COMPARISON OF ENVIRONMENTAL IMPACT OF WASTE TECHNOLOGY WITH ENERGY RECOVERY: CASE STUDY CITY OF NIŠ

Dr Biljana Milutinović[1]; Dr Mladen Tomić[2]; Petar Đekić[3]
[1] College of Applied Technical Sciences Niš, Niš, Serbia, email: biljana.milutinovic@vtsnis.edu.rs
[2] College of Applied Technical Sciences Niš, Niš, Serbia, email: mladen.tomic@vtsnis.edu.rs
[3] College of Applied Technical Sciences Niš, Niš, Serbia, email: petar.djekic@vtsnis.edu.rs

Abstract: *Waste treatment technologies have different impact to the environment. Before design and implementation of different waste treatment technologies in waste management system, the sustainability assessment must be done, but specially must be considered their impact on the environment. Environmental impact should be considered throughout the life cycle of waste, i.e. from the moment of waste generation to final treatment and disposal. In this paper the life cycle assessment was applied to compare the environmental impact of waste technology with energy recovery: incineration and anaerobic digestion, in a case study City of Niš. Emissions in air, water and soil are calculated and six impact categories: abiotic depletion (ADP), global warming (GWP), human toxicity (HTP), photochemical oxidation (POCP), acidification (AP), and eutrophication (EP) were evaluated. The obtained results show that the anaerobic digestion with biogas utilization for energy generation has overall minimum negative environmental impact in the case study City of Niš.*

Keywords: *Waste treatments, enviromental impact, life cycle assessment,*

1. INTRODUCTION

Before designing and implementing a new waste management system, it is necessary to analyse the system sustainability. This analysis includes assessment of all aspects: environmental, economic and social. When analysing the impact of waste management system on the environment, this should be considered throughout the life cycle of waste, i.e. from cradle to grave, the moment of waste generation to final treatment and disposal, respectively, life-cycle assessment (LCA) should be done. This approach has been recognized and recommended by the Commission of the European Communities [1]: "All phases in a resource's life cycle need to be taken into account as there can be trade-offs between different phases and measures adopted to reduce environmental impact in one phase can increase the impact in another. Clearly, environmental policy needs to ensure that negative environmental impact is minimised throughout the entire life cycle of resources. By applying the life-cycle approach, priorities can be identified more easily and policies can be targeted more effectively so that the maximum benefit for the environment is achieved relative to the effort expended."

Therefore, in recent years in assessing the environmental impact of waste management systems LCA was often used. Some authors reviewed the assessment methods that are used as tools to support decisions regarding waste management. They concluded that, approximately, 40% of reviewed articles are life cycle assessment-based [2]. Other authors performed critical review of published LCA studies of solid waste management systems [3]. Some authors reviewed the articles that use LCA to evaluate the environmental performance of thermal Waste-to-Energy (WtE) technologies [4]. They concluded that the quality of LCA studies of WtE technologies and systems including energy recovery can be significantly improved. Many studies have already shown the potential of LCA as a decision-supporting tool to evaluate different waste treatment scenarios and highlight the environmental hot spots [5-10]. Some authors presented a study concerning the application of the LCA methodology to support the development of the new waste management plan for the Bologna District [10]. Other focused on the LCA of alternative urban solid waste management strategies. The assessment is assumed to be applied to the waste stream of the biggest Italian city, Roma, but the final results can be considered reliable for most of the European cities, which have a similar waste composition [11]. The life cycle analysis of 10 integrated waste management systems for 3 potential post-event site design scenarios

of the London Olympic Park were also done and waste management systems were compared [12]. Tarantini et al. applied the LCA to waste management systems in Italian industrial areas [13]. In some studies the life cycle environmental impacts of a system producing biogas from agricultural wastes by anaerobic digestion and co-generating heat and electricity in a combined heat and power plant was presented and compared with fossil-fuel alternatives [14].
In this paper life cycle analysis was applied to compare environmental impact of waste management scenarios with energy recovery in City of Niš as a case study, in the framework for sustainability assessment of the waste management system [15]. Two scenarios were taken in to consideration: Incineration – incineration of waste with energy production, and Anaerobic Digestion and Recycling – anaerobic digestion with biogas utilization for energy generation and six LCA impact categories were used as criteria.

