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ENVIRONMENTAL EVALUATION OF WASTE MANAGEMENT SCENARIOS – SIGNIFICANCE OF THE BOUNDARIES

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Abstract. Life cycle concept was applied to analyse and assess some municipal solid waste (MSW) management scenarios in terms of environmental impacts, particularised for Iasi city, Romania, where approximately 380 kg/cap/yr of waste are generated. Currently, the management processes include temporary storage, collection, transport and landfilling, but separate collection, sorting, recycling and composting of solid waste, which should be addressed according to the National Strategy and European policy for waste. Four different scenarios were elaborated as alternatives to the existing waste management system in Iasi, which include both previously applied and current waste management alternatives, as well as some advanced practices. The effectiveness of the scenarios was evaluated in terms of environmental impacts based on Life Cycle Analysis, supported by GaBi software. Some environmental impact categories (acidification, eutrophication, global warming, human toxicity, and photochemical ozone generation potentials, carcinogenic substances, heavy metals, winter smog, photochemical ozone formation) were estimated based on several impact assessment methods associated to GaBi software (CML 2001, CML 96, EDIP 2003, EI95). The study emphasises the importance of system boundaries for the life cycle impact assessment process and consequently – for the optimal waste management alternative.

Keywords: environment, GaBi, life cycle assessment, solid waste, waste management technologies.

1. Introduction

The increase in the amount of solid waste generated in cities over the time due to a continuous welfare improvement and changes in life style requires the application of environmental, institutional, financial, economic and social tools to guarantee a sustainable waste management (Ghinea, Gavrilescu 2010a; Rathi 2006; Schiopu, Gavrilescu 2010a, b).

The earliest and often current trends in waste management consider somewhat safe and controlled disposal, but it has been proven that sometimes this solution led to contamination of atmosphere, water and soil; instead, an integrated waste management should involve different treatment options for all waste streams (McDougall 2005; Carlig, Macoveanu 2009; Schiopu, Gavrilescu 2010a). In some countries (e.g. Romania) the continuous growth in municipal solid waste (MSW) production was not pursued by the development of modern waste management practices, while landfilling continues to be an exclusive option for waste disposal, which can deal with all material in the solid waste streams (Rada *et al.* 2010). The need for a more comprehensive approach in this field has been acknowledged by strategic waste management documents. The acquis communautaire in the field of waste management includes 16 acts – such as Waste Framework Directive (WFD 2006), Landfill Directive (EC Council Directive 1999), national strategies and plans for waste management (NWMS 2004) – which have already been transposed into national legislation of the Member States, in particular in Romania. The closure of non-conforming landfills and setting of a program for construction and operation of waste management centres are imperative objectives, in particular in Romania, where recycling sector hit only a 2% rate of recycling from an almost 380 kg of municipal waste per capita in 2009 (FRD 2011). A relevant example in this context could be Iasi city, Romania, where the collection and transport of municipal solid waste are carried out under the control and management of local public authorities (Doba *et al.* 2008; Vinke-de Kruijf *et al.* 2009). Solid waste is collected from urban areas only, sanitation services in the rural area are missing, being present in few bordering villages alone (Iasi County Council 2009). Until 2006, there were no points for selective collection of municipal waste from the population in Iasi County (Iasi County Council 2009), although selective collection represents one of the key steps in waste recycling and implies storage of waste in specialised places. Therefore, an emerging global consensus addressing the development of the best solutions for improved waste management alternatives set together in various scenarios, with a reduced environmental impact becomes more and more effective.

This results from the increase of the people awareness *vis-à-vis* on the waste management and resource conservation; the better coherence of the regulations in this area and the constraints and penalties they impose (BALKWASTE 2010). The selection of the best scenario involves specific analyses and comparisons, usually based on the Life Cycle Assessment (LCA) methodology, which is a well-known technique for the evaluation of the environmental load of a product, process, or activity, addressing all possible environmental impacts "from the cradle to the grave" (Consonni *et al.* 2005; Ghinea, Gavrilescu 2010b; Liamsanguan, Gheewala 2008; Rigamonti *et al.* 2010).

Application of LCA to Integrated Waste Management Systems gives rise to many studies published in recent years, where the environmental aspects and potential impacts of waste management during the entire life cycle and for various scenarios are evaluated (Cherubini *et al.* 2009; Consonni *et al.* 2005; de Feo, Malvano 2009; Ozeler *et al.* 2006). LCA recommends various system diagrams, and then, by comparing such system maps of different options, environmental improvements can be made (Ghinea, Gavrilescu 2010a, b; McDougall *et al.* 2001; Morrissey, Browne 2004). One of the most important advantages of this approach is that LCA methodology allows for the development of specific models for waste management, which further facilitate the simulation of various scenarios and the selection of the best combination of alternatives, from an environmental point of view.

