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# Biowaste Management and Circular Economy: Usage of Pay as you Throw System and Autonomous Composting Units in Municipality of Probishtip

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**Abstract**

Municipal solid waste (MSW) management is still a significant environmental problem for all Balkan and Mediterranean countries, under constant pressure from relevant EU legislation and public. In general, waste management services in the Republic of North Macedonia do not comply with national and international regulations. They are incomplete and contain only inefficient waste collection and poorly controlled or uncontrolled landfill, with no additional elements of advanced waste management as defined in EU waste directives. The municipal solid waste management continues to be a significant challenge in all states of the European Community and is an important element in the transition to a circular economy. An important aspect of implementation of the circular economy assumptions in the case of MSW is a plan for reducing waste amounts deposited at landfills and enhancing the share of waste, which can be returned to the system as material and organic recycling. In the light of soon expected establishment of regional integrated and self-sustainable waste management system in the east and north-east planning regions of the Republic of North Macedonia, in order to increase awareness by the local population and hospitality enterprises for source separation schemes of organic waste, as the largest producers of organic waste, University Goce Delchev and Hellenic Mediterranean University together with Municipality of Katerini, Municipality of Yermasoyia, and Municipality of Probishtip launched a joint project co-founded by EU, "Utilizing Pay as You Throw Systems and Autonomous Composting Units for Biowaste Management in Touristic Areas." PAYT system and ACUs as innovative technologies for biowaste management involve source separation schemes of organic waste. The aim of this paper is to present the transfer and application of innovative technologies Pay As You Throw (PAYT) system and Autonomous Composting Units (ACUs) for biowaste management in Municipality of Probishtip, thus reinforce the system of circular economy (CE) in the Republic of North Macedonia.

**Keywords** PAYT · ACU · Biowaste · Source separation · Environmental protection · Circular economy

## Introduction

The European Union has set an ambitious objective for its member states of ensuring the preparation for re-use and recycling of 65% of MSW in 2035, while, at the same time, reducing its landfilling to not more than 10%. In amending a package of directives in order to implement the CE principles into European Union law, including the Waste Framework Directive and the Landfill Directive [1, 2], a good deal of attention was paid to the organic fraction of municipal solid waste (OFMSW), which is an important element in the planning of the sustainable MSW management system [3].

In 2015, EU generated 241 million tons of MSW [4]. Forty to sixty percent of the MSW was organic waste [5], representing a great challenge in terms of its management. However, at the same time, organic waste also constitutes a valuable resource as a component in the circular bioeconomy [6, 7].

From 2023, member states will be obliged, among other things, to carry out mandatory biowaste collection. As reported in literature sources, creating a circular bioeconomy based on effective use of biomass (including biowaste) is one of the major global concerns [8].

Municipal solid waste management is still one of the major environmental challenges at the national level, and although with national and regional waste plans in place. The Republic of North Macedonia with its eight planning regions has only one active standard landfill, and at least 54 non-standard municipal landfills and hundreds of dump sites and old landfills [9]. The poor quality of waste collection services is due to outdated and partially inadequate collection vehicles, poor location and waste collection facilities, poor human and financial resource management, poor performance (and cost) monitoring, etc. Methodology for charging for waste collection per square meter of housing is still in use instead of charging per kilogram of waste produced as is the practice in European countries. Regular waste collection services are mainly limited to urban areas, providing up to 90% coverage in the cities and their outskirts. In total, around 70% of the total population receive regular waste collection services, while the remaining 30%, residing in rural settlements distant from the main collection areas, manage wastes on their own [9].

Waste collection, transportation, and disposal in Municipality of Probishtip are performed by the Public Utility Company “Nikola Karev” by disposing the waste at the municipal non-standard landfill near the city. The landfill does not comply with the requirements of national and EU legislation [1, 10]. Annually, about 3300 t of MSW is generated in Municipality of Probishtip, with estimated 45.3% organic waste [11], all together disposed at a non-standard landfill just out of the city borders, and as soon as regional waste management system kick-in this should be changed, affecting current practice and costs. According to available data, on the territory of the Municipality of Probishtip, there are 22 dump sites, especially in rural areas which are not covered by the waste collection system. Currently there is no waste separation facility, while the customers (households and enterprises) are charged by the volume of their property, instead of the amount of waste they produce. Efficient waste management is an important step towards an energy and material sustainable society [12].

Municipality of Probishtip is one of the first municipalities in the Republic of North Macedonia whereas in the result of the implementation of the “Utilizing Pay As You Throw System and Autonomous Composting Units for Biowastes Management in Touristic Areas” project (acronym: “BIOWASTE”), the waste management is changed [13]. The project includes transfer and application of innovative technologies Pay As You Throw (PAYT) system and Autonomous Composting Units (ACUs) for biowaste management in three Balkan countries: Republic of North Macedonia (Municipality of Probishtip), Greece (Municipality of Katerini), and Cyprus (Municipality of Yermasoyia). The chosen municipalities are different types of touristic municipalities, as follows: Municipality of Probishtip is a less intensive touristic area with a very large number of small and decentralized communities with significant number of tourists; Municipality of Katerini is a less intensive touristic area, with short summer period directly related with the sea cost; and Municipality of Yermasoyia is an intensified touristic area with prolonged touristic summer [14]. PAYT system and ACUs as innovative technologies for biowaste management involve source separation schemes of organic waste.

As indicated in research conducted by Malamis et al. [15] in Greece, source separation schemes are a key factor for biowaste and further products (e.g., compost) quality. Similar findings can be found in a study described by Rodrigues et al. concerning biowaste from 20 treatment plants in Catalonia (Spain) [16]. Italian findings based on the study in Italia Romagna Region highlight that in regions with lower population density, it is easier to obtain positive results in the quality of waste separate collection, but it is much more difficult in densely populated areas such as large cities [17]. Similar conclusions can be found in work conducted in the Aveiro municipality (Portugal) [18]. The results obtained during the research in Portsmouth (UK) indicated that another obstacle to achieving high recycling rates might be a highly transient population [19]. On the other hand, a paper by Carvalho describes that separately collected waste treatment units are effective (in terms of costs) if they cover 400–550 thousand residents [20]. Another study from Portugal, conducted in a municipality with a population of 28 000 inhabitants, showed that selective waste collection may not cause an increase in costs (and even bring them down) if the participation of residents in it is over 40% [21]. Biowaste is not only important for waste management issues but is also a recognized source of green energy [22–24].

