**LIFE12 ENV/GR/000427 LIFE reclaim "Landfill mining pilot application for recovery of invaluable metals, materials, land and energy**

# TECHNICAL REPORT - ACTION B9

## FOR THE POLYGYROS LANDFILL, IN THE MUNICIPALITY OF POLYGYROS, CHALKIDIKI

SUBJECT:

# TECHNICAL REPORT FOR THE SOCIOECONOMIC ANALYSIS

ENVECO S.A. ENVIRONMENTAL PROTECTION MANAGEMENT & ECONOMICS
HELECTOR
Municipality of Polygyros
NTUA School of Mining & Metallurgical Engineering

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## Abbreviations

CV: Contingent Valuation

DU: Demonstration Unit

ELFM: Enhanced Landfill Mining

IRR: Internal Rate of Return

LF: Landfill

LFM: Landfill Mining

MSW: Municipal Solid Waste

NPV: Net Present Value

PCBs: Printed Circuit Boards

PL: Polygyros Landfill

RCM: Region of Central Macedonia

SCBA: Social Cost Benefit Analysis

WEEE: Waste of Electrical and Electronic Equipment

WTP: Willingness-to-Pay

# Chapter 1. EXECUTIVE SUMMARY

Landfill Mining (LFM), i.e. the process of excavating and sorting the unearthed materials from operating or closed solid waste landfills, for recycling, processing, or for other dispositions, is a potential solution to the problem of the thousands of uncontrolled and controlled landfills either operating or closed. These landfills are usually a potential source of environmental contamination and nuisance and occupy valuable land that could be utilized for other purposes; but they also contain useful materials, which could be recovered through LFM process allowing for conservation of landfill space, elimination of potential contamination sources, energy recovery and reuse of recovered materials, redevelopment of derelict land, etc. Nevertheless, LFM, like any other economic activity, has to be economically feasible. So far, the economic feasibility of LFM projects from a private point of view has been studied little and with conflicting results. On the other hand, it should be mentioned that private costs and benefits alone cannot reflect the true social worth of LFM projects. Thus, in order to come up with more informed and fair social choices it is important to estimate the private and the environmental and social costs and benefits related to LFM projects and to internalize them in the decision making process. To this end, this report aims at estimating, first, the costs and benefits of LFM from a financial and, then, from a socioeconomic viewpoint.

The analysis is based on the data gathered during the first pilot application of LFM in Greece, i.e. the results derived from the Polygyros case study. Nevertheless, the analysis extends beyond the Polygyros Landfill site by means of different evaluation scenarios, in order to increase its usefulness. To this direction, a "typical" Greek landfill site is examined, apart from the Polygyros Landfill, forming alternatives with and without revenues from disposed e-waste items.

All in all, this study aims to fulfill the following two objectives:

(a) To evaluate technical, economic, environmental and sociological issues associated with the feasibility of LFM in Polygyros area and in Greece.

(b) To draw conclusions and make recommendations on the basis of this study for the critical factors affecting the feasibility of LFM projects, in general.

The financial analysis is carried out using a typical discounted cash flow 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) are estimated.

The socioeconomic analysis, or mostly known as Social Cost Benefit Analysis (SCBA), relies on the Kaldor–Hicks (K–H) criterion according to which a project is assumed to contribute to an increase in welfare if the gainers from the project could, in principle, compensate the losers. To this direction, the SCBA analysis is based on the financial cash flows of the project, i.e. private benefits and costs, which are adjusted in order to reflect the external socioeconomic effects of the project, i.e. the project's social benefits and costs, following European and other relevant guidelines. More specifically, consistent with international practice, the approach adopted takes into consideration the following adjustments:

- fiscal corrections;

- conversion from market to shadow prices;
- evaluation of non-market impacts and correction for externalities.

Finally, in order to tackle the uncertainty involved in the estimates relating to the costs and benefits of LFM operations, the financial and socioeconomic indicators are explored using sensitivity analysis, NPV break-even analysis, and probabilistic risk analysis by means of Monte Carlo simulations.

Taking into consideration the objectives of the study, three different evaluation scenarios are examined, which are described hereinafter.

Scenario 1: Polygyros LFM project

The first scenario aims at evaluating the implementation of the LFM process to the Polygyros landfill. To this end, the existing quantity of waste disposed to the landfill site, so far, is considered. As regards the composition of waste and the rest of technical and financial assumptions required to complete the analysis, the results of the pilot application carried out on-site are used. It should be mentioned that this scenario ignores the exploitation of e-waste, since discarded electrical and electronic devices were not traced during the pilot application.

Scenario 2: “Typical” LFM project

The second scenario 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. Given that typical LFM projects do not involve the exploitation of e-waste, since discarded electrical and electronic devices were not traced during the pilot application, potential revenues associated with discarded devices are ignored from the analysis.

Scenario 3: “Advanced” LFM project

The last scenario refers to a “typical” Greek landfill, similar to that of Scenario 2. This scenario, however, foresees exploitation of e-waste, based on literature data related to the prospective e-waste volumes and on the beneficiation tests as regards the recovery of valuable materials.

In addition to the above-described basic scenarios, alternative options are examined with respect to financial assumptions (e.g. use of rented or owned equipment) and technical considerations (e.g. use of more advanced sorting systems).

Based on the results for the financial and socioeconomic analyses, the following conclusions can be drawn:

The financial success of LFM projects is not assured in all cases, and this stands especially when assigning the excavation and processing works to subcontractors. Nevertheless, if own resources in terms of equipment and personnel are used, the total cost of the process is reduced to less than half. As regards expected revenues from recyclable materials, hard plastic materials seem to have a dominant role. The separation of WEEEs adds to the financial benefits of the project. Nevertheless, the dismantling of IT equipment in order to retrieve and sell separately PCBs or the froth flotation processing of PCBs pulverized material in order to reject plastics and recover Cu and precious metals (Pd, Au and Ag), do not significantly impact the financial results. Moreover, the overall revenues are significantly affected by the recovered air-space. Yet, it has to be pointed out that in all scenarios examined a number of (significant) benefits, including energy recovery, redevelopment of the landfill area, 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.).

From a socioeconomic viewpoint, the LFM projects seem to be socially justified. This derives primarily from society's WTP towards supporting LFM policies. In this case, however, the size of the population affected is crucial, especially when the WTP value lies in the lower part of the primary estimates (i.e. those derived from the two CV surveys in the context of RECLAIM project) or of the range of published values.

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) Under examined conditions, it seems that LFM works with low processing effort are likely to be more attractive from a financial viewpoint than processes with high processing effort, e.g. WEEE utilization 'as is' vs. IT equipment dismantling in order to retrieve and further process PCBs.

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

# Chapter 2. INTRODUCTION

## 2.1. Action context and Objectives

This present report is the Deliverable of Action B9 of the LIFE reclaim Project "Landfill mining pilot application for recovery of invaluable metals, materials, land and energy", which is being funded by the European Commission through Life+ 2012 vehicle, under the contract LIFE12 ENV/GR/000427.

