Environment Protection Engineering

Vol. 47 2021 No. 3

DOI:10.37190/epe210305

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IMPLEMENTATION OF INNOVATIVE TECHNOLOGIES PAY-AS-YOU-THROW AND AUTONOMOUS COMPOSTING UNITS FOR BIOWASTE MANAGEMENT. SCALING UP THE BIOWASTE PROJECT IN THE MUNICIPALITY OF PROBISHTIP, REPUBLIC OF NORTH MACEDONIA

Municipal solid waste management is still one of the major environmental challenges at a national level, and although with national and regional waste plans in place, the Republic of North Macedonia with its eight regions has only one standard landfill active, and at least 54 non-standard municipal landfills and hundreds of dump sites and old landfills. In the light of the soon expected regional establishment of an integrated and self-sustainable waste management system in the eastern and north-eastern regions, to increase awareness by the local population and hospitality enterprises for source separation schemes of organic waste, as largest producers of organic waste, Goce Delcev & Hellenic Mediterranean Universities together with Municipality of Katerini, Municipality of Yermasoyia and Municipality of Probistip launched joint project co-funded by EU, Utilizing pay-as-you-throw Systems and Autonomous Composting Units for Biowastes Management in Touristic Areas (BIOWASTE). This paper aims to present the environmental benefits of the project implementation and scaling up process that was developed, aiming to expand the BIOWASTE project processes in the whole Municipality of Probishtip.

1. INTRODUCTION

Municipal solid waste (MSW) management remains an issue of significant importance for the Republic of North Macedonia, especially in a period when the country

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makes significant steps towards EU approximation. Despite harmonized national legislation, very little has been accomplished to comply with numerous EU directives or regulations, especially regarding organic waste and the target that the EU directives sets for 2020 [1, 2].

Municipality of Probishtip is one of the first municipalities in the Republic of North Macedonia where the waste management is changed, as a result of the implementation of the *Utilising pay-as-you-throw System and Autonomous Composting Units for Biowastes Management in Touristic Areas Project* (Acronym: BIOWASTE) [3]. Annually, about 3300 tons of MSW is generated in the Municipality of Probishtip, with estimated 56.40% organic waste, all together disposed at a non-standard landfill just out of the city borders, and as soon as the regional waste management system kick-in this should be changed, affecting current practices and costs [4].