The "Pay-As-You-Throw" (PAYT) scheme is an economic instrument for waste management that applies the "polluter pays" principle by charging the inhabitants of municipalities according to the amount of generated waste [25, 26]. "Pay As You Throw" system may be an additional incentive to reduce the waste management costs generated by hospitality enterprises and households. In this context, the source separation schemes of organic waste may be complemented by Autonomous Composting Units (ACUs) for the processing of collected organic waste and compost production, what is the main aim of the implementation of BIOWASTE project in the municipalities in Greece, Cyprus, and Republic of North Macedonia. Experience in countries with established biowaste recycling shows that the first and preferred option for biowaste recycling shall be compost production. Compost production is relatively easy and cost-effective to implement at the local and regional levels, especially using Autonomous Composting Units. Compost production can go hand in hand with production of biogas, i.e., via processes of anaerobic digestion, if organic material with high biogas-potential is available. This could increase the economic value generated per ton of biowaste [27].

Composting is the transformation of raw organic materials into biologically stable, humic substances suitable for a variety of soils and plant use. Essentially, composting is controlled decomposition, natural breakdown process that occurs when organic residue comes in contact with soil.

Composting systems depend on the proposed location, the quantity and nature of the processed material, and the proposed operational regime. The greater the potential environmental impacts, the more carefully the site, design, and operational practices must be considered and the greater the attention to environmental assessment.

There are several composting systems to choose from, based on a number of variables including type and volume of feedstock, available space, and budget.

- Open Pile: This is what it sounds like — a large pile of organic material. But must include a bulking agent to allow airflow through the pile to ensure aerobic conditions.
- Windrow: Long rows or piles of material (called windrows) are created and turned periodically with a windrow turner.
- Static Pile: Organic material is placed in a windrow, but unlike the windrow it remains unturned throughout the composting process. Often piles are covered and aerated from beneath.
- Vermicomposting: This system uses worms. The worms break down and aerate the material, creating compost.
- In-Vessel: Organic material is placed into a drum-shaped vessel to allow for rotation and control of temperature, airflow, and moisture.

Implementation of Autonomous Composting Units as an innovative technology contributes to simplification of the composting process. Composting with ACUs by in-vessel method allows to close the natural loop of the local cycle.

Recycling of biowaste contributes significantly to circular economy objectives [27]:

1. It closes biological material cycles and reduces the linear economy of landfilling and incineration of biowaste (Fig. 1).
2. It contributes to long-term soil fertility and C-sequestration by production of quality soil improvers and organic fertilizers.

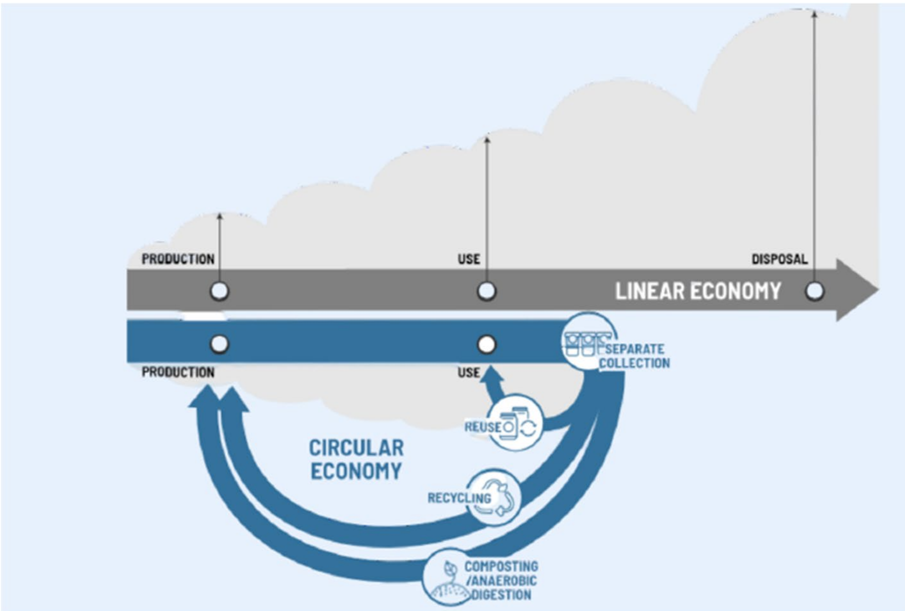


**Fig. 1** Comparison between linear economy and circular economy [28]

3. It produces bio-based products which can replace fossil-based products such as mineral fertilizers, peat, and fossil fuels.
4. It creates a local economy with sustained jobs. Based on experience in countries with established biowaste recycling infrastructure, additional recycling would lead to increased opportunities for growth in the employment. In addition, it contributes to improving farmers' incomes and to distributed jobs in rural regions.
5. It contributes to climate change mitigation, by replacing of fossil energy and fuel, peat and mineral fertilizers, and sequestration of carbon in soil and by avoiding landfill gas emissions.
6. Separating of biowaste from the residual waste also enables increased recycling rates of other waste materials (glass, plastics, paper, and metals).

The circular economy aims, among other aspects, to minimize the environmental, social, and economic damages and impacts of solid waste as well as to minimize the waste itself [29]. The CE concept offers several solutions to increasing amounts of biowaste and resource scarcity by valorizing biowaste. However, it is necessary to consistently address the environmental benefits and impacts of circular biowaste management system. Circular economy has gained attention as a key solution for mitigating the increasing generation of solid waste and resource scarcity. As opposed to the linear economy, the concept describes how to develop closed-loop technical and biological cycles by either recycling materials indefinitely with no degradation of their properties (the technical cycle) or returning materials to the natural ecosystem with no harm to the environment (the biological cycle) [30].

## Material and Methods

### Pay As You Throw

In the context of municipal-level solid waste management, the PAYT approach is an economic instrument that is applicable at the municipal level by charging residents according to the amount of waste they produce [31, 32]. The technical implementation of the PAYT is based on the following three approaches:

– Identification of waste producer;
– Waste quantity measurement;
– Disposal cost (e.g., per kilogram and/or discharge).

