LIFE BIOBEST

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GUIDING THE MAINSTREAMING OF BEST BIO-WASTE RECYCLING PRACTICES IN EUROPE

D3.3: Guideline to promote quality compost and digestate

WP3: Set of guidelines

T3.3: Compost and digestate production and quality analysis

JUNE **2024**

Public Report

Co-funded by
the European Union

LIFE21-PRE-ES-LIFE BIOBEST - 101086420

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Document citation: Walk, S. & Gambini, R. (2024). *LIFE BIOBEST D3.3 - Guideline on quality compost and digestate.*
In-text citation: (Walk & Gambini, 2024)

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1 Document attributes

This report has been carried out under a contract awarded by the European Commission, contract number: LIFE21-PRE-ES-LIFE BIOBEST - 101086420. The content of this publication is the sole responsibility of the LIFE BIOBEST project.

1.1 Document Management Control Sheet

Table 1. Document Management Control Sheet

PROJECT NAME:	LIFE BIOBEST
Full Project Title:	Guiding the mainstreaming of best biowaste recycling practices in Europe
Start Date of Project:	1st January 2023
Duration:	30 months
Type of Document:	Report
Title:	D3.3: Guideline to promote quality compost and digestate
Dissemination Level:	Deliverable – Public
Work Package & WP Leader:	WP3: Set of guidelines (CIC)
Task & Task Leader:	T3.3: Compost and digestate production and quality analysis - ECN
Related Deliverables:	D3.1, D3.2, D3.4 & D5.3
Related Milestones:	MS6 & MS7
Lead Authors:	ECN – Steffen Walk & Riccardo Gambini
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Peer Reviewers:	ZWE – Enzo Favoino CIC – Marco Ricci, Alberto Confalonieri, Michele Giavini ECN – Stefanie Siebert

Due Submission Date:	M20
File Version Date:	23 May 2024
Approval Date:	23 May 2024
Participant Portal Upload Date:	18 June 2024
Status:	Submitted
File Name:	240618_LIFE BIOBEST_WP3_D3.3_Guideline_ QualityCompost_Submitted
File Location:	P-22-04 PLP BIOBEST > BIOBEST Shared documents > WP3>T3.3>D3.3 (internal copy) Participant Portal (submitted copy)

1.2 Document Revision History

Table 2. Document Revision History

Version Number	Date	Version Type	Short Description of the Changes	Editor
0.1	24/07/23	1st Draft	Document created as 1st version	ECN – Steffen Walk, Riccardo Gambini, Stefanie Siebert
0.2	22/01/24	1st Draft	1st revision by WP leader	CIC
0.3	15/02/24	2nd Draft	Updated version after revision and input from ECN members	BGK, CIC, KBVÖ, VLACO
0.4	01/03/24	2nd Draft	Document version distributed to peer reviewers	ECN – Steffen Walk
0.5	20/03/24	2nd Draft	Peer reviewers' contributions in track changes	ECN – Stefanie Siebert ZWE & CIC
0.6	25/03/24	3rd Draft	Revision to include reviewers' contributions	ECN – Steffen Walk
0.7	25/04/24	3rd Draft	Final comments included and sent to project leader	ECN – Steffen Walk
0.8	06/05/24	4th Draft	Final linguistic and format revision	ENT – Mike Stinavage & Gemma Nohales
0.9	23/05/24	Definitive/ Approved	Definitive and approved version to be submitted	ENT – Mike Stinavage & Gemma Nohales
1.0	18/06/24	Submitted	Submitted to Participant Portal in PDF	ENT – Gemma Nohales

1.3 Guideline overview

The treatment of separately collected bio-waste is a crucial step towards a closed loop of organic resources. Depending on the technology applied, its products bear many benefits. Biogas can be a crucial component in the transition to a fully renewable energy mix and has special benefits in terms of storage capacity. Compost and digestate can both act as fertiliser, while especially compost has beneficial properties for soil improvement and soil health.

This guideline includes a technical part as well as a regulatory part. The technical part focusses on the material recycling of bio-waste, aiming at supporting the set-up of processes for the production of high-quality compost and digestate. Therefore, the guidance starts with the presentation of process options including a qualitative comparison of anaerobic digestion, composting and an integrated system combining both. Furthermore, it introduces crucial equipment for processing as well as pre- and post-treatment steps aiming at the refining of the final product.

A product characteristics analysis shows a qualitative comparison of compost and digestate products from their main origins, being bio-waste and garden waste. Furthermore, it gives an overview of crucial quality characteristics from countries and regions with a long history of a quality assurance scheme present, finalised by the presentation of two best practice cases showing the broad range of process complexity.

From there on, the regulatory part starts by introducing the crucial steps of a quality assurance scheme and its benefits towards the production of high-quality compost and digestate. Current EU framework is highlighted including minimum requirements of compost and digestate quality for different application purposes. Finally, the ECN quality assurance scheme (ECN-QAS) is introduced followed by the introduction of national QAS in conformity with the ECN-QAS.

By applying best available bio-waste treatment technologies receiving high-quality waste from an efficient collection system as well as setting up a framework for quality assurance, a high-quality of the final product will be achieved with ease. By promoting compost and digestate as beneficial products compared to mineral fertilisers from fossil resources, their acceptance will increase, opening their potential to the full range of applicable market sectors, while creating a high economic value and green jobs. In addition, their application will lead to an increase of soil health and stability as well as carbon capture, supporting the transition towards climate neutrality.

1.4 Acronyms

Table 3. List of Acronyms

Acronym	Term
ABPR	Animal By-Product Regulation
AD	Anaerobic Digestion
BW	Bio-waste
CMC	Component Material Category
DM	Dry matter
D-t-D	Door-to-door
EWC	European Waste Catalogue
FM	Fresh matter
FPR	Fertilising Products Regulation
GW	Garden or Green waste
inhab.	Inhabitant
KW	Kitchen waste
MS	Member state
NPK	Nitrogen, Phosphorus, Potassium
NQAO	National Quality Assurance Organisation
PFC	Product Function Category
QAS	Quality Assurance Scheme
WFD	Waste Framework Directive
yr	Year

1.5 LIFE BIOBEST Project Summary

EU obligations on the selective collection of bio-waste came into force at the end of 2023, increasing the availability of source-separated bio-waste for composting and anaerobic digestion. To ensure the development of bio-waste management Best Practices (BP) and the production of quality compost and digestate for soil applications, while minimizing any negative effect and closing effectively the loop, a comprehensive analysis is required regarding bio-waste management strategies, instruments and management schemes and their results given that large disparities exist among experiences in the EU.

The LIFE BIOBEST project aims to identify and validate the current best practices and management instruments along the bio-waste management chain (from generation to treatment) that allow the production of quality compost and digestate and establish a series of reference Key Performance Indicators (KPI), based on the analysis of existing databases and experiences. In a policy brief about barriers and through interconnected co-creation meetings with relevant expert stakeholders of the sector, solutions will be provided to overcome the identified technical, regulatory, economic and environmental barriers to widely adopt the proposed BPs.

Four guidelines and a comprehensive EU-wide guide will be created, together with two decision-support tree guides for local and regional authorities to adapt bio-waste management models to their specific context, offering feasible BP and management instruments to promote efficient collection and subsequent recycling of bio-waste into quality compost and digestate.

By means of an analysis of the feedstock materials, treatment practices, resulting compost and digestate quality, a proposal for premium European standards for biological waste entering composting and anaerobic digestion will be developed with the ultimate goal of promoting the certification of these materials and treatments, guaranteeing optimal management processes and a safe, beneficial return to the soil.

The outcomes of LIFE BIOBEST will promote a significant improvement of the collection and treatment systems, and consequently of the quantity and purity of the feedstock material, reducing process rejects and favouring the conversion of bio-waste into high-quality compost and digestate.

The LIFE BIOBEST consortium is led by Fundació ENT (ENT) in partnership with Consorzio Italiano Compostatori (CIC), ACR+ (Association of Cities and Regions for sustainable Resource management), European Compost Network (ECN) and Zero Waste Europe (ZWE). It is a 2.5-years LIFE Preparatory Project funded by the European Commission.

Project Total Eligible Costs: €1,664,600.07, Funding Rate: 90%, Maximum Grant Amount: €1,498,140.05.

1.6 LIFE BIOBEST Guidelines

In conjunction with the January 2024 EU separate collection mandate, the LIFE BIOBEST project investigates various facets of bio-waste management ranging from separate collection, implementation of recycling strategies, processing systems and related management options in order to create high-quality compost and digestate products.

To support upper-level authorities and decision makers in streamlining policy measures and lower-level authorities in implementing solutions, LIFE BIOBEST presents four bio-waste management guidelines. Together, these guidelines offer a strategic vision and practical approaches crucial to effective bio-waste management.

The goal is to provide guidance and support for optimising implementation of the EU obligation with evidence from high performing schemes and with the definition of performance indicators. This guidance may be applied to all the involved actors in the system to maximise the potential contribution of bio-waste to circular economy and related EU targets. Whether municipalities are in the initial stages of bio-waste implementation design or an advanced state of management, these guidelines provide a point of reference for policy and decision-makers, local authorities, waste haulers, recycling entities, and technical practitioners.

This work is crucial to promote the collection of large quantities of high-quality bio-waste in order to produce quality outputs such as compost, digestate, and biogas. Given the diversity of local contexts, these guidelines provide a comprehensive outlook on bio-waste management as well as existing best practices from a number of EU countries where management instruments are successfully applied.

The four LIFE BIOBEST guidelines are:

- D3.1 **Guideline on separate collection** provides an overview of the different bio-waste separate collection schemes and assesses the pros/cons. This guideline includes a set of Best Practices that focus on collection from households and other producers in various contexts.
- D3.2 **Guideline on governance and economic incentives** discusses the governance tools and economic instruments needed to improve management schemes. The guideline presents these instruments alongside examples of their application and includes an analysis of the economic viability of Best Practices in bio-waste management from separate collection to treatment.
- D3.3 **Guideline on quality compost and digestate** breaks down the treatment technologies and resources that support the production of compost and digestate. The guideline provides insights about the processing options, analysis of product characteristics, quality assurance systems as well as related EU legislation and the ECN quality assurance scheme.
- D3.4 **Factsheets on the analysis of best practices in communication and engagement from various countries** delves into the topic of public

communication and education. Public participation and awareness are key complementary issues to management schemes. This guideline includes an analysis of experiences from frontrunners and gives insight about impacts of communication activities.

The backbone of these guidelines is the empirical knowledge of the LIFE BIOBEST consortium and the successful experiences and instruments provided in each document. Taken individually or as one, these guidelines contain information key for institutions and stakeholders in the bio-waste value chain.

2 Focus of the guideline

The aim of this guideline is that local authorities and decision makers will find specific information on:

- **Options for process technologies** suited for the production of high-quality compost and digestate,
- Expectations for **product characteristics and qualities**,
- **Best practice cases** for bio-waste treatment including **key performance indicators**,
- A detailed **definition of quality assurance schemes**,
- Introduction to existing **quality assurance schemes** and **quality standard parameters** for high-quality compost and digestate products, national ones and the one developed by the ECN (ECN-QAS) and
- Final considerations for **product application**.

The emphasis of this report is clearly placed on the production of compost and digestate from separately collected municipal bio-waste. Other sources of organic waste are not considered. This guideline prioritises products for soil application, thus excluding biogas; despite, biogas remains a valuable product, and anaerobic digestion will be considered as the process that allows the production of digestate and an intermediate step towards compost production.

It is important to note that the industrial treatment processes described in this guideline do not only include the material conversion by means of biological treatment but also mechanical pre- and post-treatment in order to produce high-quality compost and digestate.

3 Definitions

This section provides basic definitions for terms relevant to compost and digestate that are frequently used throughout this report. These definitions are intended to help the reader differentiate between closely related concepts, thereby reducing the potential for confusion.

Soil improver

A soil improver refers to any organic or inorganic material that is added to soil with the primary objective of improving the physical and chemical properties, structure, and overall health of the soil (CEN, 2022). Soil improvers are usually rich in organic matter and aim to improve factors such as water retention, aeration, drainage, and microbial activity. They contribute to building a healthier soil ecosystem, promoting better plant growth, and preventing soil degradation over time.

Fertiliser

A fertiliser is a substance, either organic and/or mineral, that is applied to the soil to provide essential nutrients to support plant growth and development. Fertilisers are formulated to supplement the naturally occurring nutrients in the soil, ensuring that plants receive an adequate and balanced supply of nutrients such as nitrogen, phosphorus, and potassium. Fertilisers can be tailored to address specific nutrient deficiencies and improve plant productivity.

Compost

Compost is a nutrient-rich, solid particulate material that results from the controlled decomposition of biodegradable organic matter, and has been sanitised and stabilised (CEN, 2021). This decomposition process runs in an aerobic environment and is facilitated by microorganisms like bacteria, fungi, and other decomposers. The final compost commonly has a solid content of at least 50%. Compost acts as a natural soil improver and potentially also organic fertiliser with the following benefits: improves soil structure and nutrient content, improves water retention potential and therefore also reduces erosion, balances soil pH levels, improves microbial activity, and stores carbon which is of strategic importance for reducing the impacts of human-made climate change. Finally, it improves soil fertility and improves plant growth. Compost is typically applied on the soil surface or mixed into the topsoil as a soil improver.

Digestate

Digestate, a nutrient-rich, solid or liquid material is the result of anaerobic digestion (AD) of biodegradable organic matter by microorganisms (CEN, 2021). AD is a biological process that breaks down biodegradable organic matter in the absence of oxygen, resulting in the production of biogas (mainly methane and carbon dioxide) and a nutrient rich digestate.

Depending on the AD technology, digestate can be liquid, pasty, or solid. Liquid digestate is typically separated from the solid fraction of digestate but depending on the post-processing its solid content may vary and is considered as liquid digestate if dry matter (DM) ≤ 20% of fresh matter (FM) or solid digestate (DM ≥ 20% of FM) according to the definition of a soil improver within the fertilising product regulation (see section 8.1). According to Fachverband Biogas (2018), the average liquid digestate has a DM content of 6%. With its valuable nutrients it acts as an organic fertiliser and improves plant growth. With limitations, solid digestate can also act as soil improver. Overall, digestate comes with the following benefits for soil: enhances nutrient content, improves soil structure (depending on the solid content) and improves microbial activity. Digestate is typically applied directly to the soil or incorporated through irrigation systems, providing more even distribution of nutrients or post-treated (e.g., dried, pelletised).

EU Fertilising Product

EU Fertilising product refers to a fertilising product which is CE-marked when put on the market according to the EU Fertilising Product Regulation (see Section 8.1 for more information).

Product Function Category

Product Function Category is a classification system used by the EU Fertilising Products Regulation to organise different types of fertilising products according to their intended function (see Section 8.1 for more information).

Quality Standards

Quality standards refer to established guidelines, specifications, and benchmarks that define the desired attributes and characteristics of a product. In the context of compost and digestate production, quality standards outline the specific criteria that these materials should meet in terms of their composition, physical properties, nutrient content, and other relevant factors. These standards serve as reference points to ensure that compost and digestate products are of consistent quality and suitable for their intended applications. Quality standards provide a framework for evaluating and verifying the quality of the produced materials.