Up to now, several models based on LCA methodology were developed and applied for environmental assessment of the treatment and disposal of municipal solid waste (Banar *et al.* 2008; Frioriksson *et al.* 2002; Ghinea, Gavrilescu 2010b; Tsilemou, Demetrios Panagiotakopoulos 2007). Moreover, dedicated software, which can be used to develop and analyse different plans/scenarios based on LCA, in particular for solid waste management, were elaborated. In situations when municipal solid waste management systems of different communities are characterised as of rather low level in respect to recycling and recovery of materials and is limited to only some activities – such as temporary storage, collection and transport of mixed waste directly to the landfill site located outside the city – these tools allow the result modelling and scenario simulation based on Integrated Waste Management and LCA concepts (McDougall *et al.* 2001; PE International 2009).

This paper reports the main results of research aimed at comparing four alternative scenarios for municipal solid waste management in an integrated way, based on LCA analysis, in order to understand whether manipulating waste ahead of combustion can either increase the efficiency or reduce the environmental impacts. The four scenarios specific for Iasi city, Romania, are discussed and evaluated based on their environmental impact, applying the facilities offered by simulation software (GaBi4, PE INTERNATIONAL) to establish the management alternatives with the lowest impacts on the environment and the most suitable for Iasi, and for using the results in the decision-making process. The importance of boundaries of solid waste systems is also analysed.

2. Methodology

Life Cycle Assessment (LCA) is an internationally standardised methodology for environmental assessment, which is used to evaluate the environmental impact of a product or system (ISO, 2006a, 2006b). LCA consists of four major stages: goal and scope definition, inventory analysis, impact assessment and interpretation (Curan 1996; Ghinea, Gavrilescu 2010b; Iosip *et al.* 2010; ISO 2006a, 2006b). This methodology can be used for modelling and simulation of waste management scenarios. Every stage of life cycle assessment methodology is supported by GaBi (Ganzheitliche Bilanzierung = holistic balancing). GaBi software is an instrument, which allows modelling of complex processes (PE International 2009) and the application of this software media is effective under the permission of PE INTERNATIONAL. The potential environmental impacts are calculated based on plans, processes, and the inputs and outputs related to the system (PE International 2009). In this case, the plans or scenarios represent the actual waste management system for Iasi and potential improvements. All of the data needed for the life cycle inventory was gathered from the literature, the database of the software and the municipal waste services. With GaBi tool, life cycle balances were elaborated and analysed in specific ways (Buning 2004).

2.1. Description of scenarios and system boundaries

Different waste management scenarios developed for Iasi city consider the annual amount of solid waste management generated in Iasi City, as a functional unit. The composition of MSW in Iasi city is given in Table 1.

First, the management scenarios consider the collection of MSW from residential areas, transport, and different treatment alternatives (recycling, composting, incineration, landfilling). The system boundaries were then extended so that the life cycle analyses of scenarios included the use of landfilling gases and composting products, as well as the use of auto fuel.

Two groups of scenarios were elaborated and analysed: group A containing scenarios SA1, SA2, SA3 and SA4, where the system boundaries are limited to the waste processing (dotted lines in Fig. 1), and group B

Table 1. Composition of municipal waste management in Iasi for 2008 (Ghinea, Gavrilescu 2010c)

Waste fraction	Composition (mass-%)
Paper and cardboard	18.00
Glass	9.40
Metals	4.40
Plastics and composites	10.40
Organic waste	40.40
Hazardous waste	1.00
Waste electric and electronic equipment	2.00
Other (non-bulky) materials	14.40
Total	100

containing SB1, SB2, SB3, SB4, which include the processes from group A, but with extended boundaries to the other additional activities associated to waste management (landfill gases, composting products and auto fuel uses) (continuous lines in Fig. 1). All scenarios considered the following processes: temporary storage, collection and transportation, and landfilling of solid waste. Scenario S1 is considered without collection or treatment of landfill gases and leachate (as it was the situation in Iasi in 2009) (Doba *et al.* 2008); the second scenario S2 includes these activities, since a new landfill was established in Iasi in 2009, according to the provisions of the landfill Directive (the EC Council Directive 1999).