Experience so far shows that the waste tax should not only depend on the amount of waste generated but should consist of a basic and variable fee. On the one hand, this reflects the structure of waste disposal costs, which consists of fixed and variable costs, and on the other hand, the inclusion of a fixed (basic) tax helps to avoid illegal dumping practices that may increase if fees are paid only on the collected quantities of waste [33–35].

For introducing the "Pay As You Throw" system in Municipality of Probishtip, specially designed weighing equipment was installed on of the waste collection trucks owned by PUC "Nikola Karev" and coded waste bins for hospitality enterprises and households have been supplied. Waste collection bins equipped with RFID chips were distributed as presented on Figs. 2.

Waste collection vehicle Figs. 3 and 4 was upgraded with:

80 L bins for non-biodegradable waste (household use) - 80 units

1100 L bins for non-biodegradable waste (collective buildings and commercial use) – 2 units

10 L small bins for biodegradable waste - 80 units

**Fig. 2** Waste bins for hospitality enterprises and households

**Fig. 3** Process of coding waste bins for household

- A weighing scale and RFID reader for waste generator identification with data logging/transfer capabilities.
- GPS receiver and wireless data connection (GPRS, SMS, and CSD) with real-time data collection, transfer, and programming capabilities.

The "Pay As You Throw" system allows for a direct correlation of each waste producer with the quantities it generates. With such possibility, accurate data on the amount of mixed waste that each hotel, restaurant, or household produces is created the moment the RFID device identifies the user's bin on truck's receiving system. The scheme for collecting and processing the data used is shown in Fig. 5.

All data, such as weight of collected waste, date and time of waste collection, container ID (each container is linked to the appropriate waste producer address), are collected in a central database and processed with specialized software with extended analytical, reporting and exporting capabilities (csv, xls…), presented on Fig. 6, and

**Fig. 4** Waste collection vehicle upgraded with waste identification system

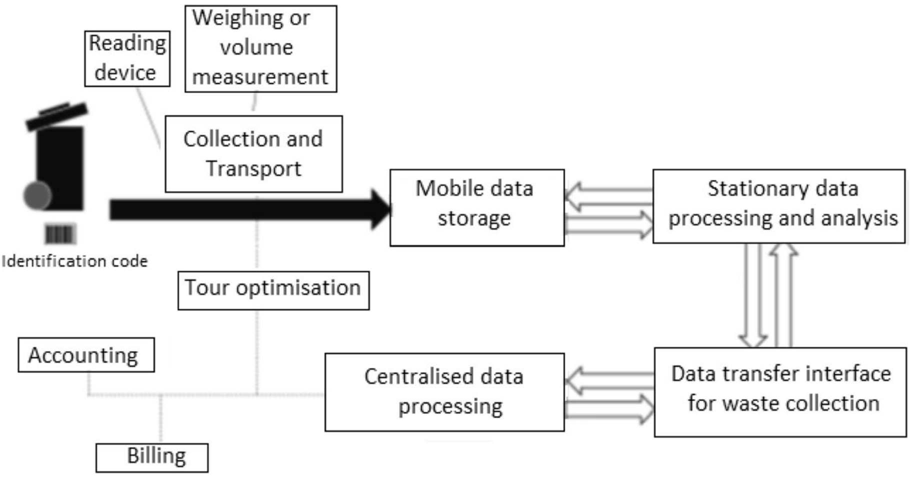


**Fig. 5** Process chart for electronic identification and data transfer in a bin identification scheme [25]

Report on logged wastebins (1): 2020-06-08 00:00:00 - 2020-06-09 23:59:59

| Symbol | Realization date | Weight (kg) | Client group | Name of WCP | Address of WCP | WCP description | Container id | Waste type | Container type | RFID | WCP ID | Approval type | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PS0749AB | 2020-06-08 11:12:17 | 3 | CO Probishtip | MATO DOOEL | 2210 Probishtip, Jakim Stojkovski 97A | | 4000000ED2B0CB | Biowaste | 1100L | 4000000ED2B0CB | 30 | RFID Reader | Probishtip, Јаким Стојковски |
| PS0749AB | 2020-06-08 11:23:33 | 11 | CO Probishtip | Cvetan Ilevski | 2210 Probishtip, 25ti maj 7 | | 4000000ED2B0FC | Biowaste | 1100L | 4000000ED2B0FC | 26 | RFID Reader | Probishtip, 25 ти Мај |
| PS0749AB | 2020-06-08 11:23:52 | 18 | | | | | | | | | | RFID Reader | Probishtip, 25 ти Мај |
| PS0749AB | 2020-06-08 11:26:52 | | CO Probishtip | Goche Arsovski | 2210 Probishtip, Toni Davitkov 8 | | 4000000ED2B0FE | Biowaste | 1100L | 4000000ED2B0FE | 18 | RFID Reader | Probishtip, 25 ти Мај |
| PS0749AB | 2020-06-08 11:26:53 | 5 | CO Probishtip | Goche Arsovski | 2210 Probishtip, Toni Davitkov 8 | | 4000000ED2B0FE | Biowaste | 1100L | 4000000ED2B0FE | 18 | RFID Reader | Probishtip, 25 ти Мај |
| PS0749AB | 2020-06-08 11:27:06 | 15 | | | | | | | | | | RFID Reader | Probishtip, 25 ти Мај |
| PS0749AB | 2020-06-08 11:27:23 | 18 | CO Probishtip | Milka Petrova | 2210 Probishtip, Toni Davitkov 12 | | 4000000ED2B114 | Biowaste | 1100L | 4000000ED2B114 | 37 | RFID Reader | Probishtip, 25 ти Мај |
| PS0749AB | 2020-06-08 11:27:35 | 25 | | | | | | | | | | RFID Reader | Probishtip, 25 ти Мај |
| PS0749AB | 2020-06-08 11:45:26 | | CO Probishtip | Aleksandar Zarevski | 2210 Probishtip, Aco Skopjanche 37 | | 4000000ED2B0C9 | Biowaste | 1100L | 4000000ED2B0C9 | 29 | RFID Reader | Probishtip, Ацо Скопјанче |
| PS0749AB | 2020-06-08 11:46:09 | 16 | CO Probishtip | Aleksandar Zarevski | 2210 Probishtip, Aco Skopjanche 37 | | 4000000ED2B0C9 | Biowaste | 1100L | 4000000ED2B0C9 | 29 | RFID Reader | Probishtip, Ацо Скопјанче |
| PS0749AB | 2020-06-08 11:46:09 | 8 | | | | | | | | | | RFID Reader | Probishtip, Ацо Скопјанче |
| PS0749AB | 2020-06-08 11:46:16 | | CO Probishtip | Aleksandar Zarevski | 2210 Probishtip, Aco Skopjanche 37 | | 4000000ED2B0C9 | Biowaste | 1100L | 4000000ED2B0C9 | 29 | RFID Reader | Probishtip, Ацо Скопјанче |
| PS0749AB | 2020-06-08 12:33:14 | 48 | CO Probishtip | Emilija Vasilevska | 2210 Probishtip, Lesnovska | | 4000000ED2B120 | Biowaste | 1100L | 4000000ED2B120 | 20 | RFID Reader | Probishtip, 22 ри Декември |
| PS0749AB | 2020-06-08 12:33:27 | 31 | | | | | | | | | | RFID Reader | Probishtip, 22 ри Декември |

