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COSTS ANALYSIS OF MUNICIPAL SOLID WASTE MANAGEMENT SCENARIOS: IASI – ROMANIA CASE STUDY

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Abstract. Effective management of solid waste has become environmentally and economically mandatory due to the increase of environmental problems. In this context, the evaluation of economic aspects is imperative since the implementation of a solid waste management system is connected with considerable investment and operating costs. The goal of this study is to assess and report the performance of various waste management scenarios in terms of costs and to determine the most suitable alternative. For this purpose, we analyzed a case study in a typical Romanian urban area, in terms of the economic impacts of four waste management scenarios. The economic evaluation was performed based on a cost structure, which we have elaborated to analyze the waste management scenarios from a cost perspective. The results indicated that the most suitable alternative for implementation from economic viewpoint in the studied area is scenario which included the following treatment/elimination methods: sorting, composting and landfilling.

Keywords: composting, costs, impacts, landfills, municipal solid waste, waste management technologies.

Introduction

Waste management is a complex topic, closely related to both the human health and the environmental quality (Ekvall *et al.* 2007; Ghinea, Gavrilescu 2011; Ghinea *et al.* 2012; Sarkady *et al.* 2013). It has become increasingly a subject of extreme significance, even more as human activities have overloaded the capacity of the biosphere to assimilate waste (Peters *et al.* 2008).

As an European Member State since 2007, Romania had to comply with a series of regulations in the field of waste management, based on the most preferred options in the waste management hierarchy (Luca, Ioan 2014; Rada *et al.* 2010; Schiopu, Gavrilescu 2010a; World Bank 2011). Unfortunately, the waste landfilling in Romania is still a largely applied solution for waste management (Panaitescu, Bucuroiu 2014; Pohontu *et al.* 2011; Schiopu *et al.* 2009; Schiopu, Gavrilescu 2010a; Schiopu, Ghinea 2013) as well as in other countries (e.g. Serbia, India) (Bjelić *et al.* 2015; Khan, Samadder 2015).

According to the European Landfill Directive, the waste management hierarchy recommends that the management of waste should result in a decrease in landfilling and an increase in waste minimization, recycling and reuse (Costiuc *et al.* 2015; Council Directive 1999; Ghinea, Gavrilescu 2010a; Orlescu, Costescu 2013; Petraru, Gavrilescu 2010; Schiopu, Gavrilescu 2010b). There are alternatives to properly manage solid waste, but the qualitative and quantitative characteristics of waste as well as various costs should be considered for the selection of the most suitable management alternative (Berechet, Fischer 2015; Costuleanu *et al.* 2015; Gaba *et al.* 2014; Ghinea *et al.* 2014; Hernández-Berriel *et al.* 2014; Taboada-González *et al.* 2011; UNEP 2009a).

In the last years various studies were performed for the costs evaluation of solid waste management (SWM) facilities. Woon and Lo (2016) compared the costs for two facilities: advanced incineration and landfill extension and also investigated the human health impact associated with these two disposal plants. D'Onza *et al.* (2016) proposed a

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full cost accounting method for the calculation of different types of waste collection costs. Xin-gang *et al.* (2016) investigated waste-to-energy considering political, economic, social and technological factors. They found out that incineration facility has good profitability, economic benefit and also significant environmental benefits. Mavrotas *et al.* (2015) developed a mathematical programming model in order to obtain a set of optimal solution – least costs, considering external costs/benefits associated with atmospheric pollution impacts, impacts on quality of life and others. Martinez-Sanchez *et al.* (2015) proposed a cost model for the economic assessment of SWM systems considering budget costs, taxes, subsidies and fees, externality costs, which was applied for evaluation of source segregation of organic waste and subsequent co-digestion of organic waste. Panepinto *et al.* (2015) compared two SWM scenarios: pyro-gasification of the residual waste after separate collection and mechanical biological treatment of the residual waste from environmental and economic point of view. For economic evaluation they considered conventional economic criteria, i.e. investment and operating costs transferred to citizens and demonstrated that from this view the pyro-gasification is more suitable/ preferable. Weng and Fujiwara (2011) applied cost–benefit analysis for evaluation of the effectiveness of MSW management systems and evaluated the impacts of the influencing factors on different costs.

Since the implementation of a municipal solid waste management (MSWM) system is connected with considerable investment and operating costs (Moutavtchi *et al.* 2008), it is important to analyze the economic aspects of waste management (Reich 2005), along with environmental issues. Moreover, the costs for implementing a waste management system are frequently taken into account equally or more than the impacts on the environment (Begum *et al.* 2006; Khan, Samadder 2015; Turskis *et al.* 2012).

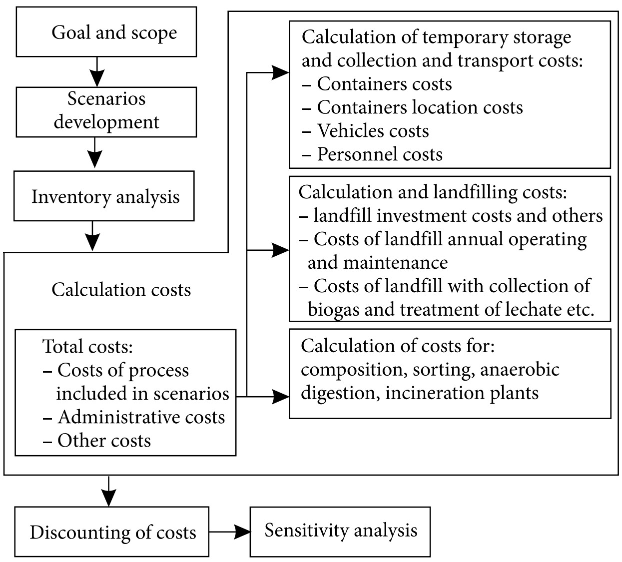

Fig. 1. Steps performed for the cost evaluation of MSWM

In this context, this paper aims to contribute to the analysis of the economic impacts of some MSWM systems. Since 2008, the MSWM system in Iasi city – Romania included a few, less sustainable options, such as: temporary storage of waste in containers, collection and transport, followed by landfilling of mixed waste. In order to fulfill the purpose of the present paper, four scenarios were developed as alternatives to the above-mentioned system. In the design of these scenarios different waste treatment processes were considered, such as: sorting, composting, anaerobic digestion, incineration, landfilling. The phases performed for the cost evaluation of municipal solid waste management (MSWM) scenarios are illustrated in Figure 1.

