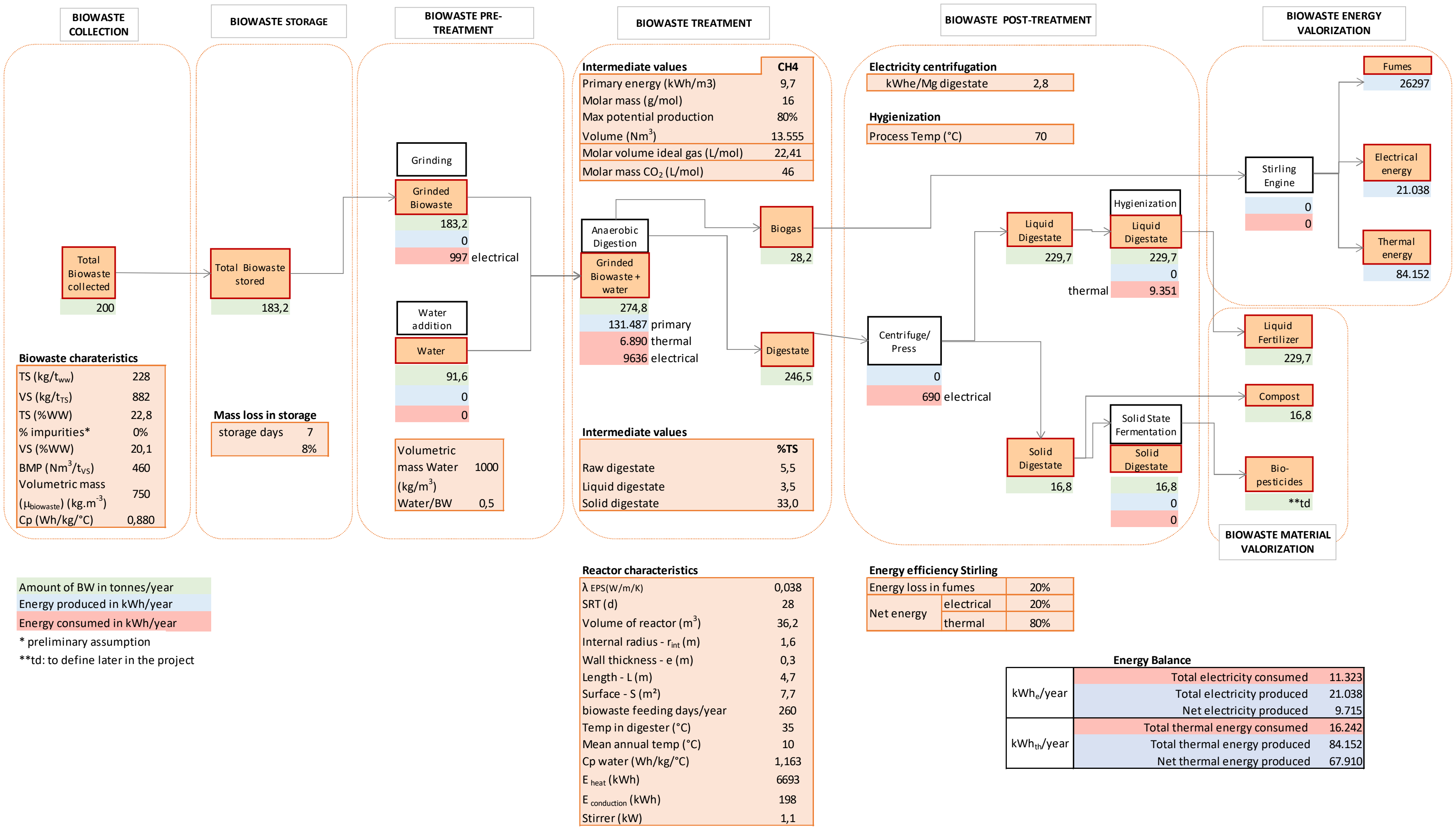


Figure 27 - Prospective mass-flow and energy balance of the DECISIVE pilot in Catalonia

3.3.5 Critical points before the implementation in the Catalonia site

The critical points forecasted for the implementation of the pilot in the UAB Campus are described below:

Scope of the pilot: The pilot is expected to be developed in two stages. The initial stage will consider only the biowaste produced in the restaurants of the campus, because the set up seems to be easier with a reduced number of stakeholders and well controlled biowaste input. In a second stage, it is expected to involve other campus premises in the source separation and collection of the biowaste. At that stage, inhabitants and other activities could be considered, from the Vila, to the Sert area, and the faculty buildings. In this part, it is important to involve all the dining areas existing in the buildings, which are usually provided with microwave ovens and bins for the waste.

Awareness campaign: Awareness campaigns have been proven to be the most effective way to increase participation, because they explain the content and the aim of the project, how to do it and provide the equipment (information panels, bins, human support, etc.) to participate. They should have a defined frequency (twice a year for example), which should include at least the beginning of the course, in order to inform all the new people (students, researchers, etc.) but also in the middle of the course to reach new arrivals. These awareness campaigns should be focused on all sectors that are users of the system. Special attention should be paid to kitchen staff, because they work in the area where more quantity and quality of biowaste can be obtained applying good practices and legal obligations.