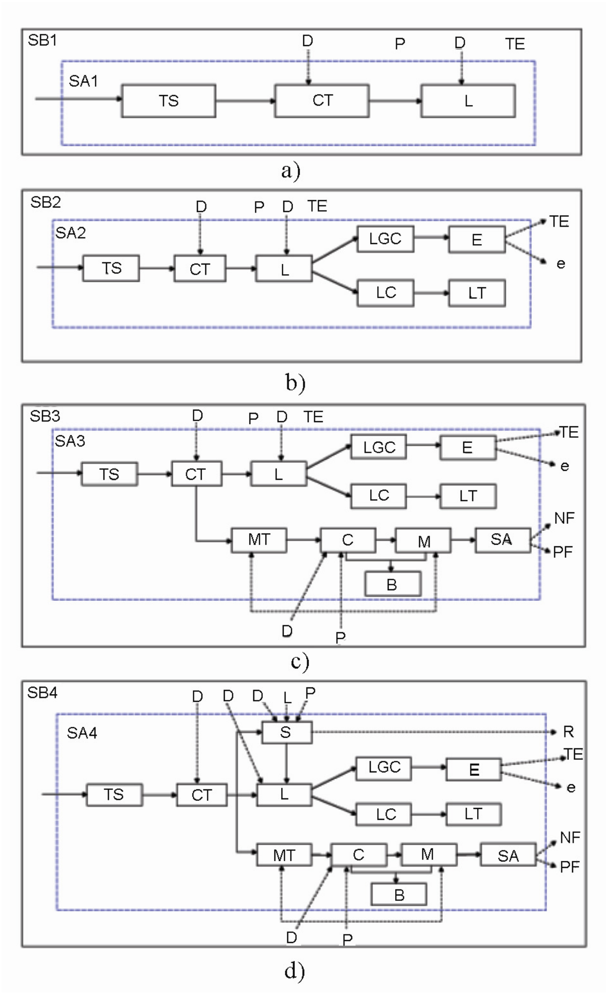

Fig. 1. Environmental boundaries for the scenarios from groups A and B: a) SA1, SB1; b) SA2, SB2; c) SA3, SB3; d) SA4, SB4 TS – temporary storage; CT – collection and transport; L – landfilling; LGC – Landfill gas collection; LC – Leachate collection; E – engine; LT – leachate treatment; MT – mechanical treatment; C – composting; M – maturing; SA – soil application; B – bio-filter; S – sorting; D – diesel; TE – thermal energy (heat); P – power; e – electricity; R – recycling; NF – nitrogen fertilizer; NP – phosphorus fertilizer

The differences between SA2 and SB2 are quite significant, because SB2 takes into account the emissions from diesel usage for collection and transport (Rem *et al.* 2009) and for landfilling of solid waste, as well as the potential production of electricity and heat from landfill biogas. Also, the effect of substitution of electricity and heat obtained from conventional production with electricity and heat from landfill biogas is taken into account (energy saving) (den Boer *et al.* 2005a; Guillet 2010; Popescu *et al.* 2009). The scenarios SA3 and SB3 include processes for treatment/disposal of waste such as composting and landfilling. Over 40% of the municipal wastes generated in Iasi are represented by organic waste, so that composting should be included in waste management scenarios (Doba *et al.* 2008; Ghinea, Gavrilescu 2010c; Iasi County Council 2009). Therefore, a composting plant with 10000 t/year capacity was considered and the station will probably operate at full capacity until 2018 (Iasi County Council 2009).

Scenario SB3 takes into account diesel emissions, the substitution of electricity and heat with those produced from landfill biogas, as well as the substitution of synthetic soil fertilizers with compost, so that the impacts associated to the production of synthetic fertilizers are avoided (den Boer *et al.* 2005a). Besides temporary storage, collection and transport, scenario A4 also contains sorting of the recyclable waste, composting of organic waste and landfilling of remains.

Although the amount of recyclable waste collected is very small in comparison to the amount of waste generated, considerable efforts are made to implement the selective collection of solid waste by collecting each type of recyclable waste in different containers and by informing citizens about selective collection (FRD 2011; Iasi County Council 2009). A good selective collection of recyclable waste at a source is a decisive step for the recycling process. These recyclables could replace virgin materials to produce a particular product and to reduce emissions from the production for paper, plastic from virgin materials and consumption of natural resources such as wood (Buning 2004; Ghermec *et al.* 2009; Suteu *et al.* 2009).

2.2. Inventory analysis

The most important part in starting an assessment of waste management is knowledge of the amounts of waste generated, and fractions and elemental composition of waste fractions. The waste amounts that will be generated in Iasi in 2018 were predicted by fraction with Waste Prognostic Tool (Ghinea, Gavrilescu 2010c). The organic waste represents the greatest fraction (38.40%) of all waste that will be generated, closely followed by paper and cardboard (19.60%), and plastics (11%).

The difference between the waste composition that will be generated in 2018 and the composition of waste generated in 2008 is not that big. The same waste fractions in the same order had the most representative values (Ghinea, Gavrilescu 2010c). The elementary composition for waste fractions was taken from literature (Buning 2004).

The inputs and outputs for every process of a waste management system scenario were established and calculated in inventory analysis.

The necessary data for the evaluation of temporary storage process include:

- number of containers, which was calculated with Eq. 1 (den Boer *et al.* 2005a):

$$NTFU_{i,j,k} = \frac{AWHa_{i,j,k}}{\left(WaDe_i/1000\right)*\left(VoTS_{i,j,k}/1000\right)*CoFr_{i,j,k}*AvFR_k}, \quad (1)$$

where: i – waste fraction; k – principal container type; j – sector; $NTFU$ – number of containers used in temporary storage of solid waste for waste fraction i; $AWHa$ – amount of waste handled of waste fraction i, (t/year); $WaDe_i$ – density of waste fraction i, (kg/m^3); $VoTS_{i,j,k}$ – chosen volume for type of container k for waste fraction i in sector j, (L); $CoFr_{i,j,k}$ – frequency of waste fraction collection, (/year); $AvFR_k$ – average filling rate of container type, (%);

