Assessing the economic viability of landfill mining projects in Greece

D. Damigos[1], A. Benardos[1], M. Menegaki[1], D. Kaliampakos[1], S. Papagrigoriou[2], Z. Gaitanarou[2], S. Stasinos[3]

[1] School of Mining and Metallurgical Engineering, National Technical University of Athens, 15780 Zografou, Greece
[2] ENVECO S.A., 1 Perikleous str., 15122 Marousi, Athens, Greece
[3] HELECTOR S.A., 25 Ermou str., 14564 Nea Kifissia, Greece

New solid waste management policies around the world envisage higher recycling and reuse rates for municipal and other waste. Today, however, thousands of uncontrolled and controlled landfills, either operating or closed, exist that are potential sources of environmental contamination and nuisance occupying valuable land that could be utilized for other purposes and, at the same time, contain useful materials. One option to tackle this problem is to follow the Landfill Mining (LFM) approach, which refers to the process of excavating, and sorting solid waste from operating landfills in order to recycle or produce energy from recovered materials, conserve landfill space, and rehabilitate/redevelop contaminated sites. This paper aims at estimating the economic feasibility of LFM projects, in Greece. The analysis is based on the technical and economic data gathered during the first LFM pilot project carried out in Greece, at the Polygyros landfill, in Chalkidiki. For the purposes of the analysis, a hypothetical "typical" Greek landfill site is examined and different alternatives are formed as regards the objectives and, consequently, the cost and benefits of the LFM operations. Furthermore, in order to account for the uncertainty involved in the parameters of the economic model uncertainty analysis via risk assessment is being conducted. The paper concludes on the basis of the findings of the study about the economic feasibility of LFM in Greece and the critical technoeconomic factors influencing the viability of the scenarios under investigation.

Keywords: Landfill mining, waste material recovery, feasibility analysis

1. INTRODUCTION

Provided that new solid waste management policies globally promote higher recycling and reuse targets for municipal and other waste, it is envisaged that in the near future the amount of waste directed to landfills will be minimized. Nowadays, however, there are thousands of uncontrolled and controlled landfills. For example, Wagner and Raymond [1], citing the work of Krook et al. [2] and Ratcliffe et al.[3], point out that in the EU alone it is estimated that there are 150,000-500,000 closed and active landfills containing around 30-50 billion m^3 of waste that could be potentially used for the recovery of useful materials and energy. These landfills, besides being repositories of materials and energy, occupy valuable land that could be utilized for other purposes and in some cases constitute sources of environmental contamination and nuisance [e.g. 4-6].

Over the past two decades, research efforts around the world have focused on developing methods to account for problems related to the above-mentioned issues. A promising solution seems to be offered by the Landfill Mining (LFM) approach, which refers to the process of excavating and sorting the unearthed materials from operating or closed solid waste landfills for recycling, processing, or for other dispositions [2,7-12]. In general, the objectives of LFM may include: elimination of potential contamination sources; recovery of energy; recovery of useful materials; conservation of landfill space; reduction in waste management costs; and rehabilitation and redevelopment of landfill sites [7,9,13]. In cases where waste have to be moved either for serious environmental reasons or for other purposes, the economic feasibility of LFM projects is not seen as a priority (Ford et al., 2013). In all other cases, however, LFM projects need to be economically feasible.

Until today, the economic feasibility of LFM projects from a private point of view has been studied little and with conflicting results. For instance, van Vossen and Prent[14], Jain et al.[15], Zhou et al. [12] and Wagner and Raymond [1] examining different case studies found that the LFM projects have the potential to provide positive monetary benefits under certain circumstances. However, contrary results have been reported by other researchers, e.g. Ford et al. [16], Danthurebandara et al.[17], Frändegård et al.[18], and Winterstetter et al.[19], i.e. the difference between the values of monetary inflows and outflows is negative. These contradicting findings are mostly related to the country and site-specific conditions occurring at the investigated case studies that affect the capital (CAPEX) and operating expenses (OPEX) of the project, as well as its revenues. Therefore, the only safe conclusion that can be drawn at the moment is that the economic success of the LFM projects is not guaranteed and, thus, each and every case should be examined on its own particular facts and circumstances before deciding whetherLFM can be implemented or not.

LFM may be a suitable approach for dealing with the problems of inappropriate waste management practices in Greece. According to relevant reports, the amount of municipal solid waste (MSW) landfilled in Greece, in 2010, was 4.2 million tonnes, equivalent to 81% of the total generated MSW [20]. Moreover, up to 2011, 109 illegal dumping sites all over Greece were in operation despite the ruling of the European Court of Justice of 2005 [20]. Nevertheless, the economic feasibility of LFM projects in the country has not been investigated, so far. This paper analyzes, for the first time, the cost and benefits of the LFM operations for a "typical" Greek landfill site using technical and economic information gathered from the first pilot project of LFM in Polygyros landfill, in Greece, in the context of the LIFE

RECLAIM “Landfill mining pilot application for recovery of invaluable metals, materials, land and energy” (www.reclaim.gr) project. To this direction, different alternatives are formed as regards the objectives and, consequently, the cost and benefits of the LFM operations and sensitivity and stochastic analyses are being conducted to account for the uncertainty involved in the parameters of the economic model, both internal and external. The paper concludes on the basis of the findings of the study about the economic feasibility of LFM in Greece and the critical techno-economic factors influencing the viability of the scenarios under investigation.

2. METHODOLOGICAL BACKGROUNG

2.1. Valuation approach

The financial analysis is carried out using a typical discounted cash flow (DCF) equity valuation approach, in real prices. For that purpose, the cash flows generated by the operation of the LFM operations are taken into consideration and the economic indicators of Net Present Value (NPV) and Internal Rate of Return (IRR) were estimated.