The scope of the Action is to conduct a complete financial and socioeconomics analysis for landfill mining, using the Polygyros Landfill (PL) as a case study and then generalizing results in order to create and an analysis tool for similar future projects on policy and economics. In order to successfully complete an Environmental & Social cost – benefit analysis at the local and national level, the following tasks must be elaborated:

- Assessment of financial and socioeconomic characteristics of Landfill Mining
- Description of the environment in the Project Area (directly related to Action B.8)
- Description of the basic environmental impacts of Landfill Mining (directly related to Action B.8)
- Estimation of the environmental cost of the above-mentioned impacts. Environmental economics secondary methodologies (like benefits transfer) will be used in order to assess possible social costs of landfill mining.
- Final assessment of the NPV of social cost or benefit from the adoption of landfill mining in the project area
- Extrapolation of results in a national level, based on survey results.

## 2.2. General Information on LIFE+ reclaim

### 2.2.1. Project Objectives

The Project aims at building a temporary pilot application on productive scale to mine parts mine parts of existing landfills, separate useful materials and produce marketable products, introducing innovation elements from the mining industry, suggesting a new concept of waste valorization. It will also assess the viability of the proposed method, as well as provide a scientific evaluation on the potential alternatives of the management of waste disposal sites.

The basic objective is to introduce Landfill Mining (LFM) as a complementary approach in the management of past Landfill (LF) (controlled or uncontrolled) sites and create a useful tool for the recovery of:

- **Materials**, especially metals
- **Space**, which equals to extra landfill capacity and extended lifetime in cases of expansion

- **Soil**, which has been disposed off along with the waste and it is a natural resource valuable to local ecosystems, as well as to landfill industry itself
- **Recyclables**, like plastic and paper products, which can be either post-processed in a suitable recycling plant or burned in modern incinerators
- **Land**, in the case of old landfills, which will lead to a successful rehabilitation scheme with minimal environmental footprint which can be easily adapted to different waste compositions and site conditions.

At the same time the Project objectives include the familiarization of the public with the issue of post-disposal-processing of waste and with the potential of the procedure for metal recovery (thus lessening the need for mining interventions) and site rehabilitation, resulting in a cleaner environment and rational waste management. The abovementioned objectives of material and/or energy recovery are widely known today in the waste processing industry and precede disposal, but have not been so far utilized in connection to (a) a wider program of waste post-disposal processing and (b) material beneficiation for valuable metals, by means of ore processing methods.

### 2.2.2. Actions and Means

In order to establish LFM as a standard waste management procedure there are two basic tasks to be completed:

- LFM consolidation and application: Detailed elaboration on all technical aspects of LFM, from designing the waste mining operation to creating alternative final products (metal concentrates) that can be directly fed into metallurgical plants.
- Environmental and Social analysis: Detailed approach on the foreseeable socioeconomic impacts of adopting LFM practices.

More analytically, the Project includes the following Actions:

1. Preparation: International experience in LFM, Permitting of additional activities in Polygyros Landfill (PL), Baseline environmental and social conditions
2. Implementation: Landfill inventory, Exploitation plan, Design of production line, Sub-contracting procedures, Pilot-scale Demonstration Unit (DU), MSW mining, operation and tests, Environment rehabilitation plan
3. Socioeconomics: EIA Study, Financial and socioeconomic analysis, Action Plan and Master Plan elaboration
4. Monitoring the environmental & socioeconomic impacts of project Actions
5. Dissemination Actions

6. Project management Actions

7. After-life communication plan

### 2.2.3. Expected Results

According to existing literature, there is considerable experience in waste mining regarding energy and soil recovery, but not regarding non-ferrous metals, since the waste requires further processing which very few have attempted to undertake. It is expected that the Project will help consolidate knowledge, give practical experience in the field and contribute to the adaptation of an innovative production line under, various site conditions and waste compositions. Specifically, the Project is expected to bring the following results:

- Web GIS database for operational landfills and dump-sites in Greece combined with a Website during and after the duration of the Project, connected with the web-GIS database application
- Processing of of waste for the production of different separation samples
- Two field environmental economics surveys on the acceptance of LFM
- Action plan on national level for LFM and Strategic Environmental Assessment on national level
- Socioeconomic analysis of LFM
- Publication of one bilingual book/album on LFM
- Dissemination of the experience and information gained, through conferences (2 national and 1 international) as well as through proper dissemination material

All results will be supported by respective Technical Reports (one of which is the present one), with documentation on the background, methodologies, alternatives examined and relevant results. In addition, a special report regarding the carbon footprint of the Project will be submitted in order to support the footprint minimization policy of the project.

# Chapter 3. INTRODUCTION TO THE SOCIOECONOMIC ANALYSIS

## 3.1. Statement of the Problem

The implementation of new solid waste management policies around the world that promote higher recycling/reuse targets for municipal and other wastes and phase out landfilling progressively for recoverable waste will minimize the amount of wastes directed to landfills in the future. Nowadays, however, there are thousands of uncontrolled and controlled landfills either operating or closed. For example, Wagner and Raymond (2015), citing the work of Krook et al. (2012) and Ratcliffe et al. (2012), point out that in the EU alone there are an estimated 150,000-500,000 closed and active landfills containing around 30-50 billion $m^3$ of waste. Besides containing useful materials, these landfills may be a potential source of environmental contamination and nuisance and may occupy valuable land that could be utilized for other purposes (e.g. Kapur and Graedel, 2006; Quaghebeur et al., 2013; Hermann et al., 2014).

One option to tackle this problem is to follow 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 (Lee and Jones, 1990; Cossu et al., 1996; Hogland et al., 1997; Carius et al., 1999; Krook et al., 2012; Marella and Raga, 2014; Zhou et al., 2015). In general, the objectives of landfill mining are summarized, as follows (USEPA, 1997; Lee and Jones, 1990; Hogland et al., 1997):

- Conservation of landfill space.
- Reduction in landfill area.
- Elimination of potential contamination source.
- Rehabilitation of dump sites.
- Energy recovery from recovered wastes.
- Reuse of recovered materials.
- Reduction in waste management costs.
- Redevelopment of landfill sites.

