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ORGANIC WASTE MANAGEMENT THROUGH THE PRINCIPALES OF CIRCULAR ECONOMY: A CASE STUDY OF THE CITY OF NIŠ

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Abstract

Circular economy allows us to reuse waste as a raw material in another process. Involving the process of organic waste management in circular economy represents a major chalange, due to the fact that little waste remains after treatment. In this paper, the organic waste, that was collected from the households and green areas of the City of Niš, is observed in order to develop the model of organic waste management that follows the prinipales of circular economy through the process of anaerobic digestion. Such a system implies a maximum valorization of organic waste for a production of compast and biogas, which are used for the transport of waste, compast and anaerobic system maintanace. The aim of this paper is to show that this system is self-sustainable with the proper process management.

Key words*: organic waste, anaerobic digestion, biogas, circular economy, managemant*

INTRODUCTION

On the major ecological problems is the increasing amount of waste, coming from various human activities. Curently, at the global level, approximately 1.3 bilion tonnes of waste are generated per year, and it is assumed that the amount will rise to 2.2 bilion tonnes of waste per year by 2025, which is a coinquence of urbanization and continuos population growth [1][2]. On the other hand, there is an increasing demand for energy, especially having in mind that fewer fossil fuel resoureces are used for energy production. The contribution of organic waste (OW) in municipal waste (MW) is very large, about 50%, and it represents a big problem, because it leads to the emission of methane into the atmosphere.

OW is recognized as a useful fraction of MW, through whose treatment it is possible to return the nutrients back to the nature, and obtain a certain amount of energy.

There are different methods for MW treatment, out of which biological and thermal methods are most used for OW treatment. When we talk about the methods for the treatment of OW, it is necessary to have in mind the limitations of some treatment. So, the presence of hazardous substances from waste in anaerobic digestion process has a negative impact on the OW to be treated. The next limit is the moisture, due to fact that the thermal treatments are limited by moisture content. Combustion offers a net positive energy balance when the moisture content is below 60%, but even than the energy of the waste is spent on evaporation of moisture contained in the waste. Also, the energy efficiency of the pyrolysis and gasification of waste decreases with the moisture contenet. Bio-oil, that is obtained during the process of pyrolysis is usable only after additional treatment. Anaerobic digestion (AD), as one of the treatments of OW, is the most convenient, because the waste with a high moisture content (up to 40%), can be treated without a prior pre-tretment, which is not the case with other treatments [3][4]. As a major advantage of AD, one can indicate that GHG emissions are small, besause the obtained methane is used as an energy source. The obtained biogas can be used as a fuel in a cogeneration plant, while the obtained digestate, can be used in agriculture as a fertilizer after additional treatment.

In recent decades, in the process of waste management, it was developed the of concept of circular economy (CE), whose primary purpuses are waste minimization, environmental protection, energy efficiency and simultaneous economic development. The aim of CE is to get closer to the “5R” principle – reduction, reuse, recycling, recovery, reclamation [7]. CE tends to close the circle of the flow of waste (material), through the use of recycled materials and returning the waste in re-use, which means that the waste that is generated durin one process is used as a raw material in another process. The concept of CE moves away from the linear economic model, summed up as “take – make – dispose”, and benifits are the mainteinace of the product value and the elimination of waste [5][6].

In order to close the circle of the flow of matter and achieve significant results, a number of studies have been conducted on the use of OW for energy production as well as the reuse of OW as a raw material. Thus, according to the research conducted in Taiwan, which shows the utilization of OW for obtaining energy by using a WTE supply chain, thus enabling energy production using certain treatments, and resulting in simultaneously solving the waste disposal problem and the supply of energy, as well as the reduction of GHG emissions [7]. In Hong Kong, a model was proposed for solving the problem of OW in in densely populated areas, where OW is treated in small reactors, which are located in housing units [8]. Also, in Norway, it has been shown that it is possible to replace commercial fertilizers and substrates, with products obtained after the treatment of OW in controlled conditions [9]. Furthermore, concept of a "zero waste" in food industry has been developed in Denmark, which means that recycling of packaging and the use of OW residues as a raw material in the second process leads to the complete elimination of waste [10].