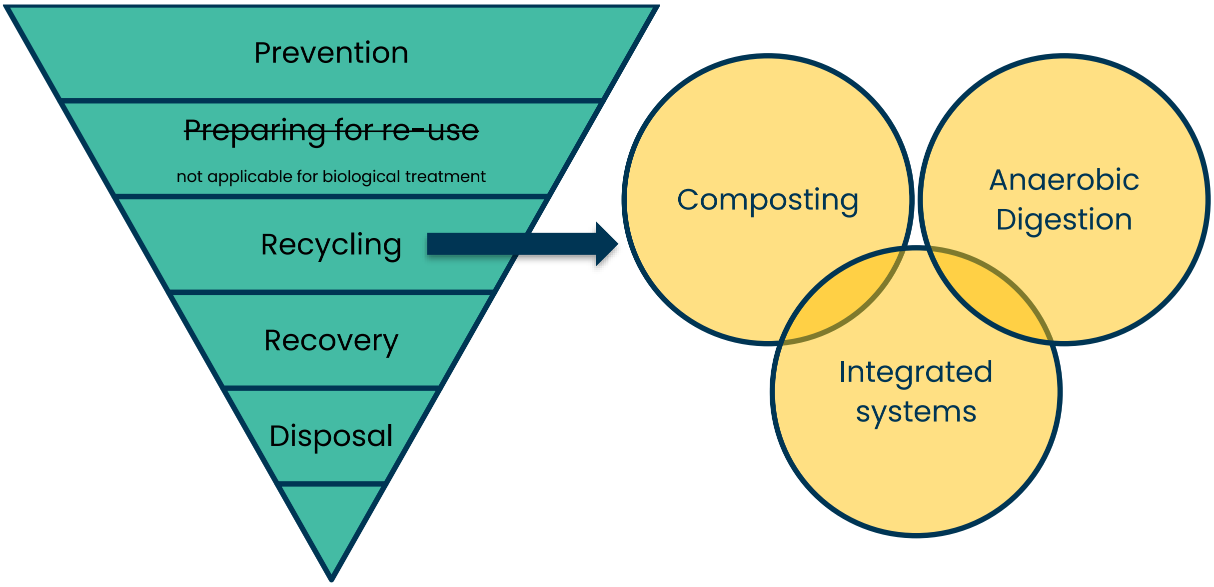
Quality Assurance (Scheme)

A quality assurance scheme encompasses a systematic approach to monitoring and ensuring the consistent quality of a product throughout its production, distribution, and use. It involves a set of procedures, protocols, and processes designed to meet established quality standards. In the context of compost and digestate production, a quality assurance scheme would involve implementing measures to monitor various stages of production, from feedstock selection and processing to final product distribution. This scheme aims to minimise variations in product quality, enhance customer confidence, and meet regulatory requirements.

4 Process options for municipal bio-waste treatment

Various techniques exist for processing separately collected municipal bio-waste, being either kitchen waste (KW), green waste (GW) or the commingled one, called bio-waste (BW). In alignment with the waste hierarchy (Figure 1) outlined in the Waste Framework Directive (WFD), the recommended approach for organic material that was not prevented, thus becoming waste, is recycling.

Figure 1. Waste hierarchy and most common recycling options for bio-waste



The initial step towards effective recycling of municipal BW involves its separate collection at the source. Numerous studies have affirmed that separate collection is essential for producing high-quality compost and digestate, enabling diverse applications including organic farming (Rodrigues et al., 2020; Tavazzi et al., 2013). Separate collection is considered as a pre-condition for this guideline and is further elaborated in the specific **LIFE BIOBEST D3.1 Guideline on separate collection.**

The recycling of BW comprises a biological step of composting, AD or a combination of both. All of these processes stabilise and transform organic matter. In industrial processes, the biological step is encapsulated within a pre-conditioning and post-refining mechanical treatment which aims at conditioning the feedstock or final product material in terms of quality. Since the quality of the incoming feedstock material has become more relevant in recent years, means of their quality assurance have developed including quality controls during collection and before entering mechanical pre-treatment. Methods and recommendations for the quality assurance of the feedstock material will be further elaborated in another project guideline on EU standards for BW entering recycling processes for high-quality compost and digestate (Walk et al., 2024).

The subsequent section outlines the circumstances under which AD, composting, or a combination of both systems operate and the reasons for their application. Additionally, it introduces pre- and post-treatment technologies and elucidates their role in impurity removal and quality improvement.

4.1 Biological treatment

This section provides an overview of the most common treatment options for municipal BW as well as a more detailed comparison of specific treatment types within each type of treatment. Furthermore, pre- and post-treatment equipment to assure a high-quality product are introduced.

4.1.1 Comparison of treatment options

Table 4 provides a general comparison of the most common treatment options for municipal BW. Please observe the following:

- ▪ Indicates a neutral/general note,
- + Indicates a beneficial condition and
- – An unfavourable condition, often linked to the other process options.

This is as well true for following comparisons in other tables.

Table 4. Comparison of the different biological treatment options as well as their advantages and disadvantages

Composting	Anaerobic digestion	Combination
Products		
Compost	Renewable energy carrier + liquid or solid fertiliser (digestate)	Renewable energy carrier + compost
Requirements for feedstock and secondary outputs		
▪ Requires rather dry organic waste (> 40% DM) ▪ Feasible feedstock: almost every organic matter, possibly mixed, with mentioned minimum DM (e.g., GW mixed with KW)	▪ Can handle organic waste with high moisture content ▪ Feasible feedstock: easily degradable, (e.g., KW, with low lignin content) ▪ Potentially requires management of potentially high amounts of process water	▪ Requires management of potentially high amounts of process water
Expected outputs (mass balances) from 100% feedstock input		
▪ 10 – 20% screening losses (impurities, coarse materials) ▪ 35 – 40% finished compost product ▪ 40 – 55% loss of weight due to water evaporation, biodegradation and gas emissions (Bilitewski et al., 2018)	▪ 10 – 20% screening losses (impurities, coarse materials) ▪ 8 - 14 % biogas (80 – 140 Nm^3 biogas per Mg digester feedstock), incl. loss of carbon for composting ▪ 66 - 82% waste water and solid output (Bilitewski et al., 2018)	▪ 10 – 20% screening losses (impurities, coarse materials) ▪ 8 – 14% biogas ▪ 15 – 25% compost
Technical requirements		
Low + Simple infrastructure + Low-tech equipment - Monitoring challenges - Process efficiency may rely on weather conditions (temperature/precipitation) - Requires more space compared to AD - Requires sufficient GW feedstock as structuring material ▪ Skill requirement for personnel depends on technology complexity	**High** + Controlled environment + Advanced technology requirements - External energy input - Very skilled personnel for operation and maintenance	**Very high** ▪ Pros & cons of single processes - Requires most technology incl. additional equipment to combine processes

Capex / Opex		
Low – medium + Main investment in space and turning equipment - Long operation time until product may offset low capex	**High** + Potential for higher revenue through fuel/energy production - Initial disadvantages due to high cost (incl. Opex)	**High** + Synergies allow for more efficient resource utilisation and generation of revenues + No need for long-term digestate stabilisation + Shorter aerobic step compared to composting - Higher combined cost
Technical robustness		
Very high + Technical failure mostly in additional machinery - Process failure due to lack of oxygen or insufficient or excess water content	**Medium - high** + Dry AD more robust compared to wet AD - In wet AD blockage of pipes may occur - Process failure may occur due to inadequate heating or acidification resulting from inconsistent feedstock	**High** ▪ Same as individual processes + Failure of one part of the technology allows the mono-use of the other for a certain time
Scaling potential		
Very high + Allows for decentralised regional small-scale treatment + Low effect of economy of scale	**Medium** + Dry AD easier to scale than wet AD - High effect of economy of scale - Decentralised systems (e.g., in rural areas) economically less feasible	**High** + Allows splitting of processes, e.g., partial flow AD

4.1.2 Composting

Composting is the biological process that, in the presence of oxygen, converts organic materials into a nutrient-rich soil improver by means of microorganisms and fungi, called compost.

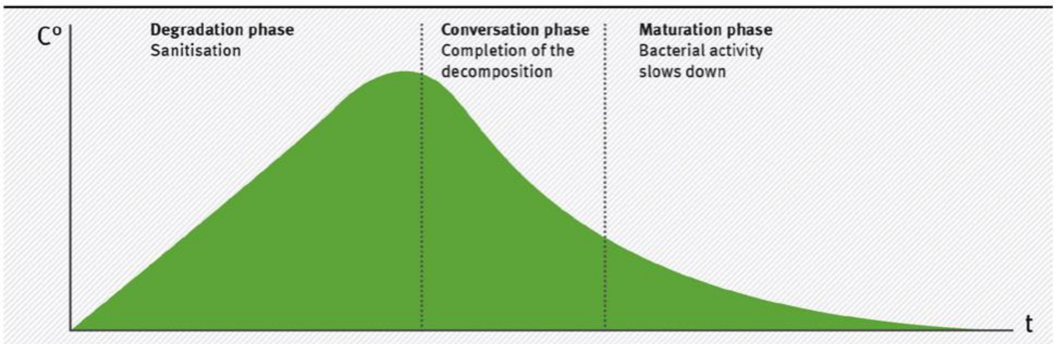
It requires structuring material that allows proper aeration by providing porosity and a balanced moisture content to the mass under treatment. Most GW can be composted alone, except for leaves and grass clippings, which require additional woody material. In contrast, mixed BW or KW usually cannot be composted alone due to its high liquid content. Therefore, additional structuring matter holding high-fibre and carbon content such as GW is an important component of the feedstock material entering composting plants, since it contributes to the porosity needed for an optimal aeration and oxygen supply.

Composting is, as of now, the favoured treatment option for separately collected municipal BW, with 70% of the separately collected stream being sent to composting plants in the European Union (Gilbert & Siebert, 2022). Southern Europe is relying more on this type of recycling technology since the soils in the region usually are organic content deficient. This makes them benefit from application of compost, by increasing soil organic matter and consequently ameliorates overall soil fertility. However, the choice of AD or its combination with composting, is largely influenced by the presence or absence of subsidy schemes for renewable energy, which may positively affect the economics of AD to a large extent.

In general, the industrial process is distinguished into 5 steps:

1. Pre-treatment: Adjustment of particle size (shredding), removal of impurities (optional), mixing. While few large-size impurities found in GW are often still removed by hand-picking, their removal in mixed BW or KW requires technical solutions (see section 4.2).
2. Active decomposition phase: This is the primary stage of organic degradation facilitated by microorganisms. Its primary objective is to ensure sanitisation, thereby achieving the necessary reduction of human, animal, and plant pathogens. When animal by-product-derived materials are utilised as input, adherence to the standard process requirements, specifically temperature-time profiles of the EU animal by-product regulation (refer to Section 8.1.4), or their national implementation regulations have to be respected. The duration of this phase varies depending on the feedstock material and technology employed, ranging from several days to weeks. In industrial composting, this phase may sometimes be divided into two stages, the first one happening in a closed, highly engineered system only for 1 to 2 weeks ("intense rotting") followed by a phase with lower-technological arrangements (e.g., windrows). Figure 2 shows a typical temperature-time profile during the composting process.

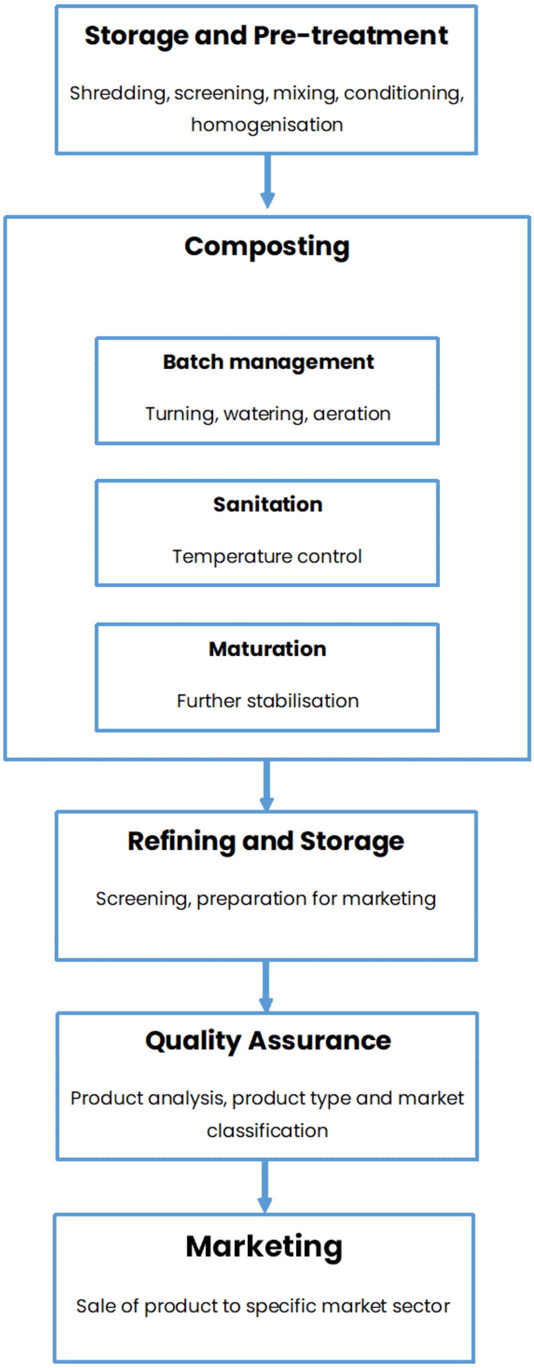
Figure 2. Typical temperature-time profile in the active decomposition phase



Source: UBA 2017, adapted from BGK 2010

3. Curing: Stabilisation of temperature and organic maturation. Can last several weeks.
4. Mechanical refining (post-treatment): Screening, wind sifting, magnetic separation, coarse fraction separation. Screening can be performed the same way as during pre-treatment, but usually with smaller mesh sizes of the sieve in order to remove coarse particles (impurities and undecomposed wooden materials) from the final product (see section 4.2).
5. Compost storage.

Figure 3. Flow scheme of composting and accompanying processes



A detailed description on the treatment processes can be accessed in the European Quality Assurance Scheme for Compost and Digestate (ECN-QAS) (Siebert & Vanden Auweele, 2018). Further information can be found as well in Amlinger et al. (2009) and Bilitewski et al. (2018).

Table 5 shows a summary of requirements for composting and examples for the most commonly used technologies as well as their potential advantages and disadvantages.

Table 5. Conditions, properties and requirements for composting process

Composting	
Requirements	
• Balanced moisture content: 50 – 60% water • Balanced carbon-nitrogen ratio: 20:1 – 40:1 • Structuring material (GW) • Oxygen: Sufficient aeration for aerobic conditions • Temperature: minimum 55 °C (10 days) or 65 °C (3 days) in active decomposition phase (for proper decomposition and sanitisation effect)	
Static and quasi-static systems Long triangular static piles (windrow shape); System can be passively or actively aerated, varying turning frequency and limitations in windrow shape and size	
Open windrow composting	
 Open windrow (Siebert, 2014)	+ Low investment costs + Turning compost possible → allows proper composting of all material + Easy to increase capacity if sufficient space - No weather protection – risk of too dry or wet batches and therefore weak processing - Adjustment of aeration and moisture difficult - Risk for fumes

Open window composting – semi-covered by fabric/foil or roof	
 Semi foil-covered composting (Siebert, 2009)  Semi roof-covered composting (Siebert, 2023)	+ Low-medium investment cost (roof, foils) + Simple weather protection + Moisture preservation - Turning of compost more difficult than without fabric/foils - Potential intake of plastics through foils - Risk of mould - Risk of fumes
Indoor composting System is usually actively aerated, turning may be adopted and its frequency is variable depending on the technology applied	
Bay composting	
 Bay composting with frequent turning (Walk, 2019)	+ Advantages of a closed system combined with windrow method + Automatic turning + Ventilated floors for aeration + Irrigation from spray systems + Weather protection + Exhaust air cleaning + Specific arrangement potentially allows continuous process management (input on one side, output on the opposite side) - Higher investment and operational cost compared to open windrowing

Tunnel composting	
 Closed container with ventilation slots (Siebert, 2022)	**+** Adjustment of aeration and moisture easily possible through ventilated floors and irrigation **+** Weather protection **+** Exhaust air cleaning **+** Turning of compost usually unnecessary in this short step **-** Higher investment and operational cost compared to open windrow **-** Relatively low flexibility in increasing capacity, that can be only achieved by increasing the number of tunnels

Scaling of process: Depending on the technology employed, a composting plant can be easily scaled-up compared to an AD plant due to the limited technology required. The limiting factor is the surface area required, as a composting process cannot grow beyond a certain height without causing compaction of the mass to be processed. Small scale facilities are feasible to avoid medium or long-distance transportation of BW (e.g., in rural areas).