1. Development of the MSWM scenarios

Iasi is one of the cities of Iasi County, which is a part of the Region 1 North East (established by Law no. 315/2004 on regional development in Romania) being the 23rd largest county in Romania. Iasi territory belongs to the temperate zone – continental pronounced, the average annual temperature of air is between 8 °C–10 °C. The urban population (in 2008) in Iasi was 391654 inhabitants according to INS (2011). The number of inhabitants in the urban area decreased in 2010–2011 and is increasing from 2012 (Fig. 2) (INS 2015).

In Iasi city the municipal solid waste is collected by a public company of local interest. In 2008, the population served by sanitation services represented approximately 46% of the number of total inhabitants of the county, the coverage in urban areas being 96% and 0.8% in rural areas (BALKWASTE 2010; Doba *et al.* 2008). After 2009 the management of waste generated in rural areas has significantly improved due to the fact that most local authorities have signed contracts with authorized sanitation operators or have developed their own system sanitation (EPAIS 2014a). The evolution of coverage degree with sanitation services for both urban and rural areas, it is shown in the Table 1.

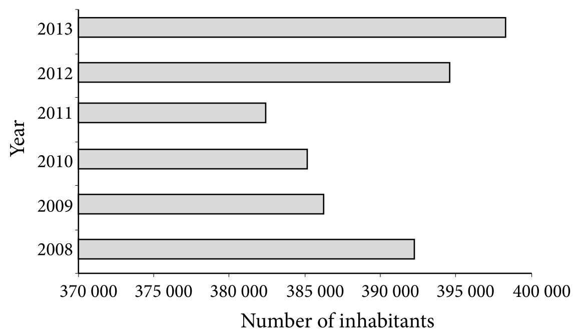

Fig. 2. Number of inhabitants in Iasi urban areas for 2008–2013 according to INS (2015)

Table 1. Evolution of coverage degree with sanitation services (according to EPAIS 2014a)

	Population served (%)				
	2009	2010	2011	2012	2013
Urban	95.8	95.14	93.71	84.27	92.98
Rural	18.38	66.23	60.14	79.93	79.72

According to the Iasi County Council (2009) the total amount of waste generated in 2008 was **272184** tons. The quantities of waste generated in 2008 in Iasi are: mixed household waste collected from households: 161045 tons; assimilable waste collected mixture of trade, industry: 23240 tons; waste from gardens and parks: 2162 tons; waste from markets: 2121 tons, street waste: 19834 tons; bulky waste: 48 tons; waste generated and uncollected: 63495 tons; waste collected selectively: 239 tons (Iasi County Council 2009).

The amounts of MSW generated collected and uncollected in Iasi for the 2009–2013 period are illustrated in Figure 3 (EPAIS 2014a, b).

67.73% from the total amount of MSW generated in 2012 (year for which data were validated by EPAIS) is represented by the household and assimilable waste followed by demolition and construction waste (with 30.44%) and waste from municipal services (1.83%) (EPAIS 2014a). The waste generation indicators for urban area expressed in kg / inhabitant and day are: 0.9 (in 2008), 0.907 (2009), 0.914 (2010), 0.922 (2011), 0.929 (2012) and 0.937 (2013). It should be noted that after installing the economic crisis (2009), indicators mentioned above were not confirmed in practice by sanitation operators (indicators in the data reported by sanitation operators show lower values) (EPAIS 2014a).

The composition of household waste (in 2012, Fig. 4) has not been determined by measurements, but was estimated using data from the annual statistical survey questionnaires completed by sanitation operators and recyclable waste collectors (EPAIS 2014a, b). In Iasi County, as well as national level, biodegradable waste is an important component of municipal waste (EPAIS 2014b). From Figure 4 it can be observed that biodegradable waste (biowaste) have the highest percentage – this category includes waste biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers or retail store, comparable waste from food processing plants. In the last years, biodegradable municipal solid waste percentage dropped from 64% in 1998 to approx. 48% in 2012 (EPAIS 2014a).

Reducing the amount of biodegradable waste generated after 2010 is due to expansion of selective collection of waste, particularly waste paper, and in rural areas were promoted information and awareness for households individual composting and construction (by involving local

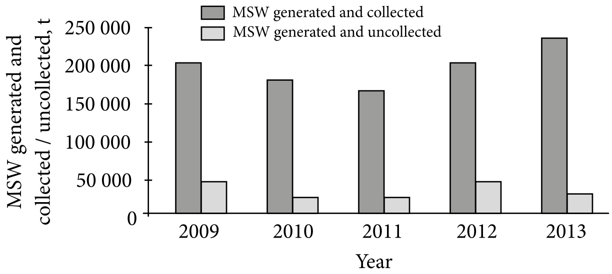

Fig. 3. Quantities of waste generated in 2009–2013

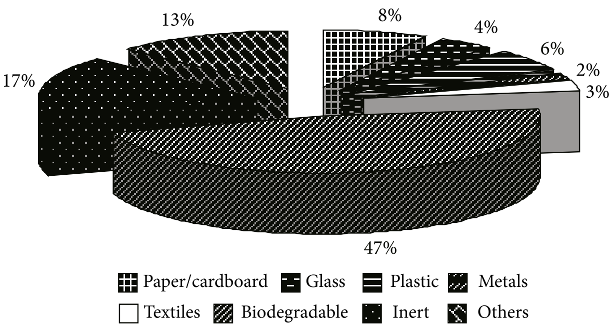

Fig. 4. The average composition of household waste in urban areas (%)

authorities) of platforms for composting manure and vegetable waste.

