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UNIVERSITATEA TEHNICĂ "GHEORGHE ASACHI" DIN IAŞI

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Faculty of Environmental Science and Engineering

CONTRIBUTIONS TO THE EFFICIENCY OF THE HOUSEHOLD WASTE MANAGEMENT SYSTEMS (CASE STUDY: CLUJ COUNTY)

\- THE SUMMARY OF THE THESIS -

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Cluj-Napoca
October, 2012

TABLE OF CONTENTS

The summary of the thesis presents some of the results of the experimental research, general conclusions and a selective bibliography. In drawing the summary were kept the same notations for chapters, paragraphs, figures, tables and equations used in the text of the thesis.

Abstract

The theme of the thesis was defined after analyzing the current situation of waste management system in Cluj county, coupled with the analysis of the objectives set out in legislation (objective with deadlines), after which it was found that there are many aspects that can be improved in this area. Later it was decided that for the replacement or improvement of some stages of the waste management system is necessary to analyze the main sources of pollution existing within this system. Thus, we have chosen as a subject Pata Rat municipal landfill and two storage areas rural areas of Cluj County. Waste rural storages was found that although they were declared closed, they are not monitored and are not yet rehabilitated and continue to pollute the environment.

To know the perception of the population regarding waste issues were conducted two surveys in urban and rural areas of the Cluj County. The analysis of the surveys noted on one hand that the population believes that in the current management of waste are real problems, and on the other hand, there doesn’t exist a good public information about these issues.

Were also studied several ways of selective waste collection at source in developed EU countries and compared to Cluj County and was found that here the collection at source is almost absent or exists in a very small extent.

In addition were estimated the amount of methane and carbon dioxide emitted by municipal landfill Pata Rat, given these gases contribute to the global budget of greenhouse gases. Also, four scenarios of waste management systems were modeled by LCA methodology (Life Cycle Assessment) to obtain the most favorable scenario in relation to the environment.

After correlating the results an integrated waste management system in Cluj County was proposed, efficient in terms of its environmental impact. To this system was applied a SWOT analysis to identify strengths, weaknesses, opportunities and threats.

Keywords:

Integrated waste management system

Life Cycle Assessment

Closed Chamber Method

IPCC 2006 DM Method

Atomic absorption spectrometry

Landfill

Selective waste collection

CHAPTER 1
INTRODUCTION

It is well known that our society is a society of economic growth and development. Undoubtedly the primary objective of any country is the growth continues. But it also requires adequate protection of the environment to ensure sustainable development of society. Among the many environmental problems, without a doubt that waste is a major problem. Quantities of waste generated in a brisk increase from year to year and the impact on the environment and therefore the community is getting bigger.

Municipal waste management is a major responsibility primarily to government authorities, but also for the population. In Cluj County municipal waste management is achieved through three main stages: mixed waste collection, transport to the landfill and disposal.

The overall objective of this thesis is to analyze the existing waste management system and develop proposals for improvements to obtain a system of integrated waste management, favorable for the environmental impact.

The specific objectives of the thesis

To get an insight into compliant environmental pollution by landfills in Cluj County, analyzes were performed on samples of surface water, soil and air samples from storage facilities in rural areas and municipal waste from landfill "Pata Rat ". Measurement of the environmental pollutants from landfill areas is important because of the negative effects they have on the environment and human health.

Also, pollutants emitted from landfills (methane carbon dioxide, nitrous oxide, VOC etc) take part in the destruction of stratospheric ozone, contribute to the photochemical smog appearance and climate change. It is important to estimate the most representative of these emissions, methane and carbon dioxide on the surface of landfills as 3% of greenhouse gas emissions in the EU are generated by landfills (EEA Report, 2011). In order to estimate the amount of methane and carbon dioxide emitted on the surface of the landfill Pata Rat, measurements were performed *in situ with closed chamber method* using a portable detector for methane and carbon dioxide (West Systems, SRL, Italy) .These were compared with results obtained using IPCC 2006 DM.

Regarding the incineration of waste, in Cluj-Napoca operates a modern incinerator for medical waste and other hazardous waste. The incinerator has an incineration capacity of 550 kg / hour and could be introduced into integrated management of household waste circuit for the incineration of household hazardous waste fractions, textile, plastic scrap etc. The assessment of the environmental impact of the incinerator was conducted in *monitoring distribution of heavy metals from incinerator ash - a case study* in which we worked. This study was conducted by Hategan et al., 2011. The results of this study refer to the following:

- Analysis demonstrates a low content of heavy metals in the bottom ash (0,0019%), the non-dangerous nature of it, which allows its disposal in the municipal landfill

- Heavy metal concentrations in flue gases discharged into the atmosphere do not exceed the legal permissible limits laid down in Decision no. 128/2002 on the incineration of waste;

- modern methods of treatment and management of waste / emissions developed in the system ensures that the immediate release of heavy metals into the environment is reduced;

- due to high environmental standards to be met, incinerators have become a solution for 'green' waste treatment, particularly those hazards.

The same authors found that both in Cluj Napoca and Romania, municipal waste aren't incinerated, though it would be a viable alternative for the correct application of an integrated waste management (Hategan et al., 2011).

In order to choose the most efficient integrated waste management system, was used GaBi4 software, version for universities, from the PE International Company, Germany. With this software were analyzed four scenarios of waste management systems and have calculated the most important potential environmental impacts. After comparing the results, was chosen the most effective scenario of waste management integrated system, in terms of environmental protection.

Structure of the thesis

The thesis is organized in 8 chapters and 201 pages, 66 tables, 74 figures, 3 annexes and 150 references. This thesis is divided into **seven chapters,** the first 4 containing predominantly theoretical. The **first chapter** presents the research and thesis motivation and objective.

Chapter 2 presents the results of two surveys conducted for urban and rural areas, in order to understand the perception of people about waste management systems. Also were analyzed and presented several systems of waste collection from different countries in Europe, for comparison with the situation in Romania and to identify ways to increase the performance of waste management systems in the country.

Chapter 3 describes the study area, the current situation of waste management in the Cluj County, the new waste management system proposed by the local authorities for the County of Cluj which currently is in the planning phase. It also describes the problems identified in the current system of municipal solid waste management in Cluj County and the county-level goals and objectives relating to municipal waste management.

Chapter 4 deals with waste issues, presenting general aspects including waste and waste stages through an integrated management system. It also summarized the current legislative framework in relation to waste management.

Chapter 5 contains information about the environmental pollution of the surface water, soil and air analyzed in the first part of the experimental chapter.

The experimental part is described in **Chapter 6,** the largest one, which contains three parts: the *first part* refers to the assessment of the impact and environmental risk in several rural deposits and in the municipal landfill Pata Rat, *the second part* refers to the assessment of methane and carbon dioxide from the surface of the municipal landfill Pata Rat, and *the third part* compared four scenarios of integrated waste management systems in order to find the best environmental performance. All three experimental parts at the end presents some preliminary conclusions.

Chapter 7 deals with proposals to improve the current system of waste management in Cluj County, based on comparative analysis.

At the end of the thesis are presented conclusions drawn from the results obtained, followed by very precisely references that refer to the theme.

The original results of the thesis were distributed as follows: 3 articles published in ISI journals, 3 papers under review for publication in ISI journals, 4 articles published in BDI journals, 1 article published in a volume of scientific events, 3 papers presented as oral communications and 3 papers presented as posters at national and international conferences

CHAPTER VI
THE EXPERIMENTAL PART AND THE METHODOLOGY

6.1. THE METHOD INTEGRATED QUANTITATIVE RISK ASSESSMENT AND ENVIRONMENTAL IMPACT (MICEIRM) - BRIEF DESCRIPTION

To assess the overall environmental quality in a given area, as well as individual components (water, air, soil), environmental management uses various methods, including: environmental audit, environmental impact assessment, environmental risk, LCA.

For the assessment of the environmental impact can use various techniques such as checklists (checklists) matrices, qualitative and quantitative models, decision support systems, review of literature (Hook et al, 2008), but it is necessary to follow simple procedures (Kuitunen et al., 2007).

The integrated method was developed as a combination of two methods: the global pollution index method and matrix of significance scale method (Gavrilescu, 2003; Macoveanu, 2005; Robu, 2005; Robu and Macoveanu, 2005).

This method for environmental impact and risk assessment (EIRA) technique was used considering the following environmental components: surface water, soil and air during the evaluation procedure. The evaluation of the environmental impact (EI) was carried out using a matrix used by Robu et al. (2005) in order to calculate the significance of the environmental component, potentially affected by the landfill site.

6.1.2. Estimation of the environmental impact and risk for rural deposits

6.1.2.1. Introduction

The two areas of Cluj County including rural areas of waste storage, where samples were taken from surface water and ground, are:

-***Area 1*** consists of: *Gârbău Region* with 2 waste storage areas: *Tog* place in Turea village and *Career* site from Corneşti village, respectively *Aghiresu Region* with 4 waste storage areas located in rural countryside: Ticu village, Ticu Colony, Arghişu and Dâncu .

- ***Area 2*** *Mociu Region* formed by 2 waste storage areas: *Sojba* place in Mociu village and *Under the hill* place from Chesau village, respectively *Suatu village* with 2 waste storage areas: *Ciscut* place in Aruncut village and Damburile place in Damburile village.

In **Figure 3.2** is shown the location of areas 1 and 2 in Cluj County.

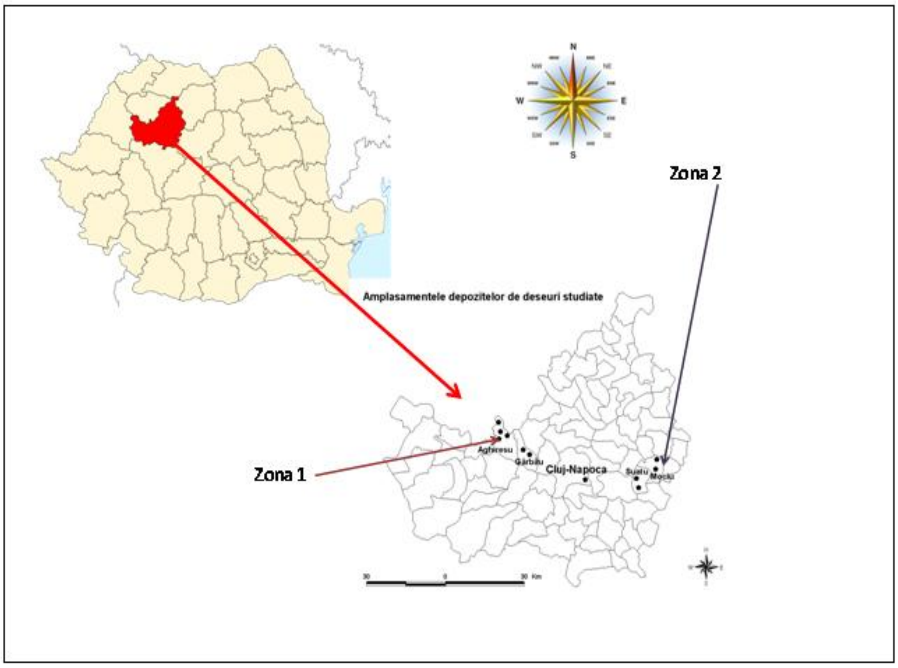

Figure 3.2. Location of the rural areas 1 and 2 in Cluj County.
(Source: Atlas of the Counties of Romania, physical, economic and touristic maps)

To evaluate the environmental pollution components (surface and ground water) in both rural areas studied were sampled surface waters near the waste disposal in rural areas and soil samples from their proximity. Then were analyzed the specific parameters for each component of the environment (water and soil) and the results were interpreted using the integrated method of impact assessment and environmental risk MICEIRM.

For soil samples (aqueous extract) were determined *physical-chemical (pH, redox potential, electrical conductivity, TDS, salinity)* using WTW Multiparameter 720 SERIES INOLAB, *humidity, humus and carbonates* by estimation method and *heavy metals* by atomic absorption spectrometry method AAS.

For water samples were analyzed *physical-chemical parameters (pH, redox potential, electrical conductivity, TDS, salinity)* using WTW Multiparameter 720 SERIES INOLAB. Also were more determined *heavy metals* by atomic absorption spectrometry method AAS (Popita et al, 2011a). ZEEnit atomic absorption spectrometer 700 is used for the determination of trace elements in solution (flame for determination of the order of mg/l and graphite furnace for determination of the order µg / l). Above parameters for soil and water, were analyzed in an integrated laboratory for analysis of water and sediment at the Faculty of Environmental Science and Engineering Cluj-Napoca.

To interpret the results the quantitative environmental impact and risk assessment integrated method was applied.