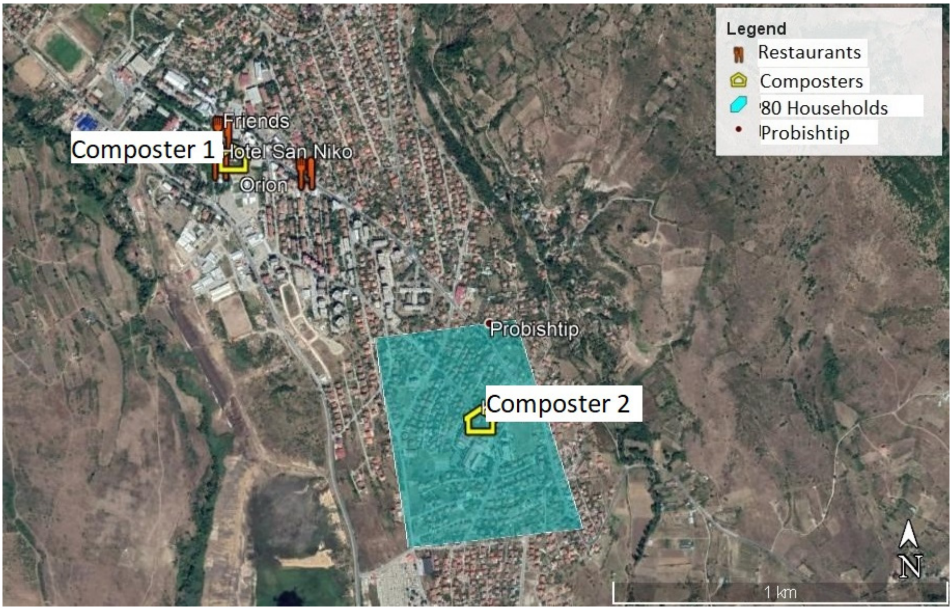

Fig. 1. ACUs locations

BIOWASTE project includes transfer and application of pay-as-you-throw (PAYT) system and autonomous composting units (ACUs) for biowaste management in the Municipality of Probishtip. PAYT system and ACUs as innovative technologies for biowaste management involve source separation schemes of organic waste in different bins (biowaste in 10 dm^3 bins and residual mixed waste in 80 dm^3 coded bins). Two ACUs with 60 t/year capacity have been installed and commissioned, one for hospitality enterprises installed nearby the city market and San Niko Hotel and the other one in Kalnishte decentralized urban area (Fig. 1) aimed to serves 80 households included in the project, for composting organic waste. Composting is the transformation of raw organic materials into biologically stable, humic substances suitable for a variety of soils and plant uses. Essentially, composting is controlled decomposition, the natural breakdown process that occurs when organic residue comes in contact with soil. Composting is an ancient technology [5, 6] but the implementation of ACUs is an innovative technology that contributes to the simplification of the composting process. Composting with ACUs by the in-vessel method allows one to close the natural loop of the local cycle. This composting method involves feeding organic materials into a drum, silo, concrete-lined trench, or similar equipment. This allows good control of the environmental conditions such as temperature, moisture, and airflow. The material is mechanically turned or mixed to make sure the material is aerated.

Using ACUs also provides people an effective solution for handling organic waste directly at the site of this biowaste.

The BIOWASTE project was implemented in three Balkan countries: the 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: the Municipality of Probishtip is a less intensive touristic area with a very large number of small and decentralized communities with a significant number of tourists, The Municipality of Katerini is a less intensive touristic area, with a short summer period directly related with the sea coast, and the Municipality of Yermasoyia is an intensified touristic area with prolonged touristic summer [7].

For introducing pay-as-you-throw system, specially designed weighing equipment built into the one waste collection truck owned by PUC Nikola Karev and coded waste bins for hospitality enterprises and households have been supplied. The use of tax instruments in the area of waste management is an increasingly popular option to create incentives that help to achieve better prevention and selective waste collection results, ensure appropriate allocation of waste management charges, and guarantee that tax collection is effective [8, 9]. In many countries, PAYT system is commonly used, having in mind that waste charges are the main available economic instrument, at local level. Such system enable the real production of waste in each home or business to be calculated, and the tax is determined by the amount and type of waste that is thrown away. Thus, PAYT systems promote waste prevention and recycling and enable the “polluter pays” principle to be applied [10–12]. Several types of benefits could be reached adopting PAYT scheme: from economic (by reducing service costs), to environmental (by both reducing waste quantity and increasing diversion rate) and social (by increasing citizen participation) points of view [13].

In addition to the implementation of innovative technologies the purposes of the BIOWASTE project are as follows:

• introducing the possibility to create organic manure from organic waste to the local population, hospitality enterprises and local self-government in order to reduce carbon footprint and to protect the environment,

- increased awareness by 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,
- improved economic status of the households and hospitality enterprises by reduced waste bills.

BIOWASTE project includes only a small area from the Municipality of Probishtip for selection, collection, and composting of the organic waste, including 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 the decentralized urban area Kalnishte. Table 1 shows the required equipment supplied in the Municipality of Probishtip for the implementation the BIOWASTE project.

Table 1

Equipment supplied in the Municipality of Probishtip for the implementation of the BIOWASTE project

Type of equipment	Number
Weighing system, records software and chip recognition system, communication, and signal processing module for one waste collection truck	1
Container of 1100 dm^3	2
Bin of 80 dm^3	80
Bin of 10 dm^3	100
Autonomous composting units (capacity 60 t/year)	2
Platforms for ACUs installation	2

The first involved group in the BIOWASTE project, hospitality enterprises, generate approximately 26.4 t municipal waste per year, of which 75% is organic waste or 19.8 t/year, 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 56.4% is organic waste or 46.7 t/year.