In the previous studies conducted in the City of Niš, it has been shown that AD represents the most suitable treatment for the treatment of waste [11]. Based on these facts, in this paper is observed OW which originating from households and public areas in order to develop a model of OW management through the process of AD which following the principles of the CE. Such a model would involve the use of products which are generated, such as digestate and biogas, where biogas, is used to meet the demands of the facility, OW and compost transport. The aim of this paper is to show that it is possible to develop a system of OW management that is sustainable in the long time with the proper process management.

2 MATERIALAS AND METHODS

2.1 Model description

The model of OW management in the City of Niš has been developed to follow the principles of CE. The basic idea for the development of this model is the elimination of OW from MW, by using CE, which aims at the utilization of products obtained after the treatment. For the case of the City of Niš, it is predicted that the OW generated at households and in green areas will be treated by the process of AD (Figure 1). The first step in the model provides for the separation of OW at the place of origin, in households.

The next step is the transport of the OW from the place of origin to the plant, where the facility is designed in such a way that there is no need for storage, so the OW that is delivered to the facility is immediately subjected to the treatment. The raw material that is delivered before the introduction of the digester is subjected to pre-treatment. In the pre-treatment the removal of metal parts from OW is carried out using a magnetic separator, which prevents the equipment from being damages. The next stage involves the removal of non-biodegradable material that may impair the quality of the digestate. At the end of the preparation, the raw material is chopped to obtain a homogeneous mixture.

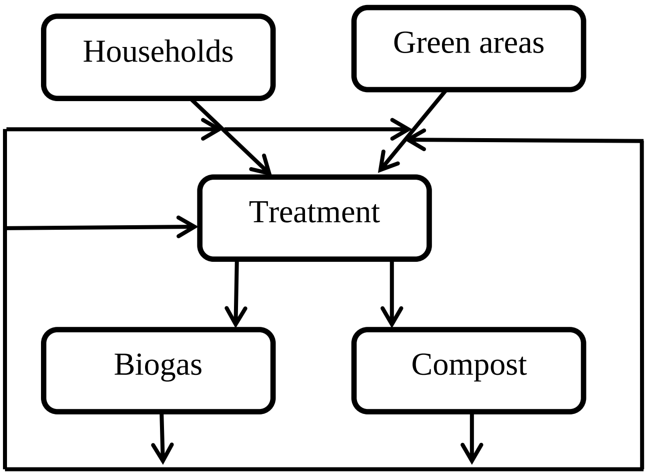

***Fig. 1**. A shematic view of the proposed model*

The organic raw material is then introduced into the digester. It is predicted that the facility is equipped with two single-stage continuous digesters. They are chosen to provide continuous and uninterrupted production of biogas. In the anaerobic digester the thermophilic process is performed at the temperature of 60˚C with the retention time of 14 days. After the end of the treatment, the biogas is obtained and collected at the top of the digester. The obtained biogas is purified in order to remove the hydrogen sulfide by adsorption on the active carbon. Biogas is then compressed, stored and later used for meeting the energy demands of facilities and transport of OW and compost. The application of CE in the model is reflected in the use of biogas to meet the demands of digesters, transport of OW from households and green areas to the facility and the obtained compost to green areas. The resulting compost is used as a fertilizer on the green areas from which the OW was first collected, thus returning the nutrients back to the nature and closing the circle of matter flow.

2.2 System boundaries

In order to achieve maximum results and the goal of applying CE in the process of OW management, it is necessary to predefine the system boundaries. Predefined conditions clearly define which products and outcomes of processes are to be expected. Thus, the OW to be treated, which originates from a household, is sorted at the place of origin, in biodegradable packaging. Then, all hazardous substances contained in the waste from households do not get into the flow of OW. The third condition is that the amount of OW treated by the process of AD is 95%. The density of the OW is 1000 kg/m³, which is the density of water, because of the fact that moisture constitutes the majority of OW composition (65%). The heating value of biogas is H_d = 26 MJ/m³. Biogas generated upon AD treatment contains 70% of methane, obtained from OW with a percentage share of 35% of dry matter. The temperature of the feed mixture at the entrance to the digester is equal to the average external temperature.