6.1.2.3. Results and Discussion

Environmental impact and risk quantification for each environmental component and important units are listed in **table 6.1.27.**

Table 6.1.27. Environmental impact and risk quantified for each environmental component

Environmental component	Importance IU units	EI environmental impact	ER Environmental risk
Surface water area 1	689.66	3,290	2,437
Surface water area 2	689.66	2,895	2,145
Sol area 1	413.79	267	129
Sol area 2	413.79	716	345

The environmental impacts and risks for soil are relatively small, the environmental impact depends directly by measured concentration of pollutants analyzed. This indicates that pollution of environmental factors is minor. The high environmental impact and risk for surface water indicate the presence of high concentrations of pollutants in water.

Figure **6.1.7** shows a comparison between impacts (EI) and environmental risks (ER) in the two studied areas.

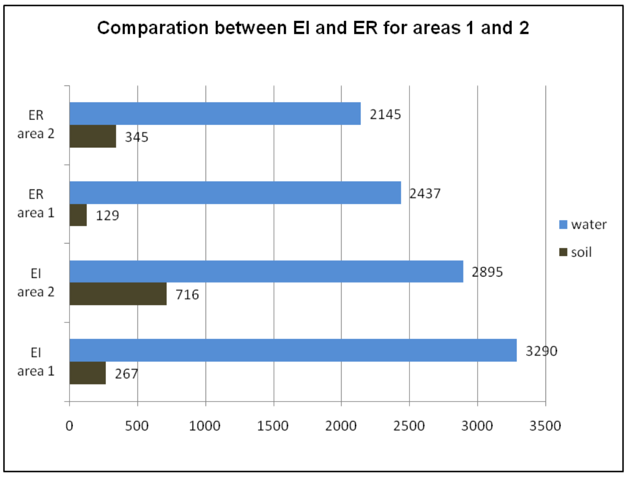

Figure 6.1.7. Comparison of environmental impacts and risks calculated for areas 1 and 2

The analysis of the chart **6.1.7** shows that EI and ER for water are higher in area 1 than in area 2, but for soil EI and ER are higher in area 2 than in area 1. From these results it can be concluded that surface water is more polluted in area 1 and the soil is more polluted in area 2.

6.1.2.5. Conclusions

After analyzing the results obtained for the two components of the environment (water and soil) in the rural areas 1 and 2, and considering the impact and risk classification of global pollution index method Rojanschi**,** it can be seen that the environmental impact *on soil* in *Area 1* has values between 100-350. It means “environment modified by human activities within admissible limits” and environmental risk is minor (in terms of parameters analyzed), but but monitoring actions are required.

For *area 2*, although the environmental impact has values between 500-700, which means "“environment modified by human activities causing disturbance on forms of life", the environmental risk has an acceptable level, but in this case it is necessary to monitor environmental components studied.

But *for surface water*, the environmental impact and environmental risk have values that exceed 1000, which means *"degraded environment, improper forms of life"* and a high risk environment. From these results we conclude that there are large amounts of surface water pollutant and is necessary to take measures to control and prevent especially the metal pollution of surface water.

6.1.3. Estimation of the environmental impact and risk for municipal landfill "Pata Rat"

“Pata Rat” is the largest municipal waste disposal facility (landfill) of the Cluj County in Romania (Fig. 1). It is located alongside the road linking the village Pata and city Cluj-Napoca, and was put into operation in 1973. It was designed for a capacity of 3.5 million tons of communal waste in an area of approximately 9 hectares and it was planned for 30 years of operation (Proorocu, 2005).

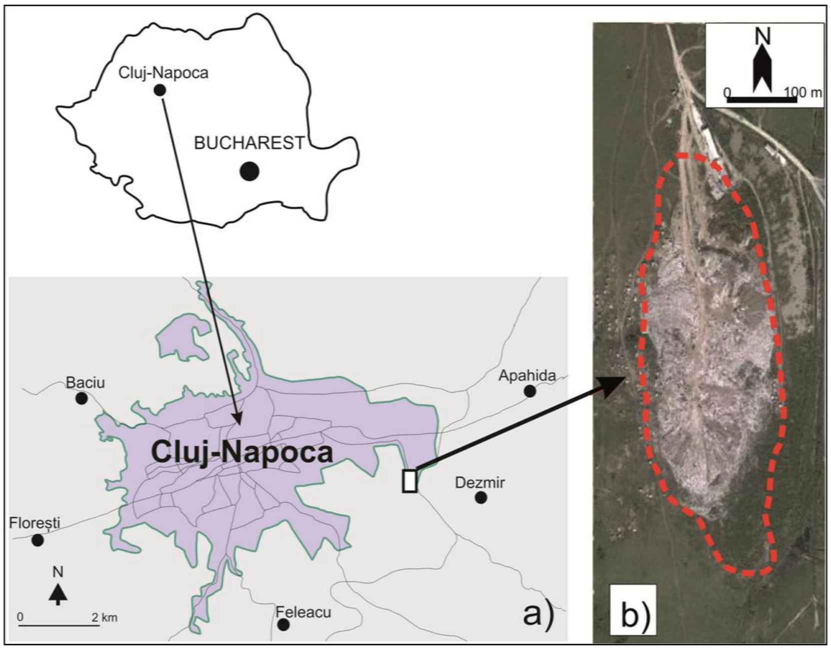

Figura 3.5. Location of Pata Rat landfill, Cluj Napoca, Romania (Source: Google Earth), a) map of Romania; b) map of Cluj-Napoca city; c) location of Pata Rat landfill

According to the inventory and the available data, the lifetime of the facility was increased by seven years and during the 37 years of operation about 8-10 million tons of municipal and industrial waste was disposed without preliminary separation or any pretreatment. Regarding the construction and the operation of the facility, it can be concluded that the facility is not considered to be safe disposal one (Medana, 2010). The waste storage facility under these conditions resulted in changes in the environmental elements: air, water, soil parameters. The waste composition on the Pata Rat landfill was: 46% biowaste, 21% plastic, 17% paper and cardboard, 3% metals, glass 3% and other waste 11%.

The potential pollution of the environment was investigated based on the following measurements:

- Surface water analysis close to the site
- Soil analysis at site
- Air pollutant analysis around the site
- Leachate analysis

For the evaluation of the *soil (aqueous extract)* were carried out measurements for the following quality indicators: pH, redox potential, conductivity, TDS, salinity and temperature of soil solution ((aqueous extract), and heavy metals (Cr, Cd, Cu, Ni, Pb, Zn). The quality of soil was assessed in consideration of the national legislation (GD, 1997). The collected soil samples were mineralized according to ISO11466 by extraction with aqua regia (3 parts HCl: 1part HNO_3). Following this, the heavy metals were analyzed with atomic absorption spectrometer (AAS) Analytic Jena, ZEEnit 700.

For *surface water,* were carried out measurements for the following quality indicators: pH, redox potential, conductivity, TDS, salinity, temperature, COC-Cr, CBO5, NH_4-N, NO_2-N, NO_3-N, total P, residue, Cr, Cd, Cu, Ni, Pb, Zn.

The samples were analyzed by standard methods according to national legislation (GD 188, 2002). A WTW 720 SERIES INOLAB type Multiparameter was used for the following measurements: pH, redox potential, conductivity, TDS, salinity, temperature, and a_Nanocolor Linus MN type digital photometer was used_for the following measurements: COC-Cr, CBO5, NH_4-N, NO_2-N, NO_3-N, total P and residue. The heavy metals (Cr, Cu, Pb, Cd, Ni, Zn) were analyzed with atomic absorption spectrometer (AAS) ZEEnit 700.

The parameters were analyzed *in the Laboratory integrated of water and sediment analysis of the Faculty of Science and Environmental Engineering Cluj-Napoca and the laboratories of the Institute of Environmental Engineering from Veszprem, Hungary*.

To interpret the results was applied the assessment of environmental impact and risk quantitative integrated method.

The soil sampling sites were selected close to the villages around the landfill, and are given in Table 1. The distances between the landfill and the villages are as follow: at North – Pata Rat (approx. 1.2 km), at East – Dezmir (approx. 1.3 km); at South – Feleacu (approx. 1.8 km); at West – Budunus Colony (approx 0.4 km).

Two surface water segments (from stream nearby the evaluated site, upstream and downstream to the effluent discharge point into the stream) were analyzed.

Pârâul Zăpodie, ce izvorăşte în apropierea depozitului de deşeuri menajere “Pata Rât”, se încadrează în clasa a IV-a de calitate, datorită depășirii indicatorilor din grupa nutrienți (azotiți și amoniu), ca urmare a scurgerilor de levigat provenite de la depozitul de deşeuri (APM Cluj, 2008, 2009, 2010; 2011).

Water samples were collected in two different periods in terms of rainfall. The first period was the fall of 2011, when there were drought conditions, rainfall was very low and the water was very polluted by the leakage of leachate from the landfill. The second period of water sampling was spring 2012, when rainfall was more abundant.

The quality of air was evaluated for the following components/indicators: NO_2, VOC, SO_2, dust (particulate matter PM10) and formaldehyde. The air quality was assessed considering the national legislation (GD 592, 2002; GD, 1993). Six samples were taken around the landfill area and close to the nearby villages: Pata, Budunus Colony, Dezmir, Apahida, Sannicoara and Someseni (Fig. 4.).

The samples were analyzed using methodologies which included different determinations, and the following methods:

- the determination of sulphur dioxide and nitrogen dioxide was carried out using a molecular absorption spectrophotometer Analytic Jena Specord 30.
- the determination of the respirable dust (PM10) was carried out with MIE Personal Data RAM pDR-1200 device, which measures and displays the actual concentration and the mean concentration within the measurement range.
- the determination of *total VOC* was carried out by gas chromatography (GC-MS), using a gas chromatograph Shimadzu GC2010GP.
- the determination of formaldehyde concentration was carried out with a portable device for the gas measurement by photo-acoustic IR spectroscopy: Multi-gas Monitor type 1302 Bruel&Kjaer series 1568766 (Cluj County and CMS SEI, 2009).

The samples were analyzed by the laboratories of the Environment and Health Center Cluj.

The leachate is the liquid generated during the storage of the solid waste in a landfill by: storm water entering into the landfill body, separation of the water contained in the waste landfilled and the decomposition of the stored biodegradable waste (MMGA MO 86bis, 2004).

The leachate samples were collected in plastic bottles tightly closed (3000 ml for each sample) by inserting the bottles into the collecting tank situated at the edge of the landfill. The collecting tank is used for the collection just of a small leachate quantity; the other part is released into the environment. The samples were collected once a year in the period of 2006-2010. The samples were analyzed by the laboratories of the Environment and Health Center Cluj for the following indicators: arsenic, total chromium, selenium, lead, hexavalent chromium, chloride, COD-Mn (Chemical oxygen demand), COD-Cr (chemical oxygen), TSM (total suspended matter) in petroleum ether, ammonia, nitrates, nitrites, phosphates, total phosphorus, sulphates, filterable residue dried at 105 ° C (fixed), total cyanide, pH, Cd, Co, Cu, Hg, Ni.

6.1.3.3. Results and discussion

To assess the environmental impact and risk through the integrated method were calculated importance units for the environmental components considered in the assessment impact: soil, air and surface water. There are two sets of results: the first set to which were used the test results obtained for water samples collected in the dry season, together with the results obtained for air and soil and the second set to which were used for the test results obtained for the water samples collected in the rainy season together with the results obtained for air and soil.

Environmental impact and risk quantification for each environmental component (the first set of water samples) and important units are listed in **Table 6.1.51.** (Popiţa et al, 2012).

Table 6.1.51. Environmental impact and risk quantification for each environmental component (the first set of water samples)

Environmental component	Importance IU units	Environmental impact EI	Environmental risk ER
Surface water	476.19	37,402	25,618
Soil	440.56	332	114
Air	314.69	63	14

For the environmental components air and soil, the environmental impact and risk values are relatively small, the average impact depending directly by measured concentration of the pollutants analyzed, which shows that the pollution of these environmental factors is minor. For surface water, the high values of the environmental impact and risk indicate the presence of high concentrations of pollutants in water (Popiţa et al, 2012).

In order to plot the obtained results, it was envisaged that the results of soil and air are the same for both interpretations. For surface water were taken into account the results of the two sets of results.

The environmental impact and risk quantification for each environmental component (the second set of water samples) and important units are listed in **Table 6.1.52.**

Table 6.1.52. Environmental impact and risk quantified for each environmental component (second set of water samples)

Environmental component	Importance IU units	Environmental impact EI	Environmental risk ER
Surface water	476.19	2,604	1,818
Soil	440.56	332	114
Air	314.69	63	14

Figure 6.1.16 represent the dependence of environmental impact and risk for the three environmental components analyzed (for the first set of results).