According to European Directive 1999/31/EC on the landfill of waste, transposed into national law by H.G. 349/2005 on waste, amended and supplemented, the target for reducing the amount of biodegradable municipal waste is July 16, 2020 – *the amount deposited should be reduced to 35% of the total amount* (produced in 1995, expressed gravimetric). For the Iasi County the amount of biodegradable waste generated in the year 1995 was 115659 tonnes and therefore the appropriate target will be for July 16, 2020: 75178 tons (EPAIS 2014b). Composting and anaerobic digestion are two solutions for reducing of biowaste landfilled. Until now these two methods were not practiced in Iasi County, but they were placed a total of 120 containers for biowaste.

Waste sanitation operators have created facilities, especially in urban areas, for recyclable waste from households, especially for paper/cardboard and plastics, but there is the possibility of collecting and others categories of recyclable like metals, textile, glass etc. Table 2 presents the amounts of waste selectively collected during 2008–2012.

The MSWM system existing in 2008 in Iasi city included only the collection of mixed waste and landfilling in Tomesti landfill (Schiopu *et al.* 2009). It represented a significant source of soil and groundwater pollution, because leachate collection network was totally improper. Leachate can migrate into soil and groundwater and generate environmental and health risks (Caliman and Gavrilescu 2009; Schiopu *et al.* 2009). Since 2009, the new, compliant Tutora landfill was built and put into operation according to the legislation. In Tutora landfill the collection and treatment of leachate is carried out according to the law. Also the collection of landfill gas is going to be set up. In 2009 a sorting station at Tutora was put into operation with a capacity of 29,000 tons/year and a composting station was at that time under construction (Schiopu *et al.* 2009; Iasi County Council 2009; Iasi County Council 2011).

In March 2012 the composting process was supposed to start, based on turned windrows method, with pyramidal shape (length of 30 m, height 2 m and width 3 m), and wetting made by the operator (waste of the windrow are 100% vegetable). Since October 2012 windrows with green waste and household waste (25–30%) were supposed to be carried out, but from various reasons the composting station did not work in 2012 and 2013 (Iasi County Council 2011; EPAIS 2014a, b).

Analyzing the amount of waste generated in the Iasi County during 2008–2013 it can be established that since 2009 the quantities of waste generated had a slight fluctuation, but overall, showed a decline. We can appreciate that this trend is mainly due to the economic crisis and less than prevention. Forecasting of MSW amounts plays an important role in planning and implementing of waste management systems (Ghinea, Gavrilescu 2010b).

The main factors that influence waste prognosis are: changes in population in the county; changes in the county's economy; changes in the demand and nature of consumer goods; changes in production technologies (EPAIS 2014a). Integrated waste management in the Iasi County has already passed from exclusive landfilling of waste (household waste and similar to household waste) to selective collection and recovery in a higher proportion of recyclable waste, including the transformation of organic waste into compost (although with poor results until now) and for the remaining waste which will end up to landfill, they are removed only in the ecological landfill Tutora.

Most communities use an integrated waste management, which means they use a variety of methods for solid waste management (EC Europa 2010; UNEP 2009b, c). These methods are included in a waste hierarchy which is accepted as a universal guideline for waste management in many countries (Ahluwalia, Nema 2007; Ghinea, Gavrilescu 2010a; Kirkeby 2005).

Based on the European Directive on landfilling, the waste management hierarchy established some actions to minimize waste, such as (Council Directive 1999; Council Directive 2008; Ghinea, Gavrilescu 2010a):

- minimizing the use of raw material in production;
- recovering and reuse material as far as possible and make it economically feasible;
- incineration and biological treatment, with energy recovery;
- landfilling, as the last option.

The waste hierarchy purpose is to generate a minimum quantity of waste and to draw the maximum practical benefits from products (Schiopu *et al.* 2007).

The waste hierarchy has some limitations: it has no measurable scientific basis, cannot consider combinations of treatment technologies and also, it does not address cost issues (Ghinea, Gavrilescu 2010a). Waste hierarchy does not attempt to assess environmental impacts for a waste management system and does not take into account any local conditions which may significantly change the environmental consequences (Kirkeby 2005).

In 2005, the European Commission adopted the "*Thematic Strategy on the prevention and recycling of waste*" which addresses waste prevention as one of the priority issues (EC 2005).

It entails the use of economic instruments to implement the waste hierarchy so that, key actions have to be set out to modernize the existing legal framework and to encourage waste prevention, reuse and recycling, with waste disposal only as a last option (EC 2011; JRC 2011). Legislative improvements are the first movement towards adapting the regulatory framework, in order to provide a legal structure that is flexible and promotes a recycling society, which avoids losses and uses resources that are found in waste (EC 2005). At European level there are a number of directives on waste management. One of the first was the 1975 Waste Framework Directive (75/442/EEC) which aimed to harmonize national measures concerning waste, foster the development of waste management plans, prevent generation of waste and promoting recycling (Council Directive 1975). Other general regulations and guidelines were elaborated related to the: waste transport (259/93EEC), incineration of hazardous waste (94/67/EEC), waste incineration and existing facilities (89/429/EEC and 2000/76/EC), waste disposal (99/31/EC), packaging and packaging waste (94/62/EC) etc (Council Directive 1989; Council Directive 1994; Council Regulation 1993; Council Directive 1999; EC 1994; EC 2000). In Romania before 1990 waste management was less considered and the first statistics were introduced in 1993 (Schiopu *et al.* 2007). The European waste legislation was transposed into Romanian legislation, the waste management objectives were established in the National Waste Management Strategy (NWMS) and the National Waste Management Plan (NWMP) was developed for NWMS implementation. In order to achieve the conformity with EU directives Romania granted some transition periods: temporary storage of dangerous waste by 2009; storage of non-hazardous industrial waste by 2013, for municipal waste sites until 2017 (NWMP 2004).

Recovery and recycling of solid waste are important solid waste management methods that have environmental benefits at every stage in the life cycle of a product from the raw material extraction to its final disposal. Troschinetz and Mihelcic (2009) showed that recyclable materials such as ferrous metals and plastics have a market value higher than paper or biowaste. Emery *et al.* (2007) demonstrated that paper and biowaste are preponderantly in waste flows and therefore are the most adequate materials for collection when targets for recycling are considered.

