Πρόγραμμα Εδαφικής Συνεργασίας Ελλάδα-Κύπρος 2014-2020

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Αποκεντρωμένη διαχείριση των βιοαποβλήτων και αξιοποίησή τους με χρήση εναλλακτικών και καινοτόμων συστημάτων επεξεργασίας

(BIOMA)

Η πράξη συγχρηματοδοτείται κατά 85% από την Ευρωπαϊκή Ένωση (ΕΤΠΑ) και κατά 15% από εθνικούς πόρους της Ελλάδας και της Κύπρου.

Άξονας Προτεραιότητας: Διατήρηση και προστασία του περιβάλλοντος και πρόληψη κινδύνων

Deliverable 5.1.4 Development of good practices for biogas use

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ΕΤΑΙΡΙΚΟ ΣΧΗΜΑ ΕΡΓΟΥ ΒΙΟΜΑ	
	Τεχνολογικό Πανεπιστήμιο Κύπρου
	Εθνικό Κέντρο Έρευνας και Τεχνολογικής Ανάπτυξης / Ινστιτούτο Τεχνολογιών Πληροφορικής και Επικοινωνιών (ΙΠΤΗΛ)
	Εθνικό Κέντρο Έρευνας και Τεχνολογικής Ανάπτυξης / Ινστιτούτο Χημικών Διεργασιών & Ενεργειακών Πόρων (ΙΔΕΠ)
	Δήμος Νάξου και Μικρών Κυκλάδων
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	Κοινότητα Παλώδιας

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ABSTRACT

The *Guide for good practice of biogas use* was drafted within the framework of the Cooperation Program Interreg V-A Greece-Cyprus 2014-2020 BIOMA "Decentralized biowaste management and its valorization using alternative and innovative processing systems" in which the involved partners were the Cyprus University of Technology (CUT), the National Centre for Research and Technology, Naxos and Small Cyclades Municipality, the Environmental Department- Ministry of Agriculture, Rural Development and the Environment and the Community of Palodia.

The Guide was drafted using the results from the pilot biowaste source-separation system tested in the Community of Palodia. The community of Palodia was chosen as the pilot application region of the BIOMA project because it comprises of a number of households that serve the dimensioning of the project. Moreover, it is a rural area with croplands -or not but also produces satisfactory quantities of biowaste. The collected biowaste is directed to an anaerobic digestion plant in the premises of CUT where it is treated separately with the aim of producing high quality biogas and compost.

The Guide constitutes a **necessary manual for Municipalities and Communities in Cyprus and other countries**, willing to initiate source-separation systems of biowaste. It includes the Guidelines step-by-step and practical advices related to how a Municipality/Community can design, implement, realize and monitor a source-separation system (in combination with the raising-awareness campaign) and the corresponding treatment system.

1 INTRODUCTION

According to the framework directive 2008/98, biowaste is defined as the biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants.

In line with article 22 of the Directive, Member States are applying suitable measures, as appropriate, to promote:

a) the separate collection of biowaste, with a view to the composting and digestion of biowaste
b) the treatment of biowaste in a way that fulfills a high level of environmental protection
c) the use of environmentally safe materials produced from biowaste.

The separate collection of municipal biowaste is a common practice applied in the EU for some decades. The spreading of such systems is expected to constitute in the next years, a crucial political axis on the municipal solid waste management sector. The ultimate goal is the anaerobic digestion of biowaste and/or its composting for the production of high added-value products and the its diversion from landfill.

A biowaste source-separation system, as every related scheme, requires a thorough and detailed design, optimal organization of cleaning services and systematic public awareness. With the combination of these three components, the success of a source-separated system is reassured. Nevertheless, appropriate design, construction, operation and monitoring of the biowaste treatment system and product control are all also necessary.

2 ORGANISATION OF A SOURCE-SEPARATION SYSTEM

The first part of this Guide describes all the necessary procedures involved in the designing of a source-separation system, which should start at least one year before the real starting date.

2.1 Ensuring the availability of the biowaste treatment unit

The municipality should ensure that its area is served by a municipal biowaste treatment plant, that is an anaerobic digestion unit.

Anaerobic Digestion

Anaerobic digestion is the controlled process of degradation of organic matter performed by microorganisms in the absence of O_2 (anaerobic conditions) that leads to the production of biogas (CH_4 and CO_2 mixture that can be used as fuel for the co-production of electricity and heat) and solid residue (digestate).

The design of the source-separation system should start at least one year before the operation of the treatment plant, so that upon operation, the source-separation system will be ready to start simultaneously.

2.2 Initial Design of the source-separation system

The design begins with the determination of the specific parameters for the delimitation of the source-separation system to be developed in the municipality.

2.2.1 Selection of the participating areas

The whole part of the municipality or a specific community/district/area can be selected with the aim of gradually expanding the system. Specific waste producers like large touristic facilities could also be included.

Advantages of selecting a part of the municipality: According to the related application results in a part of the municipality, mistakes can be avoided and prevented and the source-separation system can be optimized before its expansion.

Disadvantages of selecting a part of the municipality: It demands additional procedures for equipment supply, system organization and performing the awareness campaign. Furthermore, as the population served increases, the cost of investment and operation of the source-separation system per capita or per ton of biowaste, decreases.

In any case, the areas to be selected should not be scattered in the total area of the Municipality. Delimitation is preferred to be applied taking into account the areas served by the existing municipal solid waste (MSW) collection routes.

2.2.2 Counting the number of households within the area

The counting of the total number of households within the area where the source-separation system will be applied, uses data from Municipalities and electricity companies e.g. Electricity Authority of Cyprus (EAC), or/and water supply companies, e.g. Water Development Department, related to the corresponding active accounts. Alternatively, data from the Statistical Service of Cyprus or other countries, can also be evaluated.

2.2.3 Counting the number of stores and businesses within the area

To count the number of health care stores, tourist enterprises (hotels) and other large producers (supermarkets, flea markets) within the limits of the area where the source-separation system will be applied, data of municipalities (e.g. sit-down dining capacity) and of electricity companies related to active electricity accounts can be used.

2.2.4 Selection of materials for source-separation

The source-separation system may include garden waste either in combination with food waste or separated. The main drawbacks of joint collection procedures are the demand of containers of greater capacities and the seasonal production of garden waste.

In cases of joint collection of food and garden waste, the following should be evaluated and taken into consideration:

- Residencies with gardens ratio.
- Green waste production fluctuates, with larger quantities being observed from spring to fall.

It is suggested that the source-separation of garden waste should be performed separately from food waste.

2.2.5 Estimated quantities to be collected

When a source-separation system is designed, an estimation of the quantities expected to be collected and transported to the biowaste treatment plant is recommended.

According to BIOMA results, collected quantities amount to about 3,41 kg/resident/week for households participating in the source-separation scheme, whereas after 1 year, the participation could vary between 25%-50% of the total households' number.

This can be interpreted as: for N number of households within a specific area, the quantities of biowaste expected to be collected **Π (kg/week)** are estimated to be:

$\Pi = N \times 25\text{-}50\% \times 3{,}41$

Where:

Π: the quantity of biowaste that is expected to be collected per week (kg/week)

N: the total number of households within the area served

25-50%: the percentage of households expected to actively participate in the system one year after the initiation of the source-separation system.

3,41 kg/week: specific factor for biowaste collected according to BIOMA experience

For the estimation of the volume of biowaste collected, a specific weight equal to 500 kg/m^3 can be used.

2.2.6 Selecting the Manager of the source-separation system

Municipalities should assign to an executive member of the Cleaning Service the organization and coordination of both the source-separation system and the awareness campaign. The employment time required is described in the table below.

Table 1. Indicative employment time of the employee responsible for the source-separation system

Source-Separation (SS) phase	**Employment time**
2 - 6 months before the SS initiation	1 day per week
1 month before the SS initiation	3 days per week
During bins distribution & SS initiation	5 days per week
During application of SS	1 day per week

2.3 Selection of source-separation system

2.3.1 Domestic Drying System

The domestic drying system tested in the municipality of Palodia and which is suggested for use is “Smart Cara CS 10”. It is a device that removes humidity included in organic wastes, transforming it to a coarse powder. Thus, the volume and mass of the waste decreases rendering its disposal and subsequent treatment much easier. More precisely, with “Smart Cara CS 10”, 1 kg of organic waste turns to only 100 g after 3-6 hours. This way, uncontrolled organic waste dumping which constitutes 40-60% of domestic waste, decreases by 80-90%. The dry powder formed as final product is different from the traditional fertilizer (compost) occurring from a composting tank.