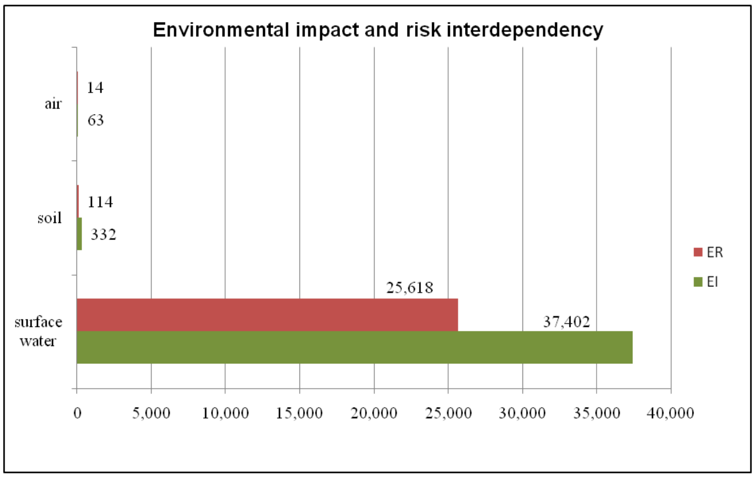

Figure 6.1.16. Graphical representation of the dependence of the environmental impact (IM) and risk (RM) for surface water, air and soil (for the first set of results)

It can be seen that EI is higher than ER for all three environmental components, but for surface water, both values for EI and ER are very high.

Figure 6.1.19 present the dependence of the environmental impact and risk for the three environmental components analyzed (for the second set of results).

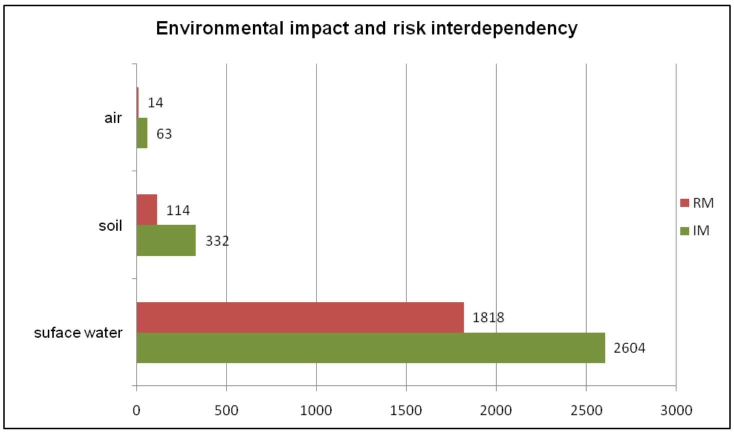

Figure 6.1.19. Graphical representation of the dependence of the environmental impact (IM) and risk (RM) for surface water, air and soil (for the second set of results)

As can be seen in Figure **6.1.22** the EI is higher than ER for all three components of the environment. For surface water, the values are lower than for the first set of measurements for both EI and ER and are higher than for air and soil.

Figure 6.1.20 represent the plot of surface water, a comparison between the environmental impacts and risks for the two sets of results.

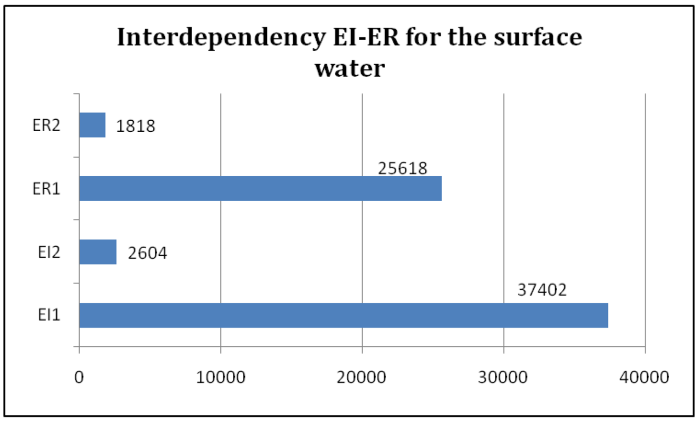

Figure 6.1.20. Comparison between the environmental impact and risk for the two sets of results obtained for surface water

From **Figure 1.6.20** it appears that the first set of analyzed samples (taken in the dry period), EI and ER *are 14 times higher* than for the second set of water analyzed samples (taken in a rainy period).

Zapodie stream classification in ecological status (MMGA MO 511, 2006), in terms of concentration of the analyzed quality indicators *(for the first set of samples)* is shown in **Table 6.1.53.**

Table 6.1.53. Zapodie stream ecological status classification in terms of the concentration of analyzed quality indicators, P $_{a1}$ downstream (■), P $_{a3}$ upstream (●)

No.	Quality indicator	Class I Very Good	Class II Good	Class III Moderate	Class IV Poor	Class V Bad
1	COC-Cr		●			■
2	BOD5			●		■
3	NH4-N					● ■
4	NO2-N	●				■
5	NO3-N		●			■
6	P total	●				■
7	fixed residue	●		■		
8	CD				■ ●	
9	Cr		■ ●			
10	Cu	■ ●				
11	Ni					■ ●
12	Zn	■ ●				
13	Pb	■ ●				

As can be seen from **Table 6.1.53,** for the sample taken from upstream of the landfill, from 13 quality analyzed indicators, *6* are *in quality class I (very good), 3 in quality class II (good),* and the remaining 4 indicators in the quality classes III (moderate), IV (poor) and V (poor).

Zapodie stream classification in ecological status (MMGA MO 511, 2006), in terms of concentration of the analyzed quality indicators *(for the second set of samples)* is shown in **Table 6.1.54.**

Table 6.1.54. Zapodie stream ecological status classification in terms of the concentration of the analyzed quality indicators, P_{a1} downstream (Δ), P_{a2} upstream (◊)

No.	Quality indicator	Class I Very Good	Class II Good	Class III Moderate	Class IV Poor	Class V Bad
1	COC-Cr				◊	Δ
2	BOD5	◊				Δ
3	NH4-N			◊		Δ
4	NO2-N			Δ	◊	
5	NO3-N	◊	Δ			
6	P total		◊			Δ
7	fixed residue	Δ ◊				
8	CD	Δ ◊				
9	Cr	Δ ◊				
10	Cu	◊	Δ			
11	Ni			Δ ◊		
12	Zn	◊	Δ			
13	Pb	◊	Δ			

As can be seen from **Table 6.1.54,** for the sample taken upstream of the landfill, from 13 analyzed quality indicators, 8 are *in quality class I (very good), 1 in quality class II (good),* 2 indicators in the quality class III (moderate) and 2 indicators in the quality class IV (poor).

Interpretation of the results for leachate

The results obtained show a high leachate pollution especially with chlorides, sulfates, ammonia and petroleum ether extractable substances. Also, leachate exceeded the limit value for Cu, Ni and total P and nitrates.

The presence of metals in larger or smaller amounts in leachate analysis depends on the type and waste quantities stored here referring particularly to hazardous household category which also includes portable batteries (Popita et al, 2010).

The measured values for COD-Cr, TSM and filtered dry residue at 105 ° C, are above the permissible limit values with several orders of magnitude. Is very well known that ammonia is highly toxic to most organisms in aquatic ecosystems, elevated levels of ammonia in water indicating the existence of advanced pollution with organic substances. From the analysis results the values for ammonia exceed the value limit with several orders of magnitude.

But is very important to know that the leachate is collected only from a certain part of the landfill (on about 15% of the landfill), that part where the waste is stored more longer than 10 years. The remaining leachate seeps directly into the soil, and may undergo to a natural self-purification effect, but it assumes the existence of large areas of soil with average porosity and a certain distance from the phreatic layer, and in this case the distance to the phreatic layer is relatively small (Cluj County and CMS SEI, 2009).

6.1.3.5. Conclusions

If we consider the impact and risk classification from the global pollution index Rojanschi method, can see that for the soil, the environmental impact has values between 100-350 which means "environment affected by human activities within acceptable limits", the environmental risk is minor and is necessary to perform a pollution monitoring. For a*ir*, the values for both environmental impact and risk are insignificant (Popiţa et al, 2012), which means that the environment is not affected by human activity, but other issues remain unresolved, such as odors, accidental pollution, etc. .

But for surface water, the environmental impact and risk have values that go far beyond 1000, which means "degraded environment, improper for life", meaning that the surface water contain large amounts of pollutants, in this case being necessary measures to control and prevent the pollution of surface water with leachate.

The first set of results for surface water shows values 14 times higher than the second set. The analysis of the two sets of measurements can concluded that the environmental impacts and risks are very high in both periods exceeding in both cases the value of 1000, but during rainy period when the stream flow is greater, due to dilution pollution is significantly lower than dry period. Both results indicate a significant pollution of the stream with pollutants from the leachate.

About the *leachate,* it is particularly important to exist a full collection, to avoid the pollution of surface water, groundwater and soil.

The presented data in tables **6.1.53** and **6.1.54** show that more than half of examined quality indicators show a very good quality of Zapodie stream before it passing through the "Pata Rat" landfill. Also, large differences can be observed between the two sampling periods.

For the sample taken downstream of the landfill (first set of samples) from 13 analyzed quality indicators, *7 are in class quality V (poor),* 1 in class quality IV (poor), and the remaining 5 indicators in the quality classes III (moderate), II (good) and I (very good). These data shows that more than half of examined quality indicators show poor water quality of Zapodie stream after it passing through the "Pata Rat" landfill.

In case of the second set of samples, the sample taken downstream of the landfill, from 13 analyzed quality indicators, 4 are *in quality class V (poor),* 1 in quality class III (moderate), and the remaining 7 indicators in quality class II (good) and I (very good). The presented data for the second set of samples shows that more than half of quality indicators show a good quality of stream water after after it passing through the "Pata Rat" landfill.

From the results presented above, it is clear that Zapodie stream change it quality class depending of the sampling periods, as follows: Zapodie stream change it quality class from II (good) in V (bad) in dry periods and, from II (good) to III (moderate) in rainy periods.

This means that for an adequate monitoring of the leachate pollution of the stream, sampling is needed throughout the all year, in order to perform the average concentrations of pollutants in water. However, regardless of dry or rainy periods, it is imperative to take measures to prevent pollution with leachate of Zapodie stream.

6.2. THE ESTIMATION OF THE EMISSIONS OF GREENHOUSE GASES (METHANE AND CARBON DIOXIDE) FROM THE MUNICIPAL LANDFILL "PATA RAT", CLUJ-NAPOCA

Methane (CH_4) and carbon dioxide (CO_2) are important greenhouse gases and major environmental pollutants, with contribution to climate change. Methane is a more potent greenhouse agent than CO_2, and has a relative shorter residence time in the atmosphere (7–10 years), in comparison with CO_2 (100 years) (IPCC, 2001). Waste landfills have been recognized as a large source of anthropogenic methane emission. Typically, CH4 emissions from solid waste disposal sites are the largest source of greenhouse gas emissions in the Waste Sector (IPCC, 2006). The global emission of methane from landfills is quite uncertain since the estimated values ranges from 16 to 57 $Mt \cdot y^{-1}$ (Bogner and Matthews, 2003; IPCC, 2001)

Particular interest has been shown in the last decades for recovering the methane and other combustible gases released from landfills, and using them as a source of energy for residential, commercial and industrial applications (Xu Xin-Hua et al., 2003).

The municipal solid waste (MSW) is generally collected from the population and disposed in landfills, and includes degradable materials (paper, textiles, food waste, straw, yard waste, etc.), partially degradable materials (wood, disposable napkins, sludge, etc.) and non-degradable materials (leather, plastic, rubber, metals, glass, ash from fuel burning as coal, briquettes or wood, dust, electronic waste, etc.).

Overall volume of the biogas composition is: 55% CH_4, 40% CO_2, 5% N_2 and small amounts of VOCs such as benzene, chloroform, 1,1-dicloretene, carbon tetrachloride and other (USEPA, 2005). Biogas also contains water vapor close to saturation point corresponding to the storage cell temperature, small amounts of ammonia, H_2S and other substances in very small quantities.

In optimum conditions at least 50% of the methane from the MSW, can be generated in the first year of waste disposal, provided that the storage area is not covered, and rainfall can infiltrate the table to store (Themelis et al, 2007).

The total release of gas at the surface is expressed by an emission factor expressed in $t \cdot km^{-2} \cdot year^{-1}$. This is the key parameter used to extrapolate gas emissions from anthropogenic and natural sources (EMEP / EEA, 2009) and allows comparing the emissions from different landfills. Biogas can be used to replace traditional sources of energy, nonrenewable and increasingly expensive (Yuzhakova et al, 2012).

6.2.1. Metodology

Study of methane and carbon dioxide emissions on the surface of the Pata Rat landfill focused primarily on *in situ* measurement of CH_4 and CO_2 emissions. Total emissions of methane and carbon dioxide was estimated using the closed chamber method (CCM) and the results were compared with those obtained by applying the IPCC 2006 Default Method to estimate the amount of methane emitted by the landfill.

It should be noted that for the first time in Romania, in situ measurements with CCM of methane and carbon dioxide emissions from the surface of a landfill were performed.