The NPV is the present value of a project’s cash flows, i.e. inflows and outflows. The primary outflows involve the investment required at the beginning of the project’s life (I_0) and the operating and other expenses, while the inflows include benefits from the recovery of recyclable materials, the potential development of reclaimed land, etc. during the project’s life. The discount rate used to estimate the value of cash flows to the present reflects the riskiness of the project; the riskier the project, the higher the discount rate. The NPV is estimated according to the following equation:

$$NPV = \frac{CF_1}{(1+r)} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \cdots + \frac{CF_n + RV}{(1+r)^n} - I_0 = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - I_0$$

where: CF_i is the cash flow generated by the LFM operations in the i-th period

I_0 is the equity investment cost

RV is the potential residual value of the facilities and the equipment required for the LFM works in the last year

r is the discount rate (expressed in real terms when cash flows are expressed at constant prices), which determines the minimum acceptable return percentage that the investment in question must earn in order to be worthwhile.

A positive NPV indicates that the project generates earnings that exceed the anticipated costs (in present value), i.e. the investment is profitable. On the contrary, a negative NPV indicates that the investment under evaluation results in net losses and, thus, it shouldn’t be undertaken.

The internal rate of return (IRR) is a related metric used to measure the profitability of an investment. The IRR is the discount rate that makes the project’s NPV equal to zero. Therefore, the calculation of IRR involves solving for IRR in the following equation:

$$0 = \sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t} - I_0$$

The IRR express the rate of growth a project is expected to generate. To this end, decision making using IRR requires comparing the IRR with the discount rate used (i.e. the cost of capital) for the investment. If the IRR exceeds the discount rate, the investment should be undertaken; if the IRR is less than the discount rate, the investment is not worthwhile.

In general, the financial analysis of an LFM project should take into consideration the following factors [e.g. 12, 16, 17, 18]:

<u>A. Capital costs</u>

- Pre-activity research and inventory costs
- Permits
- Consultancy and design costs
- Site preparation
- Purchase of excavation and hauling equipment (if the equipment is purchased)
- Purchase of screening and sorting equipment (if the equipment is purchased)
- Other installation costs (e.g. construction of materials handling facilities, incineration facilities for heat and energy recovery, etc.)

<u>B. Operating costs</u>

- Rental of excavation and hauling equipment (if the equipment is rented)
- Rental of screening and sorting equipment (if the equipment is rented)
- Labor costs
  - Skilled personnel
  - Unskilled personnel
- Administrative costs

- Fuel / Energy costs
- Maintenance costs
- Water costs
- Other costs (e.g. training in safety issues, purchase of safety equipment, disposal cost of ash from on-site waste incineration, etc.)

C. Revenues

- Revenues from recyclable and reusable materials
  - Ferrous metals
  - Non-ferrous metals
  - Glass
  - Plastics
  - Combustible waste
  - Stones and construction waste
  - Waste of electrical and electronic equipment
  - Reclaimed soil used as landfill cover material
- Value of recovered air-space (in case that landfill continues to operate)
- Value of reclaimed land for development (in case of full site reclamation and re-development of the land for other commercial purposes)
- Avoided costs of post-closure care (in case of full site reclamation)
- Avoided future liability for remediation (mainly in cases of uncontrolled landfills or unexpected events resulting in contamination)

In our estimates, however, benefits from energy recovery, redevelopment of the landfill area, and reduction in waste management costs (e.g. expenses concerning landfill closure and aftercare), were not taken into account. The latter was attributed either to existing conditions in Greece (e.g. RDF energy utilization in Greece is not possible, so far) or the technical assumptions used (e.g. size of the landfills, productivity of processing units, etc.).

In order to tackle the uncertainty involved in the estimates relating to the costs and benefits of LFM operations, the financial and socioeconomic indicators were explored using:

- sensitivity analysis;
- probabilistic risk analysis by means of Monte Carlo simulations.

Sensitivity analysis enables the identification of the most critical parameters, i.e. those having the largest impact, positive or negative, on the project's financial and socioeconomic indicators. The analysis is carried out by varying one variable at a time and allows determining the effect of each variable on the financial and socioeconomic NPV and IRR indices. The probabilistic analysis involves assigning a probability distribution to each of the critical variables of the DCF model based on literature data, experimental data, expert opinions, etc. Having established the probability distributions for the critical variables, the next stage is to perform a simulation, known as Monte Carlo analysis. This is consisted by the repeated random extraction of a set of values for the critical variables based on the characteristics of each input variable's probability distribution and the calculation, over and over again (iterations), of the project's performance indicators (financial and economic NPV and IRR). The calculations for all combinations of sampled values are then used to develop probability distributions of the NPV and IRR indices offering more comprehensive information about the risk profile of the project. A major advantage of the probabilistic analysis over the sensitivity and NPV break-even analyses is that the former may provide the full range of possible outcomes, since the performance indices are calculated across many input variables that may change simultaneously.

2.2. Technical and financial assumptions

The analysis involves the evaluation of a hypothetical landfill, having the typical characteristics (quantity and composition of waste) of a 20-30 years old Greek landfill close to an urban centre. The technical and financial assumptions related to the LFM process derive from the results of the pilot application carried out at the Polygyros landfill.

2.2.1. Description of the LFM process

The operational phase of LFM typically consists of three basic stages: excavating waste, processing the excavated material, and, managing the excavated or processed material. Waste is excavated using equipment commonly employed in surface mining and landfill operations. The excavated waste can be processed to meet several objectives, including separating bulky materials, sorting hazardous material and other unidentified waste, screening soils from waste, and sorting materials for recycling or use as fuel. Several common mechanical processes (such as magnets for ferrous metal) can be used to separate recyclable materials. According to the study of IWCS [21], in many landfill mining projects screening of the excavated waste is the most common process used.