The design of waste management systems adapted to local needs and traditions represents the key to successful development of waste recycling option, as well as other options (ISWA 2009). Recovery and recycling depend greatly on materials collecting and sorting and if these materials will eventually be used in specific branches of industry. Consequently, production technology in glass, metal, paper, cardboard and plastic industries should be adapted to use these recovered materials (NWMP 2004).

Therefore a substantial reduction in final volumes of waste could be achieved, while the recovered material and resources could be used to generate revenues, which can fund the waste management further actions (Consonni *et al.* 2005; UNEP 2009c).

Regarding the organic waste recycling sector the developing market opportunities for renewable energy and compost is hampered due to the competition with fossil fuels and chemical fertilizers (Matter *et al.* 2015). Corsten *et al.* (2013) have compared waste streams recycling and waste incineration in terms of savings in energy consumption and CO_2 emissions. They found that recycling of plastics, textiles, paper, and organic waste are the main contributors to reduction of CO_2 emissions and energy consumption.

Brunner and Rechberger (2015) demonstrated that waste to energy plants contributes to sustainable waste management, while Cucchiella *et al.* (2014) showed that the global waste incineration market has increased in recent years and will continue to grow. Massarutto (2015) reviewed the economic aspects of solid waste incineration based on literature from the last years focusing also on market failures associated with thermal treatment of waste.

Various scenarios based on the waste management hierarchy and on the legislation are or can be performed based on type, composition, amounts of waste and processes for treatment waste, chosen according with the type of waste processed. Each solid waste management system is design to satisfy specific objectives like waste policies, environmental targets, sustainable market etc. based on particular conditions: generation rates, waste composition, geographical location, treatment capacity, solid waste management technologies, stakeholders preferences and others (Ghinea, Gavrilescu 2010a; Klang *et al.* 2008; Morrissey, Browne 2004).

Considering the regulations, characteristics of solid waste and different options for treatment of waste, sustainable market, we elaborated various scenarios for MSWM system in Iasi in order to provide the scientific basis for the implementation of an integrated waste management in Iasi County. All scenarios include *temporary storage* of waste by fractions in containers, *collection* and *transport*

Table 2. Quantities of waste from households collected selectively in 2008–2012 according to EPAIS (2014b)

Year	Total quantity of waste collected (t)	PET	Plastic	Paper cardboard	Glass	Metals	Wood
2008	231	218	–	13	–	–	–
2009	689	255	64	370	–	–	–
2010	2195	620	551	999	–	25	–
2011	1331	470	210	642	3	6	–
2012	2016	310	626	1063	12	5	–

Table 3. MSWM methods included in the scenarios developed

Scenarios	Methods				
	Sorting	Composting	Anaerobic digestion	Incineration	Landfilling
S1	16% of the total waste collected	3% of the total waste collected	–	–	81% of the total waste collected
S2	16% of the total waste collected	3% of the total waste collected	3% of the total waste collected	–	78% of the total waste collected
S3	16% of the total waste collected)	4% of the total waste collected	–	45% of the total waste collected	36% of the total waste collected
S4	16% of the total waste collected	3% of the total waste collected	–	80% of the total waste collected	–

of waste (**TS-CT**). Five types of waste treatment methods: *sorting of recyclable materials* (**SO**), *composting of organic waste* (**CO**), *anaerobic digestion with energy recovery* (**AD**), *incineration with energy recovery* (**IN**) *and landfilling* (**LA**) were selective included in the new designated scenarios (**S – S4**) (Table 3).

The percentages were assumed based on the type of waste and the quantities of waste produced. The reference scenario is designated as **S** (*landfilling* of 100% of waste collected) and was used as a basis for comparison. This scenario is considered without collection or treatment of landfill gas and leachate (as it was the situation in Iasi in 2008).

The first scenario include sorting, composting and landfilling since from 2009 a new landfill was put into operation, collection and treatment of leachate and the potential production of electricity and heat from landfill biogas were considered. Regarding sorting process it was assumed that the recyclable materials after sorting were reprocessed in order to reduce emissions from the production of products such as paper, plastic from virgin materials and consumption of natural resources like wood (Ghinea *et al.* 2012).

The composting process was considered as well as the substitution of synthetic soil fertilizers with compost, so that the impacts associated to the production of synthetic fertilizers are avoided (Ghinea *et al.* 2012).

S2 compared with S1 includes the same treatment processes plus one, anaerobic digestion. This process was taken into account considering that organic waste represents almost half the amount of waste produced and besides compost, it can be obtained the biogas. S3 include besides the processes included in S1, the incineration process with energy recovery. In S4 the landfill was not considered, it was assumed that recyclable materials were sorted, organic waste composted and residual waste incinerated.

Sorting of recyclable materials (SO)

The sorting facility includes an installation with average degree of mechanization where supply is: automatic by a sorting line with mechanized means; manual sorting of plastic, metals, paper, cardboard and wood; mechanical separation of ferrous and non-ferrous metals; all fractions are bundling using baling machines; transportation of refusal, bales and containers is done mechanically. By sorting will be processed only the waste dry for obtaining recyclable fractions.

Composting organic waste (CO)

The composting process of organic waste (**CO**) includes:

- ***mechanical pre-treatment stage:*** with inputs organic waste, electricity (32% of the total energy required for the entire process) and outputs pre-treated organic waste; contaminates (5% of organic waste entering);
- ***composting phase*:**
  - inputs as pre-treated organic waste; electricity (22% of the total energy required for the entire process), water (2% input mass);
  - outputs fresh compost (81% of input mass); water content in fresh compost 50%; wastewater (125 L/t input); emissions to air represented by CO_2 (95% from %C emission to air), CH_4 (3% from %C emissions to air), NH_3 (96% from %N emission to air); emission to water represented by NH_3 (47% from %N emission to water), carbon organic (100% from % C emission to water).
- ***maturation phase:***
  - inputs: fresh compost; electricity (46% of the total energy required for the entire process); water (20% input mass);
  - outputs: matured compost (44% of input mass); wastewater (165 L/t input maturation); emissions to air represented by CO_2, CH_4, NH_3; and emission to water represented by NH_3, carbon organic.