2. MATERIALS AND METHODS

According to the International Organization for Standardization (ISO) an environmental Life Cycle Assessment (LCA) studies the environmental interventions and potential impacts throughout a product's life (i.e., from cradle-to-grave) from raw material acquisition through production, use and disposal [16]. The LCA is a tool able to evaluate environmental burdens associated with a product, process, or service by identifying energy and materials used and emissions released to the environment; moreover it allows also an identification of opportunities for environmental improvements [17]. In the definition of the LCA, the term 'product' includes not only material products but can also include service systems, for example waste management system [18]. The LCA methodology is considered one of the most effective management tools for identifying and assessing the environmental impacts related with waste management options, and for comparing alternative technologies when the location of the activity is already defined [19]. In particular, the broad perspective of the LCA makes possible to take into account the significant environmental benefits that can be obtained through different waste management processes. The general categories of environmental impacts needing consideration include resource use, human health, and ecological considerations.
At the beginning, it is essential to define why the LCA is to be carried out, and what decision is to be informed by the results. The scope of the study is expressed in terms of the system boundary, and the processes and operations which are to be included. However, for comparative LCAs, it is usually sufficient to consider only the activities which differ between the alternatives, ignoring all common operations. This simplifies the second phase, the inventory analysis. In this phase is carried out the identification and quantification of the materials and emissions crossing system boundary. The input and emission flows are termed environmental burdens or environmental interventions. In process engineering terms, inventory analysis amounts to compiling material and energy balances over the processes and operations making up the life cycle. In addition to processing operations, transport must be included explicitly; in the specific case of solid waste management, logistics can represent a significant part of the overall economic cost and environmental impacts. In principle, manufacture and disposal of plant and equipment is also part of the life cycle. According to the ISO standard [16], the life cycle impact assessment (LCIA) is a phase of the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. Interpretation is the final phase of the LCA. In this phase, the findings of either the inventory analysis or the impact assessment or both are combined in line with the defined goal and scope of the study.

3. EXPERIMENTAL RESEARCH

3.1. Case study

City of Niš is situated in south east of Republic of Serbia, in the Nišava valley. The city area covers 596.71 km^2 of five municipalities [20]. In the City of Niš, according to the census of 2011, lived 260,237 inhabitants. Niš is one of the most important industrial centers in Serbia, well-known for its industry of electronics and mechanical engineering, and the textile and the tobacco industry. The educational system is quite elaborate in the city: there are 50,000 pupils/students.
City of Niš still has not introduced a waste management system that implementing advanced treatment of waste, and the proposed methodology can support decision-makers in the planning and introduction of a new waste management system.
Amount of waste that generated in the city of Niš in 2014 is 65,348 t/y [21]. At present, the city has a dysfunctional unsanitary landfill and waste management comes down to the collection and disposal of waste in the landfill. The current situation in the city is such that the waste is collected by a public company and disposed of in unsanitary landfill. In the city there are several private companies involved in the recycling of waste (mainly metals, paper, plastics and e-waste). There are several locations with containers for the collection of recyclable materials (plastics, glass, aluminum cans, paper). In two municipalities primary selection of waste is applied. The waste is collected and transported once a week.

Table 1: The composition and quantity of waste generated annually in the city of Niš [46]

Fraction	Production (t/y)	Percentage (%)	C (%)	H (%)	O (%)	N (%)	S (%)	Moisture (%)	Ash (%)
Food waste	9,011.49	13.79	48.0	6.4	37.6	2.6	0.4	70.0	5.0
Paper	7,515.02	11.50	43.5	6.0	44.0	0.3	0.2	6.0	6.0
Diapers	2,287.18	3.5	35.5	5.67	44.0	<0.1	-		
Plastics	14,265.47	21.83	60.0	7.2	22.8	-	-	2.0	10.0
Textile	1,718.65	2.63	55.0	6.6	31.2	4.6	0.15	10.0	2.5
Rubber	3,430.77	5.25	78.0	10.0	-	2.0	-	2.0	10.0
Leather	398.62	0.61	60.0	8.0	11.6	10.0	0.4	10.0	10.0
Yard waste	8,854.65	13.55	47.8	6.0	38.0	3.4	0.3	60.0	4.5
Glass	3,522.26	5.39	0.5	0.1	0.4	<0.1	-	2.0	98.9
Metals	1,058.64	1.62	4.5	0.6	4.3	<0.1	-	3.0	90.5
Other	13,285.25	20.33	26.3	3.0	2.0	0.5	0.2	8.0	68.0
Total	65,348.00	100							