Collection system for the pilot: The collection system has to be assessed carefully as it implies need for staff and equipment. The existing stock and distribution of containers has to be analyzed and if necessary upgraded. The correct container size and typology has to be established in order to improve the implementation of the source-separated collection. This modification involves an additional cost that needs to be considered for implementing the pilot. The biowaste collected for the purposes of the project will not be delivered to the current treatment facility (Ecoparc 2), but will have to be brought to the Anaerobic Digester. This will require the development of an internal transport system that will include people and probably a new collection truck. The corresponding budget requirements for staff and equipment will be taken into account.

Use of the digestate: It is important to consider the possibilities of the use of the produced digestate taking into account the following concepts: Quantity produced, Transport to the fields, Surface requirements in relation to N content (Directive 91/676/EEC), Possibility of post treatment, in the same area of the pilot or other, Needs of space and co-substrates for composting, Quantity for SSF production and Transport for SSF production.

Energy consumption & production: In order to better meet the scope of the project, the production of energy and its use should be considered. In relation to production, the biogas produced is intended to be transformed into energy. Part of this energy can be used in the CAS, and the rest can be used in the nearby service building to produce hot water.

Contingency in case of malfunction: The contingency plan is intended to solve situations caused by isolated circumstances that affect normal function of the process. These situations should be foreseen and specific actions and proceedings for each case should be elaborated. The actions taken must be revised and validated periodically and the legal regulations must be considered. Environmental risks to soil, water and air will be minimised through an adequate contingency plan, as well as social concerns that can appear, particularly when talking about waste.

4. Conclusions

The three objectives of the present work included: 1) the selection and confirmation of the specific location for the Catalan demonstration site, 2) the development of a consistent characterization method of biowaste management systems and 3) the application of such methodology in the two demonstration sites of DECISIVE.

An ad-hoc method for the selection of suitable location for the demonstration site has been developed. It includes three types of criteria viability, desirability and potential and it can be used to evaluate any site in the future, beyond the demonstration sites of the project.

Based on the developed site selection methodology, the Campus of the Autonomous University was identified as the best location for the Catalonia demonstration site and confirmed as the demonstration site. This location appeared to have better qualities than the other options evaluated; the most remarkable one was its flexibility. Due to the strict connection between the selection of the mAD technology and the site where the equipment will be installed, and the fact that the specific technology to be used in the site will be decided later in the project, flexibility was a highly needed asset. Really important point for the selection of this demonstration site was the commitment of UAB direction.

Regarding the second objective, a comprehensive methodology for the characterization of the demonstration sites has been defined. It includes three types of study areas, the "target territory", the "study zone", and the "demonstration site" to be able to estimate key aspects of each geographical scale. The key aspects at the "target territory" level appeared to be socio-demographic specifications and definition of the current biowaste management system (number and types of stages and plants, quantitative figures on waste generation, performance of waste separation and waste treatments).

The key aspects required for the characterization of the "study zone" concern firstly the definition of the boundaries' area according to the biowaste sources' localization and then details on treatment plants: process, amounts treated, waste types treated, set of technical requirements, valuables products and effluents to environment.

The key aspects for the characterization of the demonstration site are area available, existence of water and electricity connections, definition of available area where to spread bio-based products, acceptance of adjacent population and building and environmental permits.

The characterization methodology was applied in the two demonstration sites ex-ante and ex-post the installation of DECISIVE pilots. From the ex-ante characterizations, it was possible to identify the large potentials for improvements of both sites. In the Lyon case (including the three types of areas), most of the biowaste is currently being disposed of together with the residual waste and thus its value as a bioresource is not at all exploited. In the Catalonia case, part of the biowaste is already being source-separated and the bioresources recovered, but there is also room for improvement. At regional level, 53% is estimated to be biowaste in the residual waste, at targeted territory level this percentage appeared to be around 27% while in the study zone only 19% of biowaste in generated MSW is source-separated in fact around 30% of residual waste is biowaste.

From the ex-post characterization of the two demonstration sites, it was possible to identify the needs to evaluate the adequacy of a specific site for the implementation of the alternative system in term of surface, supply of consumables, accessibility and the local demands of valuable outputs such as bio-based products (fertilizer and biopesticides) and electrical and thermal energy.

It has to be taken into account that the characterizations presented in this deliverable are preliminary based on the currently available information. The results of the characterization of the demonstration sites will be improved during the next months of the project, once current missing data such as quantification and qualitative characterization of waste generation and collection flows before the implementation of the pilots, macro and micro-impurities in biowaste flows, missing technical requirements (labour, electricity, heat and water consumptions) and quantification of effluents to environment (refuse and emissions) for each stage of the biowaste system of both baseline and alternative scenario will be estimated.

Annex A1 – Description of the process unit of a generic biowaste management system

Biowaste Source-Separation is the stage in which biowaste is discarded at the place of generation either in a dedicated bin for biowaste (source separated biowaste) or in a residual bin with other waste (non-separated biowaste) and it is stored during a short period of time to be collected afterwards. During this first storage phase some waste losses can reduce the amount of biowaste generated. This stage includes both source-separated biowaste and non-separated biowaste remaining in the residual bin.

Biowaste Collection is the stage in which biowaste is gathered for the purposes of being transported to a waste treatment facility. According to the specificity of the system, biowaste can be sent directly to pre-treatment or to a storage unit before the treatment phase.

Biowaste Storage is the stage in which biowaste is stored after it has been collected and before it is treated. This is called third storage in D3.5.