The excavation procedure, just like in Polygyros site, follows the principles of surface (open-pit) mining. More specifically, the mining of the waste is made with conventional surface mining equipment (excavators, backhoe/loaders, front-end loaders or shovels) and the haulage of the material is performed using standard dump trucks. The processing unit involves a trommel, followed by a picking line and hand sorting separation process consisting of 8 workers that collect hard and soft plastic, glass, and non-ferrous (primarily aluminum) metals. Finally there is an electromagnet unit facilitating the separation of the ferrous metals. In addition, the processing unit recovers soil that is used as landfill covered material.

2.2.2. Technical assumptions

In order to have a representative assessment of a typical Greek LFM case, it is assumed that the landfill under consideration facilitates a city of 200,000 inhabitants, with a design life of 25 years. In Fig. 1, the MSW generation per capita is given for the period of 1990 to 2007. Taken an average MSW generation per capita & year at 400 kg, this yields a total quantity of 2,000,000 tn.

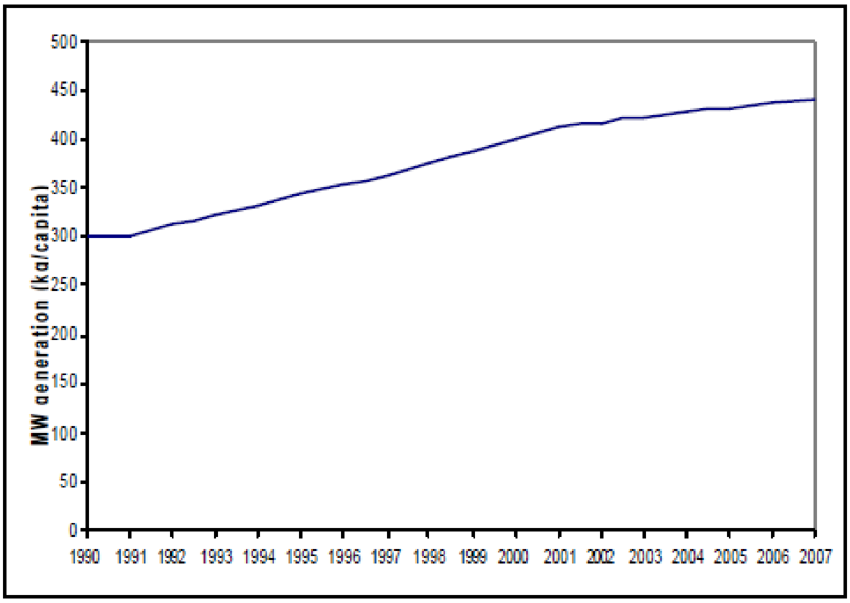

Fig. 1. Municipal waste generation per capita in Greece from 1990 to 2007 [22]

The data relating to the historical waste composition of Greek MSW have been taken from the Greek National Report from the United Nations Commission on Sustainable Development [22]. The estimated composition of Greek MSW generated from 1990 to 2007 is given in Fig. 2. It can be seen that the residual (putrescibles, organics, etc.) cover around 40% of the total content. In terms of reclaimed materials (glass, metals, plastics) their percentage ranges from 15-20% of the total waste, however this percentage varies through the years. In order to assess the composition of the MSW waste mined, it has been assumed that a recovery rate of 85-90% of the materials is achieved through the LFM activities.

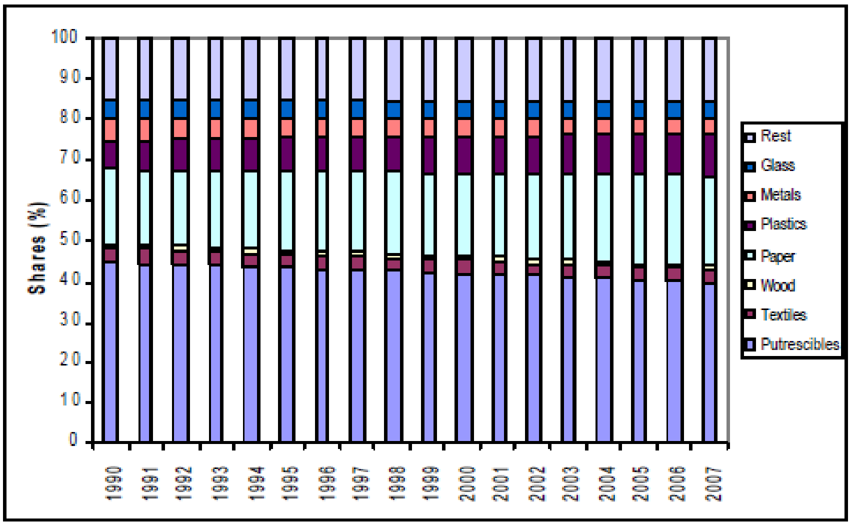

Fig. 2. Estimated composition of Greek municipal waste from 1990 to 2007 [22]

The MSW content used under this analysis is presented in Table 1, along with the expected recovery rate through the mining process is given. In terms of potential recyclables, the total metal content in the scenario is taken as 4.5%, (4% in ferrous metals and 0.5% in non-ferrous metals respectively); glass content is taken as 3.5% while the content in plastics is assumed to be 4%. These figures are in line with the data presented from the European experience, according to which the metal content found in European landfills ranges from 2% to 8% [e.g. 5, 14].