3.2. Scenario description

Scenarios were developed based on the methods of waste treatment with energy recovery. Scenario 1 provides incineration of waste with energy recovery in cogeneration plant and Scenario 2 includes energy recovery through anaerobic digestion of organic waste and recycling of recyclable waste (glass, metal and plastic). Main variation factors (annual distance driven by trucks, fuel efficiency, energy consumption, energy efficiency) of each scenario are given in order to evaluate environmental indicators. The emission factors for developed scenarios were evaluated using LCA-IWM software [22].

Scenario 1 – Incineration: Glass and metal in quantities of 4,580.90 t is recycled and residual waste (60,767.10 t) is sent to an incineration plant. Incineration is done by using a system with energy recovery. The generated electricity and heat was calculated on the base of the lower heating value content of the solid waste. The lower heating value of waste is adopted as 13.08 MJ/kg of waste [22]. The net electrical efficiency of the incinerator considered in this scenario is 27% and the thermal efficiency is 43%. Bottom ashes and flue gas treatment ashes are delivered to the landfill. The quantity of ash produced both (bottom ash and ash resulted from flue gas) was estimated by referring to Ref. [22]. Annual distance driven by collection trucks is 100,579 km. Annual distance driven by recycling trucks is 7,570 km. Energy consumed by trucks is 45 dm^3 of diesel per 100 km. Pollutant emitted from the diesel-based collection and recycling trucks and equipment for landfill operations was calculated according to Ref. [23]. Some emission factors for waste incineration included CO_2 (695.0 kg/t), NO_x (0.825 kg/t), HCl (0.00052 kg/t), N_2O (0.0083 kg/t), CO (0.136 kg/t), SO_2 (0.00112 kg/t), NMVOC (0.00027 kg/t) [23].

Scenario 2 – Anaerobic Digestion and Recycling: Organic waste (29,665.06 t) is sent to anaerobic digestion plant for the purpose of energy generation. Amount of 22,277.14 t of recyclable waste (glass, metal and plastic) is recycled. Other waste of 13,415.84 t is landfilled. In this scenario anaerobic mechanical-biological process is considered [22]. Three waste streams are assumed to constitute the recycling streams at MBT: glass, mixed plastics, and metals. The metals' content has been assumed to consist of 30% non-ferrous and 70% ferrous metals. The reject rate for all recyclable fractions is assumed to be 10%. In this scenario, the amount of biogas produced is calculated to be 136 Nm^3/t of input waste [22]. Composition of biogas produced: 61% CH_4, 39% CO_2, and the net calorific value of biogas is 22.6 MJ/Nm^3. It is assumed that biogas loss due to leakage in operations is 10%. Biogas produced in the AD process is combusted in a CHP unit to generate energy. The electrical efficiency of the CHP unit is assumed to be 35% and the thermal efficiency is 42%. The residue of the anaerobic digestion that remains inside the reactor can be treated and used as fertilizer. The amount of compost produced is 430 kg/t. Emission to air by soil application include NH_3 (0.45 kg/t) and NO_x (0.06 kg/t). Annual distance driven by co-mingled trucks is 81,437 km. Annual distance driven by recycling trucks is 26,713 km. Energy consumed by trucks is 45 dm^3 of diesel per 100 km. Pollutant emitted from the diesel-based collection and recycling trucks and equipment for landfill operations was calculated according to Ref. [23]. The emission factors for anaerobic MBT process include CO_2 (6.61 kg/t), NO_x (0.606 kg/t), CH_4 (0.958 kg/t), N_2O (0.0907 kg/t), SO_2 (0.0859 kg/t), CO (0.858 kg/t), NH_3 (1.26 kg/t) [23].