Regarding the operation of the “Smart Cara CS 10” dehumidifier, after being plugged in and activated, the grounding and drying of any organic waste placed inside can take place, without further setting or adjustment of the device. The sharpness of the cutting blades which in fact operate at a rotational speed of 6-8 turns per minute (rpm), contributes to the significant reduction of noise emissions. It is also worth mentioning that the drying time required is automatically adjusted, according to the quantity of the organic waste placed inside the dehumidifier, thus avoiding any energy waste. Moreover, apart from the killing of bacterial population presented in these wastes, the removal of unpleasant odors with the help of multiple activated carbon filters, is also achieved.

The “Smart Cara CS 10” dehumidifier contributes to the protection and preservation of hygiene and consequently of human health since it directly there is no unprocessed organic waste which is a source of pathogens and also attracts insects, which can carry diseases that could potentially affect humans. The use of the humidifier helps to improve the aesthetics of the environment, and significantly reduces its degradation occurred by the emissions of gaseous pollutants into the atmosphere (e.g. methane) through the uncontrollable organic waste decomposition.

For instance, it is reported that in the case of Palodia, the use of the humidifier is responsible for the reduction of carbon production from the respective household, of about 425 kg annually, which is equivalent to planting three trees. Furthermore, the resulting dry powder constitutes a final product of high energy value. Additionally, the use of plastic bags that may have been needed in the past to dispose of organic waste is, in this case, significantly reduced.

The dehumidifier's compact design renders its installation easy almost everywhere. Given the character of its use it is possible to be placed around or under the sink.

Figure 1. Dehumidifier "Smart Cara CS 10"

Technical Characteristics of the humidifier "Smart Cara CS 10"

Product Name	SMART CARA
Model Number	CS 10
Treatment operation	Insertion/Milling/Drying
Installation	Autonomous operation
Power	220 V/60 Hz
Energy Consumption	0,5 kW
Processing Time	≈ 3-6 hours
Capacity	≈ 1 kg
Waste Weight Reduction	≈ 80%
Odors Removal	Triple filter compact factor
Device Weight	9 kg
Device Dimensions	270 mm (W) x 300 mm (L) x 350 mm (H)
Manufacturer	MAGICCARA Co., Ltd.

2.3.2 System for the treatment of green waste and branches

The system for the treatment of green waste and branches that was centrally tested in the Community of Palodia and is proposed for use is the Branch Chipper "YAMACHIPPER VR35 – HEAVY DUTY". It is suitable for professional use in needs of fragmentation in the field of forestry, garden maintenance and decoration, tree or vegetable crops, materials production for animal feed, fuel etc.

The design offers advantages for easy use, transportation, storage and access for control and maintenance of all its parts, while offering high performance and repeated productivity in long-hours of use. The large inlet funnel combined with the long length of the blades make it possible to crumble fresh cropped soft branches with up to 9 cm diameter, but also of dry and hard branches with up to 7 cm diameter, while the fragments occurred are suitable for easy and fast integration into the soil. The chipper's outlet rotation system provides the operator the advantage to control the direction of the shredded branches without any tools.

The high quality of crushing achieved is owed to the combination with the rotator system achieving optimal torque and power during cutting. In addition to the resistant blades, the rotator and rotator's axis, only heavy-duty ball bearings of the German company FAG are used, which ensure the operation and maximal lifespan of the device. The frame of the Yamachipper is constructed so that stiffness is provided during transportation or usage. It is the only chipper available whose motor is placed on a special base with a reclining system for easy belt stretching, vibration absorption and easy change of engine oils. In fact, its ergonomic design allows the chipper to be easily moved by a single person.

The "YAMACHIPPER VR35 – HEAVY DUTY" chipper can be combined with most of the branded petrol engines from 13HP onwards, while selectively the engine may have an automatic starter in combination with a battery and a key on the start switch. Additionally, an extra advantage is the placement of a measuring instrument of the time of use of the engine so that the proper device operation and maintenance time is ensured.

Figure 2. Branch chipper "YAMACHIPPER VR35 – HEAVY DUTY"

Technical characteristics of the branch crusher

Manufacturer	Yamastik – *Agricultural Equipment*
Model	VR 35
Power needed - min-max (HP)	13-22
Automatic starter	*By choice*
Self-moving system	*No*
Blades – moving/anvil (pieces)	2/1
Max diameter of softwood (mm)	90
Max diameter of hardwood (mm)	70
Fragment thickness (mm)	1-3
Engine Turns /PTO (rpm)	3600
Performance (kg/h)	1500-5500
Wheels (cm)	37
Weight (kg)	170
Dimensions – L x W x H (cm)	180 x 88 x 138
Engine	Subaru 14Hp, Loncin 13Hp, Zongshen 13Hp

2.4 Collection frequency

Determining the collection frequency of dry food waste depends on factors such as:

- The quantities produced
- The collection frequency of mixed municipal solid waste
- The climatic conditions
- The source-selection system
- The collection (or not) of large volume of garden waste like pruning.

In countries where low temperature conditions prevail throughout the whole year it is possible to apply more rare collection practices. On the contrary, in Mediterranean climates the collection should take place at least twice per week, while during the warmer summer months it should be increased up to 4 times per week. The collection of dry food waste in summer months is appropriate to take place more often (even once more per week). At a later stage though, depending on the container fullness and the residents' suggestions, a decrease or increase of the collection rate should be examined.

Table 2. Collection frequency of food waste in other European countries.

Country	Collection in summer	Collection in winter
Palodia	2/week	1/10 days
Greece	2 times / week (not including green waste which is separately collected upon contact usually free of charge)	1/10 days
Germany	1/week	1/15 days
Austria	1/ week	1/15 days
Italy	2/ week	More intensive in south
Catalonia	3-4/ week	
England	1/ week	

The frequency is affected by the collection system. Experience has shown that the central container system requires a slightly increased collection rate for the following reasons:

- The bins are easier to fill.
- The bins are placed in common areas and odors-related issues arise potential complaints to the cleaning service.

3 AWARENESS CAMPAIGN

3.1 Objective and means of implementation

Information-awareness actions aim to:

- Inform the target-audience about the program
- Raise awareness to adopt environmentally correct behaviors, related to waste production and management according to the source-separation system
- Promote the active participation in the action.

More precisely, the objective is:

1. To inform citizens about the benefits of biowaste management and most importantly:
   - The reduction of the quantity of the mixed waste collected and the consequent decrease of the total management costs (collection, transportation, treatment and landfilling)
   - To highlight the value of biowaste in the framework of circular economy
   - The promotion of optimal environmental practices for waste management.
2. The education and awareness-raising of citizens, especially children and young people, on issues related to waste management and recycling activities in everyday life, with the aim of protecting the environment and human health.
3. Achieving social consent to location setting of the biowaste treatment facilities needed.
4. Support and enhance the know-how of citizens and agencys for the proper implementation of waste management actions.

The information-awareness campaign must:

- present reliable data on the action, underline the ease of participation of each citizen, highlight its benefits on personal and collective level, and respond convincingly to any doubts in order to gain the acceptance, trust and active participation of the population.
- promote the incentives (financial, reciprocal environmental, etc.) provided for citizens' participation and behavior change.

The awareness campaign is aimed at households, stores (health care or retail stores) and touristic enterprises with the intention of encouraging them to actively participate in the source-separation program.

At the same time the campaign aims to inform all the agencys that constitute multipliers of information, such as schools, local media and local associations.

Figure 3. Graphic representation of the awareness campaign.

The information-awareness campaign is divided into three (3) phases with intermediate and central time the time of starting the source-separation.

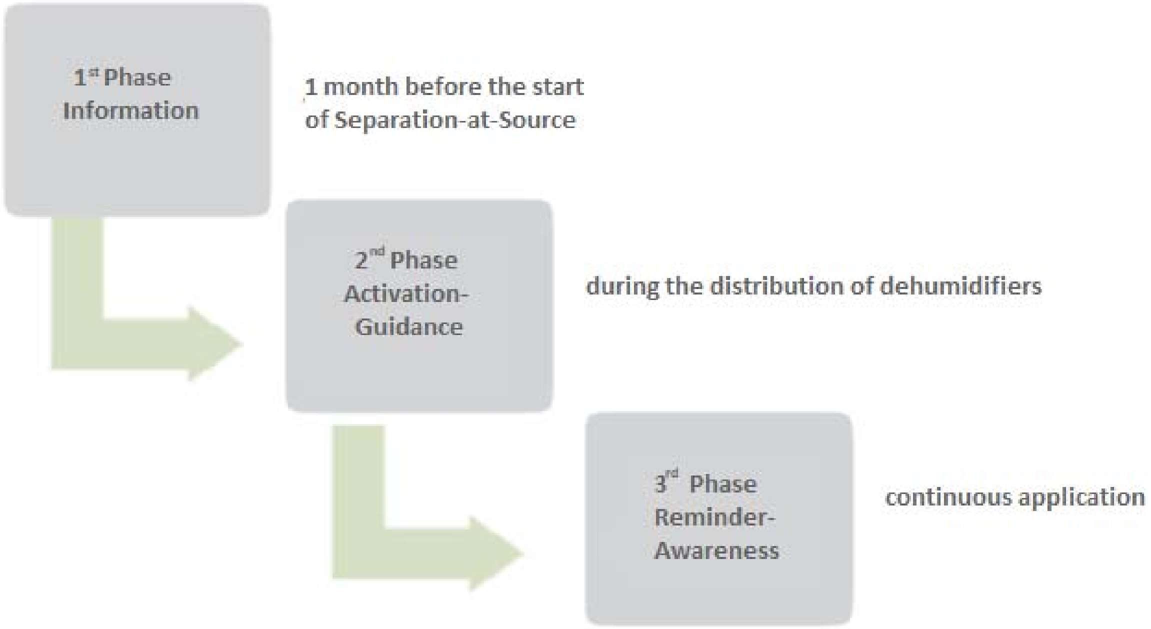

Figure 4. Phases of the information-awareness campaign.