Table 1. Composition of waste and recovery rates

Typical Greek LF composition	Value	Unit
Ferrous metals (4% @ 90% recov.)	3.60	%
Non-ferrous metals (0.5% @ 85% recov.)	0.43	%
Glass (3.5% @ 85% recov.)	2.98	%
Plastics (4% @ 85% recov.)	3.40	%
Gravel, stones (5% @ 90% recov.)	4.50	%
Fines, soil (50% @ 90% recov.)	45.00	%
Residuals, other	40.00	%

The data of the typical composition of a Greek landfill (Table 1) represent the values taking into consideration the baseline scenario. In order to account for variations and uncertainty in the composition of the waste content, maximum and minimum concentrations were also estimated, as given below:

- Ferrous metals (baseline, min, max concentration): 4%, 2%, 8%
- Non-ferrous metals (baseline, min, max concentration): 0.5%, 0.3%, 0.9%,
- Glass (baseline, min, max concentration): 3.5%, 2%, 7%
- Plastics (baseline, min, max concentration): 4%, 3.5%, 10%

As regards the LFM process, a “normal” and a “high productivity” scenario are considered. The “high” productivity scenario involves a more automated sorting system, capable of having increased processing rates. For this reason, an additional dump truck is foreseen but less personnel is needed. The technical assumptions are briefly summarized in Table 2.

Table 2. LFM process technical assumptions

Description / Index	Value	Unit
Hydraulic excavator	1	operating units
Dump trucks (normal/high)	1 / 2	operating units
Backhoe Loader	1	operating units
Productivity of processing unit (normal/high)	12 / 25	tn/hour
Net working hours	6.5	hours/day
Working days (per year)	250	days/year
Productivity/year (normal/high)	19,500 / 40,625	tn/year
Total waste volume	3,300,000	in situ m^3
Total waste weight	2,000,000	tn
Specific weight	0.6	tn/m^3
Work-force requirements (normal/high)	13 / 12	persons

Given the size of the landfill, it is assumed that LFM operations will take place for 10 years aiming to: (a) recover recyclable materials and soil, and (b) increase the disposal capacity of the landfill. To this end, avoided or reduced costs of landfill closure and post closure care and monitoring and potential revenues from the selling the land parcels, after complete reclamation have not been considered.

2.4. Financial assumptions

The cost and revenue data used in the estimates were mainly extracted by the Polygyros LFM pilot project. Wherever required additional data were gathered by directly communicating with market experts. It should be noted that the LFM process is assumed to be carried out through subcontractors (and, thus, with only minimal capital expenditures) and by means of own recourses (i.e. personnel and equipment). In Tables 3 and 4, capital and operating cost assumptions are given under two different operational scenarios, namely operation with subcontractors, and operating with owned equipment and personnel. The latter is evaluated under a normal and a high productivity operating mode.

Table 3. Capital and operating costs for LFM operations using subcontractors

Description	Cost (€)
Site preparation & Development	35,000
Administrative costs (per year)	10,000
Rental of excavation, loading and hauling equipment (per day)	840
Rental of screening and sorting equipment (per day)	2,200
Energy cost (diesel fuel, €/lt)	0.95
Energy cost (electricity, €/kWh)	0.09
Water cost (€/m^3)	0.52

Table 4. Capital and operating costs for LFM operations using owned equipment & personnel

Description	**Cost (€)**
Site preparation & Development	60,000
Administrative costs (per year)	15,000
Capital expenditure for excavation, loading and hauling equipment (normal/high)	300,000 / 400,000
Capital expenditure of screening and sorting equipment (normal/high)	800,000 / 1,800,000
Maintenance cost (per year) (normal/high)	22,000 / 44,000
Personnel cost per year (unskilled workers)	14,000
Personnel cost per year (skilled workers)	30,800
Energy cost (diesel fuel, €/lt)	0.95
Energy cost (electric power, €/kWh)	0.09
Water cost (€/m^3)	0.52

The benefits of the LFM activities are associated with the recovered materials and landfill air-space. The prices of the recyclables are influenced by the fluctuations in the metal prices (e.g. in London Metal Exchange), the structure of the local market, as well as other parameters like the quality of the materials sold and the distance between the landfill and the recycling industry. Table 5 presents the base prices of the recyclables that are used in the financial models, along with minimum and maximum estimates. The selling prices were taken from actual quotes given from recycling plants during the pilot LFM application in the PL site. The minimum and maximum values represent deviations from the sale prices related to today's market (end of 2015) and the variability in the quality of the materials. These prices were taken from contacts and direct communication with recyclable marketing enterprises operating in Greece as well from data collected from relevant price quoting sites (e.g. letsrecycle.com).

Table 5. Selling price (€/tn) of recyclables

		Sell price (€/tn)	
Recyclable type	***Base estimate***	***Min estimate***	***Max estimate***
Ferrous metals	80	60	110
Non-ferrous metals	740	660	1200
Glass	10	10	15
Plastics (mixed)*	200	100	300

* *The mixed plastics include Natural HDPE, Mixed HDPE, clear PET, coloured PET, etc.*

In addition to the revenues earned from selling useful materials, benefits derived from increasing the landfill disposal capacity and avoided costs from recovered soil used as landfill covered material are considered. The values used in the financial models derived from real cases, and are given in Table 6.

Table 6. Landfill-related benefits from the LFM process

Description	**Price**	**Units**
Benefit of recovered air-spaces (€/tn) (small landfills/large landfills)	35 / 30	€/tn
Avoidance of purchasing landfill cover material	1.34	€/tn

Finally, it should be noted that under all scenarios the discount rate used is 6%, and the taxation is set to 29%.

3. RESULTS

3.1. Deterministic analysis

As mentioned, three different sub-scenarios are examined. The first sub-scenario (Scenario A) assumes that excavation and processing activities will be carried out by subcontractors, while the second (Scenario B) and the third (Scenario C) ones assume operation with owned equipment and personnel, with low and high productivity, respectively.

3.1.1. Subcontractor scenario (Scenario A)

Given that excavation and processing works are assigned to subcontractors only limited investment costs are required. Revenues (including avoided costs) are about €615,000. The projected cash flows are given in Table 7.