2. MATERIALS AND METHODS

Compost analysis. The analysis comprises physical and chemical properties, primary and secondary macronutrients and organic components, using recognized European Normative and International Standards: pH analysis was conducted according to EN 13037:2011, humidity according to BS EN 12048:1997, chemical analysis according to ISO 11464:2006(E), ISO 11261:1995, ISO 14255:1998, MKC ISO7497:2009/ICPE and ASTM D 2974 00 using ICP-AES [14].

Evaluation of greenhouse gas emissions. To estimate the environmental benefits related to greenhouse gas emissions from the implementation of the project the national greenhouse accounts factors [15] were used prepared by the Department of the Environment and Energy in the Australian Government. The emission factor is specific for the type of activity. According to the activity, it determines the used emission factor. The scope of emissions is determined by whether the activity is within the organization's boundary, i.e., direct – scope 1 (the companies that operate landfill) or outside it, i.e., indirect – scopes 2 and 3 (the companies that disposed their waste outside the organization boundaries, e.g., waste taken to municipal landfill, have to calculate scope 3 emissions). The national greenhouse accounts factor [15] was used to determine the GHG (greenhouse gas) emissions from organic waste disposal on the landfill in the Municipality of Probishtip as well as its composting, also for determination of GHG emissions of fuel combustion from waste collection and disposal.

Analytical hierarchical process (AHP). The AHP method was used for selecting the most appropriate scenario for organic waste management in the Municipality of Probishtip. The AHP introduced by Saaty in 1980 is an effective tool for dealing with complex decision-making – setting priorities and making the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision-making process [16].

The AHP considers a set of evaluation criteria and alternative options among which the best decision is to be made. It is important to note that, since some of the criteria could be contrasting, it is not true in general that the best option optimizes every single criterion, it rather achieves the most suitable trade-off among the different criteria.

The AHP can be implemented in simple consecutive steps, such as:

Step 1. Define objective.

Step 2. Structure elements in criteria, subcriteria, alternatives, etc.

Step 3. Make a pair wise comparison of elements in each group.

Step 4. Calculate weighting and consistency ratio.

Step 5. Evaluate alternatives according weighting.

Step 6. Get ranking.

Multicriteria analysis is performed in XLSTAT, which is a powerful flexible Excel data analysis tool that allows users to analyze, customize and share results within Microsoft Excel. The AHP proposed in XLSTAT has the advantage of not having any limitations on the number of criteria, of subcriteria and alternatives.

3. RESULTS AND DISCUSSIONS

3.1. ENVIRONMENTAL BENEFITS OF THE IMPLEMENTATION OF AUTONOMOUS COMPOSTING UNITS

Environmental impacts related to waste management depend primarily on the chosen waste treatment option. In the Republic of North Macedonia, as is the case throughout much of the world, significant quantities of biodegradable waste are landfilling. The implementation of the project BIOWASTE in the Municipality of Probishtip, in addition to the financial benefit of the population, envisages environmental benefits. In this section, the evaluation of the environmental impact of the project BIOWASTE is given. Environmental impacts focus on effects associated with various emissions released into the air, water, or soil from the collection, transport, and disposal of organic waste on the landfill and the treatment options of the organic waste, such as composting process. When organic waste is deposited into a landfill, it will break down by a process of anaerobic decomposition. Organic waste creates a liquid called leachate, and two main gases – methane (CH_4) and carbon dioxide (CO_2), both being greenhouse gases [20]. Therefore, selecting and recycling organic waste reduces the harmful environmental impact such as unpleasant odor spread, damage to vegetation, air pollution, groundwater and soils pollution, landfill fire due to the easy flammability of methane, and global warming.

The main environmental benefits of composting organic waste in comparison with its landfilling are:

- reducing greenhouse gas emissions,
- reducing the amount of leachate occurring at landfills,
- decreasing landfill expansion rate,
- reducing transport for waste collection and disposal,
- utilizing nutrients, especially phosphorus, and avoiding fertilizer production,
- soil improvement and carbon sequestration.