In cases where LFM becomes a requirement, for example when wastes have to be moved either for serious environmental reasons or other purposes, the economic feasibility of the LFM project is not seen as a priority (Ford et al., 2013). In all other cases, however, LFM, like any other economic activity, has to be economically feasible; otherwise it will never be implemented. So far, the economic feasibility of LFM projects from a private point of view has been studied little and with conflicting results. For example, Van Vossen and Prent (2011) examined a 'standard landfill' of 500,000 tonnes and 5 hectares in area, based on review of available data from 60 LFM projects. The analysis primarily focused on metal recovery. They found that revenue from extracted metal is sufficient to offset mining costs by 8.2% where full separation of the waste occurs and by 18% where only ferrous metal is separated from the waste excavated. They note that re-using the freed landfill capacity as new landfill (e.g. voids pace recovery), reusing the landfill area for urban development and selling the other recovered material streams could make LFM more profitable. In the optimal case, these additional benefits might compensate the total costs and might generate a return on investment of 10 to 20%. Yet, the authors note that 'acquiring these additional benefits strongly depends upon specific local circumstances and conditions. Jain et al. (2013) considered a landfill reclamation project in Florida to recover landfill airspace and soil, reduce future groundwater impacts by removing the waste buried in the unlined area, and optimize airspace use at the site. The project entailed the excavation of approximately 371,000 in-place $m^3$ of unlined landfill airspace (including MSW and final cover soil) from approximately 6.8 ha of unlined cells. The recovery of the final cover soil, bermed soil, and reclaimed soil resulted in a savings of approximately 230,600 $m^3$ of lined airspace at a cost of US$3.09 million (i.e. US$8.33 per in-place $m^3$ airspace). The gross monetary benefit was approximately US$6 million, since the airspace recovered was valued at over US$9 million (the value of airspace was approximately $40 per $m^3$). Zhou et al. (2015) analyzed a typical old landfill mining project in China under four different scenarios. The results show that the LFM project could provide a net positive benefit between US$1.92 million to US$16.63 million. The estimates were sensitive to the benefits of land reclamation and electricity generation; indeed, the benefit of electricity generation (assuming an electricity price of US$0.54 per kWh) was the most important factor. Wagner and Raymond (2015) estimated that the value of the recovered metal from LFM operations at an ashfill was US$7.42 million. The estimated mean cost per Mt for the extraction and recovery of metal was US$158, while the minimum likely revenue was US$216. In total, 34,352 Mt of ferrous and non-ferrous metals were recovered consisting of metals (around 95%), zorba (4.6%), and mixed products (0.8%). Moreover, LFM extended the ashfill's life with an economic value of US$267,000. Frändegård et al. (2015) examined two remediation scenarios to a hypothetical landfill, namely remediation and remediation with resource recovery, concluding that private net benefits are negative. Similar findings are reported by Ford et al. (2013), who conducted a full review and evaluation of economic, technical, environmental, regulatory and sociological issues of LFM to examine the potential to mine and reclaim materials from Scottish landfills. They established a set of assumptions for a hypothetical 'typical' Scottish landfill and compared the potential savings and income of LFM with the costs of a 'do nothing' scenario. The outcome of the economic analysis is that, for the hypothetical 'typical' Scottish landfill, LFM is not economically viable. The exceptions are with 'best outcome' inputs and options where energy recovery is undertaken at the landfill. Same conclusions were drawn by Danthurebandara et al. (2015), who also used a hypothetical case examining two scenarios as regards the use of the RDF fraction. The basic outline for the hypothetical scenarios was an open waste dump site which contained 1,000,000 tonnes of waste and occupied an urban land of 5 hectares within Colombo's city limits. LFM process involved excavation, transportation, separation, fines treatment, and land reclamation. None of the scenarios were economically beneficial. Winterstetter et al. (2015) analyzed the socioeconomic viability of LFM using as case study the Remo Milieubeheer landfill site in Belgium. The study assumes that metals and the stone fraction are sold after recovery, while paper, plastics, wood and textiles are entirely converted into RDF and energetically recovered exclusively for electricity generation on-site. In one scenario a gas-plasma technology is used, and in an alternative scenario RDF is thermally treated in a state-of the art fluidized bed incinerator. Finally, the regained land at the end of LFM activities is sold. In all scenarios, the difference between the present values of cash inflows and outflows (i.e. the Net Present Value - NPV) was negative.

On the other hand, it should be mentioned that private costs and benefits alone cannot reflect the true social worth of LFM projects. For instance, Ayalon et al. (2006) performed a cost-benefit analysis of engineering and architectural-landscape rehabilitation works for the Hiriya landfill, in Israel. The findings reveal that engineering rehabilitation required for the reduction of environmental impacts is unjustifiable, since it results in net benefits of -US$21.8 million (benefit-to-cost ratio: 0.48). Nevertheless, they showed that the project is worthwhile when the benefits from converting the landfill into a public park are considered. In this case, the authors estimated that the total benefits from the engineering and architectural-landscape rehabilitation of the landfill range from US$112.7 million to US$284.7 million, while the estimated rehabilitation cost ranges from US$75 million to US$97 million. Marella and Raga (2014) implemented the Contingent Valuation Method (CVM) for estimating the community-perceived monetary benefits from the remediation of an old uncontrolled waste deposit by means of LFM and the conversion of the area into a park. Two possible distinct future scenarios were presented to the respondents. According to the first scenario, LFM is carried out for the complete removal of the deposited waste and the underlying soil affected by leachates. In the second scenario, the LFM is completed and the area is converted into a public park. Subsequently, two different estimates of residents' WTP for the above-mentioned interventions were elicited. Almost all of the respondents (91.3%) declared to be willing to pay for the LFM and the mean WTP was equal to approximately €196, similar to the findings of Sasao (2004), who reports a one-time WTP of approximately US$200 (external costs associated with the sitting of a landfill for industrial waste). Regarding the creation of the park, the percentage of those who had declared their WTP fell slightly (87%) but the amount of WTP was, on average, around €200.

## 3.2. Objectives of the study

From the above-mentioned remarks, it becomes evident that in order to come up with more informed and fair social choices it is important to estimate the private and the environmental and social costs and benefits related to LFM projects and to internalize them in the decision making process. To this end, this report aims at estimating, first, the costs and benefits of LFM from a financial and, then, from a socioeconomic viewpoint.

The analysis is based on the data gathered during the first pilot application of LFM in Greece, i.e. the results derived from the Polygyros case study. Nevertheless, the analysis extends beyond the Polygyros Landfill site by means of different evaluation scenarios, in order to increase its usefulness. To this direction, a "typical" Greek landfill site is examined, apart from the Polygyros Landfill, forming alternatives with and without revenues from disposed e-waste items.

All in all, this study aims to fulfil the following two objectives:

(c) To evaluate technical, economic, environmental and sociological issues associated with the feasibility of LFM in Polygyros area and in Greece.

(d) To draw conclusions and make recommendations on the basis of this study for the critical factors affecting the feasibility of LFM projects, in general.

## 3.3. Methodology

To evaluate the financial and economic feasibility of LFM, it is necessary to account for both financial and socio-economic benefits of the scenarios under investigation. Furthermore, in order to account for the uncertainty involved in the parameters of the SCBA model, both internal and external, uncertainty analysis via risk assessment is being conducted.

### 3.3.1. Financial analysis

The financial analysis is carried out using a typical discounted cash flow 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 the 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 period i

$I_0$ 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. In the contrary, a negative NPV indicates that the investment under investigation 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 NPV of the project 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.

The financial analysis should take into consideration the following factors:

A. Capital costs

- 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.)

B. Operating costs

- Rental of excavation and hauling equipment (if the equipment is rented)
- Rental of screening and sorting equipment (if the equipment is rented)
- Labour costs
  - Skilled personnel
  - Unskilled personnel
- Administrative costs
- Fuel / Energy costs
- Maintenance costs

- Water
- 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)

### 3.3.2. Socioeconomic analysis

The socioeconomic analysis, or mostly known as Social Cost Benefit Analysis (SCBA), is founded on the notion that a "person" (individual, policy- or decision-maker, state authority, etc.) makes decisions on the basis of a comparison of benefits and costs. The SCBA relies on the Kaldor–Hicks (K–H) criterion according to which a project is assumed to contribute to an increase in welfare if the gainers from the project could, in principle, compensate the losers. In other words, the size of the benefits must be such that the gainers could compensate the losers and still would have something positive left over (Campbell and Brown, 2003; Brent, 2006). In this case, the project represents a potential Pareto improvement. It should be mentioned, however, that the new welfare economists tried to avoid making interpersonal comparisons (Brent, 2006).