Table 7. Projected cash flows–Scenario A

	0	1	2…9	10
Capital costs	35,000			
Waste processed		19,500	19,500	19,500
Revenues		616,301	616,301	637,301
Benefit of recovered air-space		*351,000*	*351,000*	*351,000*
Recycling metals, plastics and glasses				
- Ferrous metals		*56,160*	*56,160*	*56,160*
- Non-ferrous metals		*57,720*	*57,720*	*57,720*
- Glass		*5,850*	*5,850*	*5,850*
- Plastics		*132,600*	*132,600*	*132,600*
Avoidance of landfill cover material		*12,971*	*12,971*	*12,971*
Operating costs		823,397	823,397	823,397
Rental of mining equipment		*210,000*	*210,000*	*210,000*
Rental of processing equipment		*550,000*	*550,000*	*550,000*
Administrative costs		*15,000*	*15,000*	*15,000*
Fuel / Energy		*50,020*	*50,020*	*50,020*
Water		*3,377*	*3,377*	*3,377*
EBITDA		-207,096	-207,096	-186,096
Depreciation		1,400	1,400	1,400
Earnings before taxes (EBT)		-208,496	-208,496	-187,496
Taxes (29%)		0	0	0
NOPAT		-208,496	-208,496	-187,496
Cash flow	-35,000	-207,096	-207,096	-186,096

Using a real discount rate of 6%, the NPV of the project is estimated at about €-1,520,000. The total cost is approximately €42.2 per tn of waste and the benefits €31.8 per tn of waste, respectively. In present value terms, the LFM operations result in a net loss of around €7.9 per tn of waste. Details about the breakdown of costs and benefits on a per tn of waste basis are provided in the following Tables 8 and 9.

Table 8. Cost breakdown–Scenario A

Category	**Cost (€/tn)**	**Percentage (% of total)**
Mining	10.8	25.5
Processing	30.9	73.3
Administrative	0.5	1.2
Total	**42.2**	**100.0**

Table 9. Benefits breakdown–Scenario A

Category	**Benefits (€/tn)**	**Percentage (% of total)**
Ferrous metals	2.88	9.1%
Non-ferrous metals	3.15	9.9%
Glass	0.30	0.9%
Plastics	6.8	21.4%
Landfill cover material	0.67	2.1%
Subtotal 1	***13.8***	***43.4***
Recovered air-space	18.0	56.6
Total	**31.8**	**100.0**

3.1.2. "Own resources" scenario with low productivity (Scenario B)

Given that excavation and processing works are carried out by means of own resources, a significant investment amount is necessary. Revenues (including avoided costs) are about €615,000. The projected cash flows are given in Table 10. Using a real discount rate of 6%, the NPV of the project is estimated at about €-18,500. The total operating cost is approximately €22.3 per tn of waste and the benefits €31.8 per tn of waste, respectively. In present value terms, the LFM operations result in a net loss of around €0.2 per tn of waste. Details about the breakdown of costs are provided in Table 11. The breakdown of the benefits is identical to that of Scenario A (Table 9).

Table 10. Projected cash flows –Scenario B

	0	**1**	**2…9**	**10**
Capital costs	1,160,000			
Waste processed		19,500	19,500	19,500
Revenues		*619.859*	*619.859*	*649.859*
Benefit of recovered air-space		*351,000*	*351,000*	*351,000*
Recycling metals, plastics and glasses				
- Ferrous metals		*56,160*	*56,160*	*56,160*
- Non-ferrous metals		*61,328*	*61,328*	*61,328*
- Glass		*5,801*	*5,801*	*5,801*
- Plastics		*132,600*	*132,600*	*132,600*
Avoidance of landfill cover material		*12,971*	*12,971*	*12,971*
Operating costs		*449,897*	*449,897*	*449,897*
Labour costs				
- Skilled		*154,000*	*154,000*	*154,000*
- Unskilled		*112,000*	*112,000*	*112,000*
Administrative costs		*15,000*	*15,000*	*15,000*
Fuel / Energy		*107,520*	*107,520*	*107,520*
Maintenance		*58,000*	*58,000*	*58,000*
Water		*3,377*	*3,377*	*3,377*
EBITDA		169,963	169,963	199,963
Depreciation		113,000	113,000	113,000
Earnings before taxes (EBT)		56,963	56,963	86,963
Taxes (29%)		16,519	16,519	25,219
NOPAT		40,444	40,444	61,744
Cash flow	-1,160,000	153,444	153,444	174,744

Table 11. Cost breakdown–Scenario B

Category	**Cost (€/tn)**	**Percentage (% of total)**
Ownership costs	8.1	25.9
Operating costs	22.3	71.6
Administrative costs	0.8	2.5
Total	**31.2**	**100.0**

3.1.3. "Own resources" scenario with high productivity (Scenario C)

The excavation and processing works are carried out by means of own resources. In addition, the processing unit involves a more sophisticated material handling and sorting system and, thus, the capital expenses are higher than those of the Scenario B. Revenues in that case (including avoided costs) are about €1,290,000 per year given the higher productivity. The projected cash flows are given in Table 12.

Using a real discount rate of 6%, the NPV of the project is estimated at about €2,020,000. The total operating cost is approximately €14 per tn of waste and the benefits €31.8 per tn of waste, respectively. In present value terms, the LFM operations result in a net benefit of around €5 per tn of waste. Details about the breakdown of LFM costs are illustrated in Table 13. Again, the breakdown of the benefits is identical to that of Scenario A (Table 9).