3 EXPERIMENTAL RESEARCH

3.1 Study area

The City of Niš is one of the oldest cities in the Balkans, and the city areas covers 596.71 km² with the population of 255, 518 [12]. According to the data from 2014, the City of Niš annually generates 65, 348.00 t/year of waste. The collection of generated waste is performed by the public utility company “Medijana” [13].

Since 2016, the separation of certain waste fractions (paper, metals and plastics) has been performed in two of the five city municipalities. In the other three municipalities all waste is mixed. Separate waste fractions are also collected by the public utility company once in two weeks and transported for further treatment. There are a couple of private companies engaged in recycling of electrical and electronic waste. All the other generated municipal waste is collected once a week and transported to the unsanitary landfill, where there is no further treatment, which is a major environmental problem.

Table1. Morphological composition of organic waste in the City of Niš

Fraction of waste	Quantity (t/year)	Share in total of amount of waste (%)	Moisture (%)
Food waste	9,011.49	13.79	70.0
Garden waste	8,854.65	13.55	60.0
Total	17,866.14		

3.2 The dimensioning of the facility and amount of the obtained products

AD represents a biological treatment of OW, where the final obtained products are digestate and biogas. Biogas contains methane, carbon dioxide and small amounts of hydrogen sulfide and hydrogen. Facilities for AD are built near raw materials in order to reduce the transportation costs. During the design of the facility, the mean temperature in the city of Niš is taken into account, which is 13˚C.

On the territory of Niš 49 tonnes of OW are generated annually, where high methane emission into the atmosphere occur, along with the pollution of ground and surface water. In order to determine the volume of the facility, we started from the condition that the density of OW is 1000 kg/m³. It was found that the volume of OW that is generated on a daily basis is 49m³/day, which could be rounded up 50m³/day. For a known volume of OW, it is assumed that the total volume of the digester is 700 m³. Two parallel digesters were used, with the volume of one digester of 350m³ with the diameter of 10 m and height of 4.9 m. It is known that the treatment of 1 tonne of the OW with a content of 35% of dry matter yields 150 m³ of biogas, of biogas, and the quantity of compost obtained after the treatment of 1 tonne of OW is 0.4 t [14]. After the treatment of 50 m³ OW with 35% dry matter, 8, 312. 5 m³/day of biogas and 27.5 m³/day of digestate are obtained. From the energy perspective, after some calculation, the amount of energy that can be obtained from biogas is 216,100 MJ/day. The amount of compost that is obtained after the additional treatment is 20 t/day.

3.3 Energy requirements for the maintenance of biogas facilities and OW and compost transport

Based on the predicted model, the biogas obtained after the treatment of OW would have multiple purposes. The energy that is obtained from biogas is primarily used for meeting the energy demands of the facility, then for the transport of OW from the place of origin to the facility and the transport of compost from the facility to the green areas.
The amount of heat required for heating is calculated as the product of the mass being heated, the specific heat capacity of water and the difference in temperature ($Q = m * c * \Delta t$).

The energy required to heat the feed mixture at the entrance to the digester from the projected temperature, 13 ˚C to the temperature of the thermophilic anaerobic digestion, 60˚C, is 9418.5MJ/day. The amount of biogas that is needed to heat the mixture on a daily level is 362.25 m³/day biogas (Table2).
The energy required to maintain the temperature in the anaerobic digester depends directly on the temperature The values of the average monthly temperature for the City of Niš and the temperature of the thermophilic AD process were used in the calculation. The required amount of biogas for the production of energy needed to maintain the temperature in the digester is shown in Table 2. Also in Table 2 gives the amounts of biogas for each month of the year.
Energy required for the transport of OW and compost
According to the standard for diesel fuel EN 590:2009 (European Commitete for Standarzation), the lower heating value for diesel fule is 43.1MJ/kg. Comparing the lower heating value of diesel fuel 35.85MJ/l and biogas 26MJ/m³, it can be seen that 1.37m³ of biogas can replace 1l of diesel fuel. To transport one tonne of waste from green areas to the biogas facility 7.14 l of diesel fuel or 9.78 m³ of biogas are needed. Besides the transport of OW, biogas is also used for transporting compost, which is formed after the treatment. The amount of biogas that is required for the transport of compost from the biogas facility to the green areas is the same as for the transport of OW. Table 2 shows the amounts of biogas that are required for the transport of OW and compost in the City of Niš.