To obtain the effect of composting organic waste instead of landfilling, the greenhouse gas emissions were determined and compared. All calculations (Tables 2 and 3) were according to the Australian national greenhouse accounts factors [15].

Table 2

GHG emissions by disposal organic waste on the landfill from both involved groups

Waste type	Q [t]	Conversion factor [CO_2 eq.]	GHG emissions [t CO_2 eq.]
Part of Kalnishte – 80 householders			
Garden and green waste	23.00	1.57	36.10
Food waste	23.70	2.10	49.80
Restaurant food waste	19.80	2.10	41.60
Total			127.50

Table 3

GHG emissions by composting organic waste from both involved groups

Involved group	Q [t]	Emission factor for CH_4	CH_4 emissions [t CO_2 eq.]	Emission factor for N_2O	N_2O emissions [t CO_2 eq.]	Total emissions [t CO_2 eq.]
Part of Kalnishte	46.70	0.019	0.89	0.03	1.40	2.29
Restaurants	19.80		0.37		0.60	0.97
Total	66.50		1.26		2.00	3.26

The total amount of 66.50 t organic waste generated from involved groups in the project is composted, and the GHG emission is reduced from 127.50 to 1.26 t CO_2 eq. CH_4 emissions and 2.00 t CO_2 eq. N_2O emissions or reduction of total GHG emissions is approximately 97.44%.

Diminishing the amount of landfilled waste results in reducing waste transportation from household to the landfill and opposite. The fuels used in transport generate emissions of methane, carbon dioxide, and nitrous oxide. According to the Australian national greenhouse accounts factors [15], the emission from transport using fuel for waste disposal on the landfill in the Municipality of Probishtip was determined. It can be concluded that the reduction of GHG emissions was reduced by 50%, i.e., from 0.71 to 0.35 t CO_2 eq./year because the fuel consumption was reduced by 50%.

Very important for the environment is reducing the amount of leachate occurring in landfills from the decomposition of organic waste. Composting organic waste using ACUs leads to no leachate because all the leachate produced from the decomposition of organic waste is mixed with pellets. The pellets absorb all leachate and by adding the pellets the humidity in the composting process is controlled. While composting organic waste the leachate that is appearing on the landfill will be reduced due to the smaller amount of disposal municipal waste. Selecting and composting organic waste also reduces the amount of waste discharged to the landfill, thereby reducing the need for frequent expansion and increase of the landfill area. This means that the landfill expansion rate will be decreased. Also, the environmental benefits are significant such as reduction of land degradation and damage to vegetation. In addition, the process of composting contributes to soil improvement through using a compost.

Applying the ACUs produces compost close to 10–20% from the weight of the waste, or 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, mostly free from germinable seed sand 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 [17, 18].

According to the obtained results (Table 4) following the *Law on Quality and Safety of Fertilizers, Biostimulators, and Soil Property Enhancers* [19], this sample meets the requirements to be classified as organic waste – compost. 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.

Table 4

Chemical composition of compost

Primary macroelements		Macroelements in substrates and biostimulators		Organic components	
Parameter	Contents [%]	Parameter	Contents [%]	Parameter	Contents [%]
Total N	1.00±0.06	K_2O	1.40±0.15	Organic C	53.20±0.30
NH_4-N	0.009±0.0006				
NO_3-N	0.007±0.0005	P_2O_5	0.80±0.005	Total organic matter	91.50±0.40
Organic N	0.98±0.05				
P_2O_5	0.52±0.04	Inorganic N	0.016±0.003	C/N	53/1
K_2O	1.75±0.07				
Secondary macroelements		Microelements		Harmful substances	
Parameter	Contents [%]	Parameter	Contents [mg/kg]	Parameter	Contents [mg/kg]
CaO	5.18±0.10	Total Cu	7.00±0.80	Total Cr	6.28±0.60
MgO	0.20±0.04	Total Zn	29.70±3.50	Total Cd	0.50±0.08

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.