4.1.3 Anaerobic digestion

Anaerobic digestion is the process by which microorganisms break down organic materials in the absence of oxygen. This process naturally takes place in swamps as well as in ruminants, such as cows. The absence of oxygen is the main difference to composting, which requires it. Its products are biogas as well as, depending on the post-treatment, a liquid or solid fertiliser called digestate.

AD is by now a widespread treatment process in many European countries, especially in the North of the continent. As for the preference for composting, the application of the AD process is mainly driven by the absence or presence of subsidies for renewable energy. In the case of Nordic regions in Europe, the direct application of digestate instead of compost is due to the conditions of soil, which are rich in organic content, thus favouring the production of digestate to be used on land thanks to its higher fertilising properties compared to compost.

In technical processes, AD requires external energy, mostly in the form of heat to work efficiently (endothermal process) while composting releases thermal energy (exothermal process). As a rule of thumb, the lower the temperature in AD, the slower the conversion rate to biogas. However, an overall stable process temperature is more important for process stability and biogas production than the absolute temperature, although it should be at least 30 C to be economically viable. Thermophilic conditions (>50°C) may increase biogas yield and act as a sanitisation step but also require stricter process control and more external heating. Electricity is required as well, especially for feedstock preparation, pumping of feedstock and digestate and stirring during the process.

The process of AD results in the production of digestate and biogas. The latter mainly comprises 50% - 70% methane (CH_4) and 30% – 50% carbon dioxide (CO_2), depending on the feedstock, temperature, pH and organic loading. It also contains traces of water, oxygen, hydrocarbons and sulphuric compounds. Biogas can be directly used to produce heat and electricity, or can further be upgraded into biomethane through a series of processing steps. The latter would allow it to be fed into a (national) gas grid. As an example, municipal BW yields between 80 and 140 L CH_4/kg feedstock.

The solid or liquid digestate usually needs to be further treated to be applied on land, at least with a sanitisation step (see section 8). This sanitisation can either be achieved by combined AD and subsequent composting of the dewatered digestate mixed with structuring material such as GW or by thermophilic AD.

Table 6 shows a summary of requirements for AD and examples for the most commonly used digester technologies as well as their potential advantages and disadvantages. Further information can be found in Wilken et al. (2019).

Table 6. Conditions, properties and requirements for anaerobic digestion process

<table>
<tr><th colspan="2">Anaerobic digestion</th></tr>
<tr><th colspan="2">Requirements</th></tr>
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- Low solid content – Dry AD (20 – 40%), Wet AD (5 – 20%)
- External heating
- Temperature process conditions: mesophilic: 35-49 °C up to thermophilic > 50 °C)
- Absence of oxygen
- pH between 6.5 and 8 (optimum 6.8 – 7.2)

</td></tr>
<tr><th colspan="2">Continuous wet anaerobic digestion</th></tr>
<tr><td>

Wet anaerobic digesters + gas storage (Siebert, 2023)

</td><td>

+ Low human labour intensity (continuous mode, homogenisation through stirring, diluted and therefore pumpable material)
+ Liquid digestate can be applied to (arable) soil directly (if sanitisation took place)
- Requires intense pre-treatment (shredding, impurity removal), high quantities of process water, dewatering step (if digestate should be composted) and high-capacity waste water treatment for process water
- High energy demand for heating low biomass content

</td></tr>
</table>

	- Difficulties in system cleaning - Heavy particles (sand, stones) tend to create a bottom layer if not stirred properly - Light particles (low density organic matter, plastic impurities remaining after pre-treatment) tend to create a top layer that must be periodically removed
Batch dry anaerobic digestion	
 Dry anaerobic digester boxes (Walk, 2019)	+ Batch mode technically similar to tunnel composting + Lower energy demand for heating (less inert mass to heat) + Requires low-capacity waste water treatment (compared to wet AD) - High salt contents, especially in leachate/liquid stream - Hard to achieve homogenisation - No continuous mode (=higher human labour intensity than wet AD) ▪ Anaerobic inoculum (leachate/liquid stream) circulated internally and sprayed over biomass
Continuous dry anaerobic digestion	
 Plug-flow digester under construction (Wilken, 2019)	+ Plug-flow technology allows continuous mode of rather dry and heterogenous feedstock (15-45% DM) + Specific arrangement allows continuous process management (input on one side, output on the opposite side) + Require less energy per feedstock compared to wet AD + Reduced risk for shortcuts of feedstock and therefore stable retention time - High solid content can lead to clogging of system - Difficulties in system cleaning ▪ Vertical (by gravity) and horizontal (by stirrer) set-up possible

Scaling of process: Depending on the technology, an extension of an AD plant requires high investment cost and more complex adjustments compared to a composting plant. Dry batch AD plants may be easier to expand compared to wet AD plants. As a benefit over composting, wet-AD processes require less surface area since they can grow in height.

Furthermore, the higher investment cost might be possible to amortise faster due to the gains from the production of renewable fuel/biomethane.

4.1.4 Combination of anaerobic digestion and composting

The combination of AD and composting in an integrated system benefits from an energetic recovery in combination with compost production and therefore bio-stabilisation of the digestate from the AD process. The development of these combined systems is gaining momentum, especially in regions where biogas is part of the renewable energy transition and digestate is not directly applied on land but needs to undergo a post-composting phase to be sanitised or fulfil the end-of-waste criteria according to the national legislation.

Generally, processes outlined in sections 0 and 4.1.3 can be applied in combination. One limitation is the need for digestate dewatering if a wet AD process involved. However, post-composting of digestate with structuring material benefits from a remarkably shorter aerobic phase for its stabilisation compared to the need for the rather long-term digestate storage before use if it is not intended for compost production. Furthermore, post-composting duration can be remarkably shorter compared to a composting process without upstream AD.

4.1.5 Crucial composting equipment during processing

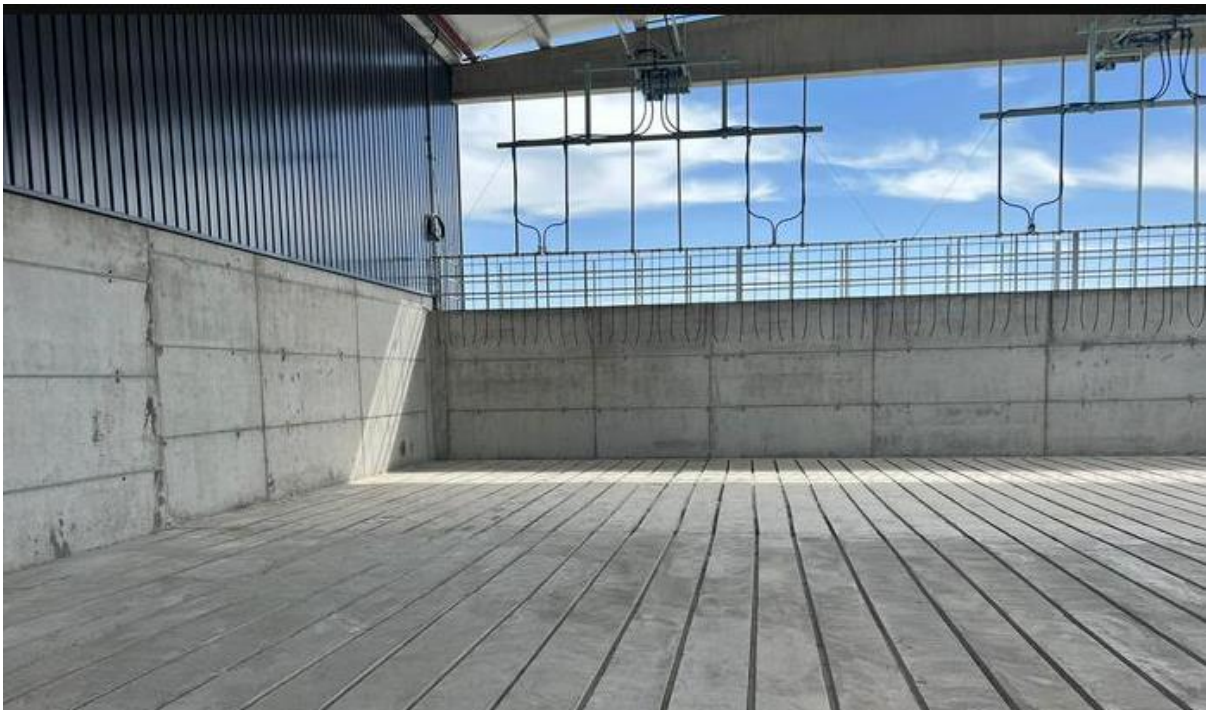
This section provides equipment for specific treatment conditions, specified in Section 4.1.1.

Figure 4 and Figure 5 show equipment used for aeration of composting piles. While Figure 4 shows turning machinery which moves along the open windrow to turn it, Figure 5 shows an integrated aeration from the bottom that does not require mechanical turning of the composting piles. As a minimum requirement, one of the options for aeration is necessary for proper compost production.

Figure 4. Turning of open windrow composting pile

Source: Siebert, 2014

Figure 5. Ventilated floors for aeration in semi-closed system and irrigation system



Source: Mancomunitat La Plana, 2023

Figure 5 and Figure 6 show different systems for irrigation. While Figure 5 shows an integrated irrigation from the ceiling, similar to a sprinkler system, Figure 6 shows manual machinery, that moves along the composting pile for irrigation.

Figure 6. Irrigation on open windrow composting pile

Source: Siebert, 2023

Figure 7 shows a biofilter, a simple technical solution for purifying exhaust fumes emitted from the composting process. Exhaust air cleaning is required when at least a part of the process takes place in closed buildings or tunnels.

Figure 7. Biofilter for the removal of fumes during enclosed composting

Source: Siebert, 2023

4.2 Mechanical pre- and post-treatment to assure high quality products

The equipment presented in this section is designed to ensure a high-quality product after treatment. In addition, there is the possibility of frequent quality control by means of visual inspection and waste composition analysis prior to treatment in order to assess and follow the evolution of feedstock quality. Several EU Member States (MS) have implemented already a methodology for feedstock quality control. **LIFE BIOBEST D5.3 Proposition of quality standards** addresses this issue in more detail.

4.2.1 Technologies during collection process

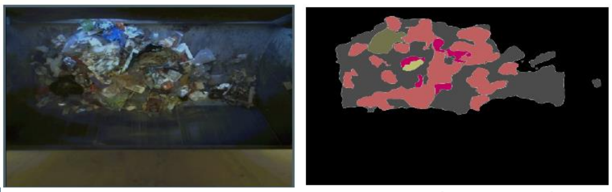
This section shows examples for solutions to improve or maintain high-quality feedstock material during BW collection (Table 7). The set-up of collection systems for high-quality feedstock is described in **LIFE BIOBEST D3.1 Guideline on separate collection.**

Table 7. Examples of quality control during collection

Bin controls

Requirements	Cost
Separate D-t-D BW collection, Staff, Legal mandate to allow for controls (open bin, enter private property)	~ 3 €/t BW collected (mainly cost for staff)
 Bin sticker (#wirfuerbio, 2023)	This activity can be performed to spot households which do not comply with sorting regulations, either prior or during collection. An option is the use a traffic light card or sticker system, to inform the households about their sorting behaviour. Measures reach until the non-collection of BW including an extra fee to collect it as residual waste. Studies show that bin controls can increase quality but need to be performed repeatedly to keep it high.

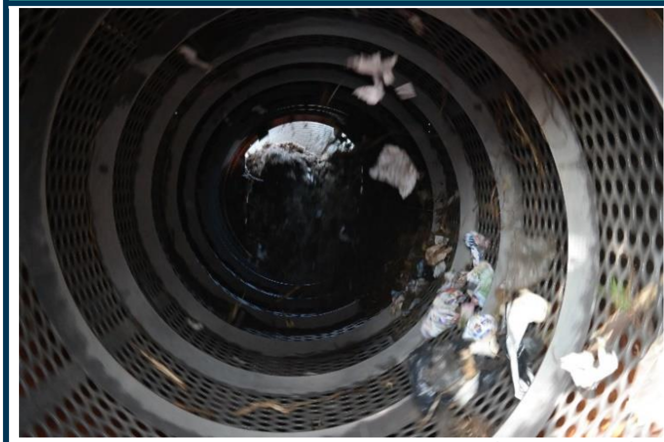
AI technology

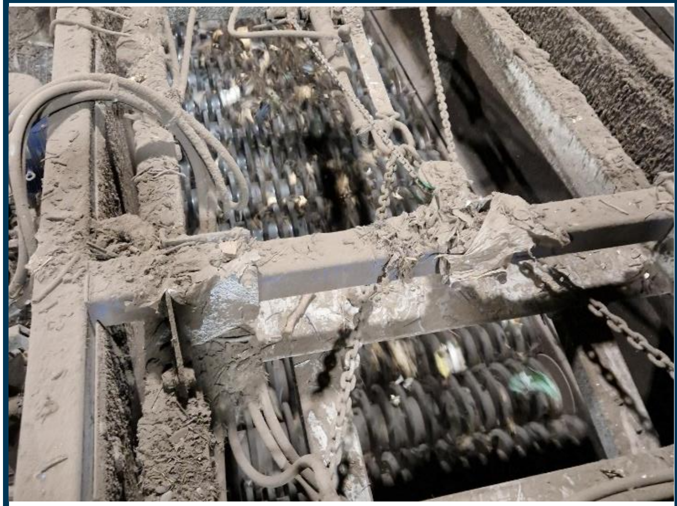
Requirements	Cost
Separate D-t-D BW collection, Waste collection truck, Technical adjustment of truck loading	25,000 – 50,000 € per truck
 AI technology identifying impurities (INFA, 2023)	A range of technical solutions, spanning from metal detection to near-infrared scanning and image recognition, have reached market maturity. Technologies work either before, during or after bin emptying. A recent study evaluated the performance of different systems (INFA, 2023).

4.2.2 Pre- and post-treatment technologies

Table 8 introduces machinery and equipment used in the pre- and post-treatment of compost and digestate.