Table2. Energy flow in the proposed model [m³/day]

Month	Obtained energy	Energy requirements				Surplus of energy
		Digester heating	Raw material heating	OW transport	Compost transport	
January	8312.5	6,525.3	362.25	550.3	189.5	685
February	8312.5	6,355.8	362.25	534.3	189.5	870
March	8312.5	5,984.3	362.25	507.8	189.5	1,268
April	8312.5	5,465.9	362.25	544.8	189.5	1,749
May	8312.5	4,687.2	362.25	478.6	189.5	2,594
June	8312.5	4,485.4	362.25	501.9	189.5	2,773
July	8312.5	3,910.3	362.25	506.7	189.5	3,343
August	8312.5	3,944.5	362.25	534.8	189.5	3,281
September	8312.5	4,496.7	362.25	521.6	189.5	2,742
October	8312.5	5,398.3	362.25	559.7	189.5	1,802
November	8312.5	5,894.2	362.25	561.1	189.5	1,305
December	8312.5	6,435.1	362.25	495.45	189.5	830
Annual	3,033,365	1,931,679	132,221	191,493	69,167.5	709,501
Daily average	8312.5	5,298.6	362.25	524.8	189.5	1,943

4. RESULTS AND DISCUSSION

4.1 Analysis of model

The basic objective of the proposed model is that the process of OW management is introduced into the system of CE. Achieving the goal is reflected in the fact that the system is sustainable for a longer period, and that it is then possible to meet the energy demands of the facility and transport OW and compost to the green areas.
The results obtained in the study are shown in Table 3, where are shown energy requirements of the facility, as well as the amount of biogas necessary for the transport.
From Table 3 it can be seen that after the energy demands of the facility and the transport of OW and compost are met, it is possible to develop a model of OW management. The obtained amounts of biogas show that after satisfying all of the energy needs, there is a surplus of biogas.

4.2 Biogas energy distribution

The energy obtained from biogas is partly used for meeting the energy demands of the facility, such as heating the feed mixture, heating the digester and maintaining the optimum temperature in the digester. Viewed from the perspective of the annual level of energy (Table 2), it can be concluded that the biggest part of energy is used for system maintenance of AD, 68% of the total energy obtained from biogas. The amount of biogas that is spent for the maintenance of the AD process is 1,931,679 m³, followed by the amount for heating the feed mixture, which is 132,221 m³ of biogas. Losses through walls can be ignored, because they are very small, about 1% of the total quantity of energy. Then, 6% of energy was used for the transport of waste, while the transport of compost used 2% of energy (Figure 2). The surplus of energy that remained after satisfying all the needs was large, amounting to 24%.

4.3 Biogas energy distribution by month

In addition to the basic distribution of biogas (Figure 2), it is essential to analyze the energy needs during a single month. Table 3 shows that the greatest energy demands are in the winter months (December, January, February), while the energy demands in the summer months (June, July, August) are much smaller. Also, in the summer months there is a larger surplus of biogas as well, which remains after satisfying all the demands. The percentage of consumption of biogas in the winter period is 81.8% of the total amount of biogas, while in the summer time it is 53.83% (Figure 3).
The amounts of biogas that are used for the transport of OW and compost are not change, but remine constans.