**Fig. 6** Processed data with specialized software

they are used to determine the total amount of waste collected, as well as monthly charging per kilogram of waste produced in line with the Pay As You Throw system.

### Autonomous Composting Units

Autonomous Composting Units facilitate the composting process. Organic waste has been collected separately and introduced into the ACUs and composted on-site, thereby reducing collection and transportation costs and treatment costs in the central unit (if any) and enabling the production of high-quality usable product (compost).

The most important parameters affecting and contributing to the efficiency of the composting process in the ACUs and obtaining compost quality are temperature, moisture content, carbon and nitrogen component ratio (C:N), and pH in the waste material. Optimal sizes of these parameters for the efficiency of the composting process are carbon and nitrogen component (C:N) ratio of 20:1 and 30:1, moisture content between 40 and 70%, available oxygen concentration greater than 5%, and pH 5.5–8 [36–38].

The carbon component of organic waste in the composting process determines whether mineralization or nitrogen immobilization will occur. If the C:N ratio is greater than 20:1, the microorganisms will immobilize the nitrogen in the biomass. If the C:N ratio is less than 20:1, nitrogen can turn into ammonia, a gas that is released into the atmosphere causing an unpleasant odor. In general, food waste is rich with nitrogen, while garden waste (leaves and branches) is carbon-rich [36].

The low moisture content prevents the composting process because microorganisms need water. The moisture content also regulates the temperature. A moisture content higher than 70% means that the compost has a higher water content than air (oxygen), leading to anaerobic conditions. Moisture content should be in range of 40–70%.

The air temperature that enters the composting machine has a great influence on the activity of the microorganisms in the composting material, and hence on the degree of its decomposition. In temperate climates, the composting process occurs most rapidly from spring to autumn, while in winter the activity of microorganisms can be delayed. Because of this, the Autonomous Composting Units also have a heater that warms the air temperature that enters the cylinder in which the waste material in the ACU is stored. The function of the heater is to warm up the air entering the ACU at a temperature higher than 10–15 °C [39].

Considering that the waste from households and hospitality enterprises as target group of the project is composed mainly of food residues, i.e., it contains more nitrogen. To maintain the ratio between carbon and nitrogen within the recommended range, pellets are added in the ACUs, increasing the carbon content. The pellets also have the function of absorbent material, that is, they regulate the composting material moisture content. The autonomous composters have two humidity and temperature sensors that allow control of the microbiological process of biowaste decomposition in three stages inside the cylinder. One humidity sensor shows the volume content of water (VWC) in the material in the cylinder of the composter (marked in brown), and the other sensor shows the relative humidity of the cylinder (marked in blue). Temperature sensors indicate the temperature of the air entering the cylinder (16 °C) and the temperature of the air leaving the cylinder (19 °C). In addition, there are sensors that indicate the temperature of the waste material in the three stages of decomposition of the material in the cylinder (Fig. 7).

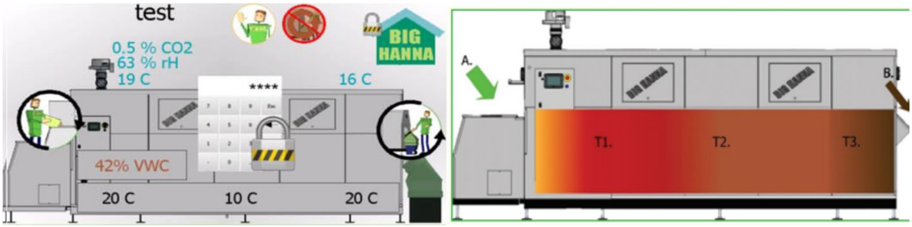


**Fig. 7** Temperature and humidity sensors of waste material at ACUs [39]. A. Input of fresh food waste and pellets into the ACU. T1, thermophilic phase, temperature: 50–65 °C, humidity 40–70%. T2, mesophilic phase, temperature: 25–40 °C, lower humidity. T3, phase of maturation, temperature: 20 °C, lowest humidity. B. The compost is automatically emptied from the cylinder

For the aerobic composting process, the minimum oxygen content should be 5%. The aeration of waste material in the ACU cylinder is made possible by air inlet and regulation of the aeration mode by adjusting the cylinder rotation speed and pause between rotations. When the cylinder rotates, all the material in the cylinder is supplied with oxygen. For further aeration of the material, the ACU has a built-in fan that runs continuously at low speeds and ensures proper air flow.

The size of the organic waste is an important factor affecting the activity of the microorganisms and the aeration of the composting material. The tinned waste has a larger area per unit volume, allowing better and easier access for the microorganisms to their substrate, which speeds up the composting process; thus, all food or garden waste that is selected and placed in the ACU must be cut into small pieces of 2–3 cm in size.