The SCBA has been used to evaluate public sector investment projects since the 1930s, although the practice became more widespread in the 1960s (Marglin, 1967; McKean, 1967). The purpose of SCBA is to facilitate a more efficient allocation of resources, demonstrating the convenience for society of a particular intervention rather than possible alternatives (EC, 2014). Relevant guidelines for the valuation of environmental impacts in project appraisal, in USA, can be found in manuals for inter alia water projects and recreational use of forested areas (Navrud, and Pruckner, 1997). SCBA is applied at an increasing rate and certain studies have been carried out, particularly in UK, Germany, Scandinavian countries, and the Netherlands (Bonnieux and Rainelli, 1999) and certain manuals for SCBA can be found in EU for investment projects (e.g. EC, 2014).

To this direction, the SCBA analysis is based on the financial cash flows of the project, i.e. private benefits and costs, which are adjusted in order to reflect the external socioeconomic effects of the project, i.e. the project's social benefits and costs (Table 1). The adjusted cash flows (social cash flow) are then used in order to estimate the Social NPV (and the Social IRR) of the project. From the external effects, monetary valuation of environmental impacts holds, perhaps, the most challenging position (Damigos, 2006).

**Table 1 -** Financial Cash Flow adjustments

| Category of impact | Influence |
|---|---|
| 1. Impacts on employees | |
| *a. Wages above opportunity cost* | Positive |
| *b. Expenditure on training* | Positive |
| 2. Profits of complementary goods | Positive |
| 3. Profits of local suppliers | Positive |
| 4. Impacts on neighbours | |
| *a. Environmental impacts* | Negative |
| *b. Impacts on infrastructure* | Negative |
| *c. Benefits to community* | Positive |
| 5. Rest of society | |
| *a. Tax payments* | Positive |
| *b. VAT and other taxes* | Positive |
| *c. Import tariffs* | Positive |
| *d. Subsidies* | Negative |

Source: Damigos (2006)

Following European Union's guidelines (e.g. EC, 2014) and other relevant documents, direct employment or external environmental effects realised by the LFM projects are reflected in the calculation of economic performance indicators (i.e. Social NPV and Social IRR). Nevertheless, indirect (i.e. on secondary markets) and wider effects (i.e. on public funds, regional growth, etc.)

have been excluded from the estimates. More specifically, consistent with international practice, the approach adopted takes into consideration the following adjustments:

- fiscal corrections;
- conversion from market to shadow prices;
- evaluation of non-market impacts and correction for externalities.

As regards direct employment effects, the shadow wage approach was adopted. Given that Greece is suffering from a high unemployment rate, the shadow wage was inversely correlated to the level of unemployment, following the shortcut formula proposed by EC (2014):

$$SW = W*(1-t)*(1-\upsilon)$$

where: SW is the shadow wage

W is the market wage

t is the income taxation

υ is the unemployment rate.

The environmental externalities were estimated using the results of the primary valuation studies conducted at local and national level by means of the Contingent Valuation (CV) method, in order to estimate the society's willingness to pay for LFM projects.

Finally, an appropriate social discount rate, s, has to be selected, which reflects the opportunity cost of capital from an inter-temporal perspective for society as a whole (EC, 2014). The social discount rate, which is often called the "Ramsey" rate (Ramsey, 1928), can be expressed by the following equation:

$$s = \delta + \eta . g$$

where: δ is the rate of pure time preference

η is the elasticity of marginal utility of consumption

g is the rate of growth of consumption per capita

There exists an ongoing debate in the literature regarding the appropriate social discount rate. The disparity in the estimates derives, in many cases, from the assumptions made when implementing the "Ramsey" rate, as illustrated in Table 2.

**Table 2** - Examples of social discount rate estimates

| | Pure rate of time preference(δ)(per cent per annum) | Marginal elasticity of utility (η) | Rate of growth in consumption (g) (percent per annum) | Social discount rate(r) (percent per annum) |
|---|---|---|---|---|
| Nordhaus (2007) | 1.5 | 2 | 2 | 5.5 |
| Stern (2007) | 0.1 | 1 | 1.3 | 1.4 |
| Weitzman (2007) | 2 | 2 | 2 | 6 |
| UK Treasury Green Book [0-30 years] (2003) | 1.5 | 1 | 2 | 3.5 |

Source: Scarborough (2010)

As regards the European countries, Florio (2014) reports social discount rates adopted from different sources. According to these findings, the social discount rate is 4% (and declines after 30 years) in France, 3% in Germany, 5% in Italy, 4% in Portugal and 4%-6% in Spain. According to EC (2014), the European Commission recommends, for the programming period 2014-2020, a social discount rate equal to 5% for major projects in Cohesion countries and 3% for the other Member States.

The socioeconomic analysis, apart from the financial costs and revenues described in previous section, should take into consideration the following parameters:

A. Costs

- Harmful effects and nuisance associated with:
  - Excavation and processing works (e.g. emission of particulate matter, releases of methane and other gases odour, escape of leachate, increased dispersal of unwanted substances such as heavy metals, etc.)
  - Energy and heat recovery from combustible waste (in case of on-site installations, e.g. emission of heavy metals, dioxins and furans, which may be present in the waste gases, water or ash, visual pollution from the facilities, etc.)
  - Waste disposal (in case that landfill continues to operate after LFM operations)

B. Benefits

- Direct employment benefits
- Environmental and social benefits associated with:
  - Minimization of potential contamination sources
  - Reduction of ‘stigma’ effect from environmental damage caused by landfills on surrounding residential property values

- Production of "green" energy and heat from combustible waste (in case of on-site installations, e.g. reduction in greenhouse gases emissions)
- Land reclamation for social purposes, such as public parks (in case of full site reclamation after LFM operations).

### 3.3.3. Uncertainty analysis

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;
- NPV break-even 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 NPV break-even analysis is useful towards estimating the points at which NPV switches from positive to negative for a number of variables, using one variable at a time. It is also possible to estimate the NPV break-even point for a number of variables affecting the costs or revenues of the project.

The probabilistic analysis involves assigning a probability distribution to each of the critical variables of the CBA 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, which consist of 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, of the project's performance indicators (financial and economic NPV and IRR). The probabilistic NPV and IRR calculations for all combinations of sampled values are then used to develop probability distribution 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.