Table 12. Projected cash flows–Scenario C

	0	1	2…9	10
Capital costs	2,260,000			
Waste processed		40,625	40,625	40,625
Revenues		1,291,374	1,291,374	1,321,374
Benefit of recovered air-space		*731,250*	*731,250*	*731,250*
Recycling metals, plastics and glasses				
- Ferrous metals		*117,000*	*117,000*	*117,000*
- Non-ferrous metals		*127,766*	*127,766*	*127,766*
- Glass		*12,086*	*12,086*	*12,086*
- Plastics		*276,250*	*276,250*	*276,250*
Avoidance of landfill cover material		*27,022*	*27,022*	*27,022*
Operating costs		565,115	565,115	565,115
Labour costs				
- Skilled		*184,800*	*184,800*	*184,800*
- Unskilled		*84,000*	*84,000*	*84,000*
Administrative costs		*15,000*	*15,000*	*15,000*
Fuel / Energy		*161,280*	*161,280*	*161,280*
Maintenance		*113,000*	*113,000*	*113,000*
Water		*7,035*	*7,035*	*7,035*
EBITDA		726,259	726,259	756,259
Depreciation		223,000	223,000	223,000
Earnings before taxes (EBT)		503,259	503,259	533,259
Taxes (29%)		145,945	145,945	154,645
NOPAT		357,314	357,314	378,614
Cash flow	-2,160,000	580,314	580,314	601,614

Table 13. Cost breakdown–Scenario C

Category	**Cost (€/tn)**	**Percentage (% of total)**
Ownership costs	7.6	35.2
Operating costs	13.5	63.1
Administrative costs	0.4	1.7
Total	**21.5**	**100.0**

3.2. Sensitivity analysis

The sensitivity analysis focused on the most critical technical and economic parameters relating to the uncertainty in the range of the estimates and the significance on the financial results, namely the price of the recyclable materials (ferrous and non-ferrous metals and plastics) and the composition of the waste. For conciseness reasons, only the results of the sensitivity analysis of scenarios' NPV to a ±20 percent change are given in Figures 3 to 5.

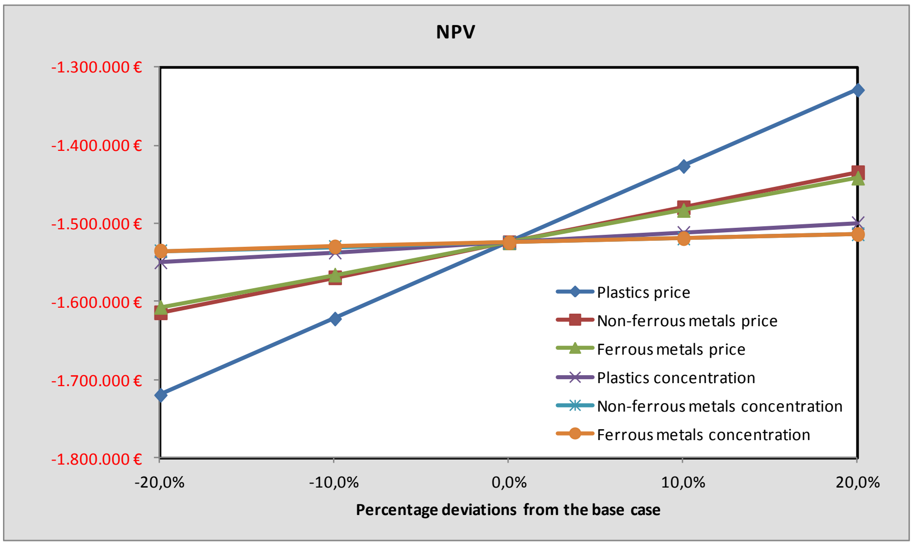

Fig. 3. NPV sensitivity analysis – Scenario A

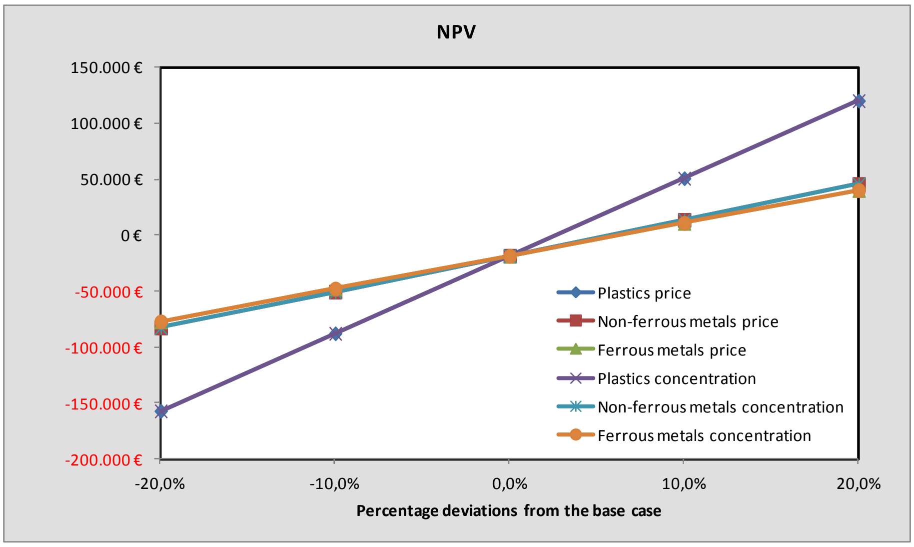

Fig. 4. NPV sensitivity analysis – Scenario B

According to the sensitivity analysis, the price of plastics and their content are the most significant factors influencing the NPV and IRR indicators of the project, in all scenarios, followed by the non-metal price and the ferrous metals price. The Scenario A remains financially unattractive even assuming a 20% increase in the price or concentrations of recyclable materials. The Scenario B, however, is deemed acceptable from a financial point of view (i.e. NPV>0 and IRR>discount factor) in case that either the prices or concentrations of recyclables increase ceteris paribus by at least 10%. Finally, according to the analysis, the Scenario C remains acceptable from a financial point of view even in case that the prices or concentrations of recyclables decrease by 20% on a ceteris paribus basis.