The actions suggested for an efficient awareness campaign are described in the table below.

Table 3. Suggested actions for efficient awareness campaign

Horizontal actions
Central campaign message
Office & contact line
Refresh of the Municipality's Website
Pages on social media
Creative equipment
PHASE A (Information)
Printed brochure & poster
Source-separation initiation letter
Update of the Municipal Council & executives of the

Municipality
Press Release- Press Conference
PHASE B (Activation- Guidance)
Notices
Door-to-Door update (bin distribution)
Instructions for use of the bins
Information Kiosk
PHASE C (Reminder- Awareness)
Information Kiosk
Reminder letters
School activities
Press Releases- Newsletters
Participation in local events

In this section, the horizontal actions that constitute the basis of the information campaign, are analyzed. They are developed at an early stage and continue to be implemented throughout the whole implementation process of the source-separation system.

3.2 Central Campaign Message

The development of the central message and identity of the information and awareness campaign is the first step in implementing all the other communication actions.

3.2.1 Logo

The source-separation logo of each region participating in a relevant program should be selected in a way that is simple to use and directly and efficiently communicates the process source-separation – anaerobic digestion- food waste composting.

3.2.2 Central Campaign message

The central campaign message should be chosen to promote the concept of anaerobic digestion of biowaste and should be understandable to all citizens. The expression "food residues' is expected to better communicate the message rather than the official term "biowaste".

3.2.3 Campaign Banner

The campaign banner should be developed in a way that it can be added to websites and online media.

3.2.4 Information brochure- poster

The information brochure for the residents of the areas served is the most detailed informative mean and potentially the most important one for the participating citizens. The brochure should at least include the following:

- The served areas, so that all citizens can be able to understand if their residence is included in the source-separation scheme.
- The way, the methods and the equipment to be used for the program's implementation.
- The definition of biowaste and biowaste types to be separately collected.
- General- concise information on the initiative of the Municipality.
- The contact details of the Municipality.

Additionally, it is recommended to use one side of the brochure as a poster, so that it can be used for a dual purpose but also to save cost. To estimate the brochure quantities, the following should be taken into consideration:

- The total number of households served
- The stores and other businesses
- The students of the local schools
- Additional pieces for events, organizations, etc.

As the number of brochure copies increases, the unit price decreases. For this reason, when issuing the brochure, the following should be avoided:

- Contain statements from politicians
- Include dates
- Include maps when there is a goal to expand the system.

All the above can be added to a letter, that will accompany the brochure each time.

3.3 Communication Office – Communication Line

The creation of a communication and information office for citizens is considered necessary for their continuous and direct contact with the competent services of their Municipality. For this purpose, the existing telephone numbers of the Municipality's Cleaning Service can be used, and one person must be thoroughly trained to answer on a daily basis. All requests must be recorded on a special form. The communication office is likely to receive calls about requests concerning new dehumidifiers (e.g. in non-served areas), replacement of dehumidifiers (in case of failure), etc.

3.4 Website

The Municipality's website update with information about the source-separation system is mandatory, since it provides citizens with updates regarding all actions provided for their region. It is recommended to include topics, such as: Who can participate? How can somebody participate? Why participate?

3.5 Pages on social media

Nowadays, the use of social media, such as Facebook, Twitter, Instagram etc. is imperative for the wide spread of initiatives, especially to young citizens. Dissemination of information among users renders information fast, immediate and effective.

3.6 Creative equipment

The waste collection vehicle collecting dry biowaste is a daily picture for the citizens within a served area and it confirms their efforts made for source-separation practices. The creation of a logo with the central message of the information- awareness campaign and the coverage of the collection vehicle with it are considered necessary.

Also, the bins for collecting dry biowaste should have a single image and should be included in the general picture of the campaign. For this reason, the design of a special sticker for outdoor containers should be accordingly assigned.

3.7 Distribution of the final product

During Phase C (Reminder- Awareness) of the awareness campaign, the goal is the continuous awareness of the citizens and their encouragement to continue participating. Therefore, the operation agent of the unit should provide served municipalities with data regarding the quantity/quality of collected biowaste, so that the awareness campaign can be improved. A relevant information should include:

- Continuous updates for citizens with press releases, door-to-door information, information kiosks, local and school events.
- Continuous information of the Municipalities about the quality (purity) and quantity of the collected biowaste per region/ route so that additional measures of action and awareness can be taken.
- Information of private producers about the operation of the biowaste treatment plant and the types of waste accepted.
- Publication of results related to the operation of the unit (produced quantity, quality, final use of biogas and soil amendment) online and organisation of press releases.
- Distribution of soil amendment-fertiliser in the served Municipalities, for the purpose of its use by themselves or the citizens.

  In the context of reciprocity of the action, soil amendment should be distributed, on a priority basis, to those who are actively involved in the separate collection and drying of biowaste, but also to the volunteers of the action. Then, if the quantities produced are larger, they will be able to cover the fertilization needs of the green areas of the Municipality. In case of even more increased production, agreements will have to be reached with retailers and wholesalers throughout Cyprus (or any other country). The soil amendment will be supplied directly to their warehouses or it will be sold to professional producers with immediate shipment to a pre-agreed location. The product sales may provide revenues that will help finance the operation of the treatment unit.

The distribution networks to be selected must ensure:

- Promotion and projection of the product in the local market
- Contacts and negotiations with local buyers
- Stock maintenance
- Physical distribution of products
- Collection and transfer of orders
- After-sales service.

4 INCENTIVES FOR THE IMPLEMENTATION OF SEPARATE BIOWASTE COLLECTION

According to the directive 2008/98/EK member states should use economic and other means to provide incentives for the implementation of biowaste hierarchy, which include, among others, landfill and incineration fees, “pay-as-you-throw” programs, extended producer liability programs, facilitation of food donation, and incentives for local authorities, or other appropriate means and measures. Thus, based on the European legislation, appropriate incentives should be established to enhance the separate collection of biowaste in all stakeholders involved in the supply chain.

Firstly, the creation of food waste- biowaste should be prevented. Member states should therefore provide incentives to collect unsold nutritional products at all stages of the food supply chain, as well as to redistribute it safely, to charities or others. To reduce the amount of food waste, consumers should also be made aware of the importance of the “Consume By” and “Best Before” dates on food packaging.

Member states should also provide waste owners with incentives, to meet their responsibility to transport their waste to the separate collection systems, in particular, through financial incentives and regulatory provisions. This directive (2008/98/EC) even proposes examples of financial incentives and other measures aiming to apply the separate selection of biowaste. However, these measures are mainly aimed at food producers and traders. Such measures include among others:

1. Fees and restrictions on landfilling and waste incineration, which provide incentives for prevention and recycling and maintain landfill as the least preferred waste management option.
2. "Pay-As-You-Throw" Programs which charge waste producers based on the actual quantity of waste produced and offer incentives for the source-separation of recyclable waste and for reducing the amount of mixed waste.
3. Tax incentives for products donation, especially food.
4. Extended liability programs for producers for different types of waste and measures to increase efficiency, economic efficiency and their governance.
5. Warranty-return payment programs and other measures that encourage the effective collection of used products and materials.
6. Proper planning of investments in waste management infrastructure, through e.g. the EU funds
7. Viable public contracts to encourage better waste management and the use of recycled products and materials.
8. Gradual abolition of subsidies that are not in line with waste prioritization.
9. Use of tax measures or other means to promote the acceptance of products and materials prepared for reuse or recycling.
10. Research and innovation support in advanced recycling and reconstruction technologies.
11. Use of the optimal available waste treatment techniques.
12. Financial incentives for local and regional authorities, especially to promote the prevention of waste production and the wider use of sperate collection programs, while avoiding support for landfill and incineration practices.