Table 8. Pre- and post-treatment technologies for compost and digestate production

Pre- and post-treatment	
Manual impurity removal	Pre-treatment
 Manual removal of impurities (Walk, 2023)	▪ Removal of coarse materials, e.g large plastic bags + Technically easy solution + Requires almost no equipment - Requires manual labour - Safety aspect - Only feasible for low impurity contents (e.g., pure GW) - Not feasible for small particles
Drum screen	Pre- & Post- treatment
 Drum screen for coarse material removal (Siebert, 2014)	▪ Separates coarse and fine material + Continuous operation (has to be cleaned sometimes) + Different mesh sizes can be applied + Feasible for pre- and post-treatment - Classification only based on particle size and not on type of material; no differentiation between BW and other materials - Requires "bag-opener" as pre-step (if bags are used for the collection of KW)

Metal detector	Pre-treatment
 Conveyor belt metal remover (Walk, 2024)	▪ Removes Fe metals via magnet ▪ Options for nFE metals exist + Low tech-solution + Continuous operation - Needs conveyor belt - No secondary purpose (if no metals present anymore)
Star sieve	**Post-treatment**
 Star sieve for specific particle sizes (Schulenborg, 2024)	▪ Separation of coarse and fine material ▪ Commonly used for conditioning the final product rather than for impurity removal + Can be used for specific particle size removals (e.g. 10 – 30 mm) - Classification only based on particle size and not on type of material; no differentiation between BW and other materials

Screw press	Pre-treatment
 Screw press for AD suspension (Schulenborg, 2024)	▪ Used to blend feedstock and digestate into a suspension for AD + Blending and pressing generates homogenous mixture + Small particle size increases conversion rate into biogas - Might require frequent cleaning - De-watering more challenging (for composting) - Could result in higher quantities of structuring material for composting
Wind sifter	Pre- and post-treatment
 Wind sifter for removal of small & light materials (Walk, 2024)	▪ Target light-weight impurities such as plastics ▪ Classification by weight and density, can be combined subsequently with near-infrared-technology to detect plastic particles ▪ A technical solution for higher density impurity removal is vibrating screens + High precision + Continuous operation - High-tech and rather expensive solution
Drying belt	Post-treatment
 Drying belt for the dewatering of digestate (Siebert, 2018)	▪ Liquid-solid separation of digestate after AD ▪ Conveyor belt ▪ Other technologies for the drying of digestate include centrifuges, presses and rotary dryers + Continuous operation + Adjustment of temperature, air flow and conveyor speed - Requires thermal energy, and in the case of centrifuges electric energy… +… But can be received internally

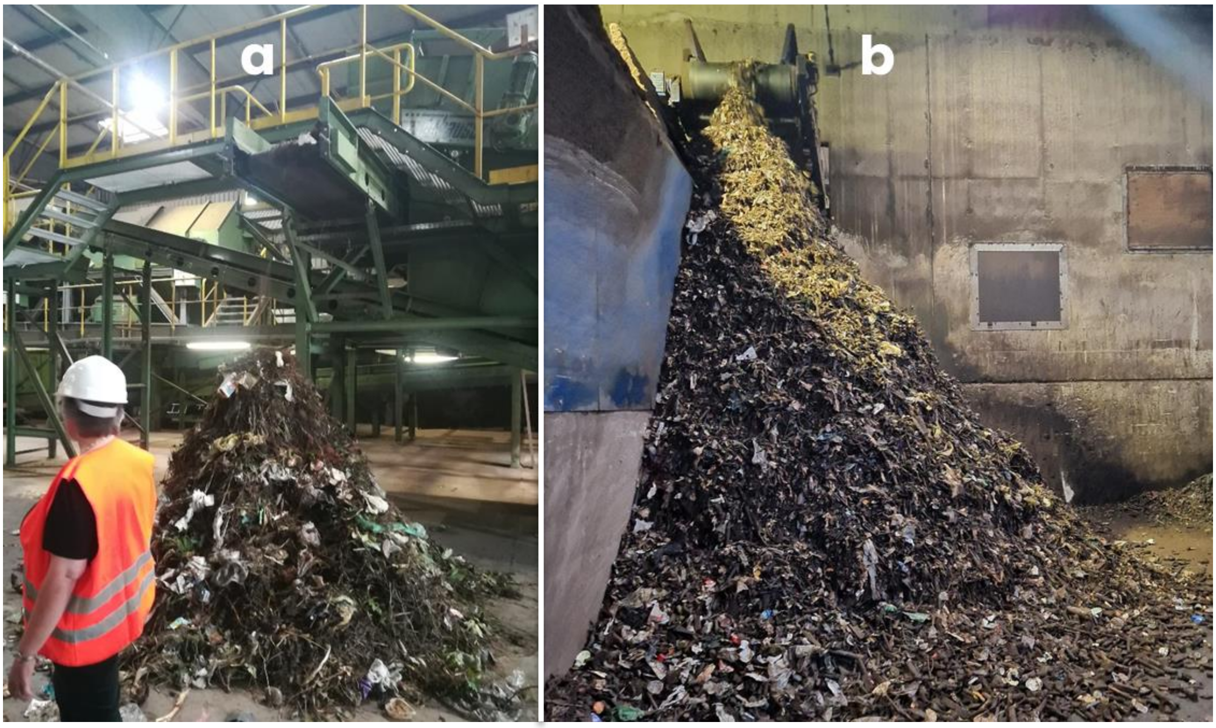
4.3 Images of rejects and products

4.3.1 Process rejects fractions

The following pictures show reject fractions generated during the processes previously introduced.

Table 8a shows the coarse fraction (>30mm) separated, e.g., by a drum screen. This comprises tree twigs, branches and impurities like plastic bags. Table 8b shows a similar material type (30 – 80 mm) that was used as structuring material for the post-composting process. To recirculate the biomass part of the fraction into composting, further treatment is needed to remove impurities (e.g., a wind sifter to remove plastics). After a certain number of composting cycles, the material may be disposed of or sent to co-incineration.

Figure 8. Coarse fraction of fresh feedstock during pre-refining (a) and during post-composting refining (b)



Source: a - Walk, 2019, b - Schulenborg, 2024

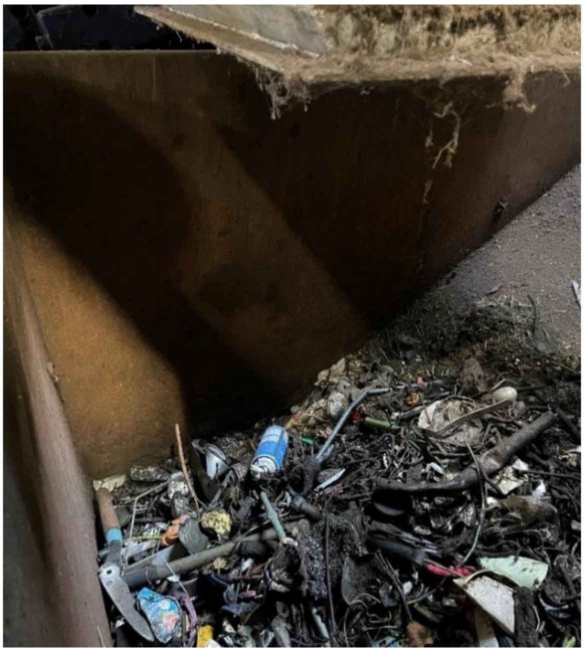
Figure 9 shows the reject of a wind-sifted material (post-composting). Besides plastic particles, also very fine product particles are commonly removed, especially when very dry.

Figure 9. Reject fraction of wind-sifted material

Source: Walk, 2024

Figure 10 shows the metals separated in the pre-treatment process using a magnet. This fraction is typically very clean due to high separation efficiency. Subsequently, most metals can be recycled.

Figure 10. Reject fraction of metal detector



Source: Schulenborg, 2024

Figure 11 shows stones and similar rejects removed by a stone trap. This process can be set up in various ways, e.g., by a 45° conveyor belt where heavy materials (e.g. stones) fall against the conveyor belt direction or by a sink-float process where heavy materials sink on the bottom and light materials float on top.

Figure 11. Reject material of stone trap

Source: Schulenborg (2024)

4.3.2 Pictures of product fractions

Figure 12 shows a final high-quality compost product that can directly be applied on soil. During refining step, it was sieved to a maximum particle size of 15 mm.

Figure 12. High quality compost with a particle size of 0 – 15 mm

Source: Siebert, 2022

Figure 13 shows a secondary product of the composting process. The material can serve various purposes, preferably its re-circulation as structuring material in the composting process, in line with the circularity attempt of the waste hierarchy. Alternatively, it can be used as biomass fuel, or, as a last option, disposed of at a landfill site. This is especially the case if, after multiple rounds of circulation, the level of impurities has reached a point where further circulation is no longer feasible.

Figure 13. Intermediate 10-30 mm fraction (e.g., sieved by star sieve)

Source: Schulenborg, 2024

Figure 14 shows the solid part of digestate after centrifugal dewatering after a wet AD process. As elaborated previously, digestate of dry AD processes do not require dewatering and usually show higher DM contents. Mixed with structuring material, digestate can be post-composted.

The liquid fraction from dewatering is commonly recirculated internally, while a partial stream is continuously sent to a wastewater treatment facility, replacing it with fresh water.

Figure 14. Solid digestate, dewatered after a wet AD process (~35% DM)

Source: Bharadway, 2022

5 Product characteristics analysis

This chapter gives an overview of examples of main characteristics of different products obtained from BW recycling, i.e., digestate, compost from GW and compost from BW. Furthermore, physical contamination is described as the quality aspect, that can be mainly influenced by pre- and post-treatment technologies. An explanation of how these characteristics and qualities fit into national and EU legal frameworks can be found in chapters 8 and 9.

5.1 General characteristics

Table 9 shows a qualitative comparison of product characteristics. These should be taken into account when selecting the process, particularly regarding the planned field of application of the products.

Table 9. Qualitative characteristics comparison of different products

Characteristic	Bio-waste compost	Green waste compost	Bio-waste Digestate
Nutrients	**	*	***
Nitrogen availability	**	*	***
Salt content[1]	**	*	***
Physical impurities (% DM)[2]	***	*	***
Heavy metals	Depends on feedstock	Depends on feedstock	Depends on feedstock
Stability and organic matter[3]	*** – **	***	* – **
Transportability	***	***	*[5] / **[6]
Odour release[4]	**	*	***

[1]Measured by electric conductivity, [2]Most concerning impurity is plastics, [3]For use as growing media, only very mature compost should be used, to be tested with oxygen uptake rate, [4]Assuming equal stability degree, [5]Liquid, [6]Dried/Solid

The area of application of both, compost and digestate, depends on regional situations (e.g., livestock density, soil types and climate conditions). In general compost can be applied for different purposes (landscaping, horticulture, agriculture, production of professional growing media) and due to its stabilised organic matter content on all soils. Compost is mainly used as a soil improver for maintaining soil organic matter and providing basic fertilisation in a crop rotation. In contrast to compost, digestate is characterised as an organic fertiliser instead of a soil improver. Stabilisation of organic matter during the decomposition process in anaerobic digestion is restricted as lignin-rich material is lacking in the AD process and is not degraded in the process. The nutrient composition and the characteristics of digestate vary depending on the input materials, the treatment process (dry or wet digestion) and the post-treatment of digestate.

5.2 Comparison of national and regional product qualities

Table 10 shows a comparison of compost and digestate products under quality assurance of the National organisations of Germany, Austria, Italy and Flanders region in Belgium which are as well those in accordance with the ECN-QAS (see Chapter 9).

5.2.1 Data background information

Regarding compost:

- All BW Compost includes GW as structuring material, either by default due to the collection system or by mixing additional amounts of GW collected separately through dedicated schemes (e.g., at municipal recycling centres) with KW, or with digestate from its AD.
- GW compost is not mixed with BW.
- In Austria, there is no distinction between compost derived from BW or GW in the quality assessment. Therefore, GW-derived compost is included in the dataset on BW in Table 10.

Regarding digestate:

- In general, no distinction was made between dried and liquid digestates.
- CIC does currently not include digestate as a final product under its quality assurance scheme. All digestate undergoes post-composting. However, in some cases digestate as a final output is produced in Italy and applied to soils according to site specific permits.
- In Flanders, Belgium, there is no digestate derived from household BW as a final product; it is all post-composted. Digestate is produced from manure, energy crops, and food waste from industry.
- In Germany, digestate under BGK QAS is produced from household BW, other similar sources, as well as from manure and energy crops.

In all countries presented, there may be additional compost and digestate products not under quality assurance schemes, as well as under different QAS. With respect to digestate, the intention was to include only those with at least a share of BW as feedstock material.

For more information on the national QAS, see Section 9.2.

Table 10. Compost and digestate characteristics of the plants under quality assurance of the national associations following the ECN-QAS

	Sample size [n]	pH [-]	Electrical conductivity[d] [dS/m]	Bulk density [g/L FM]	Dry matter [% FM]	Total impurities >2mm[e] [% DM]	Nutrients Tot. N [% DM]	P_2O_5 [% DM]	K_2O [% DM]
Reference year: 2022	**Italy (CIC, 2024)**								
Bio-waste compost	212	6.0 - 8.8	1.3 - 11.0	NA	50.6 - 94.9	<0.05[g] - 0.5	1.30 - 3.20	0.43 - 3.50	0.66 - 3.27
Green waste compost	48	6.1 - 8.5	0.5 - 6.0	NA	50.0 - 94.5	<0.05[g] - 0.5	1.10 - 2.60	0.39 - 1.50	0.57 - 2.10
Digestate[a]	-	-	-	-	-	-	-	-	-
Reference year: 2022	**Germany[f] (BGK, 2024)**								
Bio-waste compost	1890	7.2 - 9.0	1.1 - 3.3	480 - 770	51.0 - 76.5	0.00 - 0.25	1.11 - 2.13	0.50 - 1.09	0.58 - 1.74
Green waste compost	1985	7.1 - 9.0	0.5 - 1.5	440 - 776	49.0 - 76.6	0.00 - 0.12	0.76 - 1.70	0.31 - 0.76	0.88 - 1.93
Digestate	1249	8.14 - 8.74	3.9 - 9.3	990 - 1,047	2.3 - 14.0	0.00 - 0.01	4.17 - 21.54	1.20 - 5.91	2.9 - 10.4
Reference year: 2021	**Flanders (VLACO, 2024)**								
Bio-waste compost	53	7.8 - 9.1	1.5 - 4.2	NA	53.4 - 78.1	<0.05[g] - 0.40	1.7 - 2.4	0.69 - 1.39	1.0 - 2.1
Green waste compost	153	6.3 - 9.1	0.5 - 1.6	NA	48.5 - 69.9	<0.05[g] - 0.16	1.0 - 1.9	0.35 - 0.62	0.59 - 1.40
Digestate[b]	106	8.3 - 8.8	4.6 - 10.0	NA	4.3 - 12.9	<0.05[g] - 0.10	5.2 - 10.3	2.9 - 5.5	3.5 - 8.2
Reference year: 2023	**Austria (KBVÖ, 2024)**								
Bio-waste compost	166	5.9 - 8.8	0.5 - 5.7	NA	40.1 - 98.2	0.00 - 0.91	0.5 - 2.7	0.01 - 8.20	0.25 - 13.2
Green waste compost[c]	-	-	-	-	-	-	-	-	-
Digestate	131	7.2 - 9.0	NA	NA	0.5 - 81.0	0	0.5 - 18.4	0.1 - 7.1	0.4 - 22.9

[a]No digestate produced under CIC quality assurance, [b]Includes manure and other sludges, [c]not separately assessed, [d]In Germany measured as salinity in g/L, [e]In Germany >1 mm, [f]Values represent lower 10% and upper 90% percentiles, [g]Below determination limit

5.2.2 Data description and comparison

A comparison between BW compost and GW compost within a country typically shows similar pH and DM content. However, electrical conductivity tends to be higher in BW composts due to salt content from KW in the feedstock. In digestate, pH levels are generally around one digit higher than in compost. As anticipated, digestate has significantly lower DM content but higher electrical conductivity, indicating greater salt content.