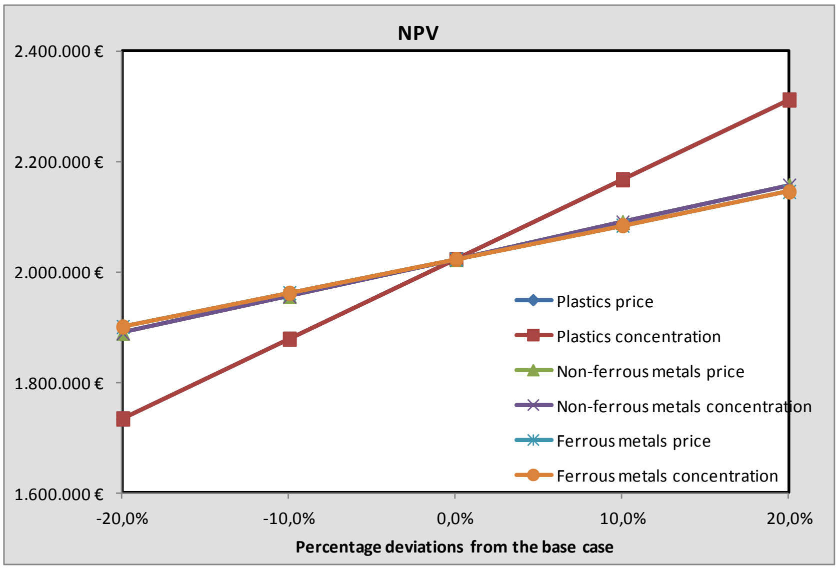

Fig. 5. NPV sensitivity analysis – Scenario C

3.3. Stochastic analysis

The parameters involved in the stochastic analysis were identical to those used in the sensitivity analysis. Due to the absence of data about the true distribution of the critical parameters, the triangular distribution was adopted, because it emphasizes the most likely value and theoretically provides a better estimate of the probabilities of reaching other values. Furthermore, the triangular distribution can model a variety of different conditions, since there is no requirement that the distribution be symmetrical about the mean. On these grounds, the assumptions were used:

- Price of ferrous metals (€/tn): min=60, most likely=80, max=110
- Price of non-ferrous metals (€/tn): min=660, most likely=740, max=1200
- Price of plastics (€/tn): min=100, most likely=200, max=300
- Concentration of ferrous metals (%): min=1.8, most likely=3.6, max=7.2
- Concentration of non-ferrous metals (%): min=0.3, most likely=0.5, max=0.9
- Concentration of plastics (%): min=3.0, most likely=3.4, max=8.5

The results of the simulation values are presented in the following Tables 14 and 15**.** For conciseness reasons, only the results of NPV indicator are illustrated.

Table 14. Monte Carlo simulation statistics

Variable	**NPV (€)**		
	Scenario A	*Scenario B*	*Scenario C*
Mean	-1,338,995	547,682	3,215,759
Median	-1,336,032	509,768	3,127,398
Standard Deviation	235,269	356,786	781,381
Minimum	-1,930,697	-267,981	1,732,006
Maximum	-662,294	2,174,073	6,421,509
Mean Std. Error	7,440	11,283	24,709

Table 15. Monte Carlo simulation percentiles

Percentage	**NPV (€)**		
	Scenario A	*Scenario B*	*Scenario C*
100%	-1,930,697	-267,981	1,732,006
90%	-1,650,131	122,123	2,266,856
80%	-1,543,239	238,849	2,508,144
70%	-1,474,837	338,771	2,733,010
60%	-1,400,831	419,081	2,964,147
50%	-1,336,115	509,356	3,126,641
40%	-1,280,528	591,245	3,314,090
30%	-1,219,745	713,865	3,560,505
20%	-1,135,122	838,750	3,878,159
10%	-1,037,485	1,028,540	4,286,578
0%	-662,294	2,174,073	6,421,509

According to the simulations, the expected NPV of Scenario A is €-1,340,000. The minimum expected value is about €-1,930,000 and the maximum value is €-660,000, which means that the probability of accepting the project from a financial viewpoint is zero. The expected NPV of Scenario B is around €550,000. The minimum expected value is about €-270,000 and the maximum value is €2,170,000. The probability of having a positive NPV value and thus accepting the project is estimated at 95.8%. The expected IRR attained under this scenario is 14.5%. The minimum expected value is around 1%, while the maximum value is around 37%. Finally, the expected NPV of Scenario C is approximately €3,200,000. The minimum NPV expected value is about €1,730,000 and the maximum value is €6,420,000. It is obvious that the project yields positive NPV values under all the scenarios generated by the probabilistic modeling process and thus it is acceptable. Likewise, the project generates high IRR values, with the expected one to be about 30%; the minimum one is estimated at 20.1% and the maximum one at 51.3%.

4. CONCLUSIONS

Based on the results of the financial analyses it becomes evident that the financial success of LFM projects is not assured in all cases. The latter seems to stand especially when assigning the excavation and processing works to subcontractors. However, it has to be pointed out that in all scenarios examined, a number of (significant) benefits such as energy recovery, redevelopment of the landfill area, reduction in waste management costs, were not taken into account. The latter, as explained, was attributed either to existing conditions in Greece and/or the technical assumptions used. This means that the financial results could be positively affected and could be different, if one or more of the abovementioned benefits were included in the analysis. Furthermore, the scenario of utilizing own resources results in an improvement of the financial indices. This is happening owing to the fact that the total cost of the process is reduced to half and less than half, as well. As regards the expected revenues from recyclable materials, hard plastic materials seem to have a dominant role. Finally, the overall revenues are significantly affected by the recovered air-space.

All in all, the following issues should be always considered prior to making any decision regarding the use of LFM process:

(a) In general, own resources in terms of equipment and personnel should be utilized. Yet, this may not be always possible, especially in short duration projects.

(b) For large quantities of waste using more sophisticated material handling and sorting systems is likely to be more financially attractive, although the capital expenses are much higher.

(c) LFM projects are probably more attractive from a financial perspective, when they are in proximity to higher populations, e.g. the recovered land is more scarce and, thus, more expensive near urban areas and the recovered-air space in the landfill is more valuable.