13. Public awareness campaigns in particular for separate collection, prevention of waste generation and waste reduction, as well as the incorporation of these issues in education and training.
14. Coordination systems, including digital media, among all relevant public authorities involved in waste management.
15. Promotion of ongoing dialogue and cooperation among all stakeholders involved in waste management, and encouraging voluntary agreements and data submission by companies in relation to waste.

It is widely accepted that the participation of citizens is also very important. Their participation in separate waste collection programs is affected by individual incentives (ecological concern, personal satisfaction, level of knowledge and commitment), as well as by the social framework and the social influence – “self-esteem” and “altruism” are clearly incentives that reinforce positive environmental behaviors.

However, when an environmentally friendly behavior is aligned with the individual well-being, a citizen is more likely to adopt and maintain this type of behavior. Before the adoption of specific individual incentives, the environmental aspect should be adequately proposed. Given the financial numbers and the need to develop a social culture in biowaste management, the implementation of collective incentives is probably more efficient as a practice. Thus, for instance, the achievement of the objectives can be linked with the channeling of a part of the revenues (or all), to collective regional institutions, to small local projects through participatory budget procedures under the control of the residents etc. This way, larger population groups (students, parents, residents) can be motivated.

Establishing individual incentives can also contribute significantly. For instance, discounts are reported on municipal services (e.g. subscriptions to the municipal swimming pool and/or gym, events, etc.) to citizens who are registered in the citizens "registry" and participate to biowaste recycling, the distribution of composting products to local agricultural associations and individuals for free or for a reduced price, etc. If the regulations of the ministries in charge modify the pricing policy of the municipalities and the municipal taxes according to what is mentioned above, it is possible that separate biowaste collection, recycling and circular economy will be equally enhanced.

The proposed regulations are based on the principle "the polluter pays" and create financial incentives for local government organizations, citizens and businesses, in the framework of circular economy and zero waste economy. The performance of each local government organization in separate biowaste collection leads to a reduction in its contributions to the respective solid waste management agent/body, which can subsequently affect citizens by reducing their charges.

"Pay-As-You-Throw" (PAYT) systems link management costs to the actual quantity of waste generated and provide incentives to implement separate collection and the diversion of significant amounts from the total municipal solid waste stream. PAYT systems support the application of the "the polluter pays" principle and consequently the management hierarchy of municipal solid waste. The implementation of PAYT systems contributes to a more proportional transfer of reductions with better results in terms of participation. It is pointed out that the incentives should be adapted according to the specific target- groups. More precisely, the participation of restaurants and hotels, since the separate biowaste collection will require significant alterations in their way of working, requires the use of specific incentives, such as e.g. establishing a special sign. In tourist areas, the participation of companies improves their environmental profile. Moreover, the municipal solid waste management systems should set different incentives for tourists, to minimize their waste and to maximize the separate biowaste selection.

In addition, citizens should be introduced to the numerous benefits they can have by acting in an environmentally responsible way and how the green initiatives affect profit, people and the planet. It should also be made clear how the money saved can be used in ways that benefit them (e.g. biofuel production for municipal waste collection vehicles, fertilizer production for municipal green areas). Furthermore, citizens should comprehend that the separate biowaste selection is not only profitable for the environment but also for their own well-being.

5 BIOWASTE TREATMENT SYSTEM

The biowaste treatment system suggested aims to treat the dried food waste and garden waste, and to optimize the production of value-added products. This system consists of the following main components: the anaerobic digester (AD), the Sequencing Batch Reactor (SBR), the composting unit, the biogas treatment unit and the odor abatement unit.

5.1 Anaerobic digestion

Anaerobic digestion (AD) is a popular method for waste management, mainly because of its useful products (biogas and digestate-compost). The first procedure for the preparation of the AD feedstock is the mixing and homogenization of the biowaste which takes place in the mixing tank. Afterwards, the biowaste from the mixing tank enters the dark fermentation reactor. Dark fermentation (absence of light) is the fermentative conversion of organic substrate to biohydrogen. The outlet of the dark fermentation reactor is the inlet of the anaerobic digester. The anaerobic digester is a closed vessel which is equipped with an agitator in order to provide mixing of the mixture. The agitator needs to be working continuingly during feeding. Inside the dark fermentation reactor and continuous stirred tank reactor (CSTR) there is a heating system providing mesophilic conditions of 37ºC. Given the feed quantity, the AD maintains a hydraulic retention time (HRT) of 30 days in order to allow effective anaerobic biodegradation. This time is a lot longer than the 4 days that the substrate remains in the dark fermentation reactor. The optimization of the operation of reactors can be affected by factors such as the organic loading rate (OLR) and the volatile fatty acids (VFA) composition. The overall anaerobic digestion process should be monitored in real time. The main safety parameter of the operation of the anaerobic digester is the pressure build up in the reactor. Pressure increase can occur in different stages of the biogas production line. The Pressure Indicator (PI) should be installed on top of the AD and connected to a serene on the PLC (Programmable Logic Controller) which will be turned on once the pressure exceeds 60 mbar over atmospheric pressure. The fermentation unit is characterized by low pH due to the accumulation of short chain fatty acids inside the reactor up to 10-15 g COD/L, mainly acetic (30-40%), propanoic (10-20%) and butyric acid (20-40%). Temperature control depends on the operation of the combined heat and power unit (CHP).

The typical parameter for monitoring the anaerobic digestion process is the quantity and quality of biogas produced from the dark fermentation and anaerobic digestion units. The typical composition of biogas for co-generation purposes is 10% H_2, 30% CO_2 and 60% of CH_4. Optimum pH for hydrogen production has been reported to be in the range 5.0-7.0, a fact that favors the activities of hydrogenase. A good practice to control the pH in the dark fermentation unit is to recirculate the sludge of the final effluent.

The effluent of the anaerobic digester passes through the solid/liquid separation system. The liquid fraction is sent to the ultrafiltration UF system and afterwards to the SBR reactor, while the solid fraction is fed to the composting unit. The solid/ liquid separation of the produced digestate is a crucial stage of the integrated unit and for this reason it needs to be effective. Otherwise, problems in the downstream treatment stages will occur. For instance, a solid fraction with high moisture content will lead to an increase in the quantity of bulking agent required, in order to reduce the moisture content to the acceptable levels for composting. Accordingly, a liquid fraction containing significant amounts of suspended solids will cause problems to the SBR operation. The ultrafiltration system aims to remove the residual solids.

During this process a recovery of up to 75% can be achieved while the concentration of solids in the concentrate is around 2.5-3%.

5.2 Combined Heat and Power system

Combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. In most applications of CHP, the chemical energy of the fuel is converted to mechanical and thermal energy. Mechanical energy is used for the production of electricity and thermal energy for the production of vapor, hot air or water. The main advantage of CHP is the better utilization of the energy content of the fuel compared to simple industrial units that produce vapor or hot water to cover the needs of a specific stage of their production line (process heat) and buy the electricity needed from electricity suppliers, or even compared to conventional power plants. In medium and large scale biowaste treatment plants, the operation of a CHP unit is fixed. Temperature control depends on the CHP unit and when the latter is not operating, the heat needed for the temperature maintenance inside the reactor is provided by an electrical boiler. When the CHP is in operation, all the heating energy is diverted to the AD unit. The energy produced can also be fed back to the process. Alternatively, the biogas can be upgraded to fuel gas for vehicles or to a natural gas-like quality of biomethane and be fed to the natural gas grid.

5.3 Sequencing Batch Reactor

The Sequencing Batch Reactor (SBR) is a type of activated sludge process for the treatment of wastewater. An SBR operates in a batch mode with aeration and sludge settlement both occurring in the same tank. Oxygen is bubbled through the mixture of wastewater and activated sludge, to reduce the organic matter (measured as biochemical oxygen demand, BOD, and chemical oxygen demand, COD). SBR produces sludge with good settling properties provided that the influent wastewater is introduced in a controlled manner. The treated effluent from the SBR is collected in the effluent collection tank.

As for the optimization of the short-cut sequencing batch reactor (SBR) the following parameters are examined:

- Setting the Solid Retention Time (SRT)

Solid Retention Time (SRT) is one of the most important parameters of the SBR unit operation. SRT defines the structure of the ecosystem evolved in the aerobic bioreactor and the amount of biomass in the aeration tank. SRT affects the operation of the SBR. At elevated SRT values the substrate decomposition rate increases and the ecosystem is more stable to changes in the feedstock composition. When treating a high strength feedstock, the SBR unit should be adjusted to elevated SRT of 40 days at least. The imposed SRT should be in accordance with the appropriate hydraulic retention time, HRT. SRT is defined as the average time that a given unit of cell mass spends in the reactor. It should be mentioned that, the effluent of the SBR does not contain any solids and the total suspended solids leaving the aeration tank will only be those removed from the settling tank. It is apparent that, by measuring the suspended solids in the aeration tank and by adjusting the removal rate of the excess sludge, the desired SRT could be imposed.