3.2. SCALING UP THE BIOWASTE PROJECT IN THE MUNICIPALITY OF PROBISHTIP

One of the project tasks was scaling up the BIOWASTE project on the entire territory of the Municipality of Probishtip. The total population in the Municipality of Probishtip is 15 313 habitants but the services of PUC use only 13 932 habitants or 4800 households. Three scenarios for possible scaling up the initial project have been analyzed.

Scenario 1 is similar to the initial project: implementation of source separation scheme of waste in different bins (biowaste in 10 dm^3 bins and residual mixed waste in 80 dm^3 coded bins or in 1100 dm^3 coded containers). Residual mixed waste will be collected by the PUC and it will be taken to the regional landfill; biowaste will be put into the ACUs by citizens.

Scenario 2 predicts a similar implementation of the source separation scheme of organic and residual mixed waste but different management of organic waste. Namely, the organic waste will be collected by PUC with a special vehicle and will be taken at a location in the industrial area where it is planned to set up ACUs with a higher capacity from the two already installed ACUs.

Scenario 3 is similar to those recommended in the *Regional Waste Management Plan for East Region*, which includes [4]:

- Two bin collection systems (recyclable waste bin and residual waste bin). Residual waste will be treated with a mechanical-biological stabilization process, while recyclable waste will be treated to a material recovery facility (MRF). Recovered materials are sold. Residues are disposed in the landfill.
- Green points for separate collection of hazardous material (electric and electronic waste (WEEE), hazardous municipal waste), construction and demolition waste, and recyclables).
- Separate collection of green waste and windrow composting of green waste.
- Home composting process on biodegradable waste selected at a source.

The necessary equipment enabling the scaling up of the project for each scenario is given in Table 5.

Table 5

Necessary equipment in the Municipality of Probishtip for implementation of the scaling up

Type of equipment	Number		
	Scenario 1	Scenario 2	Scenario 3
Set of weighing system, records software and chip recognition system, communication and signal processing module for one waste collection truck	4	4	5
Special municipal vehicle for waste collecting and transport (16 m^3)	–	2	4
Container of 1100 dm^3	26	26	24
Bin of 80 dm^3	4508	4556	4508
Bin of 10 dm^3	4816	4516	–
Autonomous composting units (capacity 60 t/year)	16	2	–
Autonomous composting units (capacity 125 t/year)	–	7	–
Platforms	16	3	–
Locations for collecting the green waste	–	–	1

Based on the above data regarding required equipment, the costs for its procurement, operating costs, positive environmental effects from the implementation of each of the scaling-up scenarios as well as other data necessary for the selection of the optimal scenario have been calculated. These data are given as a summary in Table 6.

Table 6

Required data from the proposed scenarios for conducting multicriteria analysis

Description	Scenario 1	Scenario 2	Scenario 3
GHG emissions from waste composting, t CO_2 eq.	47.04	48.76	55.63
GHG emissions when organic waste is disposed on landfill, t CO_2 eq.	1764.99	1829.34	2235.86
Reduction of total GHG emissions, %	97.33	97.33	97.51
Leachate on composting	no	no	low medium level
Volume on landfill if total waste landfilled, m^3/year	873.23	873.23	873.23
Volume on landfill if used composting, m^3/year	582.64	574.94	541.59
Reduction on landfill volume, m^3/year	290.59	298.28	331.64
GHG emissions from transport using fuel (used scenario), t CO_2 eq.	127.57	132.28	260.70
GHG emissions from transport using fuel (no used scenario), t CO_2 eq.	173.81	173.81	260.70
Reduction GHG emissions from transport using fuel, %	26.60	23.90	0.00
Composting organic waste, t	960.00	995.00	1135.36
Composting organic waste, %	47.20	48.91	56.37
Level of compliance with EU regulations	medium high		low medium
Level of compliance with MK regulations	high		
Investment costs, €	1 714 000	1 310 506	584 800
Operating costs, €/year	232 853	253 594	367 465
Level of acceptance by the population	low medium	medium high	

3.3. MULTICRITERIA ANALYSIS FOR SELECTING THE MOST ACCEPTABLE SCENARIO

In Table 7, the criteria, subcriteria and alternatives for the method of analytical hierarchical process (AHP) are given for selecting the most appropriate scenario for organic waste management in the Municipality of Probishtip.