AKNOWLEDGEMENTS
This work was supported by the LIFE+ financial instrument of the European Community in the context of LIFE RECLAIM "Landfill mining pilot application for recovery of invaluable metals, materials, land and energy" (www.reclaim.gr), Grant: LIFE12 ENV/GR/ 000427. The coordinating beneficiary is ENVECO S.A. and the associated beneficiaries are the Municipality of Polygyros, School of Mining & Metallurgical Engineering of NTUA and HELECTOR S.A.

REFERENCES

[1] Wagner, T.P., Raymond, T.: Landfill mining: Case study of a successful metals recovery project. Waste Manag. 45, 448–457 (2015)
[2] Krook, J., Svensson, N., Eklund, M.: Landfill mining: a critical review of two decades of research. Waste Manag. 32, 513-520 (2012)
[3] Ratcliffe, A., Prent, O.J., van Vossen, W.: Feasibility of material recovery from landfills (MFL) in the European Union. In: Proc. ISWA World Waste Congress 2012, Florence, Italy, 17–19 September (2012)
[4] Kapur, A., Graedel, T.E.: Copper mines above and below ground. Estimating the stocks of materials in ore, products, and disposal sites opens up new ways to recycle and reuse valuable resources. Env Sci Tech. 40, 3135–3141 (2006)
[5] Quaghebeur M., Laenen B., Geysen D., Nielsen P., Pontikes Y., Van Gerven T., Spooren J.: Characterization of landfilled materials: screening of the enhanced landfill mining potential. J Clean Prod. 55, 72-83 (2012)
[6] Hermann, R., Baumgartner, R. J., Sarc, R., Ragossnig, A., Wolfsberger, T., Eisenberger, M., Budischowsky, A., Pomberger, R.: Landfill mining in Austria: Foundations for an integrated ecological and economic assessment. Waste Manag Res. 32(9 Suppl), 48-58 (2014)
[7] Lee, G. F., Jones, R. A.: Use of Landfill Mining in Solid Waste Management. In: Proc. Water Quality Management of Landfills. Water Pollution Control Federation, Chicago, IL (1990)
[8] Cossu, R., Hogland, W. Salerni, E.: Landfill Mining in Europe and USA. In: ISWA Year Book, International Solid Waste Association (ed), pp. 107-114. (1996)
[9] Hogland, W., Marques, M., Thörneby, L.: Landfill Mining - Space Saving, Material Recovery and Energy Use. In Proc. of Seminar on Waste Management and the Environment-Establishment of Cooperation Between Nordic Countries and Countries in the Baltic Sea Region. 5-7 November 1997, Kalmar University, Kalmar, Sweden, 339-355. (1997)
[10] Carius, S., Hogland, W., Jilkén, L., Mathiasson, A., and Andersson, P-Å.: A Hidden Waste Material Resource: Disposed Thermoplastic. In: Procs. Sardinia 99, 7th International Waste Management and Landfill Symposium, 4-8 October 1999, Cagliari, Italy, pp. 229-235 (1999)
[11] Marella, G., Raga, R.: Use of the Contingent Valuation Method in the assessment of a landfill mining project. Waste Manag. 34(7), 1199-1205 (2014)
[12] Zhou, C., Gong, Z., Hu, J., Cao, A., Liang, H.: A cost-benefit analysis of landfill mining and material recycling in China. Waste Manag. 35, 191-198 (2015)
[13] USEPA - United States Environmental Protection Agency: Landfill Reclamation. Solid Waste and Emergency Response (5306W), EPA530-F-97-001, July (1997)
[14] van Vossen, W.J., Prent, O.J.: Feasibility study – Sustainable material and energy recovery from landfills in Europe, In Proc. 13th Int Waste Management and Landfill Symposium, Sardinia (2011)
[15] Jain, P., Townsend, T. G., Johnson, P.: Case study of landfill reclamation at a Florida landfill site. Waste Manag. 33(1), 109-116 (2013)
[16] Ford, S., Warren K., Lorton, C., Smithers, R., Read, A. Hudgins, M.: Feasibility and Viability of Landfill Mining and Reclamation in Scotland (Scoping Study). Final Report, Zero Waste Scotland. http://ee.ricardo.com/cms/assets/Documents-for-Insight-pages/Resource-efficiency/Feasability-and-Viability-of-LFMR-Scotland-1904130.pdf (2013). Accessed December 2015
[17] Danthurebandara, M., Van Passel, S. and Van Acker A.: Environmental and economic assessment of 'open waste dump' mining in Sri Lanka. Resources, Conserv Recycling 102, 67-79 (2015)
[18] Frändegård, P., Krook, J. Svensson, N.: Integrating remediation and resource recovery: on the economic conditions of landfill mining. Waste Manag. 42, 137-147 (2015)
[19] Winterstetter, A., Rechberger, D., Laner, H., Fellner, J.: Old landfills: anthropogenic resources or reserves? In: Proc SUM 2014, Second Symposium on Urban Mining Bergamo, Italy, 19–21 May. CISA Publisher, Italy (2014)
[20] Bakas, I. and Milios, L.: Municipal waste management in Greece. European Environmental Agency Report (2013)
[21] IWCS - Innovative Waste Consulting Services: Landfill Reclamation Demonstration Project - Perdido Landfill, Escambia County, Neighborhood and Community Services Bureau, Division of Solid Waste Management.

https://www.dep.state.fl.us/waste/quick_topics/publications/shw/recycling/InnovativeGrants/IGYear9/finalreport/Perdido_Landfill_Mining_Report_final.pdf (2009). Accessed December 2015
[22] UNCSD - United Nations Commission on Sustainable Development: Waste Management – Greece, National Reports. http://www.un.org/esa/dsd/dsd_aofw_ni/ni_pdfs/NationalReports/greece/Greece_CSD18-19-Chapter_%20IV-Waste_Management.pdf (2011). Accessed December 2015