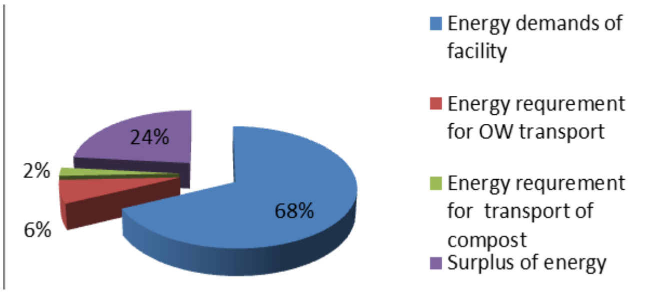

Fig. 2. *A diagram of energy distribution on the annual level*

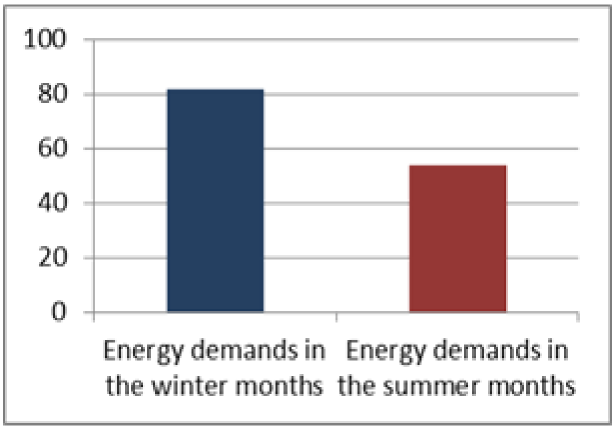

Fig. 3. *Biogas energy distribution by month*

Table3. Average temperature and energy distributions for the proposed model

Month	Average temperature [˚C]	Energy requirements for facility [MJ/day]	Amount of biogas for energy requirements for facility [m³/day]	Amount of biogas required for OW transport [m³/day]	Amount of biogas required for compost transport [m³/day]
January	2.1	179, 076.5	6,887.55	550.3	189.5
February	3.6	174,671.5	6,718.5	534.3	189.5
March	6.9	165,011.5	6,346.55	507.8	189.5
April	11.5	151,532.5	5,828.15	544.8	189.5
May	18.4	131,287.5	5,049.45	478.635	189.5
June	20.2	126,039.5	4,847.65	501.975	189.5
July	25.2	111,085.5	4,272.55	506.745	189.5
August	25	111,975.5	4,306.75	534.84	189.5
September	20.1	126,332.5	4,306.75	521.67	189.5
October	12.1	149,774.5	5,760.55	559.74	189.5
November	7.7	162,667.5	6,256.45	561.195	189.5
December	2.9	176,732.5	6,797.35	495.45	189.5
Total	13.0	53,661,414	20,639,00	191,493	69,167.5
Daily average	12.98	147,182.5	5,660.85	524.8	189.5

4.4 Amount of biogas obtained after the treatment

After processing the digestate generated during the AD process, by treating 50 tonnes / day of OW, we get 20 tonnes of compost per day, or 7300 tonnes per year. The demands for compost in green areas are 1.23 kg/m², on the annual level, as for surface of 3,030, 526 m² is 3727 t. The surplus of compost that occurs upon satisfying the need is 3,573 t, which is 49% of the total quantity of the obtained compost The compost that remains after all of the demands have been met, can be offered to citizens as a motivation for the separation of OW.

4.5 The possibility for extending the boundaries

For the predicted model, the resulting amount of biogas meets the demands, but there is the surplus of biogas. This surplus opens up the opportunity to expand the system boundaries. The amount of biogas which remains is 709,501m³ or about 24% of the total quantity. The options for the utilization of this biogas are numerous. The surplus of biogas that occurs could be used as fuel for public transport. Using the biogas as fuel for public transport contributes to reducing greenhouse gas emissions and lowering the energy dependence on fossil fuels.

5. CONCLUSION

The introduction of CE in the process of OW management provides us with the opportunity of being effective both from the economic and the environmental point of view. The reuse of waste as a raw material contributes significantly to the reduction of virgin materials. OW as a fraction of MW proved to be very useful for obtaining energy by using certain treatments. By introducing OW in the system of CE in the City of Niš, we will able to reduce OW which ends up in the landfills and exercise positive effects. Biogas that is obtained after the treatment of OW by the process of AD is used to meet the energy demands for the facility, as well as for the transport of OW and compost to green areas. After meeting the energy demands, which amount to 68% of the total quantity of biogas, and the needs of the transport of OW and compost, which are only 6%, there is a surplus of biogas, which is 24% of the total quantity. The existence of this surplus opens up a possibility for extending the system, but also points us to the fact that the system is sustainable, because it is capable of compensating for the energy. The compost which is obtained after the re-treatment and meeting the demands of green areas, leaves the surplus of 49%, it that can be offered to citizens. This shows us that it is possible to replace mineral fertilizers with compost. On the basis of the above facts, it can be concluded that it is possible to develop the system of OW management which follows the principles of CE, and that such a system is self-sustainable in the long run.

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