The total area of the landfill Pata Rat is approximately 80,000 m^{2}, thus requiring a total of 49 measurements according to the "Guidelines for monitoring gas deposits in the area" (USEPA, 1986).

The total surface of the open dumping in the Pata Rat landfill is about 80,000 m^2, which gives a total number of required measurements of 49. Due to the heterogeneity in the morphology of the landfill, the calculated number of measuring points was not sufficient for covering the entire surface. In spring (the air temperature was 16°C), 87 measurements were performed on a total surface of about 60,000 m^2, and 64 measurements in summer (the air temperature was 25°C) on a total surface of about 40,000 m^2.

Closed Chamber Method CCM

Flow measurement of methane and carbon dioxide was performed using a system based on the closed chamber technique, that is portable device for measuring the diffusion flux for carbon dioxide and methane **(figure 6.2.1.)**.

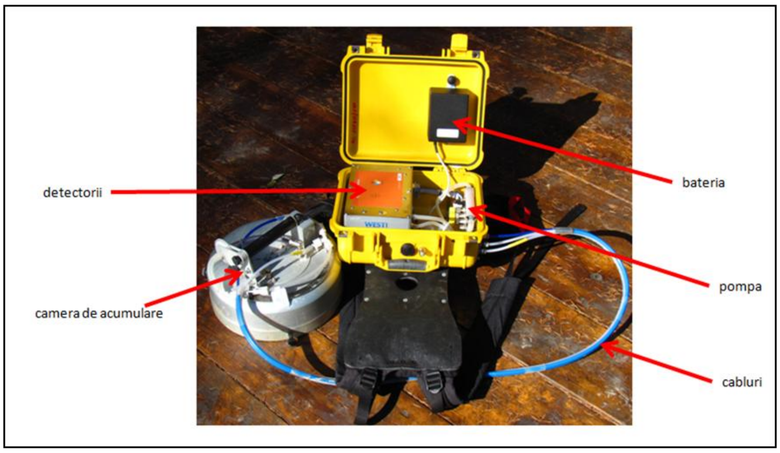

Figure 6.2.1. Portable device for measuring the diffusion flux for carbon dioxide and methane

The device is based on a system of methane detection sensors (with lower detection limit of 1 ppm and 1 ppm resolution), data being transmitted through wireless network to a Palmtop PC. Data is stored and the calculated flow (calculations are based on a linear regression) is displayed in real time. The system detects low methane flow (the order of several tens of mg CH_4 m^{-2} day^{-1} in 10-15 minutes).

The components of the portable device used for the flux measurement (diffusion) are the following: accumulation chamber with separate detectors for methane and carbon dioxide, pump, batteries, motherboard and palmtop.

Figure 6.2.2. represents the structure of the portable device used for the flux measurements (A), and the effective way of measuring the flux of gases (B).

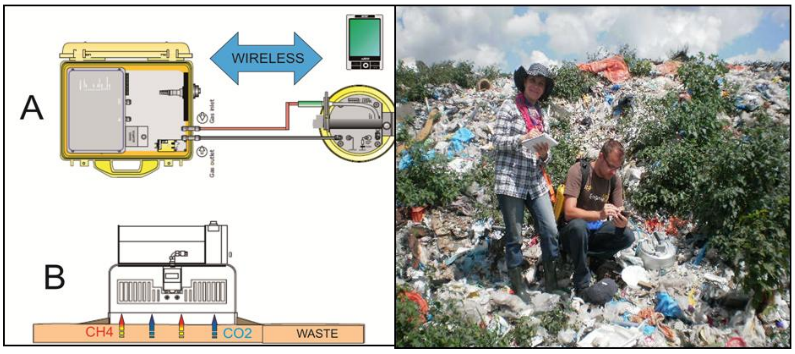

Figure 6.2.2. Left side -the structure of the portable device (A) and the effective way for measuring the gases (B); Right side – field measurements with the portable device

The closed chamber method is easy to operate and useful for addressing research objectives needing spatial and temporal variability of fluxes at a small scale. Chambers are very well suited for *in situ* measurements regarding surface-atmosphere trace gas exchange (Livingston and Hutchinson, 1995).

The method assumes sealing the volume of the chamber placed above the gas-emitting surface, and consequently the emitted gas accumulates inside the chamber (Abichou et al., 2006). If the rate of increase in gas concentration inside the chamber is constant, linear regression can be used to calculate the gas flux.

To measure the flow of methane and carbon dioxide, the accumulation chamber was located on the ground in the established measurement points, ensuring that it is well insulated from the influence of atmospheric air. To obtain a registration optimal flow curve, it was maintained for 2-4 minutes in a position capture (if are necessary measurements of very low methane fluxes, then time is 5-6 minutes or more). Between measurement intervals, the gas is trapped into the accumulation chamber and the pump guided it through the detectors of methane and carbon dioxide, which transmit the recorded data to the portable computer.

Flux Manager the software installed on the laptop, allows recording the flow curves of methane and carbon dioxide in a real time and flow calculation. This information is also stored on the memory card which can be used later on another computer for analysis.

Each investigated point is associated with a measured value flow (g / m^2 /day) and spatial coordinates (Garmin GPS Map 60). The measured values for CH_4 and CO_2 were interpolated using the program Surfer 10 (Golden Software) through the "Natural Neighbour" method.

Two sets of measurements were taken in different periods: the ”set A” in spring (March 2011) when the air temperature had an average value of 16°C, and the ”set B” in summer

(August 2011), when the average temperature was 25°C. The set A includes a total of 88 measurements and the set B includes 74 measurements A number of 87 measurements were taken into account for interpolation from the set A, and 64 from the set B. The other measurements were not interpolated due to the excessive distance by respect to the other measuring points.

Default method IPCC 2006

This method, based on the mass balance approach, was recommended by the IPCC (2006) as the default methodology for estimating the CH_4 emissions from landfills. All the empirical constants have been taken from the 2006 IPCC methodology.

The total yield of CH_4 from the total waste deposited up to the particular year is computed using the following equation:

$$CH_4 emission(Gg \cdot y^{-1}) = \left[(MSWT \times MSWF \times L_0) - R\right] \times \left(1 - OX\right) = \mathbf{9,930\ t \cdot y^{-1}} \qquad (1)$$

where: *MSWT* is the total MSW generated [Gg·y^{-1}] (197.024 Gg·y^{-1} in 2011); *MSWF* is the fraction of MSW disposed to solid waste disposal sites (80%); *R* is the recovered CH_4 Gg·y^{-1} (default 0); *OX* = oxidation factor (default 0); L_0 is the CH_4 generation potential, which depends of the morphological composition of waste (0.063).

The CH_4 generation potential (L_0) is calculated using the equation:

$$L_0\left[GgC / GgMSW\right] = MCF \times DOC \times DOCF \times F \times 16/12 = \mathbf{0.063} \qquad (2)$$

where: *MCF* is the methane correction factor for aerobic decomposition in the year of deposition (fraction) (0.8; for >5 m waste depth); *DOC* is the degradable organic carbon (0.2169); *DOCF* is the dissimilated fraction DOC (0.55) and *F* is the fraction of CH_4 in landfill gas (0.5).

The part of the waste that will decompose under aerobic conditions (prior to the conditions becoming anaerobic) in the solid waste disposal sites, is interpreted with the methane correction factor (MCF) (IPCC, 2006).

Consequently the DOC value was calculated based on the total organic carbon of waste reaching the landfill, taking into account the IPCC default values. The DOC was calculated using the equation:

$$DOC\,(GgC / GgMSW) = \left(0.4 \times A\right) + \left(0.17 \times B\right) + \left(0.15 \times C\right) + \left(0.3 \times D\right) = \mathbf{0.2169} \qquad (3)$$

where: *A* is the paper and textile fraction of MSW; *B* is the fraction of MSW composed of garden waste, green waste except food waste; 40% from biodegradable waste; *C* is the fraction of MSW composed of food waste, 60 % from biodegradable waste, and *D* is the wood and straw fraction of MSW.

6.2.2. Results and discussion

6.2.2.1. Results of the *in situ* measurements

The total amount of methane on the measured surface was estimated using "Natural Neighbor" interpolation method. This method is used for irregularly spaced points with high flow values, avoiding large cash allocation of sectors where no measurements were made.

The results of both CO_2 and CH_4 flux were found to be higher in March then August. In spring, the average CO_2 flux was 450 g m^{-2} day^{-1} compared to 220 g m^{-2} day^{-1} in summer. The average flux of CH_4 in spring was 37 g m^{-2} day^{-1}, and 22 g m^{-2} day^{-1} in summer. This is probably due to the higher moisture content in spring, after the snow cap melts, which represents an important factor for the microbial activity (Jang and Yang, 2001). By contrast, the summer was very dry. It was observed that most of the measurements ranged in the values up to 250 g m^{-2} day^{-1} for carbon dioxide and 25 g m^{-2} day^{-1} for methane.

In **table 6.2.2** the parameters for the two sets of measurements are shown.

Total CO_2 emissions on the measurable surface deposit (approximately 8 ha) is estimated at 9,102 $t\cdot y^{-1,}$ and the total emission of CH_4 is estimated at 827 $t\cdot y^{-1}$ (Popiţa et al, 2012).

Table 6.2.2. Parameters values of the CH_4 and CO_2 fluxes, for the measurements sets A and B

Parameters	**Set A**	**Set B**
No. of measurements	87	64
Air temperature °C	16	25
Atmospheric pressure mBar	982	979
Interpolated surface	6.062 ha	3.87 ha
CO_2 emission factor	148,400 $t\cdot km^{-2}\cdot y^{-1}$	80,645 $t\cdot km^{-2}\cdot y^{-1}$
CH_4 emission factor	11,850 $t\cdot km^{-2}\cdot y^{-1}$	8,966 $t\cdot km^{-2}\cdot y^{-1}$
CO_2 emission on the interpolated surface	8,906 $t\cdot y^{-1}$	3121 $t\cdot y^{-1}$
CH_4 emission on the interpolated surface	711 $t\cdot y^{-1}$	347 $t\cdot y^{-1}$
Total estimated CO_2 emission on open dump surface (approx. 8 ha)	9,102 $t\cdot y^{-1}$	
Total estimated CH_4 emission on open dump surface (approx. 8 ha)	827 $t\cdot y^{-1}$	

The results show that the measured CO_2 emission is about 11 times higher than the CH_4 emission. The values of the methane emission factor are comparable with other landfills which show similar characteristics in size, composition and height of the disposed waste (Chakraborty et al., 2011; Di Bella et al., 2011).

Figura 6.2.4 presents the contour surface map produced by using Surfer software, including the distribution of measuring points and the logarithmic flux values in $g\cdot m^{-2}\cdot day^{-1}$ for the two sets of measurements. The same figure shows lower flows of methane and carbon dioxide in the eastern part of the landfill, where the waste storage was stopped for more than 10 years.

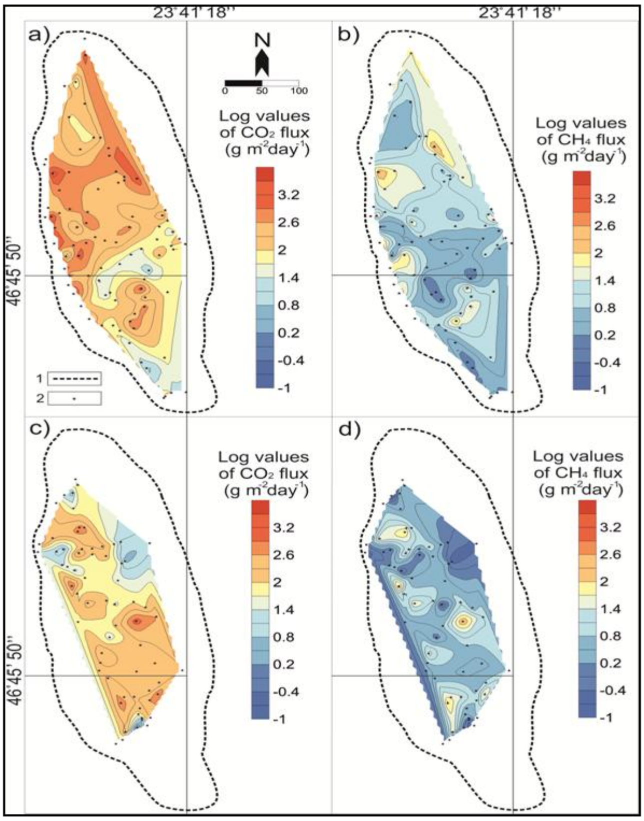

Figure 6.2.4. The distribution of logarithmic values of CO_2 and CH_4 flux; 1 – the edge of the open dump, 2 – the measuring points

6.2.2.2. Results for IPCC 2006 Default Method

An estimated methane emission of "Pata Rat" landfill was computed with the IPCC 2006 Default Method. The pre-calculation value for DOC is 0.2169, and for L_0 is 0.063. The estimated methane emission of "Pata Rat" landfill, calculated with IPCC 2006 Default Method is 9.93 Gg y^{-1} (9930 ty^{-1}), which is about 12 times higher than *in situ* measurements.