- annual quantity of material required for container fabrication (Eq. 2) (den Boer *et al.* 2005a):

$$YMCP_i = \frac{\sum NTFU_{i,j}*\left(1+EBNS\right)*CoWe_{i,j}*\left(100\%-RRUC_i\right)}{LiTi_{i,k}}, \quad (2)$$

where: $YMCP_i$ – annual quantity of necessary material for containers production from material i (kg/year); $\sum NTFU_{i,j}$ – total containers from material i and type k, (no); EBNS – extra bins necessary for different operations, (%); $CoWe_{i,j}$ – container weight for containers of material i with volume j, (kg); $RRUC$– Recycling rate of used containers for material i, (%); $LiTi_{i,k}$ – Life Time for container of material i and type k, (years);

- emissions resulting from manufacturing of material required for bins, which was calculated based on database of Gabi Software.

The necessary data for collection and transport processes include: number of vehicles and loading capacity, transport distance, fuel consumption and emissions from fuel consumption. Iasi municipality has 30 vehicles with the total loading capacity of 1881 m^3 (Doba *et al.* 2008).

The fuel consumption is estimated to 30 L/100 km (den Boer *et al.* 2005a) and the density of diesel $\rho_{diesel} = 0.845\ kg/L$ (Recycled Organics Unit 2003). The fuel consumption (L) was converted to an equivalent weight (kg) value by multiplying the volume by density. The emissions from fuel consumption are calculated knowing the emission resulted from burning of 1 kg of diesel (Recycled Organics Unit 2003).

For landfilling process, the inputs are amounts of waste fractions landfilled, fuel consumption and outputs – emissions from fuel consumption, landfill gas and leachate.

The amount of landfill gas can be found knowing that all waste fractions contribute to the production of biogas, except for inert fractions. The potential of waste biogas can be calculated with the equation proposed by Rettenberger/Tabasaran (Eq. 3), (Buning 2004; den Boer *et al.* 2005a):

$$G_p = 1.869*C_{org}*\left(0.014*\theta+0.28\right). \quad (3)$$

If $C_{org} = C_{degr}$, $C_{degr} = C_{in}*\alpha$, $\theta = 30$ Eq. 3 becomes Eq. 4:

$$G_p = 1.869*C_{degr}*\left(0.014*30+0.28\right), \quad (4)$$

where: G_p – gas potential, (m^3/t); θ – temperature in the landfill, (°C); C_{org} – organic Carbon (kg/t); α – degradation yield, (kg degr C/kg C_{in}); C_{in} – carbon input, (kg), C_{degr} – degraded carbon (kg)

Once the gas volume was calculated, it had to be converted into mass weight as the software model could not handle volumes. The density of mixed gases was calculated knowing the contents of CO_2 and CH_4 in biogas.

The biogas contains other gases so the profile of 1 kg of biogas needs to be more detailed. The trace elements of biogas were calculated with the help of two equations for estimation of emission rate of a pollutant and uncontrolled mass emissions of a pollutant (Eqs 5 and 6) (Buning 2004).

$$Q_i = \left(1+\left(\frac{C_{CO_2}\%}{C_{CH_4}\%}\right)\right)\cdot Q_{CH_4}\cdot\left(\frac{C_i}{10^6}\right), \quad (5)$$

where: Q_i – emission rate of a pollutant i, (m^3); QCH_4 – methane generation rate (m^3); C_i – concentration of i in landfill gas, (ppmv); $CCH_{4\%}$ – concentration of CH_4 in the landfill gas (55% assumed); $CCO_{2\%}$ – concentration of CO_2 and other gas in the landfill gas (45% assumed); 10^6 – conversion from ppmv.

$$UM_i = Q_i\cdot\left(\frac{MW_i\cdot 1atm}{8.205\cdot10^{-5}\cdot1000\cdot273+T}\right)\cdot rr, \quad (6)$$

where: UMi – uncontrolled mass emissions of pollutant i, (kg); Q_i – emission rate of pollutant i (m^3); MW_i – molecular weight of i, (g/mol); T – temperature of landfill gas, (°C); 8.205 ·10–5 = constant to convert emissions of i to kg; 1000 – constant, (g/K); 273 – constant 0 °C, (K); 0.34 = release rate for biogas.

The content of pollutants in the gas flow was estimated according to den Boer *et al.* (2005a). The captured biogas can be used for energy production.

Leachate can be calculated for each waste fraction separately. Calculations are based on elementary composition. The effects of each fraction on leachate can be calculated by using transfer coefficients (Buning 2004; den Boer *et al.* 2005a). Also, important data are represented by the area of landfill and annual average rainfall R (here R = 0.6737 m/year).

The necessary landfill area (A in ha) was established knowing the volume of waste landfilled. The quantity of leachate can be calculated using Eqs. 7 and 8:

$$V = A*R, \quad (7)$$

$$M = V*\rho, \quad (8)$$

where: M – mass of leachate, (kg); V – volume of leachate, (L); ρ – density of leachate (kg/L). Leachate density is assumed to be 1 t/m^3 according to the AECOM (2009).