The product characteristics reveal greater contamination with plastics, glass, metals, etc., in BW compost compared to GW compost. Digestate shows significantly lower impurity levels compared to both compost types. However, it's worth noting that the data presented for includes digestate products from feedstock with inherently low impurities, such as manure and energy crops, hence the lower impurity levels. Digestate derived solely from municipal BW or KW would likely exhibit similar impurity levels as compost from the same feedstock, based on DM (see Table 9).

Nutrient concentrations (Nitrogen, Phosphorus, and Potassium, abbreviated as NPK) are influenced by the feedstock. A comparison of NPK composition across all products indicates that digestate has the highest concentrations of all three nutrients. Nitrogen levels, in particular, are affected by both the feedstock composition and the N mineralisation during the treatment processes. Ammonification transforms N into NH_3 and NH_4-N and is further mineralised (nitrification to NO_3-N under aerobic conditions). P and K remain relatively stable in both processes, primarily influenced by feedstock composition.

A comparison among the countries presented highlights the impact of the various collection systems. In Italy, BW primarily consists of KW, whereas in the other countries, it encompasses a mix of KW and GW. Regardless of the fact that the composting process requires GW as structuring material, BW compost shows a much higher maximum electrical conductivity and salt content in Italy compared to the others. The variations in contamination levels of the products have various influences. Primarily, it originates from the feedstock whose contamination originates mainly from household KW. Hence, the proportion of impurities may correlate with the amount of KW, and mixed systems with GW tend to exhibit lower impurity levels. Moreover, this may be due to the presence or lack of a limit value for feedstock or product quality. Nutrient variances are directly tied to feedstock composition, resulting in significant variations not only between countries but also within countries.

6 Best practice examples for the treatment to high quality products

This section complements the best practice cases presented in **LIFE BIOBEST D3.1 Guideline on separate collection**. Two examples highlight treatment facilities that produce high-quality compost. These examples were chosen to showcase contrasting conditions: one featuring large-scale, technologically advanced solution combining AD and composting, and the other demonstrating a small-scale, technologically simple composting solution.

Table 11. Best practice example for treatment, Borken (DE)

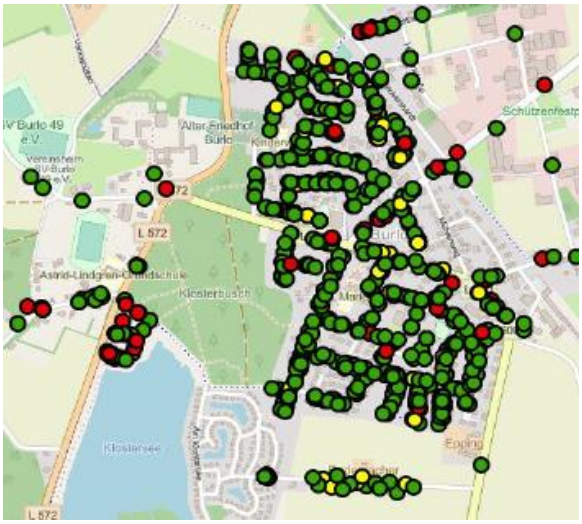
Recycling- & Bioenergie Center of Gescher Entsorgungsgesellschaft Westmünsterland (Borken district, Germany)	
 Gescher bio-waste treatment facility (EGW, n.d.)	
Theoretical population served (inhab.)	1,578,814 (2020)
Type of area	Rural + Urban
Bio-waste origin	Borken and Recklinghausen (Regions), Dortmund (City)
Collection system	D-t-D, commingled kitchen and garden waste
TREATMENT	
Model	Combined wet AD (biofilm) and bay composting. **Treatment bio-waste:** 15 - 20 days AD (partial flow) 5 - 6 weeks decomposition + maturation **Treatment green waste:** 4 weeks decomposition 8 weeks maturation

Capacity (t / yr)	Anaerobic digestion: 66,500 Bio-waste composting: 60,000 Green waste composting: 39,750 (incl. 2 decentralised plants in the area)
Current treatment quantity (t / yr)	ca. 45,000 (Borken district), ca. 18,000 (City of Dortmund) and ca. 40,000 (Recklinghausen district)
Bio-waste feedstock quality (% of impurities)	2 – 3
Product quantity (t / yr)	Compost: ca. 38,000 (10 mm) Woody biomass: 6,500 (10 – 40 mm)
Rejects (t / yr)	Pre-treatment: 3,000 (3% of input) Post-treatment: 800 (organics and ~10% plastics) & 1000 (glass and stones)
PRE-TREATMENT (Bio-waste composting line in linear order)	
Shredder, drum sieve (80 mm) and wind-sifter	Removes approx. 50% of plastics impurities and coarse (woody) fraction
Magnet (above conveyor belt)	Metal (Fe) removal
POST-TREATMENT (Bio-waste composting line in linear order)	
Drum screen (10 mm)	Refining of final compost, removal of structuring material (circulated for further composting)
Star sieve (10 – 30 mm)	Woody biomass
Star sieve (30 – 80 mm)	Conditioning of structuring material
Wind sifter (30 – 80 mm)	Conditioning of structuring material: Removal of light plastics > 30 mm
Stone trap (30 – 80 mm)	Conditioning of structuring material: Removal of glass, stones, bones, coffee pods (float-sink method)

FURTHER INFORMATION

Part of the BW is treated in a wet AD plant using fixed bed biofilm reactors. A screw press blends part of the fraction <80 mm with the digestate from the AD to form a suspension before introducing it into the reactors. The other part of the fraction <80 mm is used as structuring material for the composting with digestate. The remaining part that is not mixed with digestate is composted directly. If necessary, separately collected GW (e.g., in recycling centres) is used as additional structuring material but mostly composted separately. Aeration and irrigation during composting work automatically: 23.5 hours aeration + ~0.5 hours irrigation.

ACTIVITIES TO IMPROVE BIO-WASTE QUALITY



App-supported bin controls (Idelmann, 2023)

1. Promotion of (paper-based) collection bags
2. Participation in nation-wide information campaign #wirfuerbio
3. Bin controls via app and geo-based tracking of households with sorting issues
4. Personal approach and visits in order to solve issues

Bin controls can reduce impurities about 90%. They must be repeated frequently.

PRODUCT QUALITY

Quality analysis	Limit threshold	Garden waste compost	Bio-waste compost
Sample size		35	30
Particle size [mm]	-	15	10
Total Impurities [%]	0.5	0.04	0.05
Glass [%]	-	0.01	0.05
Plastics [%]	0.1	< 0.01	< 0.01
Surface index [cm²/L]	15	0.6	1.7

PRODUCT MARKETING

GW compost is 100% marketed to soil manufacturers. BW compost is marketed to all sectors, even organic farming and substrate manufacturers.

SOURCE OF INFORMATION

- Direct contact with Katharina Schulenborg (EGW public relations and waste consulting)
- Abfallwirtschaftskonzept 2022 - 2026
- Mechanisch-biologische Abfallbehandlung MBA
- Presentation
- Presentation: Störstofffreie Biotonne durch Verbraucherkommunikation und Tonnenkontrollen mit der geodatenbasierten Handy App

Table 12. Best pratice example for treatment, Mancomunitat La Plana (ES)

Small-scale composting plant of Mancomunitat La Plana (Catalonia, Spain)

Composting plant of Mancomunitat La Plana (porta a porta, 2023)

Theoretical population served (inhab.)	33,893 (2021)
Type of area	Rural
Bio-waste origin	14 Municipalities served by Mancomunitat La Plana
Collection system	D-t-D, mixed kitchen and small garden waste (leaves, grass, small branches)
TREATMENT	
Model	Semi-covered windrow composting with automatic aeration and irrigation system 1. 4 weeks of decomposition phase 2. Transfer through mixer (Unifeed) to refine lumps 3. 8 weeks of maturation phase
Capacity (t / yr)	1,500 (can be increased to 2,500)
Current treatment quantity (t / yr)	1,500 (+ varying GW quantities from forestry as structuring material)

Bio-waste feedstock quality (% of impurities)	<1
Product quantity (t / yr)	18 – 20% compost of input material
Rejects (t / yr)	0.5% of input BW[1]
PRE-TREATMENT (in linear order)	
Bag opening + screening + mixing	After reception, biodegradable plastic bags are opened in the Unifeed unit and material is mixed with shredded structuring material in a ratio of 2:1
Conveyor belt	Transport to final refining
POST-TREATMENT (in linear order)	
Elastic mesh screen (10 mm)	Refining of compost, removal of structuring material (circulated for further composting)

FURTHER INFORMATION

The covered facility consists of a reception area where the BW collected D-t-D is unloaded from the truck, and another, where the decomposition process is carried out, using piles with forced ventilation and in which other parameters such as temperature and humidity are also controlled, the latter with an automated irrigation system. The automatic aeration system is controlled remotely, and fans are programmed, but they can be activated automatically in case temperature probes detect an excess of the established maximum and minimum values.

The irrigation system includes two curtain-type irrigation carts that irrigate the two windrows with sectorization. The water comes from two tanks with the aim of optimising water consumption with a capacity of 140 m^3. One tank collects rainwater from the installation itself and the second tank is for leachates from the composting process. This system is remotely controlled, which optimises the entire process and minimises water wastage. Besides leachate control, the covered facility allows for odour control as well.

[1]Specific note: The plant is currently in its starting phase (since early 2023) and therefore, not all data was available until the publication of this report. This refers for example to the rejects from recirculated structuring material.

ACTIVITIES TO IMPROVE BIO-WASTE QUALITY

Bio-waste collection bins (mancoplana, 2021)

1. Promotion of compostable bags and liners
2. Bin identification with RFID system
3. Tracking of households with sorting issues
4. Personal approach and visits in order to solve issues
5. Incidences management via Telegram and service management platform

PRODUCT QUALITY

Quality analysis	Bio-waste compost
Sample size	1
Particle size [mm]	<10
Total Impurities [%]	-
Glass [%]	<0.1
Plastics [%]	<0.1

Compost is Class A quality according to Spanish Fertilizers regulation. It is proven by achieving Rottegrad V as well as low heavy metal content, far below the established limiting threshold.

PRODUCT MARKETING

BW compost is marketed to different sectors:

- Ecological Agriculture (wholesale with trucks).
- Farmers and gardeners of the area (wholesale with big bags or trailers).
- Municipal gardening.
- Users and citizens via distribution in recycling centres (using 25Kg sacks).
- Citizens as returned gift within communication campaigns.

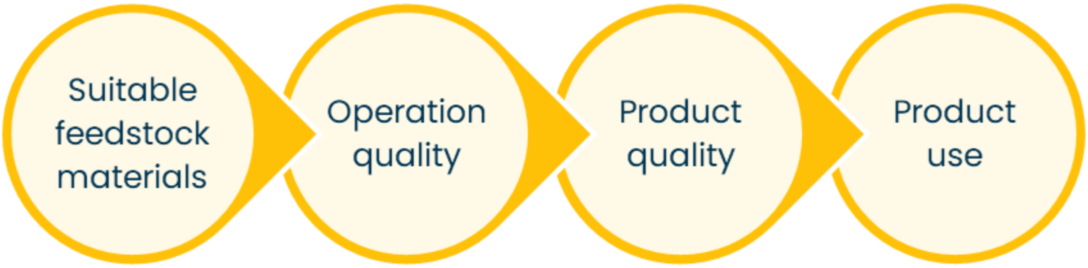
SOURCE OF INFORMATION

Direct contact to Mancomunitat la Plana and Joan Carles Moré-TGA (engineering of the facility).

7 Quality assurance schemes for compost and digestate

This section describes the fundamental elements forming a comprehensive quality assurance scheme (QAS) for composting and AD processes (Figure 15). The QAS shall include criteria for suitable feedstock materials, operation quality considering all the different treatment steps, product quality, and product use.

Figure 15. Required criteria in a quality assurance scheme



7.1 Suitable feedstock materials

Feedstock suitable for the production of compost and digestate should always originate from source-separated BW and/or agricultural residues and food waste from industries that have not been mixed, combined or contaminated with other potentially polluting waste, to ensure the highest purity from the beginning of the recycling system. Information on the source of waste shall be available in order to assess its suitability and to meet the product quality criteria for compost and digestate. Mixed municipal waste is excluded as feedstock material for quality compost and digestate. Dedicated quality assurance schemes include a positive list of feedstock materials. The visual feedstock control and the documentation of the feedstock materials is a pre-requisite for a good operation process. Furthermore, a waste composition analysis can be applied to identify the detailed waste composition intended for biological treatment. The aspect of feedstock quality control is addressed in more detailed in **LIFE BIOBEST D5.3 Proposition of quality standards.**

7.2 Operation quality

The QAS shall include requirements related to the operational process management of composting and digestion. General and specific data of the recycling facility have to be made available, and the various steps of BW treatment and their possible consequences shall be monitored and assessed. A process model shall include critical control points, and process control records have to be kept. Relating to the accepted feedstock materials the process includes a pre-treatment phase (e.g., shredding, mixing), the treatment process with sanitisation phase through effective temperature-time profiles which ensure the elimination of potential threats, the refining process and the storage of the final products.

7.3 Product quality

Composting and AD treatments of BW are associated with potential environmental and health impacts. BW entering the composting process as feedstock material determines the contaminants that can be found in the end product, and may also contain different types of pathogens (e.g., plant pathogens from grass clippings or pruning). From an environmental standpoint, finished compost and digestate applied to land change the chemical, physical and biological properties of the soil, exerting long-lasting effects (Saveyn & Eder, 2013). For this reason, specific standards must be established for heavy metals and physical impurities such as glass and plastics, to avoid soil pollution. From a health (human and plant) -related issue, limits for the presence of pathogens (of human and plant origin) and weed seeds in composts and digestates shall also be established. Quality assurance includes regular sampling and analyses of the final products.

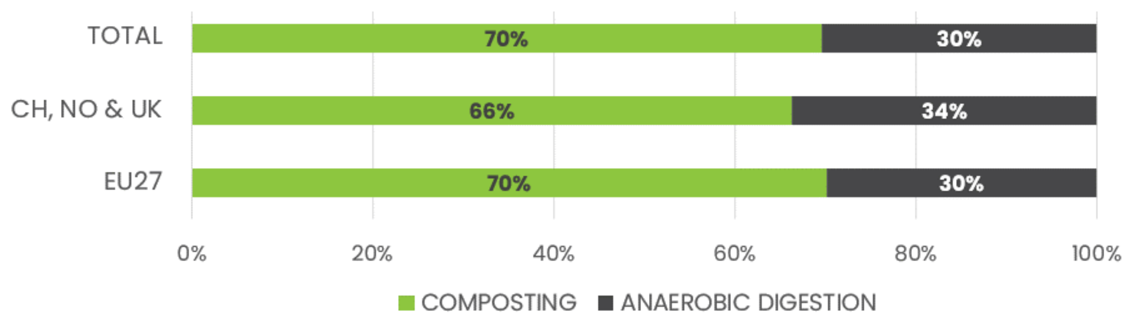
7.4 Product use

The declaration of the final product shall be made on the analytical records and shall include recommendations on the correct application of the final product for the purpose of its use.

7.4.1 Potential markets for quality compost and digestate

Currently, most of the collected BW is treated in composting as shown in Figure 16 (Gilbert & Siebert, 2022).