Table 7

Criteria, subcriteria, and alternatives for the method of analytical hierarchical process

Criteria	Subcriteria				Alternatives	Evaluators
	Environmental impact	Regulation	Costs	Acceptance by the population		
Environmental impact	GHG emissions from decomposition of organic waste	EU regulation	investment costs		scenario 1	Evaluator 1
Regulation	GHG emissions from transport using fuel	MK regulation	operating costs		scenario 2	Evaluator 2
Costs	amount of leachate				scenario 3	Evaluator 3
Acceptance by the population	landfill volume					

In Table 8 the results, of the performed multicriteria analysis are shown.

Table 8

Priorities by alternative

Criterium	Alternative				
	Scenario 1	Scenario 2	Scenario 3	IC	RC
Environmental protection	21.59	27.77	6.31	0.00	0.00
GHG emission from decomposition of organic waste	2.50	10.34	1.14	0.05	8.82
GHG emission from transport using fuel	2.95	1.30	0.34	0.03	5.65
Amount of leachate	15.24	15.24	3.05	0.00	0.00
Landfill volume	0.89	0.89	1.77	0.00	0.00
Regulation	10.78	10.78	2.99	0.00	0.00
EU regulation	7.28	7.28	1.82	0.00	0.00
MK regulation	3.51	3.51	1.17	0.00	0.00
Costs	6.60	4.36	2.64	0.00	0.00
Investment costs	0.16	0.57	1.53	0.06	10.89
Operating costs	6.44	3.78	1.11	0.01	2.13
Accepted by the population	0.34	1.89	3.96	0.05	9.44
Priorities by alternative	78.28	87.71	27.83		

The multicriteria analysis for the three proposed scenarios that was done through forming comparative matrixes for criteria and subcriteria by three evaluators showed that scenario 2 is the best and most acceptable option for the Municipality of Probishtip. Selecting the organic waste brings about meaningful environmental gains, but also a decrease in operative costs for PUC's waste management because of the lower quantity of waste that is taken to the regional landfill. For this reason, the general recommendation for the Municipality of Probishtip is to accept scenario 2 and not stopping with these modest but meaningful beginnings in selecting organic waste because that goes following the Waste Framework Directive of EU and regulations of our country.

Choosing scenario 2 does not, in any way, mean undervaluing the huge importance of the standard regional landfill. Besides, scenario 2 that has priority, also scenario 1 is acceptable for the Municipality of Probishtip.

4. CONCLUSIONS

A properly implemented PAYT system can significantly improve waste management operations through accurate waste generation data, collection frequency, and routes optimization, thus having a 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.

The benefits of implementing autonomous composting units are significant for both the Municipality of Probishtip and the entire Eastern Planning region, from an economic, and environmental aspect. This project should be an example and a starting point for changing people's habits and raising awareness for environmental protection through responsible waste management practices. A healthy environment depends on the behavior of each individual. The reduction of the amount of landfilled organic waste, thus the reduction of the harmful impact of its decomposition on the landfill depends on all of us.

Selected ACUs can operate efficiently 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. 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 the law on fertilizers, bio-stimulators, and soil additives [19].

Upscaling the system to the municipal level is the natural next step and in light of the regional waste management scheme, all benefits offered from more efficient waste management will be significantly multiplied. In addition, the officially introduced PAYT system and ACUs will allow the implementation of incentive schemes for waste selection and composting, thus improving success rates for new waste management schemes.

ACKNOWLEDGMENTS

This paper was prepared as part of the project utilizing pay-as-you-throw systems and autonomous composting units for Biowastes Management in Touristic Areas BIOWASTE, co-financed by the European Union and the National Funds of the participating countries, Interreg V-B Balkan Mediterranean 2014–2020.

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