The total fuel consumption and overall energy for composting are 5.53 L and respectively 43.5 kWh per ton of waste. The substitution of nitrogen and phosphorus fertilizers with nitrogen and phosphorus from compost was also taken into account (den Boer *et al.* 2005; Ghinea *et al.* 2012; Recycled Organics Unit 2003; Veeken *et al.* 2011).

Anaerobic digestion with energy recovery (AD)

Biogas is generated during anaerobic digestion, while the remainder can be converted into compost. The process includes:

- ***mechanical pre-treatment:*** the organic waste is prepared for digestion, while plastics, metals and oversized components are removed from the waste to be treated;
- ***fermentation:*** biogas is produced. It was assumed that the biogas production is 141 m^3/t organic wastes. From 141 m^3 biogas it can be obtained 178 kWh electricity and 391 kWh heat (den Boer *et al.* 2005).
- ***composting:*** in maturation stage the digestion residue is treated to obtain the compost that can be used further for application on soil. About 353 kg of compost are obtained from 1000 kg of organic waste (den Boer *et al.* 2005).

Landfilling (LA)

The surface area of Tutora landfill is 50 ha with a designed capacity of 8,613,000 m^3, divided into four cells that should serve the entire county. The landfill is equipped with: leachate collection system; landfill gas collection system; rainwater collection system. The leachate treatment plant is operating within the landfill, with a capacity of 84 m^3/day and uses the reverse osmosis (RO) technology. Leachate is collected and discharged into a leachate tank and then aspirated in the leachate treatment plant. The RO plant is complying with the requirements of EU directives (Council Directive 1999; Council Directive 2008). Also, we assumed that the landfill gas was used to produce energy. Considering that all waste fractions contribute to the production of biogas, excepting the inert fractions (glass, metals), the amount of landfill gas was calculated. The trace elements of biogas were also calculated according to Ghinea *et al.* (2012). The amount of leachate and leachate emission were calculated and estimated.

Scenarios 3 and 4 include *incineration* (**IN**) as one of the processes used to treat municipal solid waste, with energy recovery and metals recovery after slag treatment. The substituted processes are electricity/heat generation and primary metals production. One of the most important elements from incineration plant is the flue gas purification system. It was considered that the flue gasses generated from the combustion furnace are cleaned through an electric precipitator, where the fly ashes are then trapped by the filters. Water soluble compounds such as: sulphur dioxide (SO_2), hydrochloric acid (HCl), fine particles are removed into a scrubbing installation. Temperature of gases in the wet scrubbers drops from 250 °C to 60 °C. The next step in the flue gas purification is the deNOx system: for filtering out nitrogen oxide gasses, they are heated at 250 °C; then the nitrogen oxides are removed using ammonia (BREFF 2006). The residual products resulted from incineration process are: bottom ash, metals, other ash, salt from flue gas scrubbing, sludge. Emissions from incineration process are: nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO), dust, hydrocarbons, hydrochloric acid (HCl), ammonia (NH_3), hydrofluoric acid (HF), mercury (Hg), heavy metals, dioxines /furanes. It was assumed that the amount of energy produced can be used locally. It is mentioned that the amount of energy produced differ between the two scenarios (**S3** and **S4**).

2. Economic analysis

Economic concerns are considered key issues for decision-making and selection of waste management technologies and practices in a sustainable integrated waste management system (Begum *et al.* 2006). In order to investigate, compare and distinguish between the proposed and existing waste management scenarios from economic viewpoint, we have analyzed the total costs of these systems. The environmental impacts related to the processes included in the evaluated scenarios were translated into monetary values. The translation was done for each scenario evaluated, based on an inventory analysis.

We evaluated the ***temporary storage costs***, considering the following categories of containers: containers with a volume of 1.1 m^3 and the price of 250 €/container (Iasi County Council 2011); containers with a volume of 0.24 m^3 and the price of 60 €/container (Iasi County Council 2009). A life span of nine years has been chosen for each container type (Iasi County Council 2009). The containers location price was calculated as 1000 €/location/12 years = 83 €/year, considering three containers with 1.1 m^3/location (Iasi County Council 2011).

The necessary data for the evaluation of ***waste collection and transport costs*** included: number of vehicles and their loading capacity; transport distance; fuel consumption and emissions. Iasi municipality owns 30 vehicles with a total loading capacity of 1881 m^3 (Doba *et al.* 2008). The vehicle price was considered as 120000 €/vehicle with a life span of 12 years (Iasi County Council 2011), and a 15% interest rate of the investment per vehicle (Rhoma *et al.* 2010). The fuel consumption was estimated at 30 L/100 km (den Boer *et al.* 2005) at a Diesel price of 1 €/L (Iasi County Council 2009).

The inputs for ***landfilling process*** were as follows: the amounts of waste fractions landfilled, fuel consumption. The emissions from fuel consumption, landfill gas and leachate were regarded as outputs. The ***investment costs*** for landfill lies around 65–160 €/t solid waste (Iasi County Council 2009). For a landfill gas plant of 0.75–8 MWel (MegaWatt, electric energy), the investment costs were considered as 1500–2100 €/ kWel (kiloWatt, electric energy), while operation and maintenance costs as 55–85 €/kWel (de Jager *et al.* 2011). Leachate treatment costs was considered as 25.83 €/m^3 (Eunomia Research and Consulting 2001).

For a ***sorting plant*** with a capacity of 29000 t waste/y, ***the investment costs*** ranged from 65–150 €/t (Iasi County Council 2011). The consumptions for sorting and pre-cleaning recyclable materials like glass, plastic, metals were as follows: electricity, 10 kWh/t waste; diesel, 2.4 L/t waste; lubricants, 0.2 L/t waste. The consumptions for paper and cardboard sorting were considered as follows: electricity, 5.35 kWh/t waste; Diesel, 0.64 L/t waste; lubricants, 0.01 L/t waste (den Boer *et al.* 2005).

The investment costs for the biowaste composting plant of 10000 t/y capacity were 150-200 €/t (Iasi County Council 2009). According to Recycled Organics Unit (2003), the total fuel consumption during composting operations can be considered as 5.53 L/t of waste, while the electricity demand for composting was 10 kWh/t. The wastewater production was 125 L/t waste input (den Boer *et al.* 2005).