Leachate emissions result in emissions to water and soil. Such emissions were calculated and estimated.

For composting process, the required inventory data was calculated using specific literature and software databases. Diesel is the most common automotive fuel for equipment used at composting facilities: the total fuel consumption during composting operations was calculated as 5.53 L per tonne of waste (Recycled Organics Unit 2003). The electricity demand for composting is 10 kWh/t, water demand is 2% of the input mass; also the wastewater represents 125 L/t input, while 50% of fresh compost are composed of water (den Boer *et al.* 2005a).

Emission factors for the composting process considered were: emissions to air represented by CO_2 (95% from %C emission to air), CH_4 (3% from % C emission to air), NH_3 (96% from % N emission to air) and etc.; and emission to water represented by NH_3 (47% from % N emission to water), carbon organic (100% from % C emission to water) and etc. (den Boer *et al.* 2005a). The amount of fresh compost obtained from composting process represents 72.2% from the quantity of waste composted. Also, the input and output data regarding maturation of fresh compost and for air purification process were established by calculating, estimating and collecting these data from literature. Since application of compost on soil is associated with positive effects (den Boer *et al.* 2005a), substitution of nitrogen and phosphorus fertilizers with nitrogen and phosphorus from compost was taken into account. The inputs and outputs for production of nitrogen and phosphorus fertilizers are used from the database of GaBi software.

The composition of recyclable waste and the consumption of resources used for waste sorting are important data for the sorting process. Composition of separately collected glass, paper and cardboard, plastic, metals was established based on literature data (den Boer *et al.* 2005a). Consumption or resources used for sorting and pre-cleaning of recyclable materials like glass, plastic, metals are: electricity, 10 kWh/t waste; diesel, 2.4 L/t waste; lubricants, 0.2 L/t waste. For paper and cardboard the following values were used: electricity, 5.35 kWh/t waste; diesel, 0.64 L/t waste; lubricants, 0.01 L/t waste (den Boer *et al.* 2005a). The inputs and outputs for recycling of different recyclable materials were used from GaBi database.

2.3. Life cycle impact assessment

Impact categories such as abiotic depletion, global warming, human toxicity, photochemical oxidation, acidification and eutrophication (and others) can be analysed with GaBi 4. *Abiotic depletion* describes the reduction of the global amount of non-renewable natural resources. The natural resources such as minerals, fossil fuels and others, which represent non-living substances, are considered to be abiotic resources (den Boer *et al.* 2005b; Stranddorf *et al.* 2005). Evaluation of the availability of natural elements is covered by this impact category. *Global warming potential* (GWP) is the effect of increasing temperature in the lower atmosphere (den Boer *et al.* 2005b; Stranddorf *et al.* 2005). For a substance to contribute to global warming it must be a gas at normal temperature, stable in the atmosphere for a period of a year and to be able to absorb heat radiation (Hauschild, Potting 2005). Substances that may contribute to these impact categories are CO_2, CH_4, N_2O, CFCs, HCFCs, HFCs, Halons, CCl_4, CCl_3CH_3, CO (den Boer *et al.* 2005b; Hauschild, Potting 2005; Stranddorf *et al.* 2005). *Human toxicity* is represented by negative effects on human health of toxic substances (VOC, particles, heavy metals, POPs, NO_x, SO_2 etc.) emitted to the environment (den Boer *et al.* 2005b; Stranddorf *et al.* 2005). *Photochemical oxidation:* Ozone is formed in the troposphere under the influence of sunlight when nitrogen oxides and hydrocarbons are present. NOx, VOCs including CH_4 and CO are the substances that contribute to ozone formation (den Boer *et al.* 2005b). The high concentration of ozone is registered when there is high concentration of hydrocarbon, humidity is low and temperature is high, and air is relatively static. *Acidification:* SO_2, NO_x, HCl and NH_3 represent the major acidifying pollutants. These substances release the hydrogen ions to the environment. The potential for acidification for the pollutants mentioned above can be measured by its capacity to form hydrogen ions (den Boer *et al.* 2005b; PE International 2009). *Eutrophication* includes all potential impacts of excessively high environmental levels of macronutrients (nitrogen and phosphorus). Both terrestrial and aquatic ecosystems are influenced by the eutrophication phenomenon (PE International 2009).

3. Results and discussion

Impact evaluation of waste management scenarios, achieved with GaBi software and based on life cycle assessment methodology led to results obtained for several impact assessment methods (such as CML 2001, CML 96, Environmental Development of Industrial Products (EDIP: EDIP 1997, EDIP 2003), Eco-Indicator 95 (EI95), Eco-Indicator 99 (EI 99) and etc.) after all of the scenarios were analysed. For the two groups of scenarios described above, the environmental impacts resulting from activities like temporary storage (TS), collection and transport (CT), and treatment of solid waste were compared considering CML 2001 methodology and impact categories such as: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), human toxicity potential (HTP) and potential of generating photochemical ozone (POCP). Results with a negative sign represent the benefits, i.e., positive impacts; while those with a positive sign represent the negative impacts on environment. In the impact category, AP for treatment/elimination methods from scenarios 2, 3 and 4 from group B are registered as positive impacts and negative impacts for scenarios from group A.