# Chapter 4. TECHNICAL AND FINANCIAL ASSUMPTIONS

## 4.1. Description of the LFM process

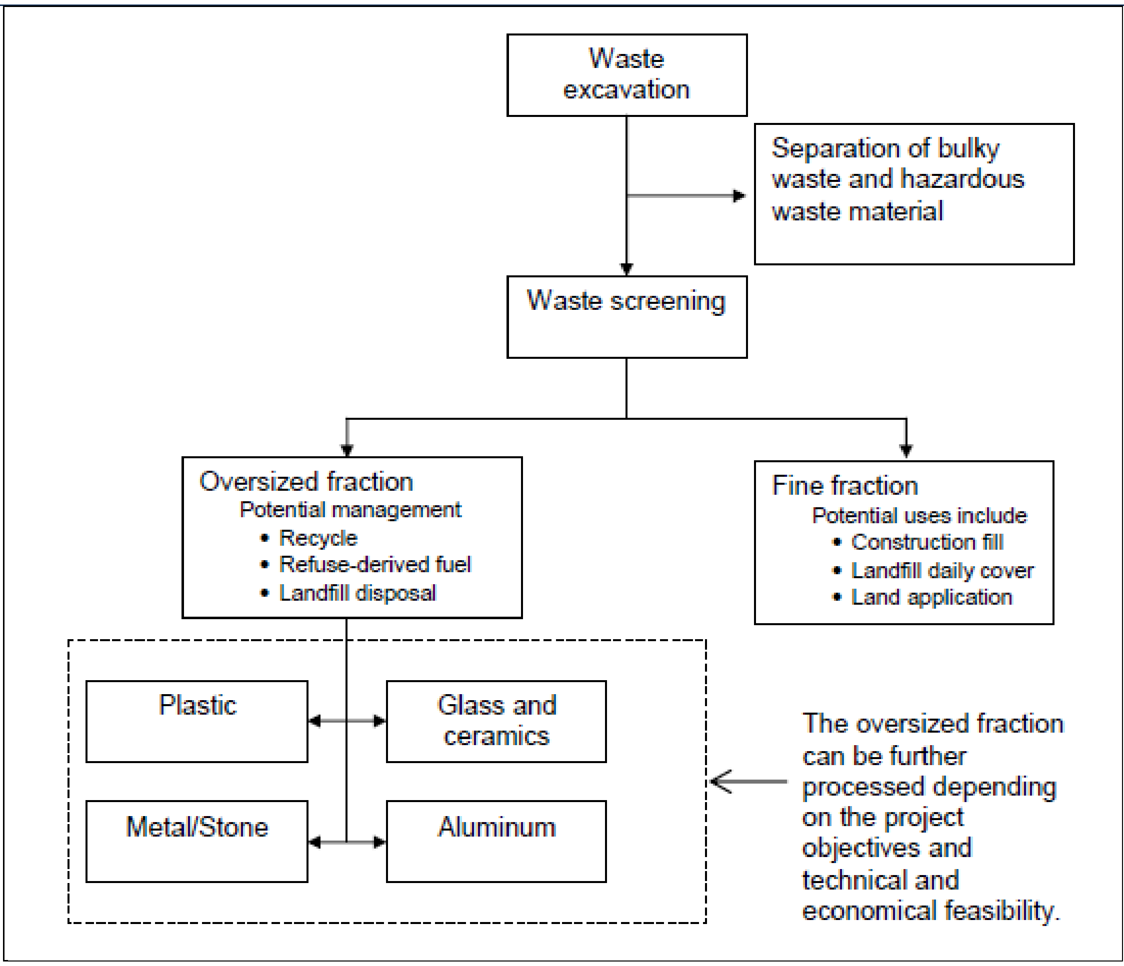
The first step in planning a landfill mining and rehabilitation project is a site survey to gather site-specific information such as its operating history, types of wastes present, dimensions, topography and physical characteristics (Salerni, 1995).

The next step of site investigation involves planning for preliminary excavation and obtaining the necessary regulatory approvals. 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 and eddy current separators for aluminium) can be used to separate recyclable materials. Identifying and sorting hazardous materials and other suspicious waste consists of an integral part of most landfill mining projects, as reported by IWCS (2009). Additional processing and managing of the excavated material are guided by the project objectives, properties and conditions of the excavated material, and processing cost and time. According to the study of IWCS (2009), in many landfill mining projects screening of the excavated waste was the most common process used.

Figure 1 presents a generalized flow chart of the process that some of mining projects employed.

The excavation procedure, through which the waste is extracted from its place, in Polygyros site, followed the principles of surface (open-pit) mining. More specifically, the mining of the waste was made with conventional surface mining equipment (excavators, backhoe/loaders, front-end loaders or shovels). According to the proposed PL mining scheme, the excavation took place from the top (+622 m level) using a hydraulic excavator at the crest area. The excavator performed quite well with high productivity, extracting the loose waste found below, up to a depth 5 m. More specifically, the waste was mined using 3 - 4 m wide and 5 m deep trenches, aligned in the NW-SE direction. The trench excavation started from one end (the NW having a length of about 30 m. At the end of the section the next cut started and developed towards the SE (or SW) direction, until the target volume of waste material is reached. Finally, a "box cut" of about 30 x 7 x 5 m has been created at the end of the operations (Fig. 2).




Source: IWCS, 2009

**Figure 1:** Landfill Mining Process

The rate of excavation was directly linked with the feeding capacity of the processing unit in order to minimize environmental problems due to the temporal stockpiling of the waste material. For this reason the excavation took place at intervals in order to maintain a relatively constant flow of materials.

At the start of the operation, the soil cover was carefully removed and stockpiled for further reuse. The exposed working face was kept to a minimum during the pilot application. The haulage of the material was performed using standard dump trucks.