Biowaste Pre-treatment is the stage that includes different mechanical processes for: i) removal of macro-impurities as well as plastic bags and any other items that can disturb the treatment or the quality of the treatment outputs, ii) waste fractions homogenization, iii) particle size adjustments etc.

Biowaste Biological Treatment is the stage in which biowaste undergoes a biological process (anaerobic or aerobic).

Biowaste Post-Treatment includes those operations focused on improvement of characteristics (dehydration/centrifugation and sieving for the produced digestate, gas cleaning for produced biogas….) of the outputs of the biowaste biological treatment stage.

Biowaste material valorization is the stage in which the outputs of the biowaste post-treatment stage are processed to increased its market value to obtain products such as fertilizer and bio-pesticides. Post-composting and/or Solid-State Fermentation after anaerobic digestion and refining after the composting process belong to this phase.

Biowaste Energy valorization is the stage in which the biogas is converted into heat, electricity or fuel. Energy conversion processes belonging to this phase are Stirling, CHP, etc. Incineration facilities with energy efficiencies above the Waste Framework Directive's threshold for energy recovery can be also included among this stage.

Biowaste Disposal is the stage in which the refuse from biological treatment is finally disposed typically in landfill or incineration facilities with energy efficiencies under the threshold to be considered as energy recovery (based on the Waste Framework Directive definition).

The concept of *"Treatment"* defined in the Waste Framework Directive (WFD)[23] represents different process units such as recovery or disposal operations, including preparation prior to recovery or disposal. Biowaste pre-treatment, biological treatment, post-treatment, energy valorization, material valorization and disposal are included in the general phase treatment.

[23] http://ec.europa.eu/environment/archives/enlarg/handbook/waste.pdf

Annex A2 - Calculation method and assumptions used for mass-flow and energy balance for mAD

The energy production potential of an anaerobic digestion (AD) plant depends on the characteristics of the substrate that is valorized. In the case of food waste (FW), *Fisgativa et al.* [2016] assessed the variability of 102 samples from several scientific studies and proposed a resume of FW characteristics that are partially presented below (*Table 27*).

Table 27 - Food waste characteristics (Source:Fisgativa et al., 2016)

	Total Solid (kg/t $_{WW}$)	Volatile Solid (kg/t $_{TS}$)	BMP (Nm^3/t $_{VS}$)
Description	*Amount of solid material left after drying the sample*	*Amount of organic matter contained in the sample*	*Maximum amount of methane that can be produced with the sample*
Mean value	*228*	*882*	*460*

WW = Wet Weight (WET sample)
TS = Total Solid
VS = Volatile Solid

Assumptions for Mass Balance of the mAD pilot

I – BIOWASTE COLLECTION

After having determined the amount of biowaste generated in the study area, it is assumed to gather the amount of source-separated biowaste for which the pilot has been dimensioned. So, in *Figure 14* and *Figure 27* the cell “total collected” indicates the amount of collected biowaste input for the pilots that will be 50 t/year and 200 t/year, respectively for the Lyon and Catalonia sites.

For simplicity reasons, the impurities content in the biowaste has not be accounted in this preliminary version of the mass balance. In reality biowaste will have macro impurities (plastic, glass, paper, etc.) that need to be removed or at source separation stage or in the pre-treatment phase.

II – BIOWASTE STORAGE

It was shown from experiments performed in the previous stage of the project, that during the storage period, the biowaste loses mass, following the equation below:

$$\%\boldsymbol{Mass\ loss} = \frac{(-\mathbf{0.0199}\ \times \boldsymbol{d}^2 + \mathbf{1.3413} \times \boldsymbol{d})}{\mathbf{100}} \tag{1}$$

Where:
d is the FW storage time prior to the AD process (days)

Assumption 1: *The biowaste is stored for approximately 7 days, so about 8.4% of the initial collected mass will be lost before the AD process*

III – BIOWASTE PRE-TREATMENT

All the stored biowaste is grinded without any mass loss. However, to ensure a correct stirring of the substrate, water must be added to the digester.

Assumption 2: *The amount of water added is about 50% of the biowaste mass.*

$$\boldsymbol{m_{water}} = \frac{\boldsymbol{m_{biowaste}}}{\mathbf{2}} \tag{2}$$

IV – BIOWASTE TREATMENT

mAD input

All the grinded biowaste and water are introduced in the mAD without any mass loss.

mAD output: biogas production

The mass of biogas that is produced during the AD process is expressed as follows:

$$m_{biogas} = m_{CH4} + m_{CO2} \tag{3}$$

Where:

$\boldsymbol{m_{CH4}}$ *is the mass of methane produced during the AD process (t)*

$\boldsymbol{m_{CO2}}$ *is the mass of carbon dioxide produced during the AD process (t)*

The mass of methane is calculated with the equation:

$$\boldsymbol{m_{CH4} = \frac{V_{CH4}}{V_m} \times M_{CH4}} \tag{4}$$

Where:

$\boldsymbol{V_{CH4}}$ *is the volume of methane produced during the AD process (m^3)*

$\boldsymbol{V_m}$ *is the molar volume of an ideal gas and is equal to 22,414 $L.mol^{-1}$*

M_{CH4} *is the molar mass of methane and is equal to 16 $g.mol^{-1}$*

The maximum volume of methane that can be produced is calculated as follow:

$$\boldsymbol{V_{CH4}^{max} = BMP \times m_{VS}} \tag{5}$$

Where:

$\boldsymbol{m_{VS}}$ *is the amount of volatile solid introduced in the AD plant (t)*