Fig. 2 illustrates the environmental impacts for *eutrophication potential*, where positive environmental impacts for treatment/elimination methods (noted TP) were observed from scenarios according to the following hierarchy: SB2 > SA2>SB3>SA3>SB4> SA4. Also, it can be observed that scenarios from group B have more significant environmental impacts than those from group A. Eutrophication includes all impacts resulting from excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil. Most of the processed waste is represented by organic waste and are recorded as benefits for Scenarios 2 because by collecting and treating leachate macronutrients are prevented from entering into the environment. Also, in case of other scenarios SB3, SA3, SB4 and SA4, positive impacts are recorded but because of the composting process and application of compost on soil the impacts are slightly lower than for SB2 and SA2. The impacts of scenarios from group B are much bigger than impact of the scenarios from group A. This can be explained by the fact that scenarios B not only considered processes (sorting, composting, landfilling) but also the substitution of materials obtained from conventional processes with the secondary materials obtained from waste processing.

The impacts induced by TP on GWP impact category are negative for scenarios SA1–SA4 and SB1, and positive for SB2–SB4 (Fig. 3). In scenarios that only considered the processing of waste and not the substitution of materials, the emissions of greenhouse gases to air were significant and when the materials obtained from processing of waste were used to replace materials obtained from conventional processes, environmental benefits were recorded. As no secondary materials were obtained in case of the SB1, this scenario would also have negative impacts on the environment.

Impacts of scenarios taking into account the impact category HTP are presented in Fig. 4. The negative impacts on environment for scenario SB1 are higher than for scenario SA1: SB1>SA1 and for scenarios 2: SA2>SB2. If SA3 and SA4 have negative impacts, the SB3 and SB4 will have positive impacts regarding the human toxicity potential. Toxic substances are emitted to the environment when waste is being processed. For scenarios SB3 and SB4, because of the substitution of materials (compost can be used instead of synthetic fertilisers, recycling materials can be used to obtain new products) the impacts on environment will be positive.

In Fig. 5, negative impacts are found for scenarios SA1 and SB1 and positive impacts for scenarios SB2, SB3, SB4 compared with SA2, SA3 and SA4. Processing of solid waste will lead to the emissions of precursors of tropospheric ozone (nitrogen oxides, VOCs including CH_4, CO) in the atmosphere, therefore negative impacts for scenarios SA1 SA2, SA3 and SA4 will be recorded. For scenarios SB2, SB3, SB4 because of the substitution of materials the impacts will be positive.

Collection and transport of solid waste have negative impacts on environment for all scenarios from both groups analysed, for all impact categories evaluated (Figs 2–5). Also, the temporary storage process generates negative impacts on environment, but much lower than the impacts resulting from waste collection and transport.

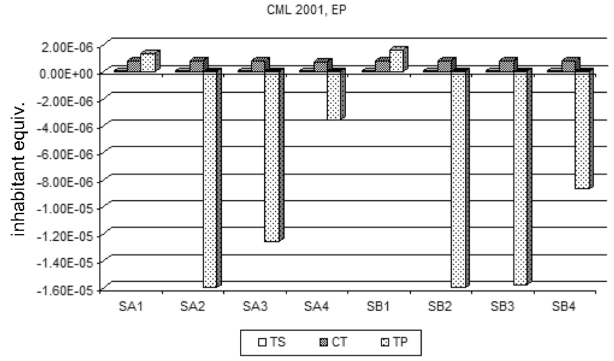

Fig. 2. Environmental impacts of scenarios from the two groups (A and B) for eutrophication potential

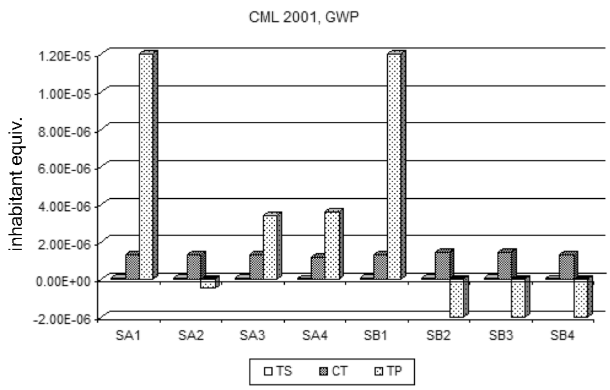

Fig. 3. Environmental impacts of scenarios from groups A and B for global warming potential

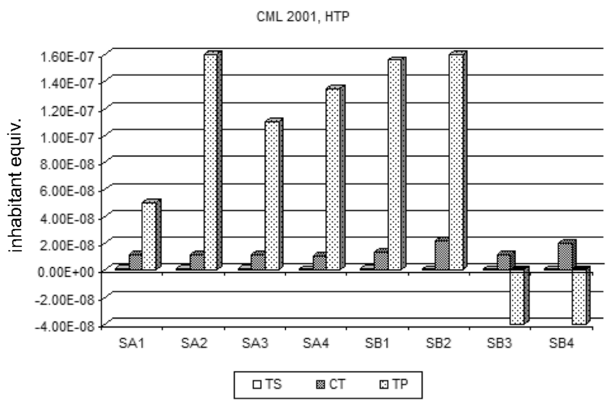

Fig. 4. Environmental impacts of scenarios for impact category – human toxicity potential