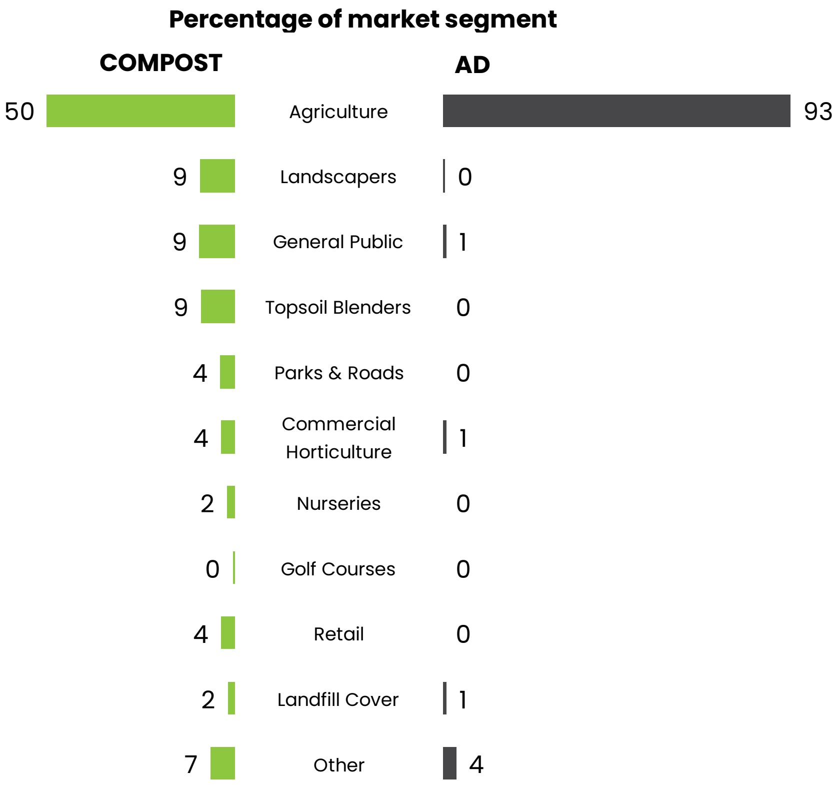
Figure 16. Treatment destination of separately collected bio-waste



Source: Gilbert & Siebert, 2022

Agriculture is the largest segment for organic recycling products, covering 50% of the total market for compost and 93% of the market for digestate (Figure 17, Gilbert & Siebert, 2022).

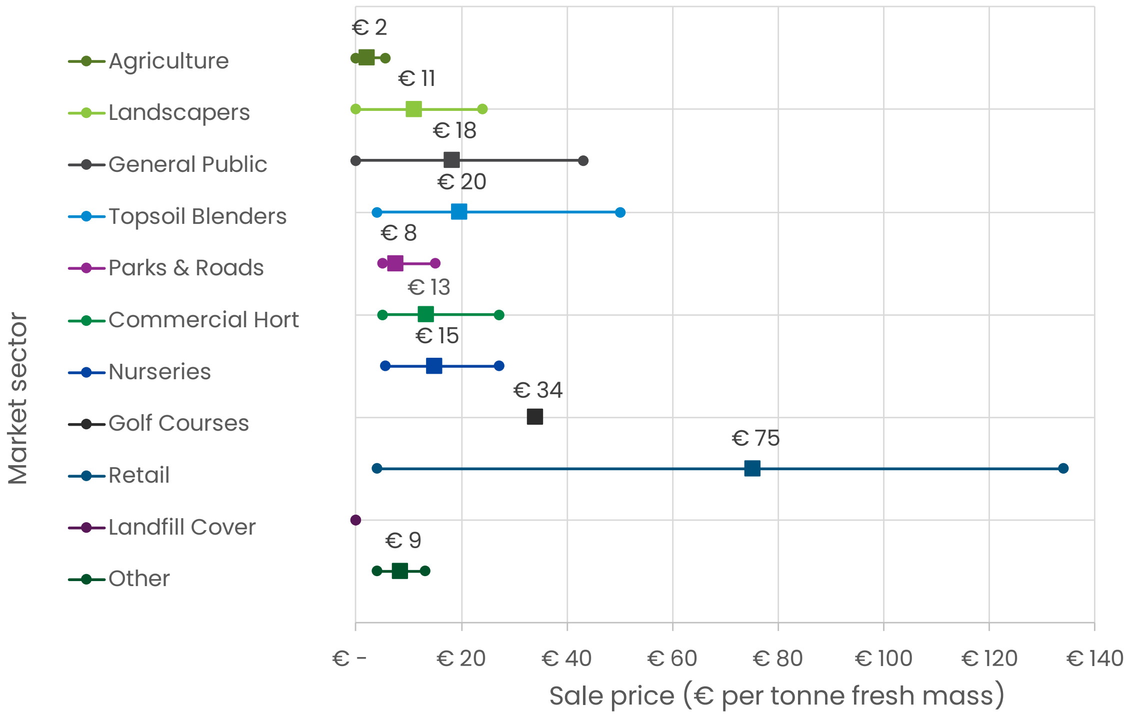
Figure 17. Market sectors for compost and digestate



Source: Gilbert & Siebert, 2022

The main reason lies in the characteristics of compost and digestate, which provide organic matter and nutrients, ameliorating the suboptimal or even poor state of European arable soils and consequently their overall fertility, making high quality compost and digestate viable solutions and increasingly demanded products by farmers. While digestate is mostly used in the agricultural sector due to its characteristics, compost is also employed in other markets – although with a lower share – such as horticulture and growing media. In fact, there is raising awareness on the role of compost as substitute of peat, whose extraction greatly contributes to climate change (Gilbert & Siebert, 2022). Other applications of compost include landscaping and urban greening. The demand for tailor-made recycled products (compost & digestate) is increasing. This is as well represented in the prices for different applications of compost as shown in Figure 18.

Figure 18. Compost prices in the EU (€ per tonne fresh matter)



Source: Gilbert & Siebert, 2022

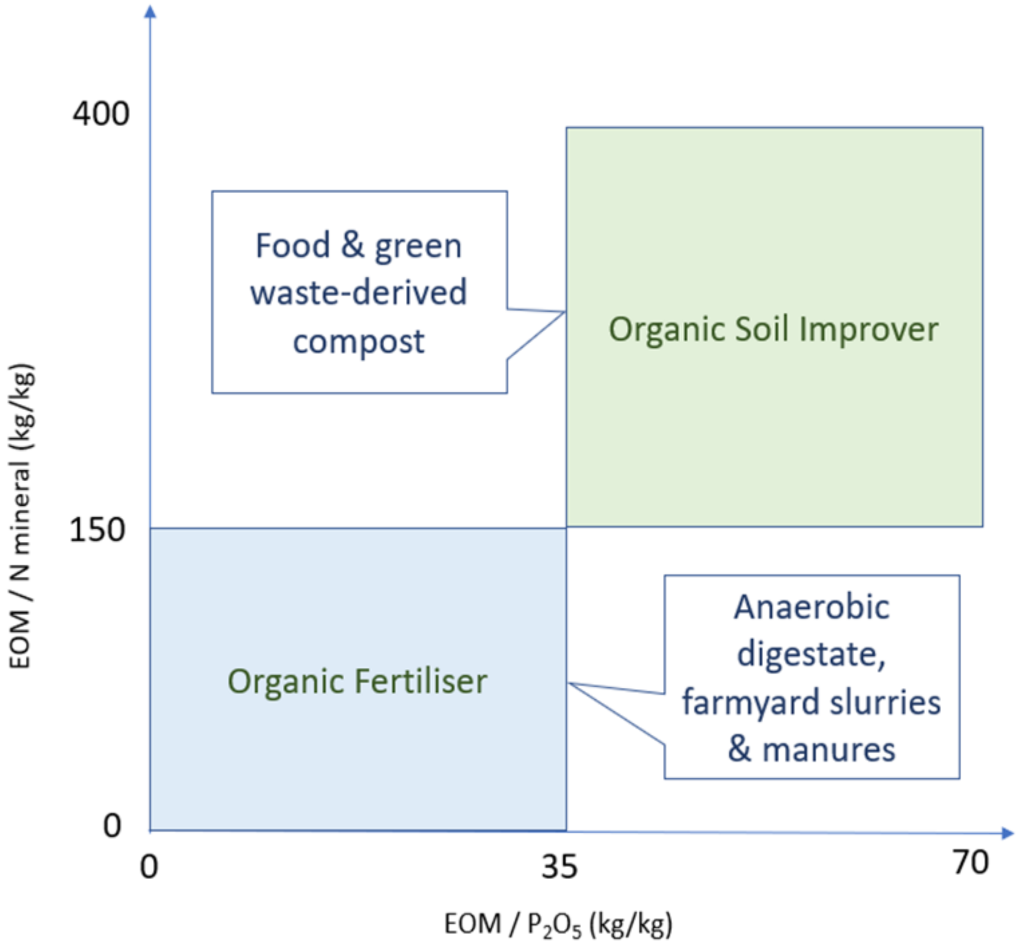
While compost has a low value in the largest market segment (2 € in agriculture), its value increases in other segments with mean prices of 75 € per tonne (retail).

7.4.2 Differences in applying compost and digestate in agriculture

Compost and digestate have different uses because of their intrinsic characteristics, which are in turn a direct effect of the type of BW feedstock used in composting and digestion plants. An increased use of KW and agricultural residues in the AD process is related to increased nutrient and salt contents in the final digestate product. The use of structured woody material for the composting process reduces nutrient and salt contents in the overall product. Additionally, the process of composting leads to humification, which converts the organic materials into a more stable form and binds mineral nitrogen onto organic matter. This results in a slower release of nutrients to soils and vegetation, thereby preventing their leakage into the groundwater and maximising their uptake by the roots.

Therefore, digestate is characterised as organic fertiliser and compost as soil improver as described in Gilbert, Ricci & Ramola (2020) and shown in Figure 19.

Figure 19. Classification of organic amendments as either an organic soil improver or organic fertiliser based on the ratio of Exogenous Organic Matter to nutrients (N & P)



Source: Gilbert, Ricci & Ramola, 2020

8 Compost and digestate within EU legislation

The application of compost and digestate to soils is governed mainly by three pieces of legislation at the European level, while at national level several countries have in place their own laws regulating the treatment of BW and the use of its products. This next chapter will present an overview of the relevant European legislative framework applicable to compost and digestate from municipal BW. Furthermore, a policy brief including the regulatory barriers at EU, national and regional level was published in the scope of the project (Stinavage & Nohales., 2024).

8.1 EU Fertilising Products Regulation

On 16 July 2019, the European Commission has published Regulation (EU) 2019/1009 (Fertilising Products Regulation – FPR), which replaced and repealed the previous Regulation (EC) No. 2003/2003 establishing the conditions for making fertilisers available on the internal market (REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, 2019). While Regulation 2003/2003 only covered the free movement in the single market for conventional, non-organic fertilisers, the new FPR was the first important deliverable of the EU circular economy action plan launched by von der Leyen Commission in 2019, adopted on 5 June 2019 and applicable as of July 2022. According to the latest version of the FPR, a fertilising product is defined as "a substance, mixture, micro-organism or any material, applied or intended to be applied on plants or their rhizosphere or on mushrooms or their mycosphere, or intended to constitute the rhizosphere or mycoshere, either on its own or mixed with other material for the purpose of providing the plants or mushrooms with nutrients or improving their nutrient efficiency." The Regulation's main objectives consist in fostering the use of organic and waste-derived fertilising products and bringing them at a level playing field with mineral fertilisers, creating new market opportunities and tackling environmental concerns not addressed by previous legislation. For further information on regulatory barriers and the legal framework, see **LIFE BIOBEST D5.2 Policy brief.**

8.1.1 Optional harmonisation

The FPR sets out common rules for BW recovery and transformation into valuable secondary raw materials such as compost and digestate that can – under certain conditions – be applied as fertilising products and be traded freely across the EU. Requirements on safety, quality, conformity assessment and labelling are defined and economic operators have to abide by all these requirements in order to make available their products with affixed the CE-mark on it. To ensure flexibility for those products that are usually marketed locally, which is often the case for organic products, the FPR is not mandatory. More specifically, individual countries can still apply their own rules to fertilising products on their national market, or have it traded in the single market according to national standards based on mutual recognition. Therefore, compliance with harmonised provisions remain optional, required only for those products which are CE marked before being made available on the common market.

8.1.2 End-of-waste status

The FPR is particularly relevant for compost and digestate, as well as for other waste-derived materials, as it lays down harmonised end-of-waste criteria applying to all EU MS. The introduction of this 'ceased-waste rule' aims at reducing the burdens and hurdles when trading these products to other EU countries, which stem from the fragmentation (or the lack) of national legislation on this matter.

8.1.3 Structure of the FPR

8.1.3.1 Product Function Categories

According to Annex I of the regulation, EU fertilising products are divided into different product function categories (PFCs), which should be subject to specific safety and quality requirements adapted to their different intended use. The seven PFCs identified in the FPR are shown in Table 13.

Table 13. Product Function Categories according to the FPR

PFC	
1	Fertiliser: (A) Organic fertiliser: (I) Solid; (II) Liquid (B) Organo-mineral fertiliser: (I) Solid; (II) Liquid (C) Inorganic fertiliser: (I) Macronutrient; (II) Micronutrient
2	Liming material
3	Soil improver: (A) Organic soil improver (B) Inorganic soil improver
4	Growing medium
5	Inhibitor: (A) Nitrification inhibitor (B) Denitrification inhibitor (C) Urease inhibitor
6	Plant bio-stimulant: (A) Microbial plant bio-stimulant (B) Non-microbial plant bio-stimulant
7	Fertilising product blend

Compost and solid digestate will most unlikely fulfil the minimum nutrient content required in the FPR for being marketed under the 'organic fertiliser' category. In fact, limit values for minimum nutrient and organic carbon content are expressed on FM and not on DM basis which prevent compost and digestate (both solid and liquid) from achieving the thresholds listed in Table 14.

Table 14. Minimum nutrient content for organic fertilisers set in the FPR

Criteria	PFC1 (A)(I)	PFC1 (A)(II)
State	Solid	Liquid
Organic carbon (C_{org})	≥ 15%	≥ 5%
Nitrogen (N)	≥ 2.5%*	≥ 2%
Phosphorus (P_2O_5)	≥ 2%*	≥ 1%
Potassium (K_2O)	≥ 2%*	≥ 2%
SUM (NPK)	(1/1/1) ≥ 4%**	(1/1/1) ≥ 3%**

All values based on FM
* As a minimum one of the three nutrient contents has to been reached
**Individually, Nitrogen, Phosphorus and Potassium shall have at least a share of 1% by mass, while the total shall be at least 4% and 3%, respectively.

For this reason, compost and solid digestate could only be placed on the EU market under the category PFC3 (A) of organic soil improvers, since they normally fulfil the criteria established for this category (see Table 15). On the contrary, liquid digestate will still not meet the DM-%' requirement defined for this category, resulting in its exclusion from the CE certification.

Table 15. Criteria for organic soil improvers laid down in the FPR

Criteria	PFC3 (A) Organic soil improver
DM	≥ 20%
Organic Carbon (C_{org})	≥ 7.5%
Composition	An organic soil improver shall consist 95% of material of solely biological origin including peat, leonardite, lignite and humic substances obtained from them, but excluding other materials which are fossilized or embedded in geological formations.

Furthermore, Regulation (EU) 1009/2019 lays down limit values for contaminants and pathogens in products falling under category PFC3. Contaminants included are cadmium, chromium IV, mercury, nickel, lead, zinc and inorganic arsenic. Values set by the FPR can be found in Table 16.