The investment costs for an incineration plant with a capacity of 100,000 t/y were around 670–902 €/t according to BREFF (2006). The levels for various categories of costs for municipal solid waste management technologies used in this study are presented in Table 4.

Table 4. Costs of municipal solid waste management technologies

Technology	Investment costs (€/T)	Operating and maintenance costs (€/T)
Sorting	122	30.72
Composting	159	30.3
Anaerobic digestion	370	70.1
Incineration	649	92.9

Annual operating and maintenance expenses include: salaries, fuel, energy, materials etc. The following costs were considered: energy, 0.076 €/kWh; water, 0.55 €/m^3; wastewater, 0.21 €/m^3 (Iasi County Council 2009). The recycling revenues and potential savings by energy use are not considered in this study because only the costs were taken into account. These revenues enter at benefits (economic, social and environmental) and will constitute the subject for a future paper. The revenues for secondary products are as follows: for paper and cardboard 20–30 €/t; glass 40 €/t; plastics 60–70 €/t; metals 150 €/t; compost 5–7 €/t; energy 1.5 €/kWh (BALKWASTE 2011; Iasi County Council 2009).

2.1. Costs calculation

The investment, operating and maintenance, administrative and other costs were calculated for each process included in the proposed scenarios. Costs for temporary storage, collection and transport (**TS-CT**) of solid waste were calculated using Eqs. (1–13):

$$C_{TS-CT} = C_{con} + C_{con-loc} + C_{vh} + C_{pers}, \quad (1)$$

where: C_{TS-CT} – temporary storage–collection and transport costs (€/y); C_{con} – container costs (€/y); $C_{con-loc}$ – containers location costs (€/y); C_{vh} – cost of vehicles (€/y); C_{pers} – personnel costs (€/y).

$$C_{con} = C_{con/y} + C_{con-m/y}, \quad (2)$$

where: $C_{con/y}$ – container costs/year (€/y) (Eq. 4); $C_{con-m/y}$ – container maintenance costs/year (€/y) (Eq. 5);

$$C_{con/y} = \frac{P_{con} \cdot N_{con}}{y_{con}}, \quad (3)$$

where: P_{con} – price per container (€); N_{con} – number of containers (Eq. 4); y_{con} – life time of containers (years).

$$N_{con} = \frac{Q}{(\rho/1000)\cdot(V/1000)\cdot\phi\cdot r}, \quad (4)$$

where: Q – quantity of waste (t/y); ρ – density of waste (kg/m^3); V – volume of container (L); ϕ – collection frequency of a certain waste fraction; r – average filling rate (%).

$$C_{con-m/y} = 4.3\% \cdot C_{con/y}. \quad (5)$$

The costs of containers location were determined using Eq. (6):

$$C_{con-loc} = N_{con} / 3 \cdot P_{con-loc}, \quad (6)$$

where: $C_{con-loc}$ – costs of containers location (€/y); – number of containers; $P_{con-loc}$ – price of location container (€/y).

The costs with vehicles were calculated using Eq. (7):

$$C_{vh} = C_{vh-f} + C_{vh-v}, \quad (7)$$

where: C_{vh} – vehicle costs (€/y); C_{vh-f} – vehicle fixed costs (€/y); C_{vh-v} – vehicle variable costs (€/y);

$$C_{vh-f/y} = C_{vh-c/y} + C_{vh-i/y} + C_{vh-t/y} + C_{vh-in/y}, \quad (8)$$

where: $C_{vh-f/y}$ – vehicle fixed costs/year (€/y); $C_{vh-c/y}$ – vehicle capital cost/year (€/y); $C_{vh-i/y}$ – vehicle insurance costs/year (€/y); $C_{vh-t/y}$ – vehicle tax costs/year (€/y), $C_{vh-in/y}$ – vehicle investigations costs/year (€/y).

$$C_{vh-c/y} = n_{vh} \cdot \left[\frac{(C_{vh-inv} - C_{vh-sal})}{D_{pv} + 0.5\cdot(C_{vh-inv} - C_{vh-sal})\cdot R_a}\right], \quad (9)$$

where: n_{vh} – number of vehicles; C_{vh-inv} – investment costs for vehicles (€); C_{vh-sal} – salvage value of vehicles (€); D_{pv} – depreciation period of vehicles (12 years); R_a – interest rate of the investment for vehicles (%).

$$C_{vh-v/y} = C_{vh-fuel/y} + C_{vh-m/y} \quad (10)$$

where: $C_{vh-v/y}$ – vehicle variable costs/year (€/y); $C_{vh-fuel/y}$ – vehicle fuel costs/year (€/y); $C_{vh-m/y}$ – vehicle maintenance costs/year (€/y).

The total costs of temporary storage were calculated with Eq. (11):

$$TC_{TS-CT} = C_{TS-CT} + C_{TS-CT-a} + C_{TS-CT-o}, \quad (11)$$

where: TC_{TS-CT} – total costs of temporary storage–collection and transport of solid waste (€/y); C_{TS-CT} – costs of temporary storage–collection and transport (€/y); $C_{TS-CT-a}$ – administrative costs of temporary storage–collection and transport (€/y); $C_{TS-CT-o}$ – other costs of temporary storage–collection and transport (€/y).

$$C_{TS-CT-a} = 10\% \cdot C_{TS-CT-o\&m}, \quad (12)$$

$$C_{TS-CT-o} = 5\% \cdot TC_{TS-CT}. \quad (13)$$

Calculation of landfilling process costs were carried out with Eqs. (14–19):

$$TC_{L-inv} = l_d + u_e + ds_c + b_{ic} + c_c + o_c, \quad (14)$$

where: TC_{L-inv} – landfill investment costs (€); l_d – land development costs (€); u_e – expenses with utility

(€); – design and service charges (€); b_{ic} – basic investment costs (€); c_c – commissioning costs (€); o_c – other costs (€).

$$C_{L-o\&m} = s + m_e - l_c + d + e\,, \tag{15}$$

where: $C_{L-o\&m}$ – costs of landfill annual operating and maintenance (€/y); s – salaries (€/y); $m_e - l_c$ – costs with material expenses and labour (€/y); d – diesel (€/y); e – energy (€/y).

$$TC_L = C_{L-inv} + C_{L-o\&m} + C_{L-a} + C_{L-o}\,, \tag{16}$$

where: TC_L – total landfill costs (€/y); C_{L-inv} – landfill investment costs (€/y); C_{L-a} – landfill administrative costs (€/y); $C_{L-a} = 10\% \cdot C_{L-o\&m}$ (€/y); C_{L-0} – landfill other costs (€/y); $C_{L-o} = 5\% \cdot TC_L$ (€/y).