This equation can also be written in a more detailed way as follow:

$$\boldsymbol{V_{CH4}^{max} = BMP \times m_{WW} \times \mathrm{TS} \times \mathrm{VS}} \tag{6}$$

Where:

$\boldsymbol{m_{WW}}$ *is the mass of biowaste introduced in the reactor also called "Wet Weight" (t)*

In real cases, the maximum methane volume is never reached because the solid retention time of the substrate is lower in AD unit than in BMP tests, and the conditions are not constantly optimal in AD units. It is usually considered that only 80% of the maximum potential is produced in real cases. The equation can be written as follows:

$$\boldsymbol{V_{CH4} = 0.8 \times V_{CH4}^{max}} \tag{7}$$

Example of mass calculation of methane for an amount of FW equal to 45.8 t/y

$V_{CH} = 0.8 \times BMP \times m_{WW} \times \mathrm{TS} \times \mathrm{VS}$

$V_{CH4} = 0.8 \times 460 \times 45.8 \times (228 \times 10^{-3}) \times (882 \times 10^{-3})$

$\boldsymbol{V_{CH4} = 3389\ Nm^3}$

Then the mass of methane can be calculated:

$$m_{CH4} = \frac{V_{CH}}{V_m} \times M_{CH}$$

$$m_{CH4} = \frac{3389 \times 10^3}{22.414} \times 16 \times 10^{-6}$$

$$\boldsymbol{m_{CH4} = 2.4\ tonnes}$$

The mass of carbon dioxide can be calculated as in equation (4):

$$\boldsymbol{m_{CO2} = \frac{V_{CO2}}{V_m} \times M_{CO2}} \qquad (8)$$

Where:
$\boldsymbol{V_{CO2}}$ *is the volume of carbon dioxide produced during the AD process (m^3)*
$\boldsymbol{V_m}$ *is the molar volume of an ideal gas and is equal to 22.414 $L.mol^{-1}$*
M_{CO2} *is the molar mass of carbon dioxide and is equal to 46 $g.\ mol^{-1}$*

Assumption 3: *The volume of biogas produced during the AD is composed of 60% of methane and 40% of carbon dioxide*

According to assumption (3):

$$\boldsymbol{V_{CO2} = \frac{0.4}{0.6} \times V_{CH4} = \frac{2}{3} \times V_{CH4}} \qquad (9)$$

So, the equation (8) can also be written:

$$\boldsymbol{m_{CO2} = \frac{2}{3} \times \frac{V_{CH4}}{V_m} \times M_{CO2}} \qquad (10)$$

Example of mass calculation of carbon dioxyde for an amount of FW equal to 45.8 t/y

$$m_{CO2} = \frac{2}{3} \times \frac{V_{CH4}}{V_m} \times M_{CO2}$$

$$m_{CO2} = \frac{2}{3} \times \frac{3389 \times 10^3}{22.414} \times 46 \times 10^{-6}$$

$$\boldsymbol{m_{CH4} = 4.6\ tonnes}$$

Then, the mass of biogas equals:

$$m_{biogas} = m_{CH} + m_{CO}$$

$$m_{biogas} = 2.4 + 4.6$$

$$\boldsymbol{m_{biogas} = 7\ tonnes}$$

mAD output: digestate production

The digestate production corresponds to the difference between the amount of substrate (biowaste + water) introduced in the mAD and the mass of biogas produced:

$$\boldsymbol{m_{Raw\ Dig} = m_{substrate} - m_{biogas}} \quad (11)$$

IV – BIOWASTE POST-TREATMENT

Centrifuge/press

The calculation of the production of liquid and solid digestate was performed according to the results of the DIVA project[24] and particularly from the results of deliverable 3a [Trémier, 2014]. The mass balance of the separation step is given by the equations below:

General equation:

$$\boldsymbol{m_{Raw\ Dig} = m_{Solid\ Dig} + m_{Liquid\ Dig}} \quad (12)$$

Where:
$\boldsymbol{m_{Raw\ Dig}}$ *is the mass of raw digestate produced during the AD process (t)*
$\boldsymbol{m_{Solid\ Dig}}$ *is the mass of solid digestate produced after the separation phase (t)*
$\boldsymbol{m_{Liquid\ Dig}}$ *is the mass of liquid digestate produced after the separation phase (t)*

Equation of total solid separation:

$$\boldsymbol{m_{Raw\ Dig} \times \%TS_{Raw\ Dig} = m_{Solid\ Dig} \times \%TS_{Solid\ Dig} + m_{Liquid\ Dig} \times \%TS_{Liquid\ Dig}} \quad (13)$$

Where:
$\boldsymbol{\%TS_{Raw\ Dig}}$*is the total solid content of the raw digestate (%)*
$\boldsymbol{\%TS_{Solid\ Dig}}$ *is the total solid content of the solid digestate(%)*
$\boldsymbol{\%TS_{Liquid\ Dig}}$ *is the total solid content of the liquid digestate(%)*

From equations (12) and (13), it was found that:

$$\boldsymbol{m_{Solid\ Dig} = m_{Raw\ Dig} \times \frac{\%TS_{Liquid\ Dig} - \%TS_{Raw\ Dig}}{\%TS_{Liquid\ Dig} - \%TS_{Solid\ Dig}}} \quad (14)$$

and

$$\boldsymbol{m_{Liquid\ Dig} = m_{Raw\ Dig} \times \frac{\%TS_{Raw\ Dig} - \%TS_{Solid\ Dig}}{\%TS_{Liquid\ Dig} - \%TS_{Solid\ Dig}}} \quad (15)$$