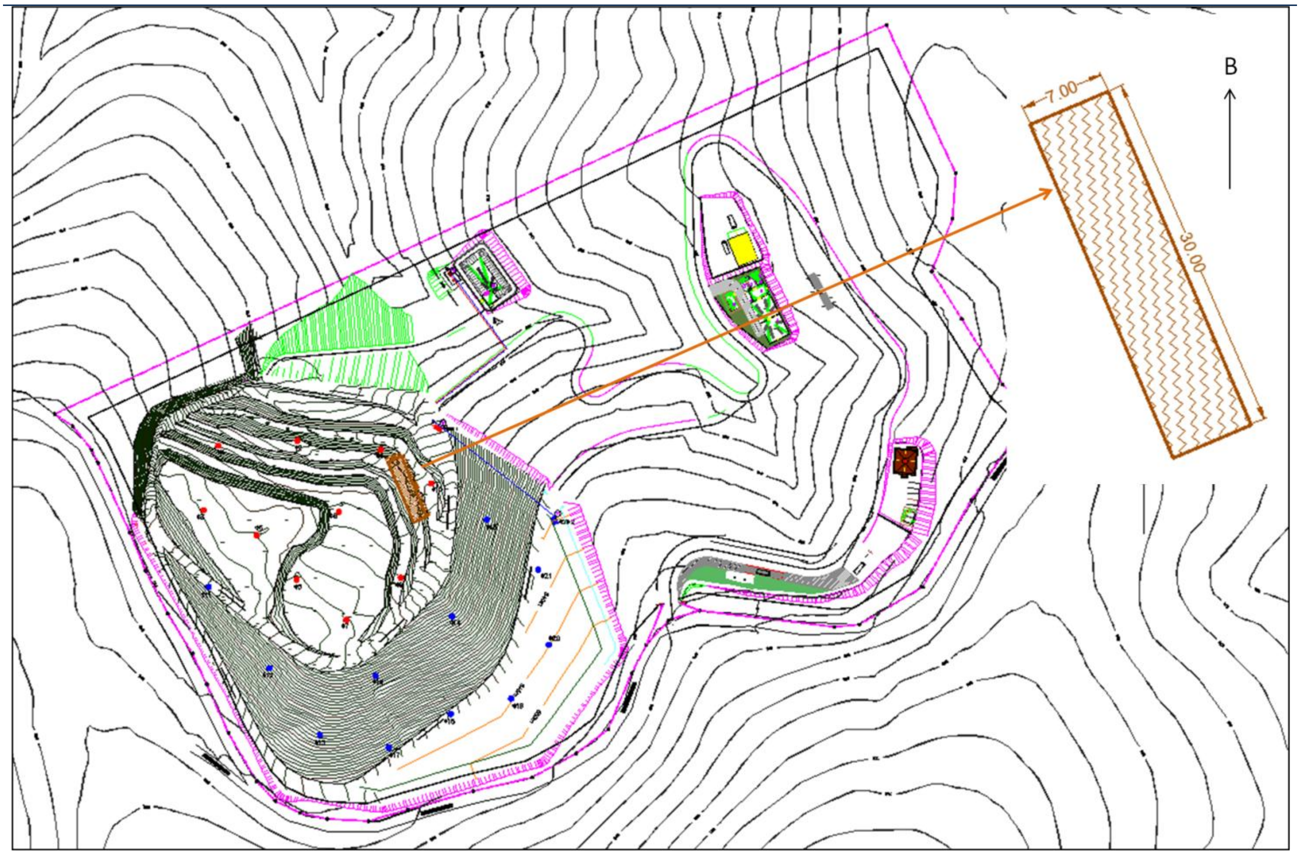



**Figure 2:** Sitting, orientation and dimensions of the final "box cut" of the landfill mining area

After waste excavation, the Pilot Demonstration Unit (PDU) operation followed the steps below:

- Transport, weighing and deposition of the waste to the designed space next to the PDU (pending area).
- Collection of a bucketful from the deposited waste and emptying it into the trommel.
- Ripping of waste bags with incorporated in the trommel knives, while spinning waste to separate it to over and under 70 mm diameter.
- Separation of the waste under 70 mm diameter into a platform tractor.
- Deposition of the waste (over 70 mm diameter) from the trommel to the picking line and hand sorting by 8 people to four recycling materials: hard plastic, soft plastic, glass, aluminium.
- Collection of ferrous material at the end of the picking line with the use of a magnet. Collection of the non recyclable waste into big bags/big buckets after the magnet.

All the big bags of the sorted recyclables, together with the non recyclable material, were weighed and placed in a spare location (storage space) by kind of material. Samples of the waste below 70 mm diameter were weighed, also.

For flexibility reasons, during the pilot application a small volume of processed waste needed to be stored in a small stockpiling area, near the entrance point of the disposal area. Figure 3 presents sitting of the excavation, the processing unit and the temporary storage area, while Figure 4 presents the layout of the PDU.


**Figure 3:** Sitting of the excavation, the processing unit and the temporary storage area

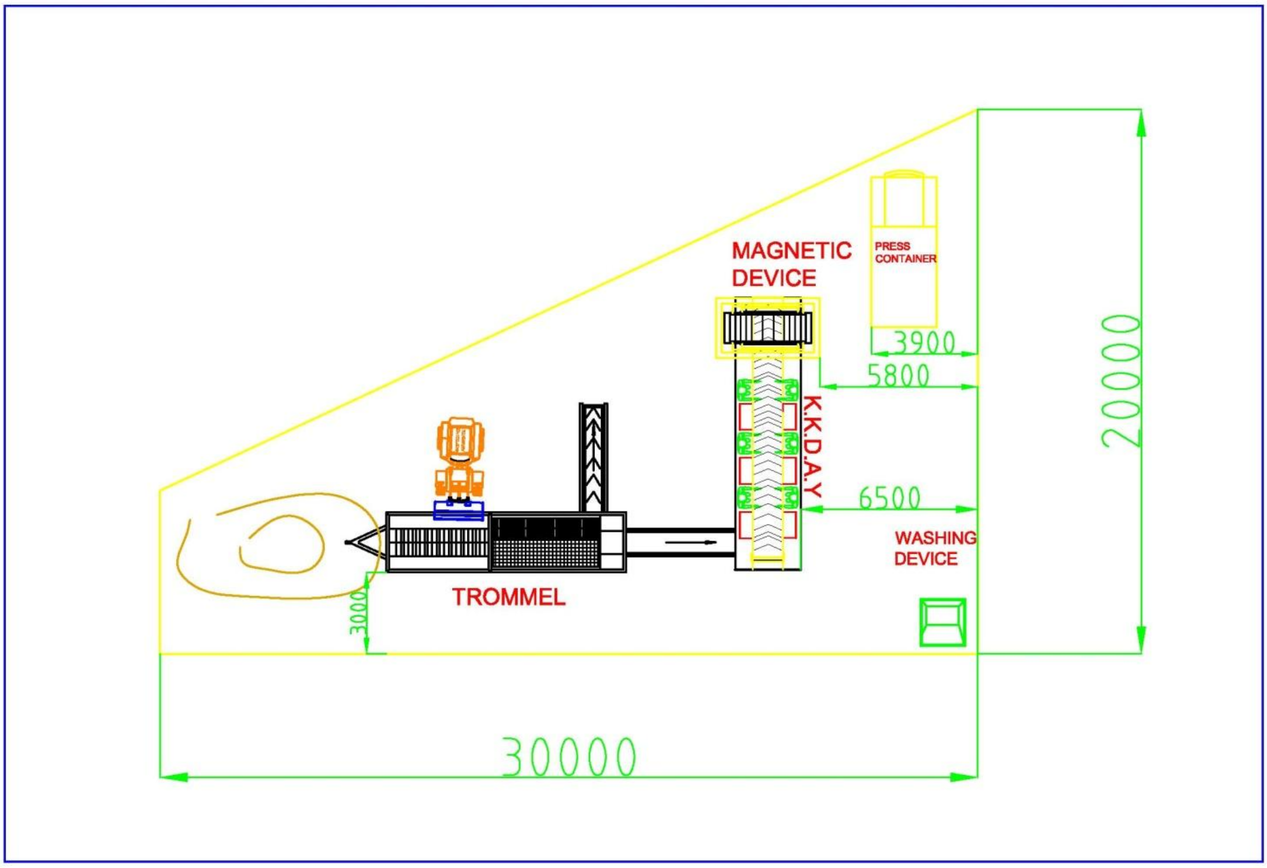



**Figure 4:** Layout of the PDU

The final task of the mining plan was the haulage and proper disposal of the processed waste back to the landfill site, along with the closure of the open trenches that have been developed by the mining operations.

It should also be noted that one of the project's expectations was to find electronic and electrical devices. However, the recycling of electronic and electrical devices started along with the operation of the Polygyros Landfill. As a result, during the sample landfill mining process no electrical or electronic waste was found. In order to achieve the target of the project, a sample of e-waste (approximately 13 kg of electrical and electronic boards) was taken from dismantled old electrical and electronic wastes, which were found in the disposal of electrical and electronic devices facility of the landfill. After acquiring the sample of electronic boards, they were given to OIKOKYKLIOS S.A. for size reduction and sorting, in order to examine the recovery efficiency of precious metals.

## 4.2. Environmental, economic and social considerations

It appears that there are three main strategic reasons for LFM operations: extraction for recycling; extraction for energy recovery; and the reclamation of land. Whilst the first two are clear economic arguments about the potential income from the deposited wastes, the third has greater potential for considering environmental and wider sustainability drivers (Fisher, 2013). These reasons may be independent drivers for LFM but may also be combined to deliver wider benefits and maximise the LFM opportunity.