- Sludge recirculation

It is noteworthy that the SBR produces sludge which is recirculated through a sludge pump.

- Membrane module cleaning

The membrane module should be cleaned once a month or according to the manufacturer. The cleaning of the membrane module requires submerging the module in 1N NaOCl solution for 2 hours. It should be noted that before repositioning the ceramic membranes, the module should be rinsed.

- Denitrifying phosphorus removal via nitrite

The denitrifying phosphorus removal via nitrite integrates phosphorus and nitrogen removal in a robust process in which the via-nitrite denitrification and phosphate uptake occur simultaneously. The activated sludge hyper-accumulates phosphorus chains inside the cell resulting to a final concentration of phosphorus in the sludge up to 55-60 g/kg of dry matter. The process requires alternating anaerobic and anoxic conditions to promote the growth of the denitrifying phosphorus-accumulating organisms (DPAOs). Under anaerobic conditions, these bacteria require 5 to 10 mg of short-chain fatty acids per mg of phosphorus removal, which are taken to form polyhydroxyalkanoates (PHAs).

- Development of a reliable automation process

The cycle of a conventional SBR is based on fixed time intervals, but wrong fixed timing may result in process degradation (e.g., due to inhibition of accumulated substances like ammonia and/or nitrite), or high energy demand (e.g. complete oxidation of ammonia). The use of specific submerged sensors could provide more flexible cycles, which are able to identify the end of the phases by monitoring key process parameters. The common sensors applied to accomplish a reliable automation of the phases are:

1. DO to control the blower frequency during the aeration phase based on DO set-point value.

2. Conductivity to control the ammonia oxidation efficiency during the aerobic period based on linear dependency with the ammonia concentration.
3. Oxidation-Reduction Potential, ORP, to control the establishment of effective anaerobic conditions. The ORP value has to be less than -300 mV to ensure that anaerobic conditions are achieved.
4. pH to control anoxic nitrite denitrification. The apex of pH under anoxic conditions indicates that nitrite was completely denitrified.

- Duration/length of the anoxic and aerobic phases

The typical length of the SBR phases are reported in the following table:

Table 4. Typical phase duration of an SBR reactor.

Sequencing Phases	Duration (min/cycle)
Filling	7.5
Anaerobic	25-60
Aerobic	160-300
Anoxic	50-80
Sedimentation	15-60
Discharge	7.5

- Nitrogen loading rate

A stable process, at a volumetric nitrogen loading rate of 0.6 kgN/m^3/d can be obtained, resulting in a nitrogen removal efficiency of up to 85-90%.

- Biomass activity

The efficient nitrogen and phosphorus via-nitrite removal can be achieved by the following biomass activities standardized at 20ºC:

- Specific Ammonia Oxidation Rate Via-Nitrite: 12-15 mgNH4-N/grMLVSS/h
- Specific Nitrite Denitrification Rate: 35-50 $mgNO_2$-N/grMLVSS/h
- Specific Phosphorus Release Rate: 3-5 mgP/grMLVSS/h
- Specific Anoxic Phosphorus Uptake Rate: 10-15 mgP/grMLVSS/h

- pH

The optimal pH range in order to achieve more than 90% of ammonia oxidation is 7,5–8. Lower range of pH may result in a limited availability of alkalinity in the mixed liquor which negatively affects the nitrification efficiencies. Higher range of pH could increase the concentration of free ammonia in the reactor over the critical inhibition value for the microorganisms.

- Dissolved oxygen

Dissolved oxygen around 1,5-2 mg/L during the aerobic phase ensures optimal conditions for microorganisms, while no dissolved oxygen should be present under anaerobic and anoxic phases.

- Temperature

The anaerobic digestate has a high temperature (30-37°C) because of the mesophilic conditions in the digester. At 30°C the growth rate of the aerobic bacteria is higher than the growth of the nitrifying bacteria, which ensure stability for the via-nitrite route.

5.4 Biogas treatment unit and odor abatement system

In order to treat biogas emissions a biotrickling filter can be used, while the odors are treated at the odor abatement system.

The biogas treatment aims to minimize the content of H_2S in the produced biogas in order to use it for combustion in CHP. As an odor abatement system, a biofiltration hybrid system can be used, to remove odors and VOCs. The last step of the treatment includes the droplet separator and the polishing filters.

After the first months of operation, an optimization of the gas treatment units should be done, so that their adequacy for the gas to-be-treated can be checked, as well as to maximize the performance and adjust the process to the real requirements of the pilot plant. This optimization should be based on the adjustment of the most influential parameters on the bioreactors: pollutant concentration, gas flow, empty bed residence time (EBRT), frequency and flows of liquid phase provided, nutrient solution composition, and pressure drop. The optimization pursuits the maximum approach of the real and the expected results defined in the design phases. Thus, the modification of the parameters leads to the achievement of the removal efficiencies estimated but also to the appropriate stability of the process. The main characteristic of the gas treatment units, the hybrid biofilter and the biotrickling filter is flexibility which allows them to adapt to the requirements of each stage. In this sense, the optimization is carried out in a simple way reducing time and associated costs.

To achieve high biotrickling filter's performance, specific operational parameters are followed.

- Gas flow optimization

This unit is fed with the biogas produced in the anaerobic digester. The biogas flow and the H_2S concentration fluctuate in accordance with the anaerobic digestion process. A suitable system can be designed so that the biogas can be stored until the minimum volume needed is accumulated. This optimization favors the supply of a more constant H_2S concentration enhancing the biomass development and also increasing the performance.

- Empty bed residence time (EBRT)

The EBRT is initially established in 3 minutes (one minute for each module). This is a long time for H_2S removal compared to studies found in literature. However, this EBRT ensures that H_2S removal exceeds 75% without altering other properties of the biogas.

- Liquid phase addition

The biotrickling filter requires a continuous liquid supply for promoting H_2S absorption in the liquid phase. An important optimization parameter is the trickling liquid velocity (TVL) which influences the H_2S availability for the bacteria. It is controlled by the flow of the liquid phase.

- Nutrient solution composition

The biological process occurred in the biotrickling filter requires a concentration of nutrients which enhances the development of biomass responsible for H_2S removal under anoxic conditions. The most important parameter is the presence of N_2 in the form of NO_3^-, because it reacts with H_2S. Moreover, the S^{2-}:NO_3^- ratio determines the products obtained SO_4^{2-} or elementary S. The optimization is carried out in order to produce SO_4^{2-} as a product since elementary S can provoke mechanical or other problems.

- Pressure drop

The biotrickling filter is designed to minimize the compaction of the packing material. A suitable packing material can be selected to avoid higher pressure drops. The optimization of the distribution of the packing material ensures a reduction in pressure drop even if an accumulation of elementary sulphur occurs.

5.5 Composting Unit

The composting unit is used for the treatment of the solid fraction of the digestate to produce stabilized compost. Composting is an aerobic biological stabilization process of organic solid and semisolid substrates. The composting unit receives both the solid fraction resulting after the dewatering tank (centrifugal separation) and the ultrafiltration concentrate. The solid digestate has undergone anaerobic biodegradation and thus, the duration of the composting process can be shorter than the one applied to untreated substrates.

Different types of microorganisms are active at different stages of the composting process. In order to optimize the unit, some important parameters are necessary to be determined by laboratory testing.

- Temperature profile and process time

It is worth mentioning that the total duration of composting ranges from 2 to 6 months depending on the feedstock used and the aeration. In the first stage of composting, also known as mesophilic stage, the material develops rapidly and the temperature increases from ambient temperature to 42ºC. This stage is dominated by mesophilic bacteria that multiply rapidly, as they use the available simple organic compounds. This stage is considered the most important phase consisting the main axis of composting evolution. The living microbial mass is considered as an integral part of each phase of the process. Rising temperatures and biodegradation are directly dependent on the composition of the organic material and the constituents of the nutrient medium, such as sugars.

The temperature is the main key to the transition from mesophilic to thermophilic phase. During thermophilic phase, the temperature increases to 55-65ºC. The thermophilic phase could have a duration of 10-20 days, depending on the raw material. After that, the temperature decreases and is maintained at 35-45ºC.

- Oxygen and Moisture content

Oxygen concentrations higher than 10% are considered optimal for the maintenance of both the anaerobic conditions and the aerobic microbial activity. Oxygen values must be greater than 5% which is considered the minimum value to avoid anaerobic environment. The oxygen concentration should show an increasing tendency throughout the whole process, indicating that agitation during sludge mixing and substrate aeration were sufficient to promote the aerobic conditions in the composting unit. Lower oxygen values, below 10% may also be observed during the thermophilic phase of composting due to the high oxygen demand for oxidation of the available organic matter by microorganisms and the stabilization of the organic substrate. During the last stage of composting, oxygen levels can exceed 20% indicative of the low decomposition rate of the organic matter, since the oxygen concentration approximates the ambient levels (21%).