The total costs of landfill with collection of biogas and treatment of leachate, composting, sorting, anaerobic digestion, incineration plants were established with Eq. (17).

$$TC \ = C_{inv} + C_{o\&m} + C_a + C_o\,, \tag{17}$$

where: TC – total costs per process (€/y); C_{inv} – investment costs (€/y); $C_{o\&m}$ – annual operating and maintenance costs (€/y); C_a administrative costs; $C_a = 10\% \cdot C_{C-o\&m}$ (€/y); C_o other costs (€/y); $C_o = 5\% \cdot TC$ (€/y).

Total costs for each scenario were calculated with Eqs. (18–22):

$$TC_S = TC_{TS-CT} + TC_L\,; \tag{18}$$

$$TC_{S1} = TC_{TS-CT} + TC_S + TC_C + TC_L\,; \tag{19}$$

$$TC_{S2} = TC_{TS-CT} + TC_S + TC_C + TC_{DA} + TC_L\,; \tag{20}$$

$$TC_{S3} = TC_{TS-CT} + TC_S + TC_C + TC_I + TC_L\,; \tag{21}$$

$$TC_{S4} = TC_{TS-CT} + TC_S + TC_C + TC_I\,, \tag{22}$$

where: TC_S – total costs for existing scenario, (€/y); – total costs for scenario 1, (€/y); TC_{S2} – total costs for scenario 2, (€/y); TC_{S3} – total costs for scenario 3, (€/y); TC_{S4} – total costs for scenario 4, (€/y); TC_C – total composting costs (€/y); TC_S – total sorting costs (€/y); TC_{DA} – total anaerobic digestion costs (€/y); TC_I – total incineration costs (€/y); TC_L – total landfill costs (€/y).

The investment costs for each scenario (expressed in €/t) were calculated by dividing the investment costs to the total quantity of waste processed.

The managing costs (expressed in €/t/y) were calculated by dividing the operating and maintenance costs to the total quantity of waste processed (Fig. 5).

Results showed that scenarios which include incineration as a process for the solid waste treatment/disposal have the highest cost, while the other scenarios that include disposal in landfills have the lowest costs. It can be observed that scenario **S4** requires the highest investment, operating and maintenance costs compared to the other analyzed scenarios.

2.2. Discounting of costs

After all costs were calculated, we converted them into present value terms or discounting costs of scenarios according to Eq. (23) (Hanley, Spash 1993):

$$PV_{S_i} = C_{Si} \cdot df \ \text{(€)}. \tag{23}$$

Discounting is "a process of assigning a lower weight to a benefit or cost in the future than to that benefit or cost now" (NORDEN 2007). The values of discount factors always lie between +1 and 0 (Hanley, Spash 1993). The discount factor was calculated with Eq. (24):

$$df = \frac{1}{(1+r)\cdot t}\,, \tag{24}$$

where: df – discount factor; r – discount rate (%); t – year payback for investment.

$$r = \frac{rd}{100} + \frac{ri}{100} + \frac{rv}{100} + \frac{rr}{100}\,, \tag{25}$$

where: r – discount rate (%); rd – annual interest rate; – annual inflation (or deflation) rate; rv – annual depreciation or appreciation of the currency; rr – risk margin.

In this study, we considered the discount rate as equal to the value of the annual inflation rate, $ri = 5\%$ and the discount time, 10 years. We have chosen a neither too large nor too small value for discount rate. The economic comparison of the different scenarios could have been led with other values of discount rates (3%, 8%, 11%) in order to establish the suitable discount rate, but this will be done in other studies.

Total costs values were determined for each scenario with Eq. (26):

$$C_{S_i} = C_{inv-S_i} + C_{m-S_i} \ \text{(€)}. \tag{26}$$

where: C_{S_i} – total costs (€), i = 1, 2, 3, 4; C_{inv-S_i} – total investment costs (€); C_{m-S_i} – total managing costs (€) calculated with one of the Eq. (18–22) according to the analyzed scenario.

Figure 6 shows that scenario **S4** is the most expensive for implementation and management, while scenario **S1** is the most convenient in terms of costs.

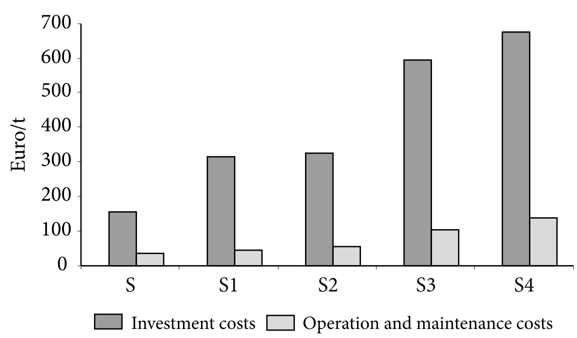

Fig. 5. Investment and operating + maintenance costs for each analyzed waste management scenario (**S-S4**)

3. Sensitivity analysis and discussion

Sensitivity analysis is performed in order to find the most vulnerable parameters in terms of costs for the evaluated scenarios (Hanley, Spash 1993). Sensitivity analysis was performed by changing the initial values for investment and operating + maintenance costs with minimum and maximum values, respectively. The values used in this study are presented in Table 5 and were established based on data from the literature (BALKWASTE 2011; Iasi County Council 2009).