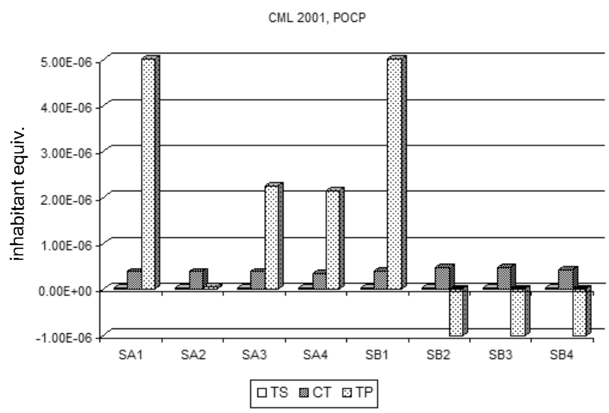

Fig. 5. Environmental impacts for photochemical ozone creation potential

Scenarios from group B can be considered to be much closer to reality and are evaluated taking into account CML 96, EI95, EDIP 2003 methodologies. Scenarios SB2, SB3 and SB4 will have positive impacts for almost all categories of impacts, while SB4 are the only scenario which induces the most frequent positive impacts than others (Fig. 6). According to the results of modelling of scenarios with CML 96 methodology, SB1 are considered to be less favourable for application/implementation from environmental point of view.

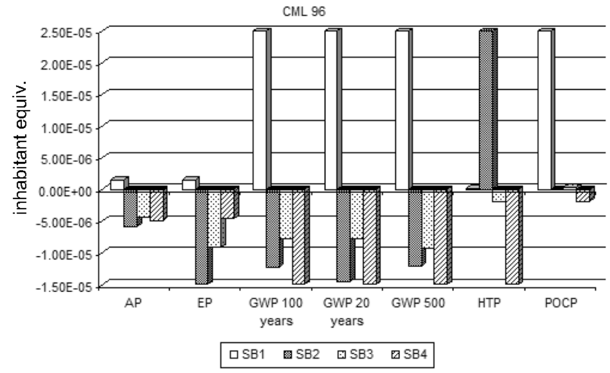

Fig. 6. Environmental impacts of scenarios from group B – CML 96 methodology

The results for EI95 methodology are expressed in indicators such as: levels of carcinogenic substances, heavy metals and winter smog. Scenarios SB3 and SB4 are the most convenient in terms of the impact they have on these indicators (Fig. 7).

According to the EDIP 2003 methodology for acidification, aquatic eutrophication, global warming and photochemical ozone formation – impact on vegetation (POF-VI), the impacts have positive values for scenarios SB2-SB4, decreasing in the order SB2> SB4 ≅ SB3 for acidification potential, SB2>SB3>SB4 for aquatic eutrophication, SB4>SB2>SB3 for global warming potential and POF-VI. Scenario SB1 will have negative impacts over all indicator categories presented in Fig. 8.

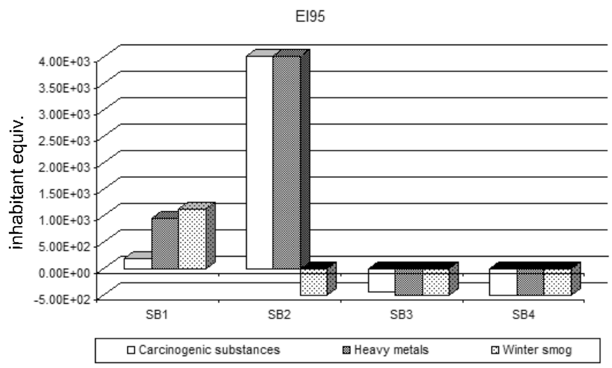

Fig. 7. Environmental impacts of scenarios from group B – EI 95 methodology

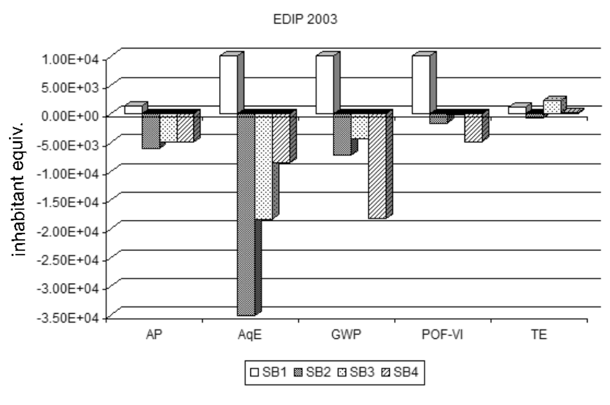

Fig. 8. Environmental impacts of scenarios from group B – EDIP 2003 methodology

Defining the system boundaries has a major influence on the results of life cycle assessment studies. Studies of scenarios with different boundaries will help the decision makers to choose the most suitable waste management system for a city from the environmental point of view. Analysis of the same scenario with varied boundaries may have different impacts on the environment.