As for the moisture content, at the beginning of the process it should not exceed 45%. During composting and in case of lower moisture content, water or other liquid waste should be added.

In general moisture levels should not exceed 55% on a dry base. At the later stages of the composting process, the moisture content falls to lower values.

- Maturity Index

Maturity is the degree or level of completeness of the composting process. Immature compost may stunt, damage, or even kill plants, rather than enhance their growth. Maturity is not related to quality, but to what stage of the composting process, the material has progressed. One of the ways to estimate the maturity index is by germination of cress (Lepidium sativum) or radish seed (Raphanus sativus), which are small seeds, quick to germinate and sensitive to phytotoxic (plant damaging) substances such as the organic acids presented in immature composts.

- Agronomical properties of the compost

Compost contains a wide range of essential nutrients for plants, that often are absent from conventional fertilizers. Unlike synthetic fertilizers, compost is able to release nutrients for months or years. It can regulate acidic and alkaline elements in soils, thus achieving the optimal pH levels.

Compost displays some important advantages. Upon compost addition, the soil is full of micro-channels and pores that retain air, moisture and nutrients. Compost contains beneficial microorganisms that can protect plants from diseases and pests. Such microorganisms are bacteria, fungi, insects and worms which contribute to the development of healthy plants. Bacteria in compost degrade organic matter and convert nitrogen from the air to the nutrients required for plants. Insects and worms penetrate the ground and maintain its sufficient aeration. These organisms and microorganisms presented in compost convert it to a natural fertilizer. It must be noted that compost production reduces or eliminates the needs for synthetic fertilizer manufacturing. Moreover, a healthy soil constitutes a critical factor for the protection of water. Compost increases the ability of soil to retain water and reduces runoff. Runoff can contaminate water by carrying soil from fertilizers and pesticides. Compost, is able to suppress harmful diseases and pests that could penetrate a poor soil.

- Stability parameters of the compost

Stability parameters presented in the following table determine a good compost quality. The uses of compost are defined according to the compost properties, like the pH (near neutral), carbon to nitrogen ratio (nutrients content indicates that the microelements quantity of compost is sufficient for agricultural applications) and the stability parameter (below 100 mg O_2/ kg dry compost/h).

Table 5. Quality parameters of compost

Parameter	**Optimum values (3-6 months of mature compost)**
C:N ratio	15-20
Moisture	35 - 60%
Organic matter (dry base)	> 50%
pH	6,5 - 8,5
Total Nitrogen (dry base)	~ 1%
Organic Carbon	25 -55 %
Total Phosporous (dry base)	~ 0,65% (1 month)
Germination Index	> 90
Maturity test	7 -8 (solvita index value)
EC	1-4 mS/cm

Ash	15-25%
Water Holding Capacity	> 60%

6 COST ESTIMATION

An initial cost estimation is presented for both the biowaste collection scheme and the biowaste treatment system.

6.1 Cost of biowaste collection system

6.1.1 Investment cost

The initial investment cost for the implementation of the source-separation system includes the following expenses:

- Cost for the supply of dehumidifiers and branch chippers
- Cost for the supply of containers/bins
- Cost for the supply of special waste collection vehicle (if an existing one is not used)
- Cost for the awareness campaign (during the first phase and first year), including the consumables for school events.

Indicative unit prices (without VAT), representative for the Greek market, are presented in the table below:

Table 6. Indicative prices for bins and waste collection vehicles.

Kind	Unit cost
Containers/Bins	
Plastic bins 10 L	6 - 10 €
Plastic bins 35-40 L	19 €
Plastic bins 50 L with wheels	20 – 34 €

Plastic bins 120 L with wheels	25 €
Plastic bins 240 L with wheels	38 €
Plastic bins 360 L with wheels	65 €
Metal bins 660 L	335 €
Metal bins 1100 L	335 €
Vehicles (waste collection vehicles, RCV)	
Press-type RCV 4 m^3	60.000 €
Press-type RCV 6 m^3	70.000 €
Press-type RCV 8 m^3	110.000 €
Press-type RCV 10 m^3	120.000 €
Press-type RCV 12 m^3	115.000 €
Press-type RCV 4 m^3	100.000 €
Mill-type RCV 6 m^3	110.000 €
Mill-type RCV 8 m^3	115.000 €
Mill-type RCV 10 m^3	125.000 €
Mill-type RCV 12 m^3	130.000 €

An indicative cost for the design of the awareness campaign is shown in the following table:

Table 7. Indicative cost for the design of the awareness campaign.

Type	Cost
Horizontal actions	
Central campaign message	1.000 €
Office & contact line	-
Refresh of the Municipality’s Website	-

Pages on social media	-
PHASE A (Information)	
Printed brochure & poster	4.000 € (for 10.000 pieces)
Source-separation initiation letter	1.500 € (for 10.000 A4 pieces)
Update of the Municipal Council & executives of the Municipality	-
Press Release- Press Conference	-
PHASE B (Activation- Guidance)	
Notices	750 € (for 10.000 A5 pieces)
Door-to-Door update (dehumidifiers distribution)- Instructions for use brochure	2.000 € (for 5.000 pieces)
Information Kiosk	2.500 € (1 piece)
PHASE C (Reminder- Awareness)	
Reminder letters	1.500 € (for 10.000 A4 pieces)
School activities	500 € (for 1000 students)
Press Releases- Newsletters	-

6.1.2 Operating cost

The operating cost of a source-separation system includes the following key expenses:

- Cost of the collection staff
- Fuel cost
- Vehicle maintenance, security and circulation cost
- Bins renewal cost (5% annually)
- Cost of the awareness campaign
- Cost of the supporting staff.

The cost of the collection staff is over the 60% of the total operation cost of a biowaste source-separation system. The fuel needs and the cost for maintenance, security and operation of the vehicles follow. For this reason, optimization of the collection routes is necessary (frequency, collection staff occupied per route, employees involved in other activities) as well as the selection of suitable vehicle (capacity, energy consumption, emissions).

Compared to the door-to-door system, the operating costs of a central-bins system are lower, because in the first case citizens are served per household or per residence. This is more distinct in regions with larger population.

The total collection cost of the Municipalities increases with the addition of extra collection systems. Nevertheless, Municipalities benefit significantly from the diversion of biowaste from landfill or their treatment as mixed waste (gate fee of the unit). Moreover, after the start of the application of landfill tax on waste, the separate biowaste collection will contribute to the reduction of the total management costs of the municipal solid waste.

Additional benefits can also be achieved by reducing the collection frequency of mixed waste, especially in regions where the collection takes place more than 5 times per week.

With the suitable software, a Municipality will be able to estimate both the operating costs of a Source-separation system and the total biowaste management costs (collection-transportation-treatment).

As for the required personnel, the essential needs for the efficient operation of a source-separation system are described below.

Table 8. Key needs in required personnel for the operation of a source-separation system.

Employees	Number of employees	Description
Collection staff	1 Driver and 1-2 collection employees per vehicle	The number of employees (1 or 2 per vehicle besides the driver) depends on the number of bins that they will have to empty during the route, on the structural features of the area and on the location of the bins (in the case of 2 employees simultaneous collection should be possible e.g. from the opposite sides of a road).
Supporting staff	1 Responsible for the source-separation and the awareness campaign. Staff for the Information Kiosks and school activities.	To organize and monitor the overall system (collection, raising awareness, rest organizational issues) and for the realization of the awareness program.
Bins Supervisor	1 Bins Supervisor part-time	To monitor the purity of the material inserted into the bins by performing visual checks and making recommendations when necessary.

6.2 Cost of the waste treatment unit

In relation to the cost estimation of a biowaste treatment system, this was analyzed in three (3) categories:

1. Fixed costs, which include the capital cost of the anaerobic digestion unit (including biogas purification), solid/liquid separation, ultrafiltration, Sequencing Batch Reactor-SBR, composting units.
2. Operating and maintenance costs, which include expenses associated with the operation and maintenance of the different waste management components.
3. Transportation costs, which include expenses associated with the transportation of the mature compost away from the plant.

This way, fixed costs are as follows:

- Anaerobic digestion unit (including biogas purification): 3-5 k€/kW
- Combined heat and energy unit: the cost of a typical CHP unit occurs taking into consideration the price of fuel and the efficiency features of the unit.
- Solid/liquid separation unit: 80-150k€ for processing capacity of $10m^3/h$
- Ultrafiltration unit: 100-200k€ for processing capacity of $80\text{-}100m^3/h$
- Sequencing Batch Reactor (SBR): 300-400k€ for 30kton of biowaste treated
- Composting unit: 400-500k€ for the composting of $8000m^3$ of material

This way, operating and maintenance costs are as follows:

- Anaerobic digestion unit: 0,4-0,7 €/tn biowaste processed
- Combined heat and energy unit: 10 €/MWhe
- Solid/liquid separation unit: 2-2,5 €/tn biowaste processed

- Ultrafiltration unit: 1,5 €/tn biowaste processed
- Sequencing Batch Reactor (SBR): 1,9 €/tn biowaste processed
- Biogas purification unit: < 0,1 €/tn biowaste processed
- Emissions treatment: <0,1 €/tn biowaste processed
- Composting unit: 0,3-0,5 €/tn biowaste processed.