Many other studies have reported an overestimated value by using the IPCC 2006 Default Method (Chakraborty et al., 2011; Jha et al., 2008) which shows an uncertainty in the total estimated emission of methane from landfills.

6.2.3. Conclusions

The present study reports carbon dioxide and methane emission performed with *in situ* measurements by using the closed chamber method. The measurements were performed in March and August 2011 and the results show a higher emission in spring, probably due to higher moisture content in the waste, which is an important factor for the microbial activity. The mean CO_2 flux was 450 g m^{-2} day^{-1} in March, compared to 220 g m^{-2} day^{-1} in August. For methane the mean value in spring was 37 g m^{-2} day^{-1}, and 22 g m^{-2} day^{-1} in summer. It was also observed that most of the measurements were clustered in the range up to 250 g m^{-2} day^{-1} for CO_2 and 25 g m^{-2} day^{-1} for CH_4.

The total methane emission for the open dumping was estimated at 827 t y^{-1} and 9,102 t y^{-1} for carbon dioxide for a surface of about 80,000 m^2.

By this method the results show that the carbon dioxide emission is approximately eleven times higher than the methane emission.

The CH_4 emission was also calculated using the IPCC 2006 default method by which 9,930 t y^{-1} was estimated. This value is much higher than those obtained with the closed chamber method, and confirms some previous studies that indicate an overestimation of the flux calculated by using the IPCC default method.

Lower emission of CH_4 can be due to: the composition of the solid waste, the uncontrolled leaching of organic matter, the open burning of solid waste and climatic conditions.

The difference between the two estimated values, using the two separate techniques, is due to the lack of site specific data. For this reason it is important to study the origins and composition of solid waste dumped on the landfill along with the CH_4 and CO_2 emissions. Also we conclude that in situ measurements are more suitable to quantify the methane emissions on landfills.

6.3. LIFE CYCLE ASSESSMENT METHOD (LCA)

The Life Cycle Assessment (LCA) is a tool that can be used for predicting and comparing the environmental impacts of different waste management systems (Finnveden, 1999; Clift. et al, 2000; Bjarnaddottir et al., 2002; Cherubini et al, 2008, Morrisey and Browne, 2004; Cherubini et al, 2009; Björklund et al., 2010). In a broader perspective, however, LCA allows to take into consideration the important environmental benefits that can be obtained by introducing into the waste management system to various processes such as: incineration with energy recovery, treatment, recycling etc (Cherubini et al, 2009).

As described by Bjarnadóttir et al. (2002), the LCA has the following applications in waste management: identification of the most environmentally friendly processes that can be inserted in the waste treatment chain; identification of the significant environmental burdens during the waste management scenarios/technology; identification of impacts, whether the improvements on waste management result in optimization or not; assessment of the environmental performance of the waste management scenario.

6.3.2. Metodology

6.3.2.1. Generalities about LCA

Life Cycle Assessment or LCA is a method of analysis and evaluation of environmental impact of a material, product or service throughout *the entire life cycle*, from purchasing raw materials to waste storage (Mattsson, 1999). Since 1994, LCA has emerged as a tool for environmental management on a global scale as ISO 14040 series of standards.

ISO 14040 standard define the *life cycle* as *"all consecutive and interlinked stages of a system, from raw material acquisition or generation of natural resources to post-use"*. Total system unit processes involved in a product life cycle is called *" product system"*.

The term " unit process " refers to any activity that creates economic value output (steel, electricity etc.), or provide economic value service (transport or *waste management).*The term "product" include physical goods and services, both at operational and strategically level (Ionescu, 2003).

The life cycle of a product begins when the product was designed and continue through the acquisition and raw materials use, manufacture or processing of waste stream associated, storage, distribution, use and withdrawal from use or recycling. (Ionescu, 2003).

The studied *product system* is limited by the environment around it, in a limited scope. Energy and material flows that cross this limit are called *inputs:* raw materials used in production, transport etc and the emissions and waste leaving the system and enter the surrounding environment are called *output elements* (Mattsson, 1999).

The limit system is the interface between the product or waste management system and the environment or other product-systems, determining which processes will be included in LCA (Eriksson et al., 2002). Through ECV can examine the generated waste throughout the entire production process and during using of the produced products. Based on these data can be traced the potential impact created on natural resources, environment and human health. The environmental impact triggered of these products can be assessed throughout their life cycle. It involves the systematic recording (in kg or kW) of the raw materials quantities and energy used to manufacture the quantities of materials and the energy consumption and emissions and the waste at different stages of their life cycle. (ECV1, 2010).

Figure 6.3.1 present the limit-system of the waste management systems.

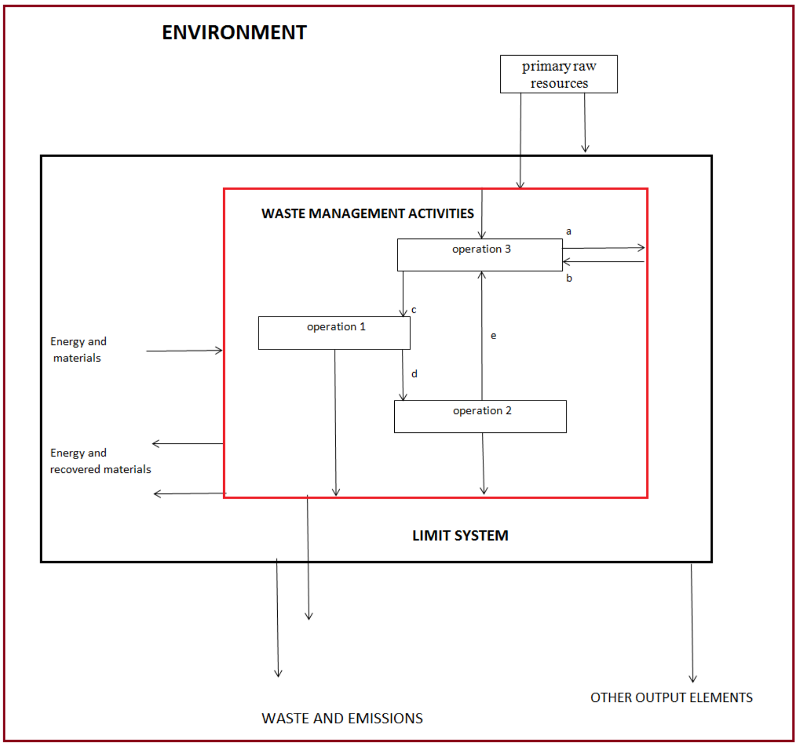

Figure 6.3.1. The limit-system of the waste management systems, Source: (Barton et al., 1996)

**a and b are open raw materials fluxes and c, d and e sunt are closed raw materials fluxes*

Limitations of LCA

LCA is an assessment tool based on a linear modeling, focusing on environmental issues rather than on economic, social issues or with other characteristics. Environmental impacts are commonly described as "potential impacts" because time and space cannot be specified exactly (Guinee, 2002). Because of its holistic nature, LCA cannot distinguish between emissions occurring in a specific location in different time periods. Therefore, LCA is more appropriate to apply to environmental problems arising at regional level. (Tarantini et al., 2009)

LCA is an analytical tool that provides *information as support for decisions,* but cannot replace the decision. In LCA, the data quality has a major influence on the results and therefore an accurate assessment of data is a very important step in LCA (Guinee, 2002).

LCA is an environmental management method used to assess environmental aspects of the product-systems and potential impacts associated and which is managed *by* following *four steps:*

- definition of the goal and scope
- the life cycle inventory analysis
- the life cycle impact assessment
- the life cycle interpretation (SETAC, 1992).

The most important categories of environmental impact potential taken into account by GaBi4 software by CML2001 method (developed by the Institute of Environmental Sciences, Leiden University, Netherlands), are presented below:

GWP (Global Warming Potential) is a measure of the effect on radiation of a particular quantity of the substance over time, relative to the same quantity of CO_2. The radiation effects related to carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are considered in the impact assessment. The GWP value of CO_2 is chosen as equivalence factor (GHK and Bio Intelligence Service, 2006).

POCP (Photochemical Ozone Creation potential) is used as a measure for estimating the airborne substances potential to form atmospheric oxidants. The POCP value of a particular hydrocarbon is a relative measure of how much the ozone concentration measured at a single location varies if emission of the hydrocarbon in question is altered by the same amount as a reference hydrocarbon, usually ethane (in this case ethene). The POCP value is not a constant and may vary over distance and time (GHK and Bio Intelligence Service, 2006).

AP (Acidification Potential) is used in order to describe the acidifying effect of the substances, their acid formation potential (ability to form ions of hydrogen). It is calculated and set against a reference substance, SO_2. (GHK and Bio Intelligence Service, 2006).

EP (Eutrophication Potential). Due to the increased biomass and the consequently heavier sedimentation of dead organic material, the oxygen dissolved in deep water is consumed faster through aerobic decomposition. This can lead to serious damage in the biological populations inhabiting the sediment. In addition to this, when certain species of algae appear in mass the direct toxic effects on higher organisms should be taken into account including human beings. While in the majority of cases phosphorus determines the degree of eutrophication activity, in marine and terrestrial ecosystems, nitrogen is most often the decisive factor (GHK and Bio Intelligence Service, 2006).

HTP (Human Toxicity Potential) reflects the potential harm of a unit of chemical released into the environment. It is based on the inherent toxicity of a compound and its potential dose. It is used to weight emissions inventoried as part of a life-cycle assessment (LCA). Total emissions can be evaluated in terms of benzene equivalence (carcinogens) and toluene equivalence (non-carcinogens) (Hertwich et al., 2001).

FAETP (Freshwater Aquatic Ecotoxicity Potential) is used in order to describe pollutants emissions into the water, which are calculated as critical volume, for each substance emitted into the air, water or/and soil. In the calculations, the time horizon is infinite. For every emission, a volume of water is calculated, which is necessary to ensure sufficient dilution to an acceptable effect level in the environment. The unit of the FAETP is expressed as 1, 4 - dichlorobenzene equivalents/kg emission. The indicator applies at global/continental/regional or local scale. (Garret and Collins, 2009)

6.3.2.2. Methodology of the present study

Definition of the goal and scope

The current study focuses on the assessment of the environmental performance of different solid waste management options that can be used on Cluj County, Romania, as follows:

- Scenario 1: waste is delivered to an open dump landfill without any further treatment;
- Scenario 2: a sorting plant and a composting facility were included in a Waste Management Center (WMC), which is situated at the same place with the landfill. The sorting plant is used for the separation of the organic and inorganic fractions. The landfill is an ecological one with environmental protection systems.
- Scenario 3: for this scenario was added a recycling facility for the recyclables fractions such as: plastic, glass, metal and wood. The recycling facility is situated inside of the WMC.
- Scenario 4: an incineration plant was included in the system, for the elimination of the residues.

In this study the MSW refers to waste generated from households, institutions and commercial areas. The types of waste we took into account are: recyclables (plastic, glass, paper, cardboard, metal and wood), bio-waste, and other wastes (textiles, hazardous waste and street waste).

The main tool used in this study was the software GaBi4, the version available for universities, developed by the Institute for Polymer Testing and Polymer Sciences (IKP) of the University of Stuttgart in collaboration with PE Europe GmbH Company, Germany. Este printre primele studii de acest gen efectuat în România, în domeniul deșeurilor, cu ajutorul acestui software specific ca instrument de analiză a ciclului de viață a sistemelor de gestionare a deșeurilor solide.

The functional unit

The functional unit in this study has been defined as the amount and composition of MSW generated in Cluj County in 2010. The system boundaries selected for the life cycle were defined as the moment when the materials ceased to have value and become waste. Some of the input parameters were approximated taking into account the specific waste composition. The waste fractions included in this study are:

- biowaste 46,5 % (vegetable waste, kitchen waste, green waste) ;
- recyclable paper 19%(journals and magazines, advertisement materials, books and phonebooks, office paper, clean paper, paper and cardboard boxes
- aluminum 3% (trays/foil, cans);
- glass 4% (clear glass, green glass, brown glass, other types of glass);
- plastic 20% (soft plastic, hard plastic, plastic bottles);
- wood 3,5%
- other waste 6% (textiles, hazardous waste, street waste, etc).

The data used as input for the model was obtained from our own investigations, or partly provided by Regional Environmental Protection Agency data base (REPA) (ARPM Cluj-Napoca, 2010).

Assumptions

The total amount of waste used as input in all four scenarios was 197,000 $Mg \cdot y^{-1}$, corresponding to the value recorded in Cluj County in 2010.

Transportul

We assumed that the transportation of waste was the same for all the scenarios. For the first scenario, the transportation was distributed between the comingled collection and the landfill. For the other three scenarios (Scenarios #2 - #4), the transportation was distributed between the comingled collection of waste and the Waste Management Center (WMC), which include the: sorting plant, composting plant, recycling plant and landfill. The WMC is situated at equal distances from each part of the County.