4. Conclusions

In this study, some waste management alternatives were investigated from the environmental point of view, based on LCA analysis. The paper analyses two groups of waste management scenarios in terms of environmental impacts: scenarios from group A with limited boundaries, which include only the specific processes involved in waste management, and systems from group B with slightly larger boundaries. The limits chosen are very important because the results regarding the impacts on environment and also the system that can be selected for implementation are influenced by the boundaries.

The study applied to waste management in Iasi city, Romania. It analysed both the existing system until 2009, the current system and also the potential scenarios with improvements to the existing system of waste management, in order to highlight how it might evolve or develop in the future, with minimum negative environmental impacts.

Further studies will analyse other processes that could be included in solid waste management system processes such as anaerobic digestion or incineration. Since this study examined environmental impacts alone, it will be sustained by the economic and social effects of solid waste management, as decision-making tools.

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APLINKOSAUGINIS ATLIEKŲ TVARKYMO SCENARIJŲ ĮVERTINIMAS – RIBŲ REIKŠMINGUMAS

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S a n t r a u k a

Analizuojant ir vertinant komunalinių atliekų tvarkymo scenarijus buvo pritaikyta būvio ciklo koncepcija atsižvelgiant į daromą poveikį aplinkai, remiantis Jasai miesto, Rumunijoje, atveju. Šiame mieste susidaro apytiksliai 380 kg/žmogui/metus atliekų. Šiuo metu atliekų tvarkymo procesą sudaro laikinos laikymo vietos, surinkimas, transportavimas ir deponavimas sąvartyne, bet pagal Nacionalinę strategiją ir Europos atliekų politiką atliekos turi būti rūšiuojamos, perdirbamos ir kompostuojamos. Todėl buvo detaliau išanalizuoti keturi skirtingi scenarijai kaip alternatyvos esamai atliekų tvarkymo sistemai Jasai mieste, įtraukiant prieš tai taikytas ir šiuo metu taikomas atliekų tvarkymo alternatyvas, taip pat pažangesnes praktikas. Scenarijų efektyvumas buvo vertinamas analizuojant aplinkosaugos aspektus remiantis būvio ciklo analize ir taikant GaBi programinę įrangą. Kai kurios poveikio aplinkai kategorijos (rūgštinimas, eutrofikacija, globalus atšilimas, žmonių apsinuodijimas, fotocheminis ozono susidarymo potencialas, kancerogeninės medžiagos, sunkieji metalai, žiemos smogas, fotocheminis ozono formavimasis) buvo vertinamos remiantis keletu poveikio įvertinimo aspektų, esančių GaBi programoje (CML 2001, CML 96, EDIP 2003, EI95). Atlikta studija pabrėžia sistemos ribų svarbą, vykdant poveikio vertinimą, taikant būvio ciklo procesą ir parenkant optimalią atliekų tvarkymo alternatyvą.

Reikšminiai žodžiai: aplinka, GaBi, būvio ciklo vertinimas, kietosios atliekos, atliekų tvarkymo technologijos.

ПРИРОДООХРАННАЯ ОЦЕНКА СЦЕНАРИЕВ ПО ОБРАБОТКЕ ОТХОДОВ – ЗНАЧИМОСТЬ ГРАНИЦ

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Р е з ю м е

При анализе и оценке сценариев по обработке коммунальных отходов с учетом их влияния на окружающую среду в городе Ясай в Румынии, где приблизительно скапливается 380 кг/чел./ год отходов, применялась концепция цикла существования. В настоящее время в процесс по обработке отходов вовлекаются временные места хранения, сбор, транспортировка и депонирование отходов на свалке. Однако на основании Национальной стратегии и Европейской политики, касаюшейся отходов, они должны сортироваться, перерабатываться и компостироваться. В связи с этим детально проанализированы четыре разных сценария в качестве альтернатив существующей в городе Ясай системе обработки отходов с использованием применявшихся ранее и применяемых в настоящее время альтернатив по обработке отходов, а также прогрессивных практик. Эффективность сценариев оценивалась на основании анализа природоохранных аспектов касательно анализа цикла существования и с применением программного оборудования GaBi. Некоторые категории влияния на окружающую среду (окисление, эутрофикация, глобальное потепление, отравление людей, фотохимический потенциал образования озона, канцерогенные вещества, тяжелые металлы, зимний смог, фотохимическое формирование озона) оценивались на основании нескольких аспектов влияния, имеющихся в программе GaBi (CML 2001, CML 96, EDIP 2003, EI95). Проведенный анализ подчеркивает важность границ системы при оценке влияния и применении процесса цикла существования, а также подборе оптимальных альтернатив обработки отходов.

Ключевые слова: окружающая среда, GaBi, оценка цикла существования, твердые отходы, технологии обработки отходов.

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