Additional costs also include the transportation of mature compost which is estimated at 0,6-1,5 €/tn compost.

All these values and sizes are initial estimates and should in any case be examined by region and country with further analysis.

7 ALTERNATIVE GOOD PRACTICES OF BIOGAS USE

7.1 Good practice of biogas use as transportation fuel

According to European and national regulations, the methane included in biogas has the same composition as natural gas. For this reason, Compressed Natural Gas vehicles (CNG) can also be operated with biomethane. CNG has already been proven itself in Europe as transportation fuel. Thus, biomethane conversion to CNG is expected to allow the transportation sector to have access to renewable energy sources in the future. Good practice examples of biomethane use on CNG vehicles are presented below.

In Switzerland vehicles can be fueled with “Naturegas” at corresponding filling stations. The “Naturegas” is a mixture of natural gas and biomethane with a minimum biomethane content of 10%. In Switzerland there are about 140 filling stations where natural gas/ biomethane can be used for fueling.

In Magarethen am Moos in Austria, after starting up a biomethane gas station, three Steyr tractors equipped with a standard diesel engine, were modified in 2008 to a combined biodiesel-biomethane operation. The tractor operates with about 65% biomethane and 35% biodiesel. Thus, it is for the first time proven that even with diesel engines, modification to biomethane is possible and economically viable. After nearly 5 years of experience in real operation, tractors were found to have around 20% more power and 15% less consumption.

In St. Gallen in Switzerland, the vehicles used by the Taxi Frosch GmbH type VW Passat EcoFuel operate with a unique system. The Passat TSI EcoFuel goes preferably with natural gas/ biogas and then automatically switches to operation with petrol when the three gas tanks are empty. The exclusive use of natural gas/ biogas is of high priority for Taxi Frosch, and the refueling times are designed in such way so that no liter of gasoline is used.

In Lille, France, the biowaste of the Municipality was used to supply municipal buses with fuel. This project was the first attempt of biomethane inclusion in the natural gas grid in France. The project started in the 90's when CUDL (Urban Community of Lille), who was responsible for both public transportation and several wastewater treatment plants, decided to use biogas from sludge treatment as fuel for their buses. In 1995, the first filling station was established and diesel buses were converted accordingly in order to run on biomethane. By 1998, 4 buses were running on biomethane.

In 1992, a global waste strategy for waste was voted, which promoted the biowaste recovery through anaerobic digestion. At first, the gas was attempted to be directed to the bus station for refill purposes, yet it was then decided to be injected to the grid, avoiding the need of gas storage (the gas is produced continuously while the bus refilling occurs during the night). The anaerobic digestion unit started in 2007. The first biogas injection in the grid was achieved in 2011.

The anaerobic digestion plant treats about 108.000 tons/y of biowaste from households, public markets and catering services. It generates about 4 million Nm^3 of biogas and 34500 tons of compost each year. In 2013, it processed about 69000 tons of biowaste and 1,84 million Nm^3 of raw biogas was produced. Approximately 10% of this is used to provide heat to the process. 835000 Nm^3 of biomethane were injected into the grid, generating about 600000€ of revenues. About 430 buses are in use, among which 95% run on biogas.

The use of waste collection vehicles running on biogas has been increasing for several years in the Paris. Its advantages in terms of noise and air emission are especially interesting in the dense urban areas. For instance, in 2003 the city of Paris launched a program to shift from diesel to biogas vehicles, especially for waste collection. Out of the 241 lorries owned by the municipalities, 167 run on biogas, and so do 225 out of 245 lorries used by private contractors. Madrid is one of the leading cities in Spain in the use of biogas for transport. Its municipal transport company (EMT) and the municipal solid waste management company, use modified vehicles powered by biogas. Another pilot initiative for promoting related practices is a small fleet of 10 taxis powered by biogas to demonstrate the environmental benefits of such fuels.

A major advantage of using biogas over traditional diesel buses, is the reduction of harmful tailpipe emissions including particulates (negligible) and NOx emissions, which are substantially lower. The new buses acquired by EMT produce between just 30 - 50% NOx emissions compared to equivalent buses running on diesel fuel.

After several traffic reduction schemes in the 1980's failed to improve air quality, Linkoping municipality in Sweden, decided to experiment with alternative fuels for its municipal fleets. Between 1989 and 1993, five biogas buses manufactured by Scania were tested. The success of these vehicles led to another 20 buses being replaced by biogas vehicles in 1998, and at present the entire bus fleet (at least 64 buses), the entire municipal waste collection fleet, and at least 125 other vehicles including many taxis are fueled by biogas. In Linkoping, each bus running on biogas fuel contributes to reducing NOx emissions by 1,2 tons and CO_2 by 90 tons per year. Regarding the initial target, to improve the air quality in the city center, the conversion of the bus fleet from diesel to biogas has led to substantial air quality improvements. Biogas buses are also quieter than their diesel predecessors, which is important for a city center.

After upgrading, the biogas is compressed to 4 bar, enabling its transfer by the underground gas grid to the bus station, around 2km away. Five public biogas filling stations are also connected to the grid, and there are at least 7 other biogas filling stations in the Linkoping region, all of which are run by Svensk Biogas. At the bus station, biogas is compressed to 200 bar and stored. Buses are filled up automatically at night. Forty-five buses can be filled up simultaneously, although there are also quick filling stations available. All new licensed taxis in the city must run on a renewable fuel (either bio-ethanol or biogas). Also, older municipal vehicles are gradually being replaced by biogas vehicles once they reach the end of their lifespan.

Biogas has also been well established as a transportation fuel in Switzerland. Only in Zurich, five anaerobic digestion units treating organic waste from households and restaurants produce fuels for 1200 cars and lorries. Cities that developed vehicle fleets which have been efficiently running on biogas for more than ten years now include Lille (124 vehicles), Reykjavik (44 vehicles) and Rome (12 vehicles).

In the United Kingdom in 2008, a group of companies (SITA in collaboration with GasRec, BOC and the Linde Group) produces liquid biomethane (LBM) from landfill gas at its landfill site in Alburt, Surrey. In 2010 SITA trialed the performance of LBM dual fuel vehicles over diesel counterparts of similar age. It was shown that duel fuel vehicles are 12-18% more efficient than diesel vehicles. The dual-fuel vehicles were also found to emit between 25% and 37% less CO_2. After one year of trials in Leeds, it was found that the use of biomethane powered waste collection vehicles can deliver both reduced GHG emissions and cost savings for UK local authorities. The trial vehicle, a Mercedes-Benz Econic LLG with a spark ignition engine running solely on biomethane gas, is estimated to have achieved a 49% saving in GHG emissions, compared to diesel Econics. Tesco has also set in operation 25 Iveco EcoDaily light commercial vehicles fueled by sustainable liquid biomethane for its online retail and delivery services. There are many other examples of municipalities and companies in UK which are currently examining CNG vehicles and the CNG/ biogas operation.

At present, Sweden leads the world in terms of use of biogas as a transport fuel. Over 100 GWh/a (10 million m^3) of biogas is upgraded in one of the 22 existing biogas upgrading plants and used as vehicle fuel, representing around 2% of the country's total transport fuel demand. Based on the experience gained from projects with municipal fleets of buses and taxis, the Swedish program now aims for commercial expansion of vehicle fleets and infrastructure for biogas refuelling stations. Currently there are some 14 local fleets (including those in the cities of Linköping, Vasteras, Uppsala, Kristianstad, Gothenburg and Stockholm) where the major part of the urban public transport systems is operated on biogas. In all cases the biogas derives from the anaerobic digestion (AD) of sewage sludge, biodegradable municipal wastes, commercial and industrial organic wastes and energy crops. Biogas from the Vaxtkraft AD plant, located 8km outside Vasteras, is combined with biogas from the sewage treatment plant, upgraded, piped into the city center, compressed, stored and then is used as a vehicle fuel. This AD plant treats source separated kitchen waste and specially grown energy crops. The upgraded biogas (under a 4 bar pressure) is compressed to 330 bar and then stored, before being used to re-fuel the city's bus fleet. At 330 bar, 6000 m^3 (at atmospheric pressure) of upgraded biogas can be stored in a volume of 32 m^3, in large gas storage tanks in a ventilated gas storage facility. In total, the biogas occurred from both plants substitutes the equivalent of 2,3 million liters of petrol needed per year, a sufficient quantity to supply all the city buses (at least 40 buses), 10 refuse collection vehicles and approximately 500 cars and other light transport vehicles.