The extraction of wastes for their recycling potential depends mainly on the material values in the market place for specific recyclates. Metals and plastics are those materials which have the highest values and the lowest level of degradation within a landfill site. These are, therefore, often cited as targets for LFM. However, there may be others that have a specific local value. The benefits to resource security need to be considered.

Recovery of material for conversion to energy seeks to extract the value of the un-degraded portion of the biomass that has been disposed of. Although it could not be considered a 'renewable' source of energy in the purest sense, with dwindling fossil fuels and the need for more sustainable use of natural resources, waste from landfills may provide a short- to medium-term resolution to energy demand. Waste in landfill sites may also satisfy future demand for waste supplies in mass burn incineration facilities in locations where waste minimisation is expected to impact on future trends.

The reclamation of land may be driven by one or a combination of the following objectives:

- Landfill sites may be in locations that could be suitable for traditional development purposes;
- The landfill site may form a physical barrier to a development that is planned;
- It may be contaminating the groundwater or surrounding area and the source requires removal; or,
- There may be a need to reuse the available landfill space at that site for different kinds of wastes, more suitable to long-term disposal, such as non-reactive hazardous wastes (e.g. asbestos).

In general, the potential benefits of LFM are summarized below (USEPA, 1997; Lee and Jones, 1990; Hogland et al., 1997):

- Revenues from recyclable and reusable materials, e.g., ferrous metals, aluminium, plastics, and glasses.
- Revenues from combustible reclaimed waste that can be mixed with fresh waste and burned to produce energy.

- Avoided costs from recovered soil that can be used on site as daily cover material on other landfill cells. In addition, a market might exist for reclaimed soil use in other applications, such as compost.

- Increased disposal capacity that could lower the total cost operating cost of the landfill. An additional benefit from the extension of the useful life of existing landfills is associated with avoided costs and time savings to locate, design, permit, and construct new landfills.

- Avoided or reduced costs of landfill closure and post closure care and monitoring;

- Revenues from selling the land, after complete reclamation, for other uses.

- Recovery of hazardous wastes, if uncovered during LFM operations especially at older landfills, which could be managed in an environmentally sound manner. Consequently, LFM should be avoided in situations where a properly engineered landfill is unavailable to receive the remnants of the excavated material that cannot be recovered or treated by other means.

Nevertheless, LFM operations are not risk-free from an environmental point of view. LFM involves a number of steps, which could give rise to dangerous situations and harmful effects on human health and the environment, such as releases of landfill gases and odours during excavation works, releases of leachate, etc. Other potential impacts include noise, increased traffic on roads between the landfill and resource recovery facility, extra mixing and handling of waste at the resource recovery facility, etc. (e.g. Krook et al., 2007 & 2012; Ford et al., 2013). Reclamation activities shorten the useful life of equipment, such as excavators and loaders, because of the high density of waste being handled. Lack of knowledge about the nature of waste buried might be a limitation regarding safety issues, e.g. physical injury from rolling stock or rotating equipment, exposure to hazardous materials or pathogens during mining or processing, subsurface fires, etc. Health risks to the general public appear to be minimal. As regards other social issues apart from nuisance and safety considerations, LFM operations could increase employment. Social acceptant issues are site specific and should be examined via social surveys in each specific case.

It should be noted that many of the conditions present at the landfill and its surroundings will be unique to the specific landfill, and specific to the age of the waste being excavated. Thus, environmental risks can be managed if considered in advance of the operation and appropriate mitigation measures are designed and implemented in discussion with regulators. Pertinently, these risks would require addressing in an environmental permit application and the regulator would require all risks are identified, appropriately assessed and mitigation measures put in place, where necessary, prior to permit issue and commencement of operations.

The economic risks are similar to traditional mining operations but are enhanced by the heterogeneous nature of the wastes in a landfill, which could result in (Joseph et al., 2004; Reno Sam, 2009):

- Poor quality of recovered materials.

- Ineffectiveness of substituting recovered tin cans for scrap aluminium cans.

– Poor separation of recovered materials.

– Low-value and limited applications of recovered materials.

The uncertainty of what LFM will produce is a clear factor to be addressed. Whilst the extremes are the hazardous risk mentioned above, whether the materials excavated will be marketable or not is a clear factor to be determined. Ensuring that they meet the requirements of end-users and re-processors will ensure that the LFM operation is successful. If material recovery is not the aim, i.e. LFM operations target to land reclamation and re-development, a critical factor is to ensure that any residual contamination of the land or groundwater is removed.

## 4.3. Evaluation scenarios

Taking into consideration the objectives of the study, three different evaluation scenarios are examined, which are described hereinafter.

Scenario 1: Polygyros LFM project

The first scenario aims at evaluating the implementation of the LFM process to the Polygyros landfill. To this end, the existing quantity of waste disposed to the landfill site, so far, is considered. As regards the composition of waste and the rest of technical and financial assumptions required to complete the analysis, the results of the pilot application carried out on-site are used. It should be mentioned that this scenario ignores the exploitation of e-waste, since discarded electrical and electronic devices were not traced during the pilot application.

Scenario 2: "Typical" LFM project

The second scenario 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. Given that typical LFM projects do not involve the exploitation of e-waste, since discarded electrical and electronic devices were not traced during the pilot application, potential revenues associated with discarded devices are ignored from the analysis.

Scenario 3: "Advanced" LFM project

The last scenario refers to a "typical" Greek landfill, similar to that of Scenario 2. This scenario, however, foresees exploitation of e-waste, based on literature data related to the prospective e-waste volumes and on the beneficiation tests as regards the recovery of valuable materials.

In addition to the above-described basic scenarios, alternative options are examined with respect to financial assumptions (e.g. use of rented or owned equipment) and technical considerations (e.g. use of more advanced sorting systems).

## 4.4. Technical assumptions

In order to prepare the financial models described in the following sections, a number of assumptions were made relating to both technical and financial matters. As for the technical parameters and assumptions made for Scenario 1, these are based on the pilot testing phase that took place in the PL site during the summer of 2015 and incorporate the main findings and conclusions drawn. Many of the data related with the waste processing scheme, e.g. the production capacity, are also used in the other two scenarios. As already noted, Scenario 2 takes into account the waste composition of typical Greek landfills aged 20-30 years old, while Scenario 3 further incorporates e-waste (WEEE) presence in the waste stream processed. It should be noted that in the scenarios examined the LFM process is being done through contractors (and, thus, with only minimal capital expenditures) and through owned equipment. Moreover, in Scenarios 2 and 3 a "high productivity" LFM process is also considered by means of a more automated sorting system.

The technical assumptions that have been taken into account are discussed in detail hereinafter.

Scenario 1: "Polygyros" LFM project

The Polygyros landfill currently contains around 65,000 $m^3$ or 39,000tn of MSW. This quantity is excavated and processed in order to: (a) recover recyclable materials and soil, and (b) increase the disposal capacity of the landfill. The assumptions of the 1st scenario are given in Table 3.