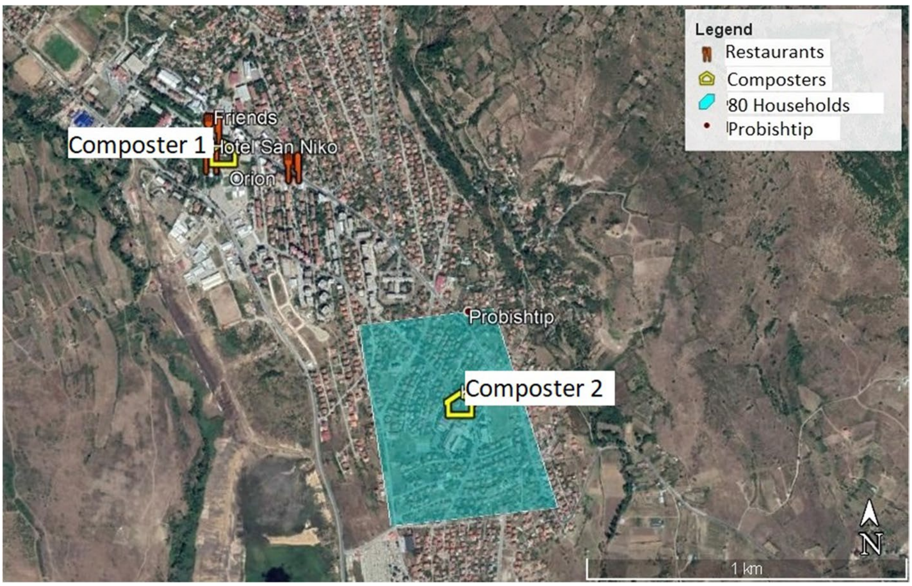


**Fig. 8** ACU locations

Two ACUs with 60 t/year capacity have been installed and commissioned, one for hospitality enterprises installed nearby City market and “San Niko” Hotel and the other one in Kalnishte urban area (Fig. 8) aimed to serve 80 households included in the project.

ACUs are equipped with an odor control system, such as a biofilter. The air is pushed into the biofilter and filtered through bark so that the smell is reduced significantly. The reduction is estimated to 90% [40].

Taking into account that households and hospitality enterprises staff involved in the project have poor knowledge on the possibility to turn organic waste into organic fertilizer/market product, as well as full disability with organic waste selection procedure and its benefit on the household’s budget, appropriate information/learning materials have been prepared and distributed, and all participants were trained in several sessions and hands-on trainings for ACUs management, i.e., active involvement in process of waste separation.

## Results and Discussion

Food waste has been recognized as a global issue due to its environmental [41], economic [42], and social [43] impacts with global consequences, requiring a change in political actions [44–48]. Food waste and losses mobilize a remarkable amount of natural resources. It consumes around 25% of all water used by agriculture each year [48]; 23% of all croplands, equivalent to all croplands in Africa [49]; while it generates around 8% of annual global greenhouse gases (GHG) emissions [50]. The International Panel of Experts on Sustainable Food Systems (IPES) identified that 20% of the food produced in the European Union is wasted with the cost of 143 billion euros annually, including wasted resources and environmental impacts [51]. Half of all vegetable grown is lost or wasted before reaching the consumer (by mass; [52]). Social and ethical dilemma touches upon, among others, the undernourished of 815 million people [53] while excessive consumption in high-income countries leads to billions of tons of quality food thrown away [49].

The food waste management, as a part of MSW management, continues to be a significant challenge in all states of the European Community and is an important element in the transition to a circular economy. An important aspect of implementation of the circular economy assumptions in the case of biowaste (including food waste) is a plan for reducing biowaste amounts deposited at landfills and enhancing the share of biowaste, which can be returned to the system by material and organic recycling. To increase awareness by the local population and hospitality enterprises for source separation schemes of organic waste, as the largest producers of organic waste, Goce Delchev and Hellenic Mediterranean Universities together with Municipality of Katerini, Municipality of Yermasoyia and Municipality of Probishtip launched a joint “BIOWASTE” project.

The “BIOWASTE” project covers only a small area from Municipality of Probishtip for separation, collection, and composting of the organic waste, having two target groups. The first target group was one larger and a few smaller hospitality enterprises, while the second target group involved 80 households from decentralized urban area Kalnishte.

The first involved group in the “BIOWASTE” project, hospitality enterprises, generate approximately 26.4 t municipal waste per year, of which 19.8 t/year (75%) is organic waste, while the generated municipal waste quantity in the second target group, 80 households in Kalnishte urban area, is approximately 82.88 t/year of which 46.7 t/year (56.3%) is organic waste.

During the implementation phase of the "BIOWASTE" project, two approaches have been implemented, i.e., Pay As You Throw (PAYT) system and Autonomous Composting Units (ACUs) for biowaste management in Municipality of Probishtip.

Several benefits could be reached adopting the PAYT scheme: from economic (by reducing service costs) to environmental (by both reducing waste quantity and increasing diversion rate) as much as social (by increasing citizen participation) points of view [35].

The economic benefits from implementation of PAYT in Municipality of Probishtip are presented in Table 1, showing monthly costs of a household for waste disposal using PAYT.

The percentage share of organic waste in the total municipal waste identified in the BIOWASTE project at households is higher than the amount set out in the National Waste Management Strategy [11]. The higher percentage of organic waste arise from the fact that households included in the project are part of a decentralized urban community with larger yards, which results in a larger amount of organic waste.

The calculation was made in accordance with data obtained within the project: total amount of household waste per year (1036 kg), the percentage share of organic waste in the total municipal waste (56.3%), and the costs for waste disposal per ton (63.8 €). Costs for waste disposal per square meter of area were taken from PUC in Probishtip.

Table 1 shows that monthly costs for waste disposal per household will be reduced only if PAYT is applied, after separation of the organic waste at source takes place. PUC will have economic benefits, because of reduction of the total waste amount by 56.3%, resulting in reduced costs for waste transport, as well as economic benefit from compost.

Implementation of PAYT is necessary to meet the National and European Waste Management regulations [1, 9, 10], as well as to motivate the population to apply source separation scheme that will reduce monthly costs for waste disposal, and especially because of the environmental benefits and human health.