7.2 Good practice for biogas injection into the natural gas grid

A key requirement for the biogas usage at gas stations is the production of biomethane, which is usually produced in biogas plants after upgrading. Some examples of good practices for the production of biomethane and its injection into the natural gas grid are presented below.

The biogas production plant in Margarethen am Moos in Austria, nearby the Vienna airport, was established by farmers in 2005. The plant was designed for electricity and heat production. Additionally, a public heating and electricity supply grid has been implemented in the town as the first biomethane fuel station based on the membrane upgrading technology has been operating since 2007. In 2011, MethPOWER took over the biogas plant maintaining the participation of the founder farmers, thus increasing the biogas production. Therefore, the production capacity of the plant has increased to over 3 MW. The plant processes exclusively agricultural residues.

The first biogas upgrading plant of Vienna Municipal Department 48 is already operational. Through a special process, the biogas produced from kitchen scraps is upgraded to biomethane. This way, the whole natural gas grid of Vienna can be supplied. The plant processing 22000 tons of biowaste (food waste) produces over 1 million cubic meters biomethane annually, which is supplied to 900 Viennese households. This saves about 3000 tons CO_2 yearly. Wien Energie customers are supplied with CO_2-free gas which can be used for gas water heaters, gas stoves and for the fueling of vehicles as well. This constitutes a further step towards increasing the share of renewable energy sources but also the reduction of fuel imports for the municipality of Vienna.

In the Kompogas Utzendorf plants operating today in Switzerland, the daily delivered biowaste is processed through an optimal energy utilization system. The biogas obtained by a fermentation process is then converted into electrical energy and heat. Alternatively, or in combination with it, the biogas can be upgraded and be injected into the natural gas grid. Depending on the biowaste composition, about 105-130 m^3 of biogas per ton of biowaste processed, which equals to 70-90 liters of gasoline, are produced. The Kompogas (biomethane) which can be used as vehicle fuel or for combined heat and power to generate electricity, is considered today as one of the most environmentally friendly, accessible to a broad population and renewable fuel available.

The Valdemingómez Technology Park in Madrid, has been hosting since 1978 all the urban waste treatment facilities of Madrid, which reach over 4000 tons of waste generated in the city on a daily basis. The biomethane introduced to the grid was equivalent to the energy needed for 190 buses of EMT (municipal transport company of Madrid).

Several good practice examples for biomethane injection are also present in France. In 2015, 14 biomethane injection sites were reported by the distribution gas grid of the country (GrDF).

Table 9: List of plants injecting biomethane into the gas grid in France.

Units injection biomethane	Description	Production (GWh/y)
Lille-Sequedin (Nord)	AD plant for household biowaste	18

Methavalor (Moselle)	AD plant for household biowaste	5
Bioenergie de la Brie (Seine-et-Mame)	AD plant in a farm (livestock effluent, whey, beet pulp)	13
AgriBioMethane (Vendee)	AD plant in a farm (manure, slaughterhouse fat waste from biscuit factory)	8
Letang Biogaz (Seine-et-Mame)	AD plant in a farm (energy crops, discarded potatoes)	13
0 Terres Energies (Seine-et-Mame)	AD plant in a farm	13
Wannehain (Nord)	AD plant in a farm (manure, waste from vegetables and cereals)	8
Bio'Seine (Aube)	AD plant in a farm	18
Panais Energie (Aube)	AD plant in a farm	13
Sioule Biogaz (Allier)	AD plant in a farm (manure, cereal residues)	3
Pre Saint-Loup (Pas-de-Calais)	AD plant in a farm (manure)	12
Andelnans (Territoire de Belfort)	AD plant in a farm (manure)	5
Champs Fleuris (Ille-et-Vilaine)	AD plant in a farm (manure, vegetable waste, cereal waste)	5
Henin-Beaumont (Pas-de-Calais)	AD plant in a farm after mechanical recycling plant processing municipal solid waste	32
Total		163

8 PROBLEMS

In this section the typical problems, mistakes and expected failures are presented in relation to the different stages of the overall process from biowaste drying to the biogas and compost production.

Possible problems that could occur include:

- Failure or incorrect handling of the domestic dryer
- Mistaken separation of the organic fraction of the municipal solid waste
- Clogging of the domestic dryer’s filter
- No self-forwarding of branches in the chipper, increased fuel consumption, low quality of chips produced, blockage of the chipper’s outlet, vibrations increase.
- Chipper’s blades are less sharp and efficient, or haver breakage
- Dust and odors during chipping
- Collection of biowaste with high moisture and odor content (e.g. not well dried food waste)
- Collection of waste that has remained in collection bins for long periods (e.g. due to strike) – odors emission during unloading
- Extended storage in collection facilities due to inability to process waste (technical failure)- odors emissions
- Disposal of waste at the treatment plant with impurities in bags (anaerobic conditions that cause odors).
- Compulsory storage at the treatment plant because of peak period or other incidents.
- Presence of animals, rodents or vermin in the reception of dry biowaste.

- Temperature fluctuations over 2-3ºC inside the anaerobic digester.
- VFA to alkalinity ratio over 0.35 inside the anaerobic digester, leading to unstable pH.
- Lack of macro or micro- nutrients inside the anaerobic digester.
- Deregulation of nitrogen balance inside the anaerobic digester. In a pH range of 7,5-8 ammonia is soluble and can inhibit methanogenic bacteria at concentrations over 1500mgN/L. For pH value greater than 8, free ammonia may be toxic for anaerobic biomass.
- Hydraulic Retention Time (HRT) lower than 20-30 days causing alkalinity or methanogens leaching.
- System overload (over 4-6 kg COD/m^3/d) resulting in VFA accumulation during acidogenesis.
- Intense odor release during compost maturation. Possible causes may be:
  - Insufficient aeration
  - Big pile of waste
  - Moisture surplus
  - Temperature exceeding 60-65ºC
  - Surface water concentration.
- Intense ammonia odor at the beginning of the active biodegradation phase of composting due to excess nitrogen (C/N ratio below 20:1) or significantly high pH values. If the fumes are intense, pain or swelling in the eyes may occur.
- Wet pile with intense odors because of insufficient aeration (strong odor from spoiled butter, vinegar and spoiled eggs).
- No pile temperature increase because the pile is too small or too dry.
- The pile has suitable moisture content and odor but no temperature increase occurs because of high C:N ratio (lack of nitrogen).

- The temperature increases but not to satisfactory levels during the initiation phase of composting, because of either low pH values or no right mixing/shredding of the raw materials.
- Low pile temperature during composting due to small pile size, insufficient moisture content, insufficient aeration or insufficient quantity of rich-in-nitrogen waste.
- High pile temperature during composting. Possible causes are the following:
  - Big pile size
  - Compression of leaves or other materials.
  - Low C/N ratio, surplus nitrogen.
  - Accumulated heat in pile.
- Suitable moisture and temperature values only in the center of the pile during cold months due to its small size (external surface cools down) or its surface wetting occurring from rainfall.
- High temperatures at the end of the composting process due to decomposition of strongly degradable substances.
- Many impurities in the pile.
- Non biodegraded materials visible at the pile edges.
- Presence of animals, rodents or vermin in the pile.

All the above are only few of the problems that one could face during the implementation of this ambitious plan. Other issues could also occur and should be accordingly handled in an equally efficient way.

9 CONLCUSIONS AND FUTURE STEPS

In the not too distant future, biowaste will have to be more widely used as a resource for the production of second-generation biofuels. Nevertheless, it is clear that without incentives on a European level, it is unlikely that the less developed member states will apply relevant measures to increase practices such as the biowaste conversion to biofuels and compost, options that are more beneficial to the environment and the economy. Instead, they are expected to prefer the ostensibly easier choice, without taking into consideration the real-time environmental benefits and costs.

The anaerobic biowaste and green waste treatment has not yet gained the focus it deserves because of its ecological advantage. There is need for action two-fold: (1) to increase the biowaste quantity collected and (2) to lead a big part of the biowaste to composting and anaerobic digestion units.

Moreover, it is debatable whether the separate collection of kitchen and garden waste is mandatory or the sustainable use of gardening and garden fractions from mixed waste is possible. Nevertheless, the production of biogas and compost from the separate waste collection shows higher efficiencies and presents better-quality characteristics than the corresponding products occurring from mixed waste. The potential for technological optimization is multiple.

The relation between food waste management, production and use of biogas and composted materials and the sustainable food/ biomass production consists a key element for both the circular economy and bio-economy concept. This needs to be further investigated by the responsible decision-makers in relation to their valuable long-term and mid-term consequences but also the economic and environmental pillars.

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