3.3. Life cycle impact assessment

The life cycle impact assessment was done using LCA-IMW software [22]. The methodology within the LCA-IWM project provides means for assessment of alternative municipal solid waste management system. The borders of

assessment are extended to include the environmental, social and economic impacts occurring at all stages of a waste management system, i.e.: temporary storage of waste, collection, transport, waste treatment and final disposal. The assessment starts at the moment waste is put in a temporary storage system. The functional unit of the proposed assessment method is the amount of waste generated in a city and entering the waste management system within one year. In the current study, the functional unit is the total amount of municipal solid waste generated in city of Niš in one year of legacy period. The total annual quantity of generated waste for each of the developed scenarios is 65,348 t.
Result of inventory data was classified to the six impact categories:

- Abiotic Depletion Potential (ADP) – accounts for positive aspects of the recovery of waste, both in form of recycling as well as energy recovery. The resources which are saved due to recycling and recovery replace abiotic resources which would have to be otherwise extracted.
- Global Warming Potential (GWP100) – accounts for greenhouse gases over 100 years. Typical emissions for waste management which contribute to global warming potential include fossil CO_2, N_2O and CH_4.
- Human Toxicity Potential (HTP) – concerned with negative effects on human health of toxic substances emitted to the environment. Emissions from waste management with the most significant impact within this category include: heavy metals (Cr(VI), Hg, Ni, Cu), dioxins, Ba and Sb.
- Photochemical Oxidation Potential (POCP) – relevant emissions for this impact category within waste management are: NMVOC and CH_4 from landfills and emissions of NO_x and CO from thermal processes,
- Acidification Potential (AP) – for waste management the major impacts within this category arise from NO_x emissions from thermal processes, NH_3 from biological processes and SO_2 emissions from electricity production.
- Eutrophication Potential (EP) – accounts for nutrients causing an increase in the rate of supply of organic matter in an ecosystem. Referring to the waste management the EP is attributed to atmospheric emissions of NO_x and NH_3, P and N to water from biological processes.

4. RESULTS AND DISCUSSION

Based on a developed scenarios and defined amount and waste streams, the environmental burdens for both scenarios were calculated and presented in Table 2 [22]. According to the environmental burdens for each scenario it can be concluded that CO_2 is discerned as the dominant gas in mass emitted in both scenarios. Scenario 1 (Incineration) has much higher CO_2 emission (695 kg/t) than Scenario 2, due the energy consumption for equipment for flue gas cleaning system. Scenario 1 is also larger contributor of heavy metal and dioxins emissions due to the fact that in this scenario there is an incineration of comingled waste (including Cl-rich plastics). This condition favors the formation of dioxins. On the other hand, due to the decomposition of organic waste, Scenario 2 (Anaerobic Digestion and Recycling), has higher emission of CH_4 (0.958 kg/t). Also, for the same reason, the emission of NMVOC (0.0623 kg/t) is higher than in Scenario 1.

Table 2: Comparison among airborne emissions from scenarios

Emission factors (kg/t)	Incineration	Anaerobic Digestion and Recycling
CO_2	6.95E+02	6.61E+00
CO	1.36E-01	8.58E-01
CH_4	1.01E-02	9.58E-01
NO_x	8.25E-01	6.06E-01
N_2O	8.30E-03	9.07E-02
SO_2	1.12E-03	8.59E-02
NMVOC	2.70E-04	6.23E-02
NH_3	1.35E-02	1.26E+00
HCl	5.17E-04	2.00E-03
HF	1.95E-03	1.20E-03
Cr	1.64E-06	7.99E-07
Hg	1.08E-05	5.59E-06
Ni	2.72E-06	2.66E-07
Cu	1.29E-06	n.a.
PCDD	7.40E-11	4.20E-14
PM10	8.51E-03	6.66E-03