Table 16. FPR limit values for heavy metals and pathogens in organic soil improvers

Parameter	Limit value for PFC3 (A) Organic soil improver (mg/kg DM if not mentioned different)
Cadmium (Cd)	2
Chromium VI (Cr VI)	2
Mercury (Hg)	1
Nickel (Ni)	50
Lead (Pb)	120
Copper (Cu)	300
Zinc (Zn)	800
Arsenic (As)	40
Salmonella spp.	Absent in 25g or 25 ml
E. Coli / Enterococcaceae	≤ 1000 (CFU/g)

8.1.3.2 Component Material Categories

EU fertilising products have to consist solely of determined component materials categories (CMCs), which are set in annex II of the FPR. Each one of these component materials is subject to specific process requirements and control mechanisms. Compost and digestate from waste-derived materials are included in this list as CMC3 (compost), and CMC5 (other digestate than fresh crop digestate) respectively, and they are both subject to temperature -time profiles and environmental criteria that have to be fulfilled and assessed. Plant-based digestate – so-called fresh crop digestate in the FPR – are listed under CMC4 and are excluded from the scope of this guideline.

CMC 3: Compost

Feedstock material accepted in the composting process includes separately collected BW, animal by-products belonging to categories 2 and 3 according to Regulation (EC) 1069/2009 (Animal By-Products Regulation – ABPR, see section 8.1.4). Sewage sludge, industrial sludges – including sludges from the food and feed industry - and mixed municipal waste are excluded from the list instead, and thus not permitted as feedstock for the production of CE-marked compost.

According to the FPR, there are four temperature-time profiles suitable for the composting process that shall be interchangeably applied to be legible for the CE mark, as displayed in Table 17.

Table 17. Temperature-time profiles for composting under the FPR

Temperature-time profiles for composting under the FPR
70 °C or more for at least 3 days
65 °C or more for at least 5 days
60 °C or more for at least 7 days
55 °C or more for at least 14 days

In addition, the final compost has to meet environmental criteria encompassing physical impurities and organic pollutant restrictions, depicted in Table 18. For BW from animal by-products the standard transformation requirements of the ABPR has to be respected.

Table 18. Environmental Criteria set in the FPR

Environmental Criteria	
Polycyclic Aromatic Hydrocarbons (PAH_{16})	≤ 6 mg/kg DM
Sum of physical impurities (> 2mm): Glass Metals Plastics	≤ 5 g/kg DM ≤ 3 g/kg DM ≤ 3 g/kg DM ≤ 3 g/kg DM*
*The criterion for plastics will tighten starting from 16 July 2026 with a new limit-value of ≤ 2.5 g/kg DM. This limit will be re-assessed by 2029, taking into account the progress made with regards to the separate collection of BW.	

Finally, compost shall meet stability criteria laid down in the FPR. The regulation allows for flexibility in the method used to evaluate stability, by setting two alternatives shown in Table 19.

Table 19. Stability criteria for compost set in the FPR

Alternative Stability Criteria for Compost	
Oxygen uptake rate	Maximum 25 mmol O_2/kg organic matter/h
Self-heating factor	Minimum Rottegrad III

CMC 5: Digestate other than fresh crop digestate

Authorised feedstock materials entering AD plants are equivalent to the ones laid down for the composting process. In accordance with the FPR, different temperature-time profiles can be employed for the production of digestate (see Table 20), which can then undergo a post-composting phase observing the standards highlighted in the previous paragraph.

Both solid and liquid digestates can be used as components of EU fertilising products, provided that these fractions are obtained by mechanical separation of digestate.

Table 20. Temperature-time profiles for anaerobic digestion under the FPR

Temperature-time profiles for anaerobic digestion under the FPR
Thermophilic at 55 °C/24 h/hydraulic retention time of 20 days
Thermophilic at 55 °C incl. pasteurisation step 70 °C-1h
Thermophilic at 55 °C followed by composting
Mesophilic at 37-40 °C incl. pasteurisation step 70 °C-1 h
Mesophilic at 37-40 °C followed by composting

For BW from animal by-products the standard transformation requirements of the ABPR has to be respected.

Digestate, just like compost, needs to fulfil environmental parameters concerning impurities and organic compounds. Indeed, the limits foreseen for physical and chemical contamination in the final digestate are equivalent to the ones set for compost, as well as the future revision and re-assessment of macro-plastics thresholds (see table Table 18).

Finally, digestate (liquid or solid) shall meet stability criteria laid down in the FPR. The regulation allows for two alternatives when choosing the method used to evaluate stability, described in Table 21.

Table 21. Stability criteria for digestate set in the FPR

Alternative Stability Criteria for Digestate	
Oxygen uptake rate	Maximum 25 mmol O_2/kg organic matter/h
Residual biogas potential	Maximum 0.25 L biogas/g volatile acids

8.1.4 Animal By-Products

For EU Fertilising products of component material categories which include animal by-products (e.g., catering waste, manure) as defined in the Animal By-Products Regulation (EU) No 1069/2009 the end point of the manufacturing chain for animal by-products has to be reached and the process requirements of both regulations (ABPR and FPR) should apply cumulatively to EU fertilising products. For compost and digestate the end point in the manufacturing chain is laid down in Regulation (EU) 2023/1605. This regulation determines end points in the manufacturing chain for organic fertilisers and soil improvers manufactured in the EU beyond which they are no longer subject to the ABPR, provided that they are used as component materials in EU fertilising products in accordance with the FPR. In turn, when determining the end point, Regulation (EU) 2023/1605 refers to Regulation (EU)

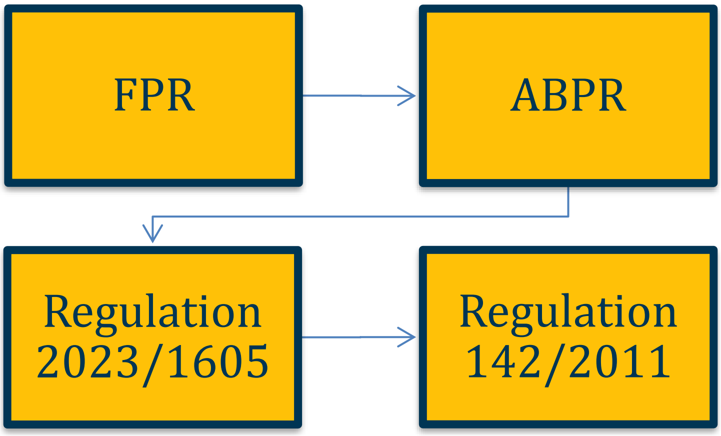
No 142/2011 implementing the ABPR (Figure 20), where the standard transformation parameters for processing animal by-products in composting and biogas plants are laid down, as shown in Table 22.

Table 22. Standard transformation parameters according to Reg. (EU) No 142/2011

Standard Transformation Parameters	
Temperature	70 °C
Time	At least 1 hour
Particle size	Max. 12 mm

If compost and digestate are placed only on national markets, though, the ABPR allows for alternative transformation parameters under specific conditions and sets as well a derogation by which national competent authorities are empowered to authorise the use of parameters different from the ones laid down in the same regulation. Conversely, the FPR only considers the standard transformation parameters for ABP-derived compost and digestate. Further information on the implementation of the ABPR can be accessed in the ECN Good Practice Guide 'How to comply with the EU Animal By-Products Regulation at Composting and AD Plants' (Amlinger & Blytt, 2013). The local perspective and barriers to comply with the ABPR is addressed in **LIFE BIOBEST D5.2 Policy brief.**

Figure 20. EU Legislation concerning Animal by-products



8.1.5 Process requirements and conformity assessment

The final fertilising products can be placed on the market according to a specific conformity assessment procedure laid down in the FPR. Rules apply to the certification at both PFC and CMC level. If compost or digestate from waste materials are used in an organic fertiliser, soil improver or growing media, an external conformity assessment – including process and product control – by a notified body is mandatory.

According to Module D1 of the FPR – which regulates the quality assurance of the production process for those PFCs containing CMC3 and CMC5 – manufacturers have to put in place a quality management system covering quality objectives and their organisational structure, as well as technical documentation. A minimum sampling frequency is established for compost and digestate, according to the annual flow of feedstock material expressed in tonnes.

Importantly, the notified bodies carrying out external conformity assessments have to fulfil various criteria and have to be accredited and perform their activities only upon the approval of their notification by the notifying authority of the EU MS in which they are established. At the act of notification, the conformity assessment body must declare for which fertilising products it intends to get accreditation. Manufacturers can file a request for the assessment of their quality assurance scheme to the notified body of their choice, as long as it is accredited and registered in the NANDO portal (European Commission, n.d.).

8.2 Organic Production Regulation

Regulation (EU) 2018/848 is the current legal act establishing obligations for organic production and labelling of organic products (REGULATION (EU) 2018/848 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, 2018). The new Organic Regulation is the result of a long revision process that involved the repealing of the previous regulation on organic production and labelling together with other various implementing acts. Obligations on the authorisation of fertilisers, soil improvers and nutrients in organic production are set in art. 24. These products and substances can be accepted when they are essential for building up and maintaining fertility of the soils or fulfilling specific nutritional requirements of crops.

In this regard, Annex II of Implementing Regulation (EU) 2021/1165 (2021), respecting the correcting Regulation (EU) 2023/2229 adopted on 25 October 2023, establishes a list of these products and substances while setting further requirements for their authorisation and use in organic production. Compost and digestate produced from household waste figure among the materials accepted, followed by specifications and conditions for their application. These conditions include feedstock materials, production requirements and limit values for contaminants. Contamination limits of heavy metals for compost and digestate used in organic farming are stricter than the ones laid down in the FPR, as shown in Table 23.

Table 23. Contamination limits for composted or digested bio-waste according to the Organic Production Regulation

Compound products or products containing only materials listed hereunder	**Description and specific conditions**
Composted or anaerobically digested BW	• Product obtained from separate BW collection at source, which has been submitted to composting or to anaerobic fermentation for biogas production • Only vegetable and animal BW • Only when produced in a closed and monitored collection system, accepted by the EU MS
Parameter	**Limit value for separately collected bio-waste (mg/kg DM)**
Cadmium (Cd)	0.7
Chromium (Cr, total)	70
Chromium VI (Cr VI)	Not detectable
Mercury (Hg)	0.4
Nickel (Ni)	25
Lead (Pb)	45
Copper (Cu)	70
Zinc (Zn)	200

9 Description of existing product quality standards

This chapter reviews already existing quality standards for compost and digestate in EU MS. Quality assurance schemes for products originating from composting and AD processes have been successfully established in many MS over the last 25 years. The development of these standards addressed the need of sustainably managing organic resources and creating a demand for quality compost and digestate as soil amendments and fertilisers. The overview will take into consideration the different national collection systems (BW, KW or GW) and end-of-waste criteria which underpin the existence and application of different quality standards among EU countries. Firstly, the ECNs QAS including quality standards is introduced followed by country-specific QAS that are in conformity with the ECN's one. In the Annex, further QAS are introduced for countries and regions that are not (yet) in conformity with the ECN-QAS.

9.1 ECN-QAS

The European Compost Network has developed an independent quality assurance scheme (ECN-QAS) covering the basic requirements for a pan-European compost and digestate standard. The ECN-QAS was created in 2010 and consequently registered as Trade Mark for certified quality assurance organisations, compost and digestate products at the European Register of Community Trade Marks (OHIM2012/210: TM No 011007168), to harmonise the requirements across Europe and thereby creating an EU-wide market for these secondary products. Not only ECN-QAS wishes to harmonise existing quality assurance schemes across Europe, but also to support national quality assurance organisations (NQAO) establishing quality assurance schemes for compost and digestate. The manual produced by ECN comprises different parts addressing requirements to be met by NQAOs in order to be recognised under ECN-QAS, as well as a quality manual for compost and for digestate. ECN standards and quality criteria for compost and digestate are currently referenced in the Fertilising Products Regulation. In addition, the ECN-QAS was cited in the 2014 JRC-IPTS report on End-of-Waste criteria for compost and digestate. ECN therefore offers the EU a ready-made, pan-European quality scheme, which has been recognised by the European Commission and which can readily be transferred into European Standards for compost and digestate.

The ECN-QAS for compost and digestate presents common terms and definitions, and a positive lists of feedstock materials and possible additives based on the European Waste Catalogue (EWC), which assigns a code to each waste type. In terms of compost and digestate characteristics, the ECN-QAS defines declaration rules for fertilising properties, material properties and biological parameters, while setting specific precautionary environmental criteria for hygiene, impurities and pollutants applying to both final products (Table 24).

Table 24. ECN-QAS quality parameters

Quality criterium	Parameter	Unit	Limit value
Soil improvement	Organic Matter	% d.m.	≥ 15
Inorganic pollutants	Lead (Pb)	mg/kg d.m.	≤ 130
	Cadmium (Cd)		≤ 1.3
	Chromium (Cr)		≤ 60
	Copper (Cu)		≤ 300
	Nickel (Ni)		≤ 40
	Mercury (Hg)		≤ 0.45
	Zinc (Zn)		≤ 600
Undesired ingredients and properties	Impurities	% d.m.	≤ 0.5
	Weed seeds	L	≤ 2
Hygiene	Salmonellae	25g/d.m.	Absent

With regard to analytical test methods for these parameters, the ECN-QAS refers to the ones elaborated by the Technical Committee of the European Standardisation Organisation, CEN 223 "Soil improvers and growing media" (CEN/TC 223, 2016).

Minimum requirements on sample taking and analysis of compost and digestate are included in the ECN-QAS, with frequency depending on the treatment capacity and type of feedstock material of the specific composting/digestion plant. The general formula established by the ECN-QAS for compost and digestate analysis is as follows: Amount of feedstock material / 10.000(t) + 1 = analyses per year, 12 per year maximum. For digestate resulting from crops and manure the maximum number per year is set at 4 analyses. It is also recommended to have a 100% external sampling.

9.2 Country specific quality standards – in conformity with ECN-QAS

Some European countries have – alongside standards established by national law – long-standing national quality assurance schemes for composting and AD managed by national organisations (Figure 21). At present, four national quality assurance schemes for compost (KBVÖ AT, Vlaco BE, BGK DE, CIC IT) and two for digestate (Vlaco BE, BGK DE) have undergone conformity assessed according to ECN-QAS based on the ISO/IEC standard 'Conformity assessment for bodies certifying products, processes and services' (ISA/IEC 17065). These NQAOs were awarded the ECN-QAS label and composting plants or digestion plants participating in one of these ECN conformity-assessed NQAOs can also display the ECN quality mark. These four cases are Austria, Belgium, Germany and Italy, which will be analysed more in detail in the following sections.

Figure 21. Levels of quality assurance schemes

Source: Own elaboration

9.2.1 Austria

9.2.1.1 Legislation

The Compost Ordinance of 2001, which is currently under revision, sets up quality requirements for compost produced from waste. Requirements regulate the production, marketing and labelling of compost as a product, meaning that also end-of-waste criteria are established. It includes requirements regarding compost designation and specification, waste materials (waste codes) with approved origin, type and frequency of quality measurements for certain feedstock materials, as well as type and schedule of records and documentation. The ordinance classifies compost into three different quality-based categories and defines raw feedstock materials accepted for each one of them. The three classes, built around the heavy metals content of the finished compost, are: 'A+' meaning top quality, which is accepted in organic farming; 'A' which stands for high quality and is suitable for agricultural use; and finally, 'B' for minimum quality, applied in non-agricultural contexts. Moreover, Austria has in place a series of national standards and guidelines establishing requirements for a quality assurance scheme for compost. In Austria, digestate produced from organic residues is considered waste until proper recovery in the soil, according to the Waste Management Act 2002.