One result of the DIVA project was the establishment of two equations that linked the TS content of the raw digestate to the TS content of solid and liquid digestate depending on the separation system used. When using a centrifuge, TS contents of liquid and solid digestate can be calculated as follows:

$$\boldsymbol{\%TS_{Solid\ Dig} = 32.72 + 5.59 \times \%TS_{Raw\ Dig}} \quad (16)$$

and

$$\boldsymbol{\%TS_{Liquid\ Dig} = 3.29 + 3.43 \times \%TS_{Raw\ Dig}} \quad (17)$$

[24] Project ANR- 10-BIOE-007 – Industrial Research Program BIOENERGIES 2010 supported by the competitiveness cluster Agrimip. Coordination: Irstea Rennes and Solagro. Project realised from December 2010 to December 2014.

The TS content of the raw digestate is calculated as follows:

$$\%TS_{Raw\ Dig} = \frac{m_{TS\ Dig}}{m_{Raw\ Dig}} \times 100 \qquad (18)$$

Where:
$m_{TS\ Dig}$ *is the mass of total solid contained in the raw digestate (t)*

And the mass of TS is calculated below:

$$m_{TS\ Dig} = m_{VS\ Dig} + m_{nVS\ Dig} \qquad (19)$$

Where:
$m_{VS\ Dig}$ *is the mass of volatile solid contained in the raw digestate (t)*
$m_{nVS\ Dig}$ *is the mass of non-volatile solid contained in the raw digestate (t)*

Assumption 4: *The non-volatile solid represents the content of matter that is not organic and that cannot be biodegraded during the AD process. This quantity is the same before entering the mAD and at the output of the mAD.*

According to assumption (4), equation (19) can be written as follows:

$$m_{TS\ Dig} = m_{VS\ Dig} + m_{nVS\ biowaste} \qquad (20)$$

Assumption 5: *The mass of volatile solid contained in the digestate corresponds to the volatile solid of the biowaste that was not degraded during the AD process. This amount of volatile solid is called the "residual volatile solid" and is denoted "*$VS_{res\ biowaste}$*".*

Equation (20) is then written:

$$m_{TS\ Dig} = m_{VS\ res\ biowaste} + m_{nVS\ biowaste} \qquad (21)$$

The amount of residual volatile solid is equal to:

$$m_{VS\ res\ biowaste} = m_{VS\ biowaste} - m_{VS\ consumed} \qquad (22)$$

Assumption 6: *The mass of volatile solid that was consumed during the AD process was entirely transformed into biogas*

From assumption 6 it is possible to say write:

$$m_{VS\ consumed} = m_{biogas} \qquad (23)$$

So, with equation (20) (applied to the initial biowaste), equation (22) and equation (23), the equation (21) is:

$$m_{TS\ Dig} = m_{VS\ biowaste} - m_{biogas} + m_{nVS\ biowaste}$$

$$m_{TS\ Dig} = m_{VS\ biowaste} - m_{biogas} + m_{TS\ biowaste} - m_{VS\ biowaste}$$

$$m_{TS\ Dig} = m_{TS\ biowaste} - m_{biogas} \qquad (24)$$

Finally, the TS content of the raw digestate is calculated as follow:

$$\%TS_{Raw\ Dig} = \frac{m_{TS\ biowaste} - m_{biogas}}{m_{Raw\ Dig}} \times 100$$

$$\%TS_{Raw\ Dig} = \frac{m_{biowaste} \times \%TS_{biowaste} - m_{biogas}}{m_{Raw\ Dig}} \times 100 \quad (25)$$

Example of the mass of liquid digestate that is produced during mAD for an amount of FW equal to 45.8 t/y

$$\%TS_{Raw\ Dig} = \frac{m_{biowaste} \times \%TS_{biowaste} - m_{biogas}}{m_{Raw\ Dig}} \times 100$$

$$\%TS_{Raw\ Dig} = \frac{45.8 \times 22.8 \times 10^{-2} - 7.1}{61.6} \times 100$$

$$\boldsymbol{\%TS_{Raw\ Dig} = 5.5\%}$$

Then, the TS content of the liquid digestate equals:

$$\%TS_{Liquid\ Dig} = 3.29 + 3.43 \times \%TS_{Raw\ Dig}$$

$$\%TS_{Liquid\ Dig} = 3.29 + 3.43 \times 8.7 \times 10^{-2}$$

$$\boldsymbol{\%TS_{Liquid\ Dig} = 3.5\%}$$

And the mass of liquid digestate produced during the AD process:

$$m_{Liquid\ Dig} = m_{Raw\ Dig} \times \frac{\%TS_{Raw\ Dig} - \%TS_{Solid\ Dig}}{\%TS_{Liquid\ Dig} - \%TS_{Solid\ Dig}}$$

$$m_{Liquid\ Dig} = 38.7 \times \frac{8.7 - 33.2}{3.6 - 33.2}$$

$$\boldsymbol{m_{Liquid\ did} = 57.4\ tonnes}$$

Hygienization

All the liquid digestate is hygienized without any mass loss.

SSF

All the solid digestate is composted with or without the SSF step without any mass loss. However only part of solid digestate will go to SSF (around 10% of total output digestate) and the SSF will work only partially during the project in both sites.