The implementation of innovative technologies (Pay As You Throw system and Autonomous Composting Units) of the "BIOWASTE" project in Municipality of Probishtip contributed to:

- Introducing the possibility to create organic manure from organic waste to the local population, hospitality enterprises and local self-government to reduce carbon footprint and to protect the environment.
- Increased awareness of the local people that they can earn of what they now consider as waste.
- Reduced pollution of the landfill by reducing the volume of organic waste.
- Improved cash-flow in the municipal waste management enterprise by reduced costs for waste transport.

**Table 1** Monthly costs of household for waste disposal

| | Charged per m$^2$ area | PAYT | PAYT, with previously selected organic waste |
|---|---|---|---|
| Waste per household (kg/month) | 86.33 | 86.33 | 37.73 |
| Costs for waste disposal (€/t) | - | 63.8 | 63.8 |
| Costs for waste disposal per household (€/month) | 3.1 | 5.5 | 2.4 |

– Improved economic status of the households and hospitality enterprises by reduced waste bills.

Applying the ACUs produces compost close to 10–20% from the weight of the waste, or from 42.78 t of waste on average are obtaining 6 t/year compost. To be used as a fertilizer and soil conditioner, compost must meet certain quality requirements, such as optimal maturity, favorable contents of nutrients and organic matter, favorable C/N ratio, neutral or alkaline pH, low contents of heavy metals and organic contaminants, no components that interfere with plant growth, mostly free from impurities, free from seeds and living plant parts, low content of rocks, typical smell of forest soil, and dark brown to black color. These parameters of compost depend on the season [54, 55].

Laboratory analysis showed that compost material from installed ACUs in Municipality of Probishtip has black color, no smell, pH = 8.87, 68.4% humidity, total organic matter: 91.5%, and carbon/nitrogen quota: 53:1. The obtained compost is rich with organic matter and nutrients (primary and secondary macronutrients) in a total and readily available form for plants and can be applied to the soil without harmful consequences, in an appropriate manner as recommended by experts [56].

According to the obtained results (Table 2) and in accordance with the Law on Quality and Safety of Fertilizers, Biostimulators and Soil Property Enhancers [57], this sample from ACUs meets the requirements to be classified as organic waste—compost.

The application of compost in the soil increases the organic matter in the soil, which positively affects the structure of the soil and the stability of soil particles, which is especially important for light soils and soils on sloping terrains, where there is a risk of erosion. This way of enriching the soil improves the capacity of the soil for water, and the plants better tolerate dry conditions on lighter and more sandy soils.

The compost obtained in ACUs will be used by PUC "Nikola Karev" in Probishtip, first 5 years, as a fertilizer to improve the quality of the soil on public green areas in the municipality and in the preparation of seedlings for landscaping. After this period, the compost can be sold to local farmers by market price.

## Conclusion

Biowaste is produced through the entire supply chain. In the MSW management system, biowaste-generating sources are households and hospitality enterprises [58, 59]. Literature data indicate that the share of organic fraction of municipal solid waste (OFMSW) varies on average from 30 to 40% [60–62]. In the Republic of North Macedonia, organic fraction in MSW is estimated around 45.3% [9]. A key factor that affects the possibility of further use of biowaste is its quality; in particular, the impurities in the material collected [63–65]. This factor is closely related to the efficiency of the OFMSW separate collection system.

A properly implemented PAYT system can significantly improve waste management operations through an accurate waste generation data, collection frequency, and routes optimization, thus having direct impact on cost and environmental footprint. Although generally seen as innovative, PAYT systems are based on robust, well-proven, and available technologies, allowing local companies to enter this market, thus reducing service costs and providing opportunities for local growth and employment.

**Table 2** Chemical composition of compost

| Primary macro elements | | Macro elements in substrates and biostimulators | | Organic components | |
|---|---|---|---|---|---|
| Parameters | Percentage (%) | Parameters | Percentage (%) | Parameters | Percentage (%) |
| Total N | 1 | $K_2O$ | 1.4 | Organic C | 53.2 |
| $NH_4$-N | 0.009 | | | | |
| $NO_3$-N | 0.007 | $P_2O_5$ | 0.8 | Total organic matter | 91.5 |
| Organic N | 0.98 | | | | |
| $P_2O_5$ | 0.52 | Inorganic N | 0.016 | C/N | 53/1 |
| $K_2O$ | 1.75 | | | | |
| Secondary macro elements | | Micro elements | | Harmful substances | |
| Parameters | Percentage (%) | Parameters | mg/kg | Parameters | mg/kg |
| CaO | 5.18 | Total Cu | 7 | Total Cr | 6.28 |
| MgO | 0.2 | Total Zn | 29.7 | Total Cd | 0.5 |

Selected ACUs can operate efficiently in colder climate conditions if proper waste selection and regular feed are assured. Odors, equipment noise, and site hygiene are important aspects for wider acceptance of the waste selection and composting activities. If properly used, bio-filters can eliminate any nuisance odors from the process (noise is not an issue). Compost produced was confirmed as reach with organics and nutrients and can be safely used as organic fertilizer and soil additive. Test performed confirmed full alignment with requirements of low on fertilizers, bio-stimulators, and soil additives (Official Gazette of RM, No.27 from 014).

Environmental, economic, and social benefits arising from the project include reduction of waste quantities that are landfilled, reduction of transportation cost for PUC, reduction of charges for hospitality enterprises and households participating in separation scheme, and reduction of environmental pollution caused by landfill gas emissions and leachate.

The experience, knowledge, information, and data collected from the realization of the BIOWASTE project will be important for all tourism municipalities on the Balkan Peninsula and the Mediterranean region. Finally, the implementation of the BIOWASTE project can be significant for many municipalities comprised of small and isolated communities, for which waste collection costs are sometimes twice as high as those in urban areas. In this concept, the municipal waste selection scheme is specifically designed for the hospitality enterprises and small/decentralized communities and is geared towards biodegradable waste (food waste and green waste). The main objective is to achieve a quality separation of biodegradable waste from other municipal waste as well as its appropriate treatment at a specific location.

In addition to the above listed environmental, economic, and social benefits, the implementation of the BIOWASTE project also pointed out certain weaknesses in the MSW management. Namely, households and hospitality enterprises involved in the project had to select organic waste from the rest and bring it to the ACU themselves, activity not welcomed by the enterprises, no matter if the aim of organized workshops was raising public awareness of the benefits of organic waste separation and composting. Therefore, during expanding this project, consideration should be given to transporting the selected organic waste by a separate vehicle from PCU to the ACU.