9.2.1.2 KBVÖ QAS

In addition to the legal obligations the KBVÖ represents the NQAO managing the Austrian quality assurance scheme, providing a mandatory comprehensive quality management for its members. It is based on the Austrian standards (ONS2206-1 und -2, and the technical guideline ONR192206).

As of 2022, Austria has 410 composting plants, collectively capable of processing a minimum of 1.71 million tonnes per year and treating 1.38 million tonnes in the same year. Among them, 256 plants (63.4%) are members of KBVÖ. These plants treated 824,000 tonnes of organic waste (~60%) in 2022.

9.2.2 Belgium – Flanders

9.2.2.1 Legislation

Belgium is divided into three regions – Flanders, Wallonia and Brussels – and waste policy falls under regional jurisdiction (Vlaco, 2023). The Flemish region is the only one which has in place quality standards for compost and digestate, therefore only Flanders will be considered for the purpose of this guideline. The reference legislation is the VLAREMA regulation which contains requirements for the use of treated BW as a secondary raw material (fertiliser or soil improver) and describes all the requisites for the certification of compost and digestate products. VLAREMA sets up limit values for the most important environmental parameters, both organic (e.g., PAH, PCB, other organic compounds) and inorganic (e.g., heavy metals).

9.2.2.2 VLACO QAS

Vlaco vzw operates as NQAO in Flanders since 2004, while being established in 1992 to promote the production and use of quality compost, and is supervised by the Public Waste Agency of the region.

Vlaco quality assurance system encompasses all the steps of the BW treatment, from feedstock quality acceptance to quality assessment of the end products, by way of control points through the whole chain. According to Vlaco QAS, to cease to be waste and be considered secondary raw materials, compost and digestate shall be used in a reasoned manner and in application fit for purpose, otherwise they maintain their waste status.

Vlaco has set up a QAS which goes beyond the values imposed by VLAREMA legislation, by adding parameters indicating the agronomic importance of the end products (nutrients, soil organic matter) as well as the physical and biological quality aspects (impurities, viable seeds, stability) (Vlaco, 2021). Vlaco QAS includes thresholds for green compost, compost derived from catering waste, vegetable, fruit and GW, and finally quality parameters for digestate (Vlaco, 2021).

Vlaco has received ECN quality label for compost in 2011 and for digestate in 2014, respectively.

In 2022, Vlaco conducted quality assurance of all BW treatment plants in Flanders, since quality assurance is a legal requirement when BW is co-treated. These amount to 116 BW treatment plants, including 45 GW composting and 10 BW composting facilities, along with 38 AD plants and 23 others (handling BW or biothermal drying of manure). A total of 241 quality certificates were issued in the same year, covering the following treatment quantities in 2022:

- BW composting plants: 276,000 tonnes of household BW, 70,000 tonnes of GW and 17,000 tonnes of BW from the food/feed industry were treated, amounting to 363,000 tonnes in total.

- GW composting plants: 567,000 tonnes of GW
- AD plants: 1.6 million tonnes of household BW, 410,000 tonnes of manure and 150,000 tonnes of energy crops were treated, amounting to almost 2.2 million tonnes in total.

These plants (under Vlaco QAS) produced 100% of the compost and digestate from BW in Flanders.

9.2.3 Germany

9.2.3.1 Legislation

In Germany, two different ordinances are relevant for compost and digestate quality standards. The revised Bio-waste Ordinance (BioAbfV) published in 2022 regulates the application of treated and untreated BW and mixtures in and on soils (Kleine Novelle Der Bioabfallverordnung (BioAbfV), 2022). It also covers suitable raw materials, quality and hygiene requirements, and treatment and investigations of such BW and mixtures. The Bio-waste Ordinance regulates – from a precautionary perspective – the waste side (e.g. heavy metals) of the application, whereas the fertiliser law regulates the nutrient part. The Fertiliser Law (Düngeverordnung (DüV), 2017) sets the frame for the good practice of fertilising and shows special requirements for organic fertilisers. It includes the restrictions for the application of fertilisers with essential nutrient contents in winter periods and restricts the application of organic fertilisers to an average of 170 kg N/ha. In addition, compost and digestate have to be declared in accordance with the German Fertiliser Ordinance (Düngemittelverordnung (DüMV), 2019). A declaration of the fertiliser type, raw material, nutrients and other product properties is obligatory. Threshold values for impurities or contaminants like PFT, PCCD or dlPCB, included in the Fertiliser Ordinance are obligatory for compost and digestate, too.

9.2.3.2 BGK QAS

In 1989, together with the introduction of BW separate collection in Germany, the German Compost Quality Assurance Organisation – BGK – was founded. BGK is recognised by RAL, the German Institute for Quality Assurance and Certification, and as of today it carries out monitoring and controlling activities on the quality of compost, digestate, sewage sludge, sewage sludge compost and other type of fertilisers.

The quality assurance starts with a recognition phase, where the candidate plant must provide evidence of the fulfilment of process and product requirements set by BGK QAS.

BGK has received the ECN quality label for compost in 2011 and for digestate in 2014, respectively. In 2023, a total of 750 members take part in the BGK's quality assurance system for compost and digestate. This relates to 536 composting plants, 144 AD plants, and 70 combined AD and composting plants (BGK, 2024). The following quantities were treated in 2023:

- BW and GW composting plants: 3.81 million tonnes of household BW, 3.95 million tonnes of GW and 0.1 million tonnes from other sources, amounting to 7.87 million tonnes in total.
- AD plants (excl. treatment of renewable energy crops): 0.86 million tonnes of separately collected BW, 0.04 million tonnes of GW and 3.19 million tonnes from other sources, amounting to 4.09 million tonnes in total.

9.2.4 Italy

9.2.4.1 Legislation

According to the Italian Legislation (Fertiliser Law, D.Lgs 75/2010 and subsequent amendments) the end-of-waste status of BW is represented only by compost, which is classified as a soil improver and is divided into four categories depending on the type of feedstock material:

- GW Compost: compost produced from GW only;
- BW Compost: compost produced from BW, including both food- and GW;
- Sludge Compost: compost produced including sludge inside the mixture of different feedstock.
- Compost from waste from the agri-food chain: compost produced from digestate of agro-industrial sludge, wastewater and agro-industrial sludge, animal waste, and GW (Ministero delle politiche agricole alimentari e forestali, 2022).

The Italian standard for end-of-waste compost established in the Fertilisers Law comprises agronomical parameters (pH, moisture content, carbon and organic nitrogen, etc.), environmental parameters (heavy metals and physical impurities), as well as sanitisation parameters (Salmonella, E. Coli) (CIC, 2021). In Italy, digestate is always considered waste. The only way to gain the status of product for digestate is to undergo a post-composting treatment and be marketed as compost.

9.2.4.2 CIC QAS

A voluntary QAS for compost is running in Italy since 2003, managed by the Italian Composting Association and focusing on the end-product quality produced by the associated plants (Consorzio Italiano Compostatori – CIC).

Three phases can be distinguished in the process leading to the awarding of CIC label for compost: application, recognition and monitoring. At first, the candidate plant applies to join the voluntary scheme provided by CIC through the submission of specific documentation, which then leads to the recognition phase where sample taking is carried out by CIC experts and accredited independent laboratories take care of the analyses (CIC, 2021). Finally, if successful, the process leads to the awarding of CIC quality mark to the end product, while granting the plant with a licence to use the label for marketing purposes. The quality of the compost is continuously monitored by CIC to ensure that the plant is allowed to operate under its scheme.

CIC quality parameters for compost are based on the Italian Fertiliser Law which disciplines the use of BW as a secondary material (fertiliser or soil improver).

As of 2021 (last data available), 35% of compost produced in Italy falls under CIC quality label, equal to more than 725,000 tonnes of finished product coming from more than 50 plants adhering to the CIC QAS (Centemero et al., 2023). CIC has first obtained the ECN-QAS mark as conformity assessed NQAO for compost in 2018.

10 Final considerations for product application

Following the examples of quality aspects presented in Chapter 5 and illustrated with two typical practical cases in Chapter 6, it becomes clear that a mandate for a comprehensive EU-wide quality assurance scheme is key to enable the application of compost and digestate across a broad spectrum of market sectors. The qualitative comparison of different compost and digestate products from municipal BW gives a good indication for the expected relative composition, quality aspects related performances, hence most suitable applications (Table 9, Section 5.1). Indeed, as highlighted in Section 7.4, compost and digestate produced is currently **applied in at least eleven different market sectors**.

While the FPR establishes general quality requirements for compost and digestate (Section 8.1), the ECN-QAS elevates these for high-quality products, including stricter limits for inorganic pollutants (Section 9.1). However, adapting requirements for **organic farming** necessitates further quality adjustments as presented in Section 8.2. The pivotal role of a QAS in ensuring highest quality becomes obvious by taking a look at the actual qualities of compost and digestate produced under QAS (Table 10, Section 5.2). A study found that the quality of more than 70% of the produced compost in Germany was already in accordance with the requirements of the Organic Production Regulation (Gottschall et al., 2023), which could likely also apply to the QAS certified products of the other countries mentioned.

Some market sectors, e.g., **horticulture**, (still) permit blending of compost and digestate with other components like peat as stated in the REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (2019). However, quality requirements for compost and digestate used in horticulture align with those for agriculture as stated in the FPR. However, the quality requirements used for horticulture needs to take specific criteria (e.g., electrical conductivity, stability, DM, pH value) into account. Knowledge of the quality criteria for a particular horticultural product is therefore essential.

The use of compost and digestate in **urban areas**, e.g., landscaping, parks, and green infrastructure, adheres to the outlined quality standards. Specific attention must be paid on the maturity of the product to minimise odours and ensure a quality that meets visually appropriate aesthetics. Additionally, compost, in particular, contributes to urban maintenance measures like erosion control and stormwater management, which are, however, important for most of the market sectors.

A critical criterion for utilising compost and digestate in **growing media** is a low salt content (e.g., assessed via electrical conductivity) and a high maturity, which implies the full oxidation of ammonia (a presence in comparatively high concentrations in less matured composts and digestates may cause phytotoxicity) into nitrate and the full decomposition of other phytotoxic intermediate by-products (Siebert & Gilbert, 2018).

Certain **pH-sensitive species** (acidophilic ones, e.g., Azalea, Rhododendron, Skimmia, Pieris, etc.) may require compost blended with peat to lower its pH, since composts are typically sub-alkaline.

11 Lessons learned and main messages

This section concludes from the previous descriptions and summarises important steps to promote high quality compost and digestate.

- **High-quality feedstock** material eases the production of **high-quality products**.
- **Pre- and post-treatment** is important for **improving the quality** of and refining the final product.
- Know **benefits of anaerobic digestion and composting** as well as their combination. Be aware of **local circumstances and technical potentials for treatment** in order to select a preferred treatment pathway as well as the required capacity. Consider the principle of proximity when planning the location of the treatment plant.
- **Best practice cases** showcase that with different type of technology, similar products can be obtained. However, advanced processes can deal with lower quality of input material.
- Get acquainted with **EU legislation and the ECN-QAS** if national legislation is inappropriately developed.
- Requirement to **implement a national body** that develops or adapts standards as well as a QAS for high-quality compost and digestate.
- Countries with a fully developed quality standard and QAS also produce the highest quality of compost.
- Know about the **different market sectors** that may require different specifications for compost and digestate.
- Be aware of the fertiliser market and the marketing potentials with composts and digestate from different feedstock materials and with different product qualities that may be suitable for different end uses. The **continuous production of high-quality compost and digestate will increase the acceptance of the customers** and create a higher value on the market as compared to non-quality assured products.
- In contrast to mineral fertilisers, **digestate and especially compost have positive long-term properties on soil health and stability** in addition to the fertilising properties. These **benefits shall be communicated to promote the use** of high-quality compost and digestate to farmers and other end users in order to increase their acceptance.

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Annex - Non-conformity assessed QAS / Other

Catalonia - Spain

Catalonia has no comprehensive QAS in place, but has set up a specific strategy to improve the quality of the feedstock materials.

Estonia

Estonia has end-of-waste regulation for compost and digestate in place. In 2013 the regulation "Requirements for producing compost from biodegradable waste" was enforced in Estonia. The ordinance regulates and sets requirements for the production site, production technology and limit values for various parameters. In 2016 the regulation "Requirements for biogas digestate generated from biodegradable waste" was enforced in Estonia. These regulations function as end-of-waste legislation, enabling producers of compost and digestate generated from biodegradable waste to certify compost and digestate as a product.

Based on the manual of the ECN-QAS Estonia has set up a quality assurance scheme for compost and digestate. This QAS is owned by the Certification Centre of Recycled Materials which has been accredited according to ISO/IEC 17065 as a certification body for compost and digestate quality assurance since 2016.

Finland

Products from organic waste are sold as fertilizers for agriculture or landscaping and under the supervision of the Finnish Plant Production Inspection Centre. According to the Finnish legislation, only officially certified products can be put on the market. The certified products are controlled on a regular basis for pathogens, heavy metals and nutrients.

Based on the manual of the ECN-QAS, Finland has developed a quality assurance scheme for compost and digestate which is owned by the Biocycle and Biogas Association.

France

Based on the manual of the ECN-QAS France has developed a quality assurance scheme for compost which is owned by Réseau Compost Plus (label Amendement Sélectionné Qualité Attestée - ASQA). The ASQA foresees a three-years audit cycle. During the first year one preparatory and one complete audit are performed, followed by a surveillance audit in the second year and a renewal audit during the last one.

Netherlands

Product quality standards for compost in the Netherlands are specified in the Fertiliser decree accompanying the Fertiliser law. Minimum content of organic matter is set at 10% DM and limit values for heavy metal contamination are outlined. The standards also set limitations for physical impurities.

Furthermore, it exists a voluntary standard called "Keurcompost" which goes beyond the limits and thresholds legally established, setting stricter requirements which are verified by third party audits and accredited auditors. Keurcompost requirements are on processing (temperature-time and sanitisation), quality management, and on impurities standards in compost differentiated between glass, stones and others; two categories are defined, differing in terms of limit values for impurities (Keurkompost, 2023). This standard is executed jointly by BVOR and DWMA, the Dutch Bio-waste Management Association and Dutch Waste Management Association, respectively (BVOR, 2023).

Sweden

Avfall Sverige is the owner of the quality assurance scheme "Certifierad återvinning (Certified Re-use)" including certification rules for digestate (SPCR 120) and compost (SPCR 152). RISE – Research Institutes of Sweden (former SP) is the external independent control body for the certification scheme which includes external revision and issuing of certificates. The certification scheme was launched in 1999 and during 2015, 18 co-digestion plants produced quality certified digestate (called bio-fertiliser) according to SPCR 120. During the same time, there was one composting plant producing compost from GW (private gardens and public areas) according to SPCR 152.

The QAS "Certifierad återvinning" is requiring the plants to have a documented control system for the entire production system as well as documented routines for audit of their suppliers. The selection of number of suppliers as well as type of suppliers for annual audit is based on risk assessment. The QAS includes limits for content of metals and visual impurities larger than 2 mm. The limit for impurities was recently changed from 0,5% DM (weight) to 20 cm^2/kg liquid digestate (less than 20% DM) or 60 cm^2/kg solid digestate (more than 20% DM). The change of unit and analysis method was due to the fact that most found impurities are plastic foil with low weight. The QAS also includes demands for analysis based on type and size of the plant. ABP-regulation is included in the certification rules.

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Co-funded by the European Union

LIFE BIOBEST is a project co-founded by the European Union

LIFE21-PRE-ES-LIFE BIOBEST - 101086420

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