Assumptions for Energy Balance of the mAD pilot

Energy fluxes are linked to electrical and thermal equipment used in the global mAD scheme, in *Figure 7* estimated thermal and electricity production and consumption are indicated. Only four categories are using such equipment: the pre-treatment step, the treatment step, the post-treatment step and the energy valorization step. Thus, only they will be discussed below. Fuel requirement especially for transportation collection stage will be evaluated later in the project.

I – BIOWASTE PRE-TREATMENT

The sole pre-treatment identified in the mAD plant scheme is a grinder. To evaluate the amount of energy that is needed to grind the collected and stored biowaste, the data of a professional meat grinder was used[25].

Assumption 7: The chosen grinder has a capacity of 680kg/h and a power of 3.7kW

The quantity of electrical energy that is used to grind the biowaste is calculated as follow:

$$E_{electrical} = W \times t \tag{26}$$

Where:
W is the power of the grinder (W)
t is the working time of the device (h)

The working time of the device corresponds to:

$$t = \frac{m_{biowaste}}{Q_{\ grinder}} \tag{27}$$

Where:
$Q_{grinder}$ is the capacity of the grinder ($t.h^{-1}$)

Then, equation (27) can be written:

$$E_{electrical} = W \times \frac{m_{biowaste}}{Q_{\ grinder}} \tag{28}$$

Example of the electrical energy consumed by the grinder for an amount of biowaste of 45.8t

$$E_{electrical} = W \times \frac{m_{biowaste}}{Q_{\ grinder}}$$

$$E_{electrical} = 3.7 \times \frac{45.8}{680 \times 10^{-3}}$$

$$E_{electrical} = 249\ kWh$$

II – BIOWASTE TREATMENT

Primary energy production

The biogas that will be produced from the anaerobic digestion process has a specific primary energy that has been evaluated considering the following Assumption:

Assumption 8: About 9.7 kWh of primary energy can be produced with 1m³ of methane

So, the total energy production can be written:

$$E_{primary} = 9.7 \times V_{CH4} \tag{29}$$

Example of the primary energy produced from an amount of biowaste of 45.8t/y

$$E_{primary} = 9.7 \times V_{CH4}$$

$$E_{primary} = 9.7 \times 3389$$

[25] http://www.birosaw.com/products/hhp-heavy-horse-power-meat-grinders/

$E_{primary} = 32877\ kWh$

Thermal energy consumption

The thermal energy consumed for the mAD reactor is divided into two types of energy: the energy needed to heat the biowaste when entering the digestate and the energy lost by conduction through the mAD walls.

The energy needed to heat the biowaste when entering the mAD unit is calculated using the thermodynamic equation:

$$E_{heat} = (m_{biowaste} \times C_{p,biowaste} + m_{water} \times C_{p,water}) \times \Delta T \qquad (30)$$

Where:
C_p is the specific heat capacity of the considered component (Wh.kg^{-1}.°C^{-1})
ΔT is the difference between the digester's temperature and the initial temperature of the biowaste (°C)

Assumption 9: The mean specific heat capacity of a biowaste (from restaurants or households) was estimated to equal 0.880 Wh.kg^{-1}.°C^{-1}. For water, $C_{p,water}$ = 1.163 Wh.kg^{-1}.°C^{-1}.

***Assumption 10:** The mean annual temperature in Europe is estimated to equal 10°C. This value can change according to the specific location. For Catalonia a value equal to 15°C seems more reasonable.*

Example of the thermal energy consumed by the mAD for an amount of biowaste of 45.8t/y

$$E_{heat} = (m_{biowaste} \times C_{p,biowaste} + m_{water} \times C_{p,water}) \times \Delta T$$

$$E_{heat} = [(45.8 \times 10^3) \times (0.880 \times 10^{-3}) + (22.9 \times 10^3) \times (1.163 \times 10^{-3})] \times (35 - 10)$$

$E_{heat} = 1673\ kWh$

The energy loss because of conduction phenomenon is calculated by using Fourier's law which depends on the digester geometry. In the case of a cylindrical reactor, the law is expressed as follows:

$$\varphi_{cond} = \varphi_{wall} + \varphi_{top} + \varphi_{bottom}$$

$$E_{cond} = 2\lambda \times \Delta T \times \left(\frac{\pi \times L}{ln(e)} + \frac{S}{e}\right) \times t \qquad (31)$$

Where:
λ is the thermal conductivity of the insulating material that covers the digester walls (W.m^{-1}.K^{-1})
L is the length of the reactor (m)
ΔT is the difference between the digester's temperature and the external temperature (°C)
e is the wall thickness (m)
S is the surface of the top and the bottom of the reactor (m²)
t is the number of hours during which the mAD is working for one year (h)

Assumption 11: The insulating material used on the mAD is an expanded polystyrene[26] (EPS), which has a thermal conductivity equal to 0.038 W.m^{-1}.K^{-1}

Assumption 12: The dimension of the reactor is not known. The internal radius of the reactor and the wall thickness were chosen as follows:
$L = 3 \times r_{int}$; $r_{int} = 5 \times e$; $S = \pi \times r_{int}^2$

[26] http://www.eps.co.uk/applications/properties.html

Then the volume of the reactor is equal to:
$\boldsymbol{V_{mAD} = 3 \times \pi \times r_{int}^3}$