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## Declarations

**Consent to Publish** The authors declare their consent to publish this article in the journal of *Circular Economy and Sustainability*.

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## References


1. European Comission (1999) Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste; European Comission: Brussels, Belgium
2. European Comission (2018) COMMISSION IMPLEMENTING DECISION (EU) 2018/1147 of 10 August 2018 establishing best available techniques (BAT) conclusions for waste treatment, under Directive 2010/75/EU of the European Parliament and of the Council (Notified under Document C(2018) 5070); European Comission: Brussels, Belgium
3. Kyriakopoulos GL, Kapsali VC, Aravossis KG, Zamparas M, Mitsikas A (2019) Evaluating circular economy under a multi-parametric approach: a technological review. Sustainability 11:6139
4. Eurostat (2018) Municipal waste generation and treatment, by treatment method. Available online: http://ec.europa.eu/eurostat/web/environment/waste/main-tables (accessed on 12 October 2018)
5. Fava F, Totaro G, Diels L, Reis M, Duarte J, Carioca OB, Poqqi-Varaldo HM, Ferreira BS (2015) Biowaste biorefinery in Europe: opportunities and research and development needs. New Biotechnol 32:100–108
6. Lokesh K, Ladu L, Summerton L (2018) Bridging the gaps for a "circular" bioeconomy: selection criteria, bio-based value chain and stakeholder mapping. Sustainability 10:169
7. Vea EB, Romeo D, Thomsen M (2018) Biowaste valorisation in a future circular bioeconomy. Procedia Cirp 69:591–596
8. Sherwood J (2020) The significance of biomass in a circular economy. Bioresour. Technol. 300
9. National Waste Management Plan of the Republic of North Macedonia 2018 – 2024, MOEPP, Skopje 2018
10. Waste Framework Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives
11. East Region – Regional Waste Management Plan; Project: "Preparation of regional waste management plans and strategic environmental assessments for east and north-east regions", EuropeAid/130400/D/SER/MK
12. Alvesa L, Silvab S, Soares I (2020) Waste management in insular areas: a Pay-As-You-Throw system in Funchal, 7th International Conference on Energy and Environment Research, ICEER 2020, 14–18 September, ISEP, Porto, Portugal
13. Zlatkovski V, Dimov G, Naskova Lj, Mihajlov M, Mirakovski D, Hadzi-Nikolova M, Zendelska A, Lazarov D (2020) Utilizing "pay as you throw systems and autonomous composting units for biowastes management in touristic areas – Biowaste", Project no. BMPL/22/2156/2017, Interreg Balkan-Mediterranean BIOWASTE, Brochure
14. Maragkaki AE, Papadaki A, Sabathianakis G, Poda K, Naskova Lj, Misseris T, Zlatkovski V, Zapounidis K, Manios T (2019) Utilising pay as you throw systems and autonomous composting units in Balkan Med countries, 16th International Conference on Environmental Science and Technology Rhodes, Greece, 4–7 September 2019
15. Malamis D, Bourka A, StamatopoulouMoustakas K, Skiadi O, Loizidou M (2017) Study and assessment of segregated biowaste composting: the case study of Attica municipalities. J Environ Manag 203:664–669
16. Rodrigues LC, Puig-Ventosa I, López M, Martínez FX, Ruiz AG, Bertrán TG (2020) The impact of improper materials in biowaste on the quality of compost, J. Clean. Prod. 251, 119601
17. Passarini F, Vassura I, Monti F, Morselli L, Villani B (2011) Indicators of waste management efficiency related to different territorial conditions. Waste Manag 31:785–792
18. Rodrigues J, Oliveira V, Lopes P, Dias-Ferreira C (2015) Door-to-door collection of food and kitchen waste in city centers under the framework of multimunicipal waste management systems in Portugal: the case study of Aveiro. Waste Biomass Valorization 6:647–656
19. Timlett RE, Williams ID (2009) The impact of transient populations on recycling behaviour in a densely populated urban environment. Resour Conserv Recycl 53:498–506