For the Scenario #4 the transportation should increase because of an extra distance of the residues transportation to the incineration plant. Although of the short distance between the WMC and the incinerator (≈10 km) we didn’t take into account the distance.

Therefore, being a constant for all scenarios, the transportation of MSW to the treatment site was not included in the analysis. The assumptions regarding the collection and transportation were made because of lacking of the statistical data at national level and because of the short distance between the collection points and WMC (< 1000 km) which represent a small contribution to the environmental impacts waste management system (Smith et al., 2001; Beigl and Salhofer, 2004; Salhofer et al., 2007).

We assumed that for all the scenarios the waste collection is comingled. Energetic and environmental burdens associated to the comingled waste collection were not taken into account in the current study (the collection is not investigated because it is assumed to be the same for all scenarios).

System boundaries

The processes included in the scenarios are summarized as follows:

- Composting, incineration, recycling and landfilling;
- Direct emissions of pollutants generated from composting, recycling, incineration and landfilling;
- Energy recovery.

We considered that the impact of the scenarios is the sum of the impacts generated from each process. The MSWMSs were compared in the LCA context and the following processes were considered: biological (aerobic digestion) treatment, recycling, incineration, and landfilling of MSW.

The Scenarios

The four scenarios considered in this study with the system boundaries are represented in **figure 6.3.5.**

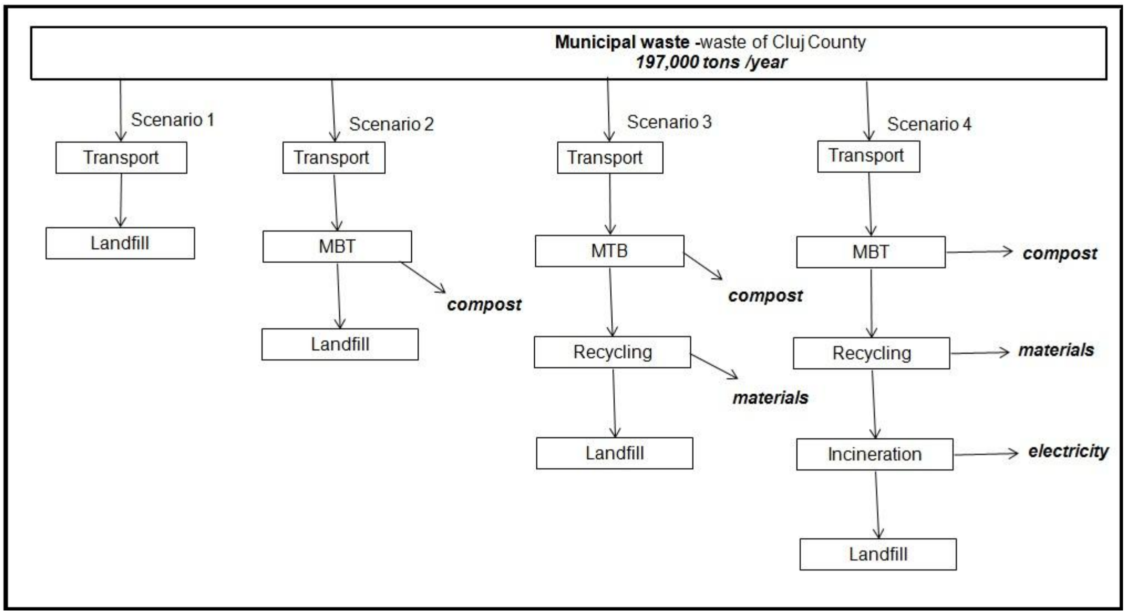

Figure 6.3.5. The scenarios of MSWMS used in the present study

Scenario #1.

In case of Scenario #1 (representing the current status of MSWM in Cluj County), landfilling was the only waste disposal method. The total MSW generated was transported to the landfill. By comparison, about 62% of the total MSW generated at EU level was landfilled in 1995 and it decreased to 44% in 2005 (ETC/RWM, 2008).

The first scenario consists of three major steps: collection (commingled without preliminary separation), transportation, and landfilling of MSW.

The total amount of waste used as input in all four scenarios was 197,000 $Mg \cdot y^{-1}$, corresponding to the value recorded in Cluj County in 2010 (ARPM Cluj-Napoca, 2010). This amount was used as input for all four scenarios. Waste composition was kept the same for out all four scenarios.

Scenario #2 was fed into the model in order to assess the possibility of improving the current MSWMS. In this case, a composting facility was added for the bio-waste stream, before landfilling. From about 197,000 Mg y^{-1}, an amount of 92,000 Mg (46.5%) of wet waste was treated to obtain compost (59,000 Mg), while the dry waste (105,000 Mg) was transported to the landfill. The residual waste from the aerobic treatment (33,000 Mg) was also transported to the landfill.

Scenario #3 includes the following steps: collection, transportation, composting, recycling and landfilling. The recycling of the following waste streams: paper, glass, metal, plastic and wood was added in order to recover the recyclables and to save the raw materials. The amounts of recyclables were calculated (33,000 Mg paper, 39.000 Mg plastic, 8,000 Mg glass, 6,000 Mg metal, 7,000 Mg wood) and sent to recycling. The residual waste from recycling (24,000 Mg), composting (33,000 Mg) and the fraction "other waste" (12,000 Mg) were transported to the landfill.

Scenario #4 combines the incineration and landfilling as final treatment and elimination methods for the residual waste. After composting and recycling, the residual waste was transported to the landfill together with the textiles and street waste from the fraction "other waste" (total 66,999.50 Mg). The hazardous waste from the fraction "other waste" (788.00 Mg) was transported to incineration. Basic ash resulting from the incineration is also transported to the landfill (214, 01 tons) (**figure 6.3.6**).

Figure 6.3.6. refers to the mass balance carried out for the Scenario #4.

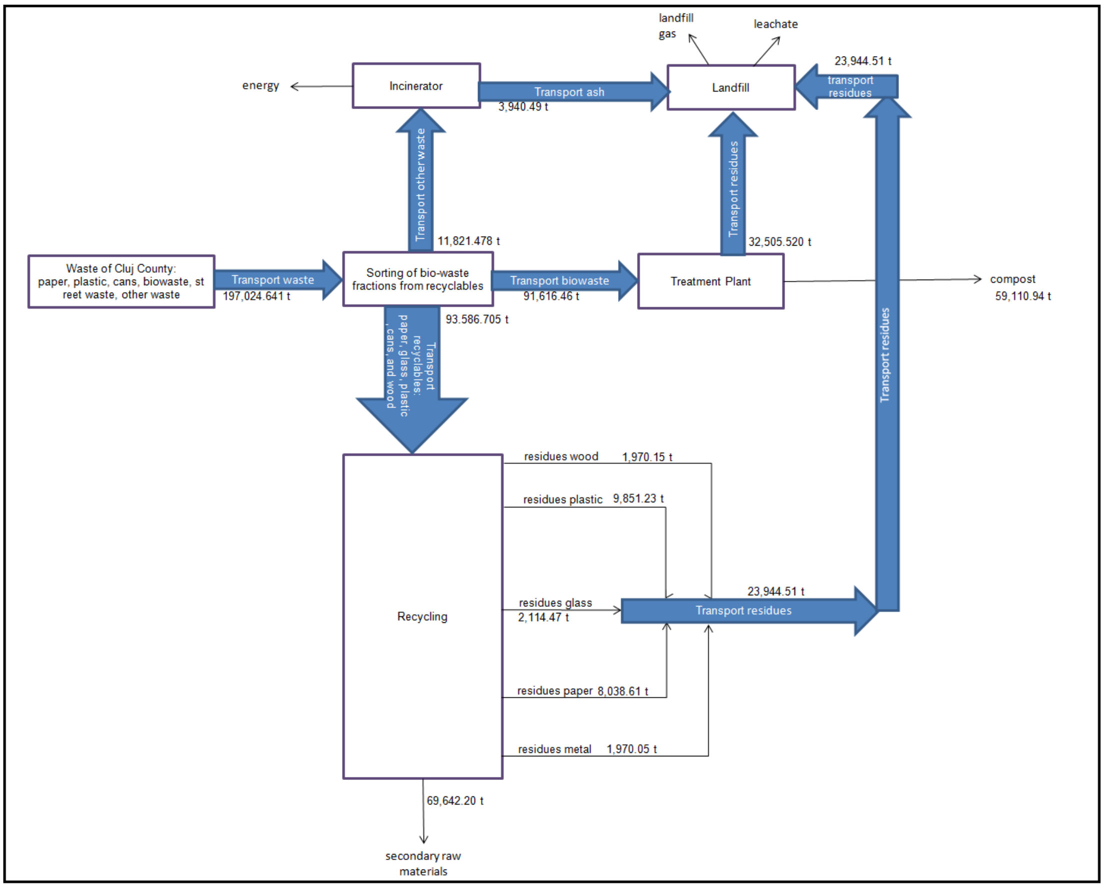

Figure 6.3.6. The mass balance carried out for the Scenario #4

Life cycle inventory analysis evaluation

In this study we used GaBi4 software as a tool for life cycle analysis of solid waste management systems. We used the version for universities, this program was designed by the Institute for Polymer Testing and Polymer Science, University of Stuttgart in collaboration with the PE Europe GmbH, Germany.

GaBi4 software is a tool that creates complete balance of the life cycle prepared on the inventory that helps to analyze data and interpret results. The system can be used as part of the modeling methods and analysis related to the interlinked processes.

Its fundamental characteristics allow the analysis of material and energy, related with the study of the objectives, the limits-system requirements, the reference quantities and the environmental impact assessment. GaBi 4 is also a modular system which means that the plans, processes and flows form modular units.

It has a clear and transparent structure, a database for life cycle inventory and life cycle analysis and quantitative models which are carefully separate, from this reason the individual modules are easy to handle.

The system is flexible and transparent and can be easily extended to new systems or to the latest breakthroughs from the life cycle impact categories. The software can calculate the balance at various levels of detail, enabling the identification of weaknesses (PE Europe GmbH and IKP University of Stuttgart, 2012).

The available data used in this study were obtained from REPA (Regional Agency for Environmental Protection). These include waste quantities, composition and operational data from the landfill. In cases where specific data were not available, were used data from the European GaBi4 program data (which include data on infrastructure, raw materials, chemicals and energy).

6.3.3. Results and discussion

The simulation results provided a better understanding of the environmental aspects of the considered scenarios. This was achieved by using the LCA method, a tool to compare different treatment and/or disposal options. The results obtained from this study support the conclusion that LCA, as an environmental assessment tool, can be successfully applied in an Integrated Solid Waste Management System (ISWMS) as a decision support technique and can be expediently implemented for waste management activities. The LCA remains basically an estimation based technique, since it works with uncertainties (Ekvall et al., 2007) and still there is a lack of consensus regarding the methodology on the determination of the quality of data and range and effect of uncertainties (Bernstad and Jansen, 2011).

For the obtained results normalization was applied according to the normalization study of Wegener et al., (2008). Normalization consists in a numerical characterization of environmental interventions from the inventory analysis by multiplying them with the characterization factors in the context of the applicable impact categories (Pennington et al., 2004).

Figures 6.3.7 and **6.3.8** show the comparison between the scenarios contributions to the environmental impact categories. The negative values of the environmental potential impacts means that they can be avoided, so that scenario has a positive impact on the environment. (PE Europe GmbH and IKP University of Stuttgart, 2012).