First of all, only the investment costs were changed and the calculations were performed again according to Eqs. (1–22). Results are shown in Figure 7a. Then, the operating + maintenance costs were varied using the minimum and maximum values. The results are shown in Figure 7b. In this analysis, different monetary valuations were applied, but the same environmental impact results were considered. Figure 7 (a, b) show that results are dependent on the manner the cost assumption was made. The **investment costs** are sensitive for scenarios **S2, S3** and **S4**. The variation in investment costs for anaerobic digestion has a great influence for the final costs of scenario **S2**. The variation of investment costs for the incineration process influences the total costs of scenarios **S3** and **S4**. The operating and maintenance costs for scenarios **S3** and **S4** are sensitive to any kind of variation, due to the operating and maintenance costs for incineration.

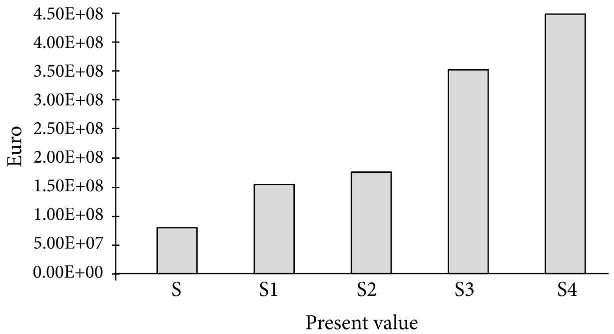

Fig. 6. Present value/discounting costs for the evaluated scenarios

a)

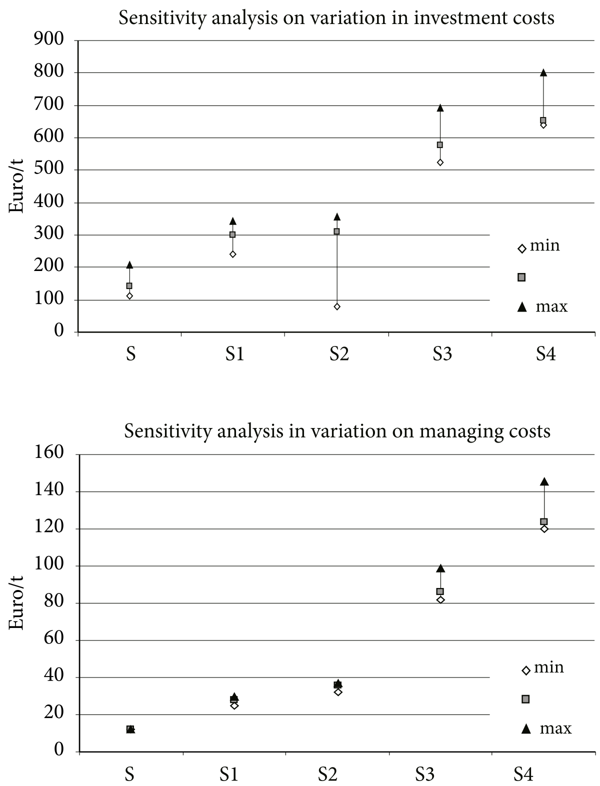

Fig. 7. Sensitivity analysis of the variations in: a) in investment costs; b) in managing costs

It was expected that the investments and managing costs for scenarios that include incineration to be sensitive. This situation was also observed in other studies (BALKWASTE 2011).

Results showed that the incineration process is the most expensive solid treatment method and scenarios which include this process involves the highest costs (S3 and S4). Scenarios S1 followed by S2 are suitable for implementation from cost perspective.

Even landfilling, which has the lower costs should be avoided because has a major contribution to the GWP and EP, these situation observed also by Batool and Chuadhry (2009), Cherubini *et al.* (2009), Eriksson *et al.* (2005), etc. According to Eriksson *et al.* (2005) materials recycling combined with incineration and anaerobic digestion would probably be the best solution to avoid landfilling as much as possible.

Assamoi and Lawryshyn (2012) calculated the cost and the revenue of solid waste landfilling and incineration. They also showed that the investment capital and operating costs for incineration are higher than those for landfilling and concluded that incineration facility becomes competitive financially when the landfill facility is located at a considerable distance from the city (500 km).

Moutavtchi *et al.* (2008, 2010) developed a cost structure model for solid waste management which included capital costs, operating costs, other costs (that we have also considered in this paper), in addition to this they included costs for extensive and routine repairs, infrastructure costs, investment project services costs, costs for current monetary damage caused by pollution of the environment, environmental taxes.

Rhoma *et al.* (2010) developed a mathematical model for estimating solid waste management costs including: logistic costs, vehicle costs, personnel costs, container costs etc. They applied the model for evaluation of SWM system from Duisburg city considering three scenarios with normal and full services.

Our model developed in this paper contains some variables and some equations for calculation similar to

Table 5. Minimum and maximum values for investment and operating + maintenance costs

Technology	Investment costs		Operating + maintenance costs	
	Minimum (€/t)	Maximum (€/t)	Minimum (€/t)	Maximum (€/t)
Sorting	65	150	16.4	37.8
Composting	150	200	28.6	38.1
Anaerobic digestion	300	387	56.8	73.3
Incineration	645	800	92.3	114.5

those presented by Rhoma *et al.* (2010) and Moutavtchi *et al.* (2008, 2010). The calculation model developed by us is simple, easy to use, but can be improved by adding the costs of the environmental impact (the costs required to reduce the emissions in the product chain "from cradle to grave" to a sustainable level, costs for sustainable energy sources etc.) and others.

In the further studies we will calculate the benefits that could result from the implementation of these scenarios so that the evaluation will be more complete and the cost benefit analysis method will be applied, the costs/benefits and benefits/costs ratios and net present values will be calculated.

Conclusions

In this paper we have investigated economic aspects of different municipal solid waste management scenarios. A structure of costs was proposed for the evaluation of waste management scenarios.

The comparison of costs for different scenarios and processes included in each scenario showed that the scenario which includes sorting, composting and landfilling is the most suitable alternative to the existing municipal solid waste management system in Iasi city, Romania, but the analysis could be extrapolated to other similar case studies.

In addition, the calculation of benefits would be necessary in an integrated cost-benefit analysis, in order to establish the economic feasibility associated with the implementation of different waste management scenarios. Subsequently, the benefits can be compared with the costs, and the net profit of each management alternative can be also determined.

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