The volume of reactor needed to valorize the biowaste is equal to:

$$\boldsymbol{V_{mAD} = \left(\frac{Q_{biowaste}}{\mu_{biowaste}} + \frac{Q_{water}}{\mu_{water}}\right) \times SRT = Q_{biowaste} \times \left(\frac{1}{\mu_{biowaste}} + \frac{1}{2 \times \mu_{water}}\right) \times SRT} \quad (32)$$

Where:
$\mu_{biowaste}$ *is the volumetric mass of the biowaste (kg.m*$^{-3}$*)*
$Q_{biowaste}$ *is the loading rate of biowaste in the mAD (kg.j*$^{-1}$*)*
μ_{water} *is the volumetric mass of water (kg.m*$^{-3}$*)*
$Q_{biowaste}$ *is the loading rate of water in the mAD (kg.j*$^{-1}$*)*
SRT *is the solid retention time of the biowaste inside the mAD reactor (j)*

Example of the calculation of the mAD volume for an amount of biowaste of 45.8t/Y, a SRT of 28 days and a feeding frequency of 260 days per year (only during worked days)

$$V_{mAD} = Q_{biowaste} \times \left(\frac{1}{\mu_{biowaste}} + \frac{1}{2 \times \mu_{water}}\right) \times SRT$$

$$V_{mAD} = \left(\frac{45.8 \times 10^3}{260}\right) \times \left[\frac{1}{750} + \frac{1}{2 \times 1000}\right] \times 28$$

$$\boldsymbol{V_{mAD} = 9.0\ m^3}$$

Then, the internal radius of the reactor can be written as follows:

$$\boldsymbol{r_{int} = \sqrt[3]{\frac{V_{mAD}}{3 \times \pi}}} \quad (33)$$

Example of the dimensions of the mAD for an amount of biowaste of 45.8t/y, a SRT of 28 days and a feeding frequency of 260 days per year (only during worked days)

The internal radius:

$$r_{int} = \sqrt[3]{\frac{V_{mAD}}{3 \times \pi}}$$

$$r_{int} = \sqrt[3]{\frac{9.0}{3 \times \pi}}$$

$$\boldsymbol{r_{int} = 1.0\ m}$$

The length of the reactor:

$$L = 3 \times r_{int}$$

$$L = 3 \times 1.0$$

$\boldsymbol{L = 3.0\ m}$

The wall thickness:

$e = r_{int}/5$

$e = 1.0/5$

$\boldsymbol{e = 0.2\ m}$

The surface of the top and the bottom of the reactor:

$S = \pi \times r_{int}^2$

$S = \pi \times 1.0^2$

$\boldsymbol{S = 3.1\ m^2}$

Example of the thermal energy lost by conductivity

$$E_{cond} = 2\lambda \times \Delta T \times \left(\frac{\pi \times L}{ln(e)} + \frac{S}{e}\right) \times \mathrm{t}$$

$$E_{cond} = 2 \times 0.038 \times 10^{-3} \times (35 - 10) \times \left(\frac{\pi \times 2.7}{ln(0.2)} + \frac{2.5}{0.2}\right) \times 24 \times 365$$

$\boldsymbol{E_{th}{}^{cons} = 163\ kWh}$

Electrical energy consumption

In the case of a constantly stirred tank reactor, the electrical energy consumed mostly consists of the agitation of the substrate. The calculation was done with equation (26):

$$\boldsymbol{E_{stirrer} = W \times \mathrm{t}} \tag{34}$$

Where:
W is the power of the stirrer (W)
t is the working time of the device (h)

Assumption 13: *The stirrer is used every day and all-day long. Its power depends on the model chosen*[27] *(i.e. SIDEMIX350 for 50t/year and SIDEMIX450 for 200t/year)*

Example for 45.8t/y of biowaste

$E_{stirrer} = \mathrm{W} \times t$

$E_{stirrer} = 0.55 \times 365 \times 24$

$\boldsymbol{E_{stirrer} = 4818\ kWh}$

III – BIOWASTE POST-TREATMENT

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[27] http://www.mixel.fr/en/agitators/standard-agitator/horizontal-agitator/sidemix/

Centrifugation

The energy needed for the centrifugation was estimated according to the DIVA project, in which the electrical energy of a centrifuge was measured [Déchaux, 2015] and was equal to:

$$\boldsymbol{E_{centrifuge} = 2.8 \times m_{digestate}} \tag{35}$$

Where:
2.8 represent the energy needed to centrifuge 1 ton of digestate ($kWh.t^{-1}$)

Example for 38.7t/y of digestate

$E_{centrifuge} = 2.8 \times m_{digestate}$

$E_{centrifuge} = 2.8 \times 38.7$

$\boldsymbol{E_{centrifuge} = 108\ kWh}$

Hygienization

The thermal energy used for the hygienization step is calculated using equation (29) applied to the liquid digestate:

$$\boldsymbol{E_{hyg} = m_{digestate} \times C_{p,digestate} \times \Delta T} \tag{36}$$

Assumption 14: The specific heat capacity of the liquid digestate is equivalent to the specific heat capacity of the water
i.e. $C_{p,water} = C_{p,digestate} = 1.163\ Wh.kg^{-1}.°C^{-1}$

Example for an amount of liquid digestate of 57.4t/y and a temperature of hygienisation of 70°C

$E_{hyg} = m_{digestate} \times C_{p,digestate} \times \Delta T$

$E_{hyg} = (57.4 \times 10^3) \times (1.163 \times 10^{-3}) \times (70 - 35)$

$\boldsymbol{E_{hyg} = 2338\ kWh}$

IV – BIOWASTE ENERGY VALORIZATION

Assumption 15: Only 80% of the theoretical energy contained in a given volume of biogas is produced when using the Stirling engine which is called the "net energy". The 20% left is lost as fumes.