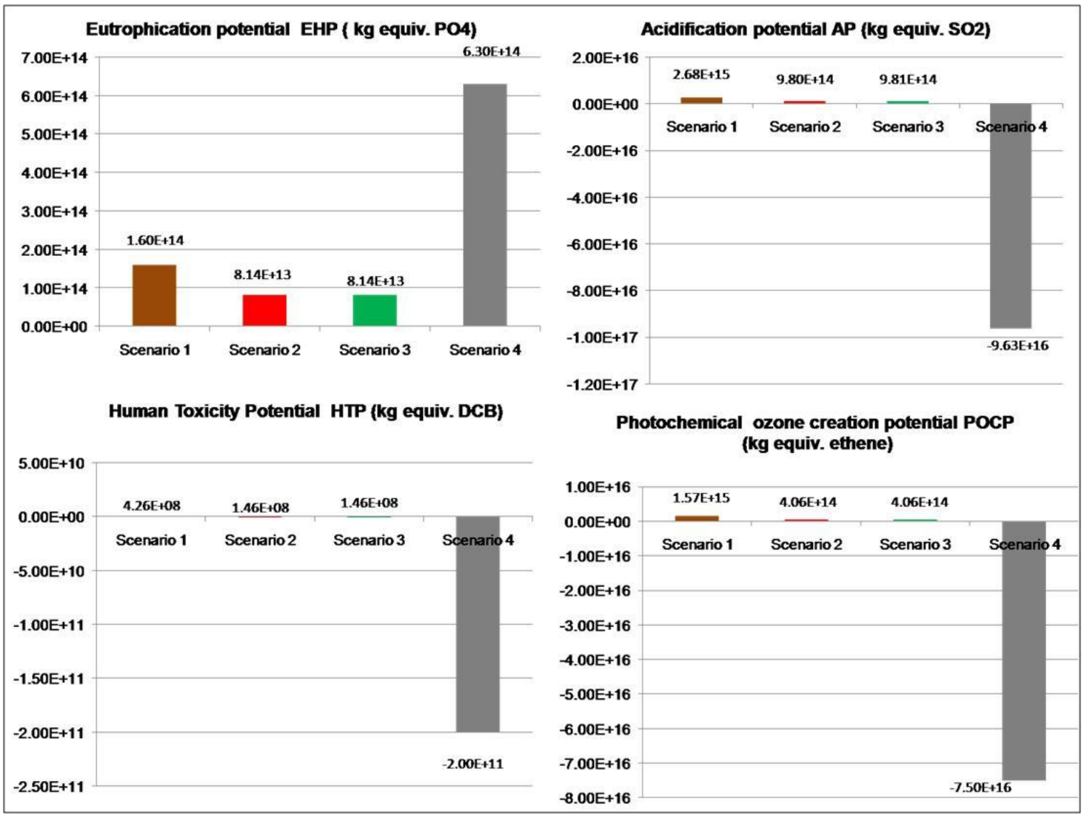

Figure 6.3.7. *Contributions of the Scenarios 1-4 regarding the potential environmental impacts: EHP, AP, HTP and POCP.*

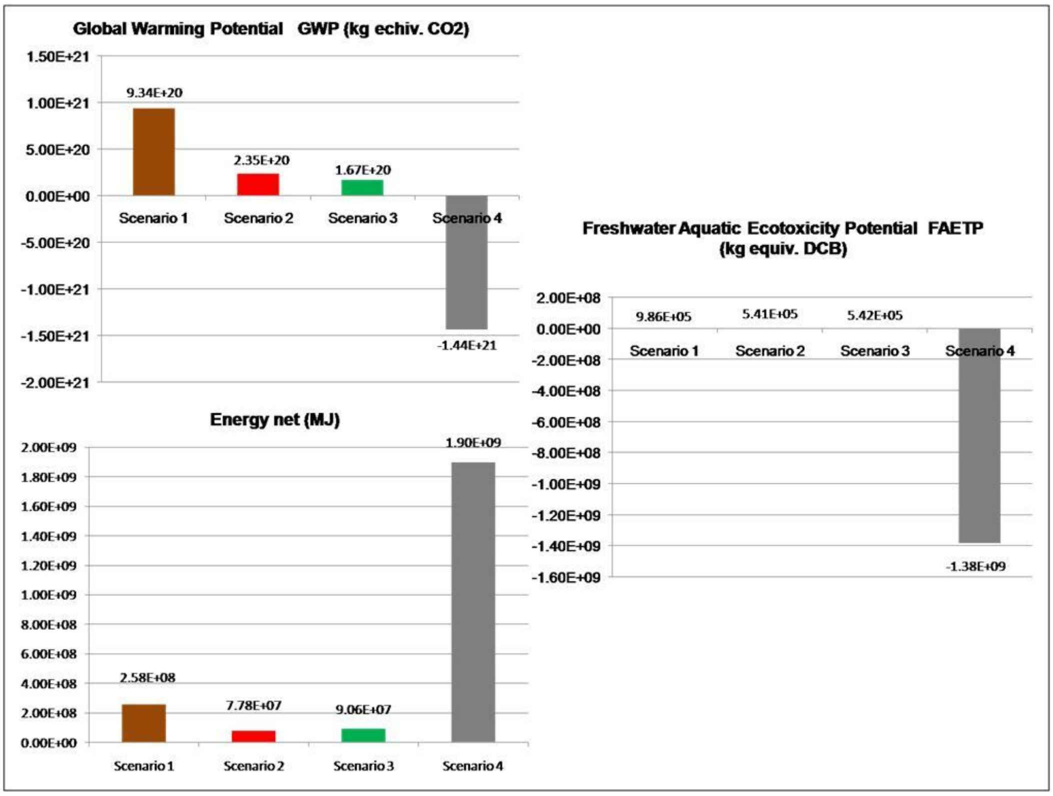

Figure 6.3.8. *Contributions of the Scenarios 1-4 regarding the potential environmental impacts: GWP, FAETP and Energy net.*

The results show that Scenario # 4 provides the largest energy recovery due summation of the biogas energy produced from the landfill, with energy production from the incinerator. Scenarios # 1 and # 2 have the lowest values.

Direct emissions of pollutants from landfill and incineration plays an important role, while the potential impact of transport and infrastructure has not very high. Also a major importance has the energy recovery from incineration processes and landfill (by using the biogas).

6.3.4. Conclusions

This study considered four MSW treatment management scenarios which were conducted in order to determine the most environmental "friendly" municipal solid waste management system for Cluj County, Romania.

The main conclusions that can be drawn from this study are as follows:

- In all scenarios, the generated impact for the global warming category has a dominant contribution;
- In all scenarios, the impact on eutrophication potential play an important role;
- For the energy category, the Scenario #4 (which contains the incineration) had the highest value for the energy recovery from waste incineration.

It should be underlined that Scenario# 4 was the best option for all environmental impact categories due to the electric energy recovery from waste incineration and due to the lowest values for all environmental categories, except the eutrophication potential. The results of this study are dependent on the actual MSW characteristics and management in Cluj County. In other areas the results of the environmental evaluation may be different due to MSW characteristics, technology, and available data.

The results show that an integrated waste management system based on separation of waste, with different waste fractions taken to different waste treatment technologies (Scenario #4), would be efficient for the Cluj County.

CHAPTER VII
PROPOSALS TO STREAMLINE THE CURRENT SYSTEM OF WASTE MANAGEMENT IN CLUJ COUNTY

After analyzing the problems identified in the current waste management in the county of Cluj and the simulations of the waste management scenarios, we consider to propose an integrated waste management system (IWMS) in Cluj County **(Figures 7.2 and 7.3.)** (Popita et al, 2011).

To explain more in detail the steps of the system has been defined the urban area and rural area and were presented the main steps of this system for these two areas: collection, transport, treatment, incineration and landfilling.

Urban Area

For selective waste collection in *urban area* is proposed a combined system comprising:

- - Automatic recycling (they should be purchased by producers of packaging) *packaging glass, PET and aluminum doses*, to financially stimulate citizens to collect waste selectively;

- Selective collection at source *of paper, solid waste mixed with metal, household hazardous waste and organic waste (biowaste).* The collection should be correlated with the frequency of lifting them by sanitation companies and the creation of a calendar collection.

- Selective collection at source or collection at points for *WEEE, portable batteries* and *bulky waste.* For these types of waste is required a calendar collection by sanitation companies (Popita et al, 2011).

IWMS can keep the structure proposed by project authorities Cluj county, as follow: Three transfer stations in Huedin, Mihai Bravu and Gherla; An Integrated Waste Management Centre in Cluj Napoca IWMC, consisting of: 1 plant for sorting, materials recovery; 1 plant for mechanical-biological treatment of biodegradable waste; 1 ecological landfill; Additional infrastructure (wastewater treatment plant, utilities, administrative facilities, etc.).

The integrated management system for urban waste proposed in Cluj County includes more steps as seen in **figure 7.2.**

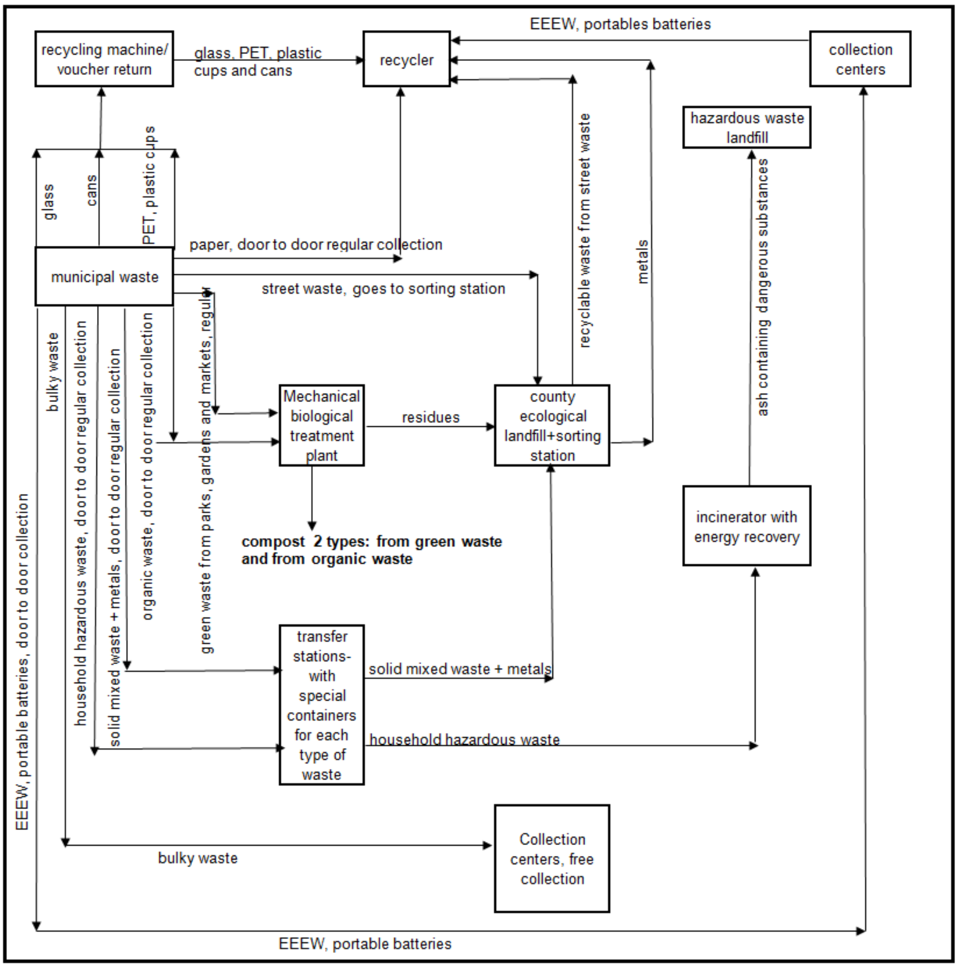

Figure 7.2. Integrated management system for urban waste proposed in Cluj County (Popita et al, 2011)

Glass, PET, cans and paper waste goes directly to recyclers. Mixed solid waste with metals and hazardous waste will be collected periodically and then transported to transfer stations (due to large distances to deposit or incinerator).

Household hazardous waste will be transported from transfer stations and then to the incinerator with heat recovery, and mixed waste and metal will be transported to the ecological county landfill where will be an ecological station for sorting ferrous and nonferrous metals. From there the metal will be sent in turn to recycling. Bottom ash from the incinerator will be sent to a landfill because isn't classified as hazardous waste (Popita et al, 2011, Hațegan et al, 2011; Waste to resources, 2010)

Bulky household waste will be taken by each citizen to special collection centers where it will be received for free. Bulky waste will be transported to the Mechanical Biological Treatment Station (MBTS) for shredding and than to the ecological landfill. Electrical and Electronic Equipment Waste (EEEW) and portable batteries will be collected periodically from source to be taken to special collection centers and then recycled Residues from MBTS will be transported to the ecological landfill.

Organic waste, as well as green waste from parks, squares and gardens will be taken directly to a Mechanical Biological Treatment Station (MBTS), where they will get two types of compost that can be sold later. Street waste will be sent directly to the county ecological landfill where it will be sorted. Recyclable waste obtained by sorting (paper/cardboard, plastic, ferrous and nonferrous metals), will be sent to recyclers. (Popita et al, 2011).