Result of inventory data was classified to the impact categories: Abiotic depletion (ADP), Global warming (GWP100), Human toxicity (HTP), Photochemical oxidation (POCP), Acidification (AP), and Eutrophication (EP). Environmental burdens CO_2, CH_4, CO, N_2O were grouped into the emissions which contribute to the global warming impact category; heavy metals (Cr(VI), Hg, Ni, Cu), dioxins, Ba and Sb into human toxicity; H_2S, HCl, HF, SO_2, and NO_x into acidification; NO_x, NH_3 into eutrophication; and CH_4, CO, NO_x, and NMVOC into photochemical oxidation. The impact indicators were calculated associated to the product emission amounts and their respective equivalency factors.
In order to compare the magnitude of the impacts in the different categories, the characterized results have been normalized. In the normalization step, the results are related to the overall environmental impacts in a certain region for a certain year. Thus the results can be described in e.g. Inhabitant Equivalents (IE). Characterization values of the each impact categories are analyzed. Normalization values are given in Table 3.

Table 3: Normalized values of impact categories

Impact categories	Incineration	Anaerobic Digestion and Recycling
Abiotic depletion (ADP)	0.0142	-0.00000078
Global warming (GWP100)	2.3000	0.0328
Human toxicity (HTP)	0.0352	0.0356
Photochemical oxidation (POCP)	0.0073	0.0466
Acidification (AP)	0.2530	0.1930
Eutrophication (EP)	0.1420	0.0824

According to the obtained results of life cycle impact assessment, the Scenario 2 (Anaerobic Digestion and Recycling) contributes to savings in abiotic depletion, and it is the preferable in term of abiotic depletion potential (-0.00000078 IE). Scenario 1 (Incineration) is bigger contributor to the greenhouse effect (2.30 IE): the CO_2 emissions of the incinerators dominate the contribution of the system. It means that the foreground system (main process) generated was greater global warming potential than that generated by background system (electricity production). When the focus is only on GWP, Scenario 2 would be better choice with the lowest global warming potential (0.0328 IE).
The analysis of toxicity categories shows the similar contribution of emissions in both scenarios. Scenario 2 indicates the bigger contribution for photochemical oxidant formation. It is particularly contributed by the organic waste decomposition. The impacts of the system in photochemical oxidation are mainly due to CH_4 and NMVOC emissions. Scenario 1 is the preferable in term of photochemical oxidation potential (0.0073 IE). Both scenarios are contributors for acidification due to NO_x, SO_2, HCl and HF emissions. It means, acidification potential from electricity production could offset the main processes resulting in high value of impact indicator. The release into the environment of NO_{3-} and NH_3 contained in the leachate and wastewater, even if treated in a wastewater treatment plant, represents the biggest contribution to eutrophication. Therefore, if the impact indicator for eutrophication is the main consideration, the better scenario is presented by Scenario 2 (0.0824 IE).

5. CONCLUSIONS

The Life Cycle Analysis was often used technique for environmental assessment of waste management systems, because, it gives the possibility of comparing defined scenarios in terms of the individual impact categories. This methodology was applied to compare environmental impact of waste management scenarios with energy recovery in City of Niš as a case study. Two scenarios were taken in to consideration: Incineration – incineration of waste with energy production, and Anaerobic Digestion and Recycling – anaerobic digestion with biogas utilization for energy generation. Six above mention life cycle impact categories were considered.
Selected emissions to air and impact category indicator for assessment lead to the following conclusions:

- In view of abiotic depletion, global warming, acidification, and eutrophication, Scenario 2 (Anaerobic Digestion and Recycling) was found to be the more feasible.
- In terms of photochemical oxidation, scenario 1 (Incineration) gives the higher value of saving.

Results of conducted life cycle analysis for developed waste management scenarios with energy recovery in the case study, the City of Niš, show that the best ranking scenario, i.e. scenario with minimum negative environmental impact is Recycling and Anaerobic Digestion, scenario which includes recycling of waste (plastic, glass, and metal) and anaerobic digestion of organic waste with energy recovery from biogas.
These results shown also that the LCA methodology allows us to construct an environmental data set and examine the environmental impact of the life cycle of various waste treatment methods to support a decision making on the solid waste management strategy for energy.

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