The energy lost as fumes is then calculated as follow:

$$\boldsymbol{E_{fumes} = 0.2 \times E_{primary}} \tag{37}$$

Example for an amount of biowaste of 48.5t/y

$E_{fumes} = 0.2 \times E_{primary}$

$E_{fumes} = 0.2 \times 32877$

$\boldsymbol{E_{fumes} = 6575\ kWh}$

Assumption 16: *80% of the neat energy produced by the Stirling engine is a thermal energy. The 20% left is the electrical energy that can be produced.*

The electrical energy is calculated as follow:

$$\boldsymbol{E_{electrical} = 0.8 \times 0.2 \times E_{primary}} \tag{38}$$

And the thermal energy is calculated:

$$\boldsymbol{E_{electrical} = 0.8 \times 0.8 \times E_{primary}} \tag{39}$$

SSF

SSF process will not need either heat or stir, so it can be assumed that its energy balance is almost zero. However, energy demand could be evaluated applying a proportionality factor to the lab-scale SSF reactor.

Annex A3 - Estimation for Grand Lyon biowaste generation based on the French environmental agency's methodology

Household kitchen waste

→ Based on the number of inhabitants and not the number of people per household

But, the INSEE (official French statistical service) estimate that there are 2.3 people per household.
According to ADEME only 50% of the total quantity of the biowaste is really available for a further valorization. This ratio is thus used to focus only on the recoverable fraction.

	Raw biowaste		Available biowaste	
Total population (2013)	Q. foodwaste (kg/y/capita)	Total raw foodwaste (t/y)	Ratio of biowaste available	Total foodwaste (t/y)
1 343 469	100	134 347	50%	67 173

$$Q_{Fwi} = Nb_{pop} \times 100_{kg/}$$

Note: for all restaurant / collective catering:
According to ADEME,[28] about 70% of the raw quantities of foodwaste are recoverable for further valorization.

Traditional restaurant:

→ Based on the number of employees:

$$Q_{Fwi} = Nb_{employee\ i} \times 2\ 920_{meals/employee} \times 185_{g/meal}$$

Nb. of restaurants	Average per restaurant			Nb. meals / year	Quantity of biowaste in Grand Lyon (t/year)	
	Nb worker	Nb. meals/year	Q. foodwaste (t/y)		Raw	Available
3 103	4.7	13 695	2.5	42M	7 862	5 503

Collective catering (administrative and company restaurants)

→ Based on the number of employees:

$$Q_{Fwi} = Nb_{employee\ i} \times 14\ 840_{meals/employee} \times 180_{g/meal}$$

Restaurants in the area			Average per restaurant				Nb. meals / year	Quantity of biowaste in Grand Lyon (t/year)	
Total nb.	Nb. incl.*	% incl.	Nb worker	Nb. (meals/y)	Ratio of fw (g/meal)	Q. fw (t/y)		Raw	Available
515	347	67 %	8	118 079	180	21.3	40M	7 375	5 163

** All collective catering except the one serving hospitals and schools (avoid double counting)*

School canteen

→ Based on the real number of meals served (survey for secondary schools and some primary schools) or estimated with the number of student.

If the nb. of meals is known: $Q_{Bw} = \boldsymbol{N_{meals/y}} \times 185\ or\ 280_{g/meal}$

Else : $Q_{Bw} = \boldsymbol{N_{students}} \times \boldsymbol{N_{meals/student/y}} \times 185\ or\ 280_{g/meal}$

[28] (Estimation des gisements potentiels de substrats utilisables en méthanisation, ADEME, 2013)

Level	Nb. Schools and students				Schools with data about nb. meals served	Nb. meals / year	Ratio of bw (g/meal)	Quantity of biowaste in Grand Lyon (t/year)	
	Public		Private					Raw	Available
Primary	543	*120 811*	105	*24 134*	165	7 834 379	185	1 449	1 014
Secondary	166	*85 112*	107	*44 874*	128	12 895 961	280	3 610	2 527

Health facilities
Depends if hospital or other health facilities (retirement home, etc.).

For hospitals:

$$Q_{FW} = \left(N_{meals\ patients} + N_{meals\ employee}\right) \times 185_{g/meals}$$

For other health facilities:

$$Q_{FW} = C_{apacity} \times Nb_{meals.week^{-1}} \times Nb_{meals.days^{-1}} \times 52_{week.year^{-1}} \times 185_{g/meals}$$

Type	Nb. establishments	Nb. meals / year	Ratio of fw (g/meal)	Raw biowaste in Grand Lyon (t/y)	Available biowaste in Grand Lyon	
					Ratio of biowaste available	Total biowaste (t/y)
Hospitals	40	15 707 410	185	2 905	70%	2 034
Other health facilities	874*	15 443 948		2 857		2 000

* For "other health facilities" the total number include the establishment that do not provide any catering service.

Biowaste flow:
Estimation of biowaste quantities from targeted sources.
Note: It is not the official values but the estimated ones based on the methodology developed in the WP 3.3. The values are the quantity of waste available for collection, not the total biowaste produced (i.e. fraction of the raw biowaste production that can be collected) (ref.: ADEME 2013)

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