Rural Area

The integrated management system for rural waste proposed in Cluj County includes more steps as seen in **figure 7.3.**

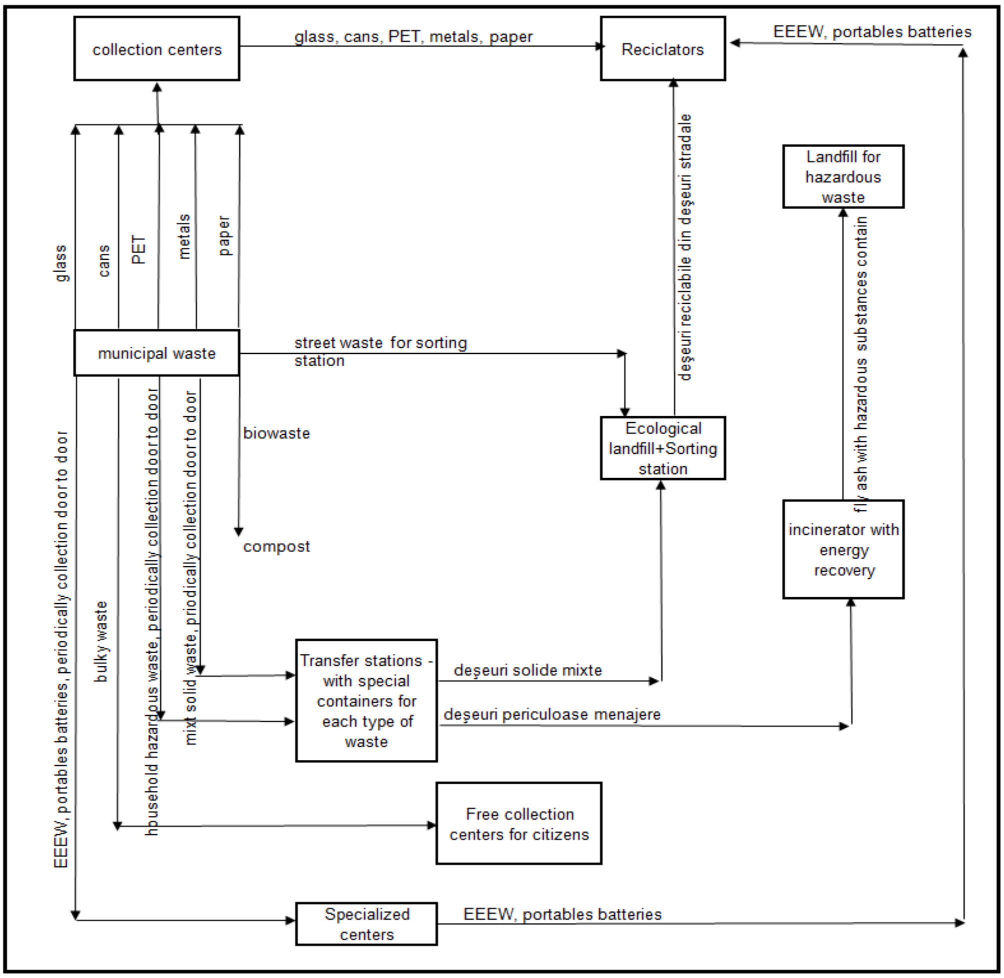

Figure 7.3. Integrated management system for rural waste proposed in Cluj County

The integrated waste management system in the rural area will be set up into *collection centers* to operate warehouse system to the following categories of recyclable waste: *glass*, *PET*, *aluminum*, *paper*, *cardboard and metal*, they will then be taken directly to recyclers.

Organic waste will compost directly into households, to be used as fertilizer for gardens.

Bulky waste, WEEE, batteries, portable, mixed solid waste and household hazardous waste will be collected and picked up by sanitation companies. *WEEE and portable batteries* will be taken to specialized centers. *Bulky waste* will be taken to the transfer station, where it will reach MBT, which will follow the same course as those collected in urban areas. *Household hazardous waste mixed* with *solid waste* will be transported to the incinerator with heat recovery (Popita et al, 2011).

In order to interpret the obtained results for the IWMS proposed, a SWOT analysis was performed which leads to conclusions on meeting the goals and objectives of the study.

SWOT analysis was performed to identify strengths, weaknesses, opportunities and threats for IWMS.

CHAPTER VIII
CONCLUSIONS

In recent decades, solid waste management has become an important area for scientific and technological research worldwide. Key issues of the environment, such as pollution, energy recovery and even human health effects have a direct connection with waste management. Reducing the environmental impact of the waste management is an emergency, and this can be achieved by using appropriate techniques and technologies. Due to the complex nature of the waste, it is necessary to use complex technology treatment / disposal, in order to handle all types of waste in a sustainable way.

The thesis was motivated by the analysis of the current waste management system in Cluj County, coupled with the analysis of the objectives set out in legislation (objective with deadlines) and the prospect of an integrated waste management at county level. The results of two surveys conducted in two areas (urban and rural) of Cluj County were also taken into account. Analysis led to the following conclusions:

- majority of respondents do not know the real situation of waste management in their locality
- development of a waste management system in both urban and rural areas is accepted and expected by the public
- most people are interested in the existence of payment facilities for selective waste collection and is willing to take risks for payment fines
- population is willing to collaborate with institutions who have duties in this area, for a better waste management
- is necessary to initiate awareness and information campaigns for the general public or specific groups of consumers

After analyzing these questionnaires and the literature, it was found that the biggest problem in waste management in the Cluj County is the lack of an integrated waste management. The environmental factors and assessment of pollution caused by non-compliant landfills in the county are also important.

The experimental part of the study and the methodology of the thesis is structured in *three main areas of research:*

- Assessment the environmental pollution (water, air, soil) caused by waste rural deposits and municipal landfills
- Estimation of the methane and carbon dioxide emissions on the surface of Pata Rat landfil
- Modeling of waste management systems to Cluj County and finding the optimal choice in relation to the environment.

The first line of research aims to outline an overview of the current waste management in the Cluj County and evaluate the environmental pollution caused by landfill. For this we studied the current system of waste management from bibliographic sources (the specialty documents presented by the Regional Environmental Protection Agency Cluj) and from field visits conducted in rural and urban areas in the county. Note that the last comprehensive study at Pata Rat landfill that included analysis of surface water, soil, air and groundwater was conducted in 2001, by a specialized company.

It is the first time that water and soil analyzes were made to assess the pollution of these environmental factors of the waste rural deposits of Cluj County. During these field visits were taken samples of water, soil and air in order to assess their physical and chemical caracteristics. Water samples were collected from streams that pass near waste rural deposits and the soil was collected around them. The physical-chemical analyzes of the water were: determinations of pH, TDS, conductivity, redox potential, salinity and metals (Cr, Mn, Pb, Cd, Fe, Ni and Zn).

Waters analyzed in two rural areas were determined by high values for Ni, Pb, Cd and Cr. Interpretation of results was made using the environmental impact and risk assessment integrated method EIRAIM. Environmental impact and risk for surface water have high values which mean that it contains large amounts of pollutants being necessary measures to control and prevent its pollution by metals.

Soil analysis of rural area 1 shows that from 8 measurements for Pb, 6 values are above normal value NV provided by law and for Cd only 1 sample exceeds the normal value. In rural area 2 from 8 measurements for Pb, 1 value exceeds the intervention threshold, 1 exceed the threshold value and the remaining 6 exceeding normal values. For Cd, from 8 samples, 3 of values were beyond NV and for Cu and Ni only 1 sample exceeds NV. From the above it is clear that the soils from the two areas are polluted with heavy metals, but to a much lesser extent than the water. To use this land for less sensitive uses, it is necessary to monitor the areas and restore the landscape. From field observations comes out that largely rural land used as waste disposal facilities are abandoned, not refurbished or monitored by local authorities, and these lands can be considered as output from the usable circuit. Moreover, they can be outbreaks of infection for animals and even people who live near these areas.

Zapodie stream quality, which is flowing near the Pata Rat landfill shows worsening downstream and recorded concentrations that exceeds the maximum permitted by law on all elements analyzed, reaching quality class V (bad). In addition to the tests performed on water samples taken from rural areas, to stream Zapodie were analyzed in addition the following chemical parameters: COD-Cr, BOD5, NH_4-N, NO_2-N, NO_3-N, total P and fixed residue.

Analyzes performed on soil samples regarding the heavy metals concentration indicates a higher pollution with Cu and Pb, whose averages exceed NV from legislation.

The level of air pollution is relatively low, except for episodes of accidental ignition of landfilled waste. Air samples indicate no exceedances of NV from legislation.

However, from field observations, we emphasize that in addition to those described above there is a strong visual pollution and persistent odor that affects nearby communities. It is likely that leachate that seeps into the soil to affect the groundwater quality, as indicated by the studies carried out in 2001.

People living nearby are exposed to the dangers of infection with various diseases due to the development of a large number of insects and rodents, known as vectors of infectious and parasitic diseases. Herds of animals grazing in the area and watering of Zapodie stream, downstream of deposit, by ingesting large amounts of pollutants from the water are exposed at risk of disease together with the people who consume products made from these animals.

Regarding Pata Rat landfill is necessary to take urgent measures: collect the leachate to prevent further pollution of surface water and groundwater eventually; stop all forms of various recyclable waste storage; initiate the closure of the landfill, collection and treatment of the biogas, post-closure monitoring, cleaning the area, evacuation of people who are living within the confines of this landfill; coating and refurbishment of the landfill with topsoil.

A second line of research is to estimate the methane and carbon dioxide emissions on the surface of the Pata Rat landfill. This estimation was performed to assess the amount of biogas that generates this landfill. According to the information that we hold, is for the first time in Romania when methane and carbon dioxide emissions from a municipal landfill were measured in situ by closed chamber method CCM.

From the two sets of measurements in two different seasons (spring and summer 2011) results average values for methane emissions of 827 $t\cdot year^{-1}$ and 9.102 $t\cdot year^{-1}$ for carbon dioxide. In spring of 2011 there were performed 88 measurements on a surface of 60,000 m^2 and in summer 2011 were performed 74 measurements over an area of about 40,000 $m^{2.}$

Methane emission was calculated with the Default Methodology IPCC 2006 method (DM) too and obtained a value of 9.93 $Gg\cdot year^{-1}$ (9930 $t\cdot year^{-1}$). This is about 12 times higher than the estimated emission by in situ measurements, which confirms an overestimation of methane from other previous studies. The results of this study concluded that the estimated amount of methane measured in situ is more reliable than that determined by the IPCC 2006 DM.

The third line of research is to model four waste management systems and to choose the optimal choice in relation to the environment. This study was performed using a specific Life Cycle Assessment software GaBi4, the version for the universities (provided by the company PE International Germany). This is the first study conducted in Cluj County (Northern Part of Romania) for solid waste management systems with this particular software as a tool for life cycle analysis.

LCA is an internationally recognized method to identify and assess environmental impacts of waste management systems and allows the important environmental benefits that can be obtained by introducing various processes in the waste management systems.

Four different waste management systems were considered. The municipal solid waste (MSW) taken into account in this study is the waste generated by the population, institutions and commercial areas as follow: recyclable waste (plastic, glass, cardboard, metal and wood), biodegradable waste and other waste (textile and hazardous household waste).

Scenario # 1 refers to the current waste management system that includes the mixed waste collection, followed by transport to the an open dump municipal landfill. The second scenario shows an improvement of the scenario # 1 with a mechanical-biological treatment (MBT) of biodegradable waste being added before landfilling. The landfill is an ecological one. Scenario # 3 includes the following steps: collection, transport, MBT, recycling and landfilling in an ecological landfill. Scenario # 4 includes incineration as a method for minimizing the volume of household hazardous waste and landfilling remains the final disposal method of the residues from the treatment operations.

The results show that LCA as environmental assessment tool can be successfully applied as a decision support for the solid waste integrated management system and can be used properly for waste management activities. Scenario # 4 was found to be the best option due to the low greenhouse gases emissions and energy recovery, coming mainly from incineration.

The proposals to improve the current waste management system in Cluj County covers a major restructuring of the whole system by introducing the incinerator, the transfer stations, the sorting and recycling facilities into this circuit and not at least by introduction different methods of collection in rural and urban areas. It was considered that the human factor is very important and therefore proposed a combination of methods to stimulate the selective collection from the population (eg recycling machines, recycling waste disposal centers, differentiated fees for mixed waste depending on the amount of recyclable waste collected selectively) with methods of coercion (such as fines for non-compliance of the decisions adopted jointly by citizens and local governments). We also believe that organizing periodic and ongoing information campaigns to citizens about the proper functioning of the system by the public administration and the introduction in schools (regardless of the profile) of a large and regular information about the proper general waste management has a great importance.

After the SWOT analysis we believe that the proposed system has much strength that demonstrates the reliability and feasibility of the system. Threats that are related to the political instability and the penalties that may be imposed in case of non-compliance of the targets are dangerous and require a swift implementation of an integrated waste management system.

As a *general conclusion* and recommendation for future waste management projects, we consider necessary the execution of proper investigations and analysis, in situ measurements and using of modern interpretation methods for the results, before taking major decisions and adopting the specific solutions.

Potential research directions

Studies and research projects that may have as a starting point this paper, could be the following:

-improving the integrated management system proposed in this paper with the economic feasibility

- finding modern solutions for closing the open dump landfills

-estimation of methane and carbon dioxide emissions by in situ measurements for the open dump landfills in each region, and comparison with the emissions reported by Romania at international level.

- study the systems of methane capture from open dump landfills surface and applying the appropriate system for each landfill.

- development of detailed simulations, with the specific software for life cycle assessment (GaBi4) for each operation treatment / disposal part that goes into the waste management system and including the details of transport and different methods of waste collection.

- extension of the studies using GaBi4 program to other categories of waste.

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