20. Carvalho P, Marques RC (2014) Economies of size and density in municipal solid waste recycling in Portugal. Waste Manag 34:12–20
21. Gomes AP, Matos MA, Carvalho IC (2008) Separate collection of the biodegradable fraction of MSW: an economic assessment. Waste Manag 28:1711–1719
22. Demirbas A (2006) Biogas production from the organic fraction of municipal solid waste, Energy Sources Part A Recovery Util. Environ E 28:1127–1134
23. Kigozi R, Aboyade A, Muzenda E (2014) Biogas production using the organic fraction of municipal solid waste as feedstock. Int J Res Chem Metall Civ Eng 1:107–114
24. Campuzano R, González-Martínez S (2016) Characteristics of the organic fraction of municipal solid waste and methane production: a review. Waste Manag 54:3–12
25. Morlok J, Schoenberger H, Styles D, Galvez-Martos HL, Zeschmar-Lahl B (2017) The impact of pay-as-you-throw schemes on municipal solid waste management: the exemplar case of the county of Aschaffenburg, Germany. Resources 6:8. https://doi.org/10.3390/resources6010008
26. Drosi G, Lorandi M, Bossi A, Villani F, Avaki J (2020) Pay As You Throw - systems for municipal waste management: Italian experiences and a new proposal. Environ Eng Manag J 19:10
27. Bio-waste management plays a keyrole in bioeconomy, https://www.compostnetwork.info/policy/circular-economy/bio-waste-management/
28. Vilella M (2020) Sustainable finance for a zero waste circular economy, Zero Waste Europe, December 2020
29. Mancini DS, Medeiros GA, Paes MX, Souza de Oliveira BO, Pereira Antunes ML, Gabbay de Souza R, Ferraz HL, Bortoleto AP, Puppim de Oliveira JA (2021) Circular economy and solid waste management: challenges and opportunities in Brazil. Circular Economy and Sustainability 1:261–282. https://doi.org/10.1007/s43615-021-00031-2
30. McDonough W, Braungart M (2002) Cradle to cradle: remaking the way we make things, 1st edn. North Point Press, Suite, NY, USA
31. Karkanias C, Malamakis A, Kontogianni S, Somakos L, Chatzistelios G, Chasapidi TR, Tsalidis S, Lykourentzos C, Aravosis K, Tatsiopoulos S, Moussiopoulos N (2015) Pay-As-You-Throw project: monitoring the aspects of implementation, Proceedings of the 5th International Conference on Environmental Management, Engineering, Planning & Economics, Mykonos island, Greece, 14 – 18.06.2015
32. Janice L, Canterbury (1992) Pay-as-you-throw lessons learned about unit pricing of municipal solid waste, U.S. EPA Office of Solid Waste
33. Feasibility of pursuing PAYT (Pay-As-You-Throw) options for Mt. Lebanon, 2014 http://www.mtlebanon.org/index.aspx?nid=2190
34. Thomas W, Barry IV (2017) When trash costs money: analyzing the impact of Pay-As-You-Throw programs in Massachusetts. Journal of Environmental and Resource Economics at Colby 4:1
35. Elia V, GraziaGnoni M, Tornese F (2015) Designing Pay-As-You-Throw schemes in municipal waste management. Waste Manage 44:188–195. https://doi.org/10.1016/j.wasman.2015.07.040
36. Cooperband LR (2000) Composting: art and science of organic waste conversion to a valuable soil resource. Laboratory Medicine 31:6
37. Schuchardt F (2005) Composting of organic waste, compost quality, environmental biotechnology, Wiley Online Library
38. Abdul Kadir A, Nur Wahidah A, Jamaludin SN (2016)An overview of organic waste in composting, MATEC Web of Conferences 47.05025.2016
39. Susteco BIGHANNA ACU Manual (2018)
40. Susteco BIGHANNA Biofilter Manual (2018)
41. UNEP (2014) Prevention and reduction of food and drink waste in businesses and households - guidance for governments, local authorities, businesses and other organisations, Version 1.0.
42. Garrone P, Melacini M, Perego A (2014) Opening the black box of food waste reduction. Food Policy 46:129–139. https://doi.org/10.1016/j.foodpol.2014.03.014
43. Evans D (2011) Blaming the consumer-once again: the social and material contexts of everyday food waste practices in some English households. Crit Public Health 21:429–440. https://doi.org/10.1080/09581596.2011.608797
44. Evans D, Campbell H, Murcott A (2012) A brief pre-history of food waste and the social sciences. Sociol Rev 60:5–26. https://doi.org/10.1111/1467-954X.12035

45. WRAP (2013) Household food and drink waste in the United Kingdom 2012. Banburry, UK
46. IFPRI (2016) 2016 global food policy report. Washington, DC. https://doi.org/10.2499/9780896295827
47. EC (2018). A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment. {COM (2018) 673 final}. Brussels
48. Searchinger T, Waite R, Hanson C, Ranganathan J, Dumas P, Matthews E, Klirs C (2019) Creating a sustainable food future. A menu of solutions to feed nearly 10 billion people by 2050, World resources report
49. Kummu M, De Moel H, Porkka M, Siebert S, Varis O, Ward PJ (2012) Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland and fertilizer use. Sci Total Environ 438:477–489. https://doi.org/10.1016/j.scitotenv.2012.08.092
50. IPCC (2019) Summary for policymakers climate change and land, an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernemental panel on climate change. https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf
51. IPES (2019) Towards a common food policy for the European Union the policy reform and realignment that is required to build sustainable food systems in Europe, Report. http://www.ipes-food.org/_img/upload/files/CFP_FullReport.pdf
52. Henningsson S, Hyde K, Smith A, Campbell M (2004) The value of resource efficiency in the food industry: a waste minimisation project in East Anglia. UK J Clean Prod 12:505–512. https://doi.org/10.1016/S0959-6526(03)00104-5
53. FAO (2017) The state of food security and nutrition in the world 2017. Building resilience for peace and food security, Rome
54. Hanc A, Ochecova P, Vasak F (2017) Changes of parameters during composting of bio-waste collected over four seasons. Environ Technol 38, 13–14, pp 1751–1764 https://doi.org/10.1080/09593330.2016.1246611
55. Oviedo-Ocaña ER, Torres-Lozada P, Marmolejo-Rebellon LF, Hoyos LV, Gonzales S, Barrena R, Komilis D, Sanchez A (2015) Stability and maturity of biowaste composts derived by small municipalities: correlation among physical, chemical and biological indices. Waste Manage 44:63–71. https://doi.org/10.1016/j.wasman.2015.07.034
56. Testing Report of compost material 2020/353, UNILAB, Goce Delcev University Stip, May, 2020
57. Law on Quality and Safety of Fertilizers, Biostimulators and Soil Property Enhancers, Official Gazette of Republic of North Macedonia, No. 27, 2014
58. Borrello M, Caracciolo F, Lombardi A, Pascucci S, Cembalo L (2017) Consumers' perspective on circular economy strategy for reducing food waste. Sustainability 9:141
59. Corrado S, Sala S (2018) Food waste accounting along global and European food supply chains: state of the art and outlook. Waste Manag 79:120–131
60. Jedrczak A (2019) Composting and fermentation of biowaste—advantages and disadvantages of processes. Civ Environ Eng Reports 28:71–87
61. Edjabou ME, Jensen MB, Götze R, Pivnenko K, Petersen C, Scheutz C, Astrup TF (2015) Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation. Waste Manag 36:12–23
62. Karak T, Bhagat RM, Bhattacharyya P (2012) Municipal solid waste generation, composition, and management: the world scenario. Crit Rev Environ Sci Technol 42:1509–1630
63. Abad V, Avila R, Vicent T, Font X (2019) Promoting circular economy in the surroundings of an organic fraction of municipal solid waste anaerobic digestion treatment plant: biogas production impact and economic factors. Bioresour Technol 283:10–17
64. Do Carmo Precci Lopes A, Robra S, Müller W, Meirer M, Thumser F, Alessi A, Bockreis A (2019) Comparison of two mechanical pre-treatment systems for impurities reduction of source-separated biowaste. Waste Manag 100:66–74
65. Cerda A, Artola A, Font X, Barrena R, Gea T, Sánchez A (2018) Composting of food wastes: status and challenges. Bioresour Technol 248:57–67

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