**Table 3** - Main technical assumptions under Scenario 1.

| Description / Index | Value | Unit |
|---|---|---|
| Hydraulic excavator | 1 | operating units |
| Dump trucks | 1 | operating units |
| Backhoe Loader | 1 | operating units |
| Productivity of processing unit | 12 | tn/hour |
| Net working hours | 6.5 | hours/day |
| Working days (per year) | 250 | days/year |
| Productivity/year | 19,500 | tn/year |
| Total waste volume | 65,000 | in situ $m^3$ |
| Total waste weight | 39,000 | tn |
| Specific weight | 0.6 | $tn/m^3$ |
| **Polygyros LF composition** | **Value** | **Unit** |
| Ferrous metals | 1.1 | % |
| Non-ferrous metals (only aluminium) | 0.3 | % |
| Glass | 0.3 | % |
| Plastics | 3.4 | % |
| Soft Plastics | 5.6 | % |
| Landfill cover material (gravel, fines) | 17.8 | % |
| Organics, Other | 71.6 | % |

In addition to the above-mentioned parameters, the analysis also considered the consumption of fuel, electricity and water during the LFM operations.

Scenario 2: “Typical” LFM project

This scenario uses a typical municipal solid waste (MSW) composition of Greek landfill sites, 20-30 years old, located near urban centres. 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. 5, the MSW generation per capita increased is given for the period 1990 to 2007. Taken an average MSW generation per capita & year at 400 kg, this yields a total quantity of 2,000,000 tn.

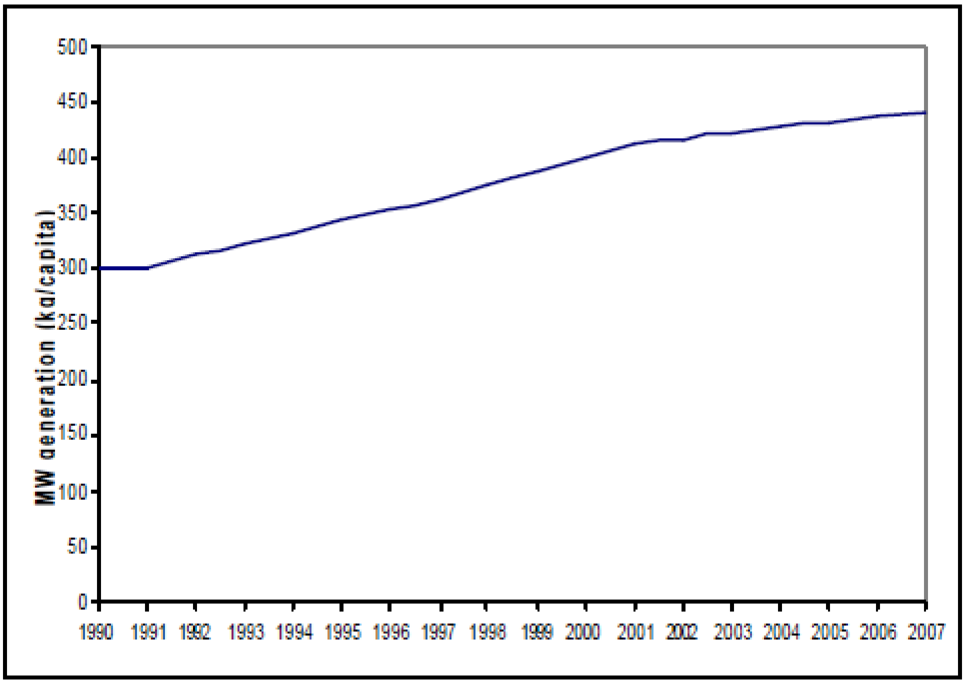



**Figure 5:** Municipal waste generation per capita in Greece from 1990 to 2007 (source: UN-CSD, 2011).

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 (UN-CSD, 2011). The estimated composition of Greek MSW generated from 1990 to 2007 is given in Fig. 6. 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 affected through the LFM activities.

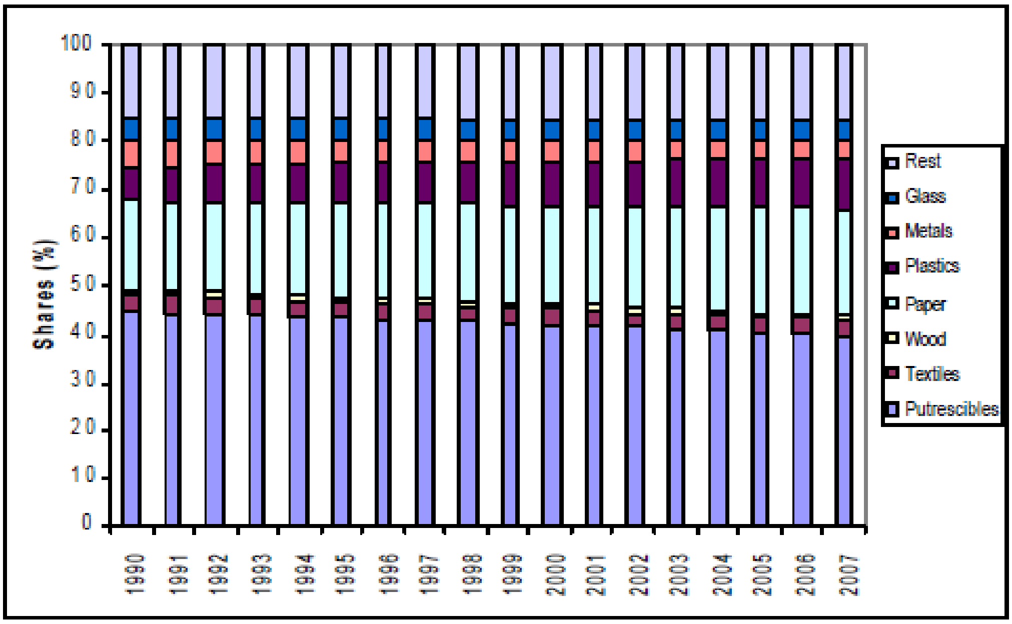



**Figure 6:** Estimated composition of Greek municipal waste from 1990 to 2007 (source: UN-CSD, 2011).

Relevant data on the materials found in LFM projects are also presented in Table 4, according to which the metal content found in European landfills ranges from 2% to 8%. According to van Vossen and Prent (2011) the average metal content is around 2%, with 85% (1.3% in weight) to be comprised of ferrous metals with the rest 15% (0.7% in weight) from mixed non-ferrous ones (Table 5). Also, Wagner and Raymond (2015), based on US-EPA data, mention that the metals constituted 8.92% by weight of the total amount of MSW generated (75% ferrous, 16% aluminium, and 9% other non-ferrous metals).

The final MSW content used under this scenario is presented in Table 6, where also the initial content 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.

**Table 4** - Composition of excavated waste from several LFM cases

| | Collier County, FL-US (Krogmann and Qu, 1997) | Edinburg, NY-US (Krogmann and Qu, 1998) | Burlington NJ-US (Hull et al., 2005) | Måsalycke, Sweden (Hogland, 2002) | Filborna, Sweden (Hogland et al., 1995) | Perungudi, India (Reno Sam, 2009) | Remo,Flanders, Belgium (Quaghebeur et al., 2012) | Data from 60 LFM projects (van Vossen and Prent, 2011) |
|---|---|---|---|---|---|---|---|---|
| Paper (% | 12 | 16 | 13 | 29 | 14 | - | 8 | 5.3 |
| Plastic (%) | 18 | 15 | 14 | 7 | 19 | 11 | 17 | 4.6 |
| Glass (%) | 5 | 7 | - | - | - | 0.8 | - | 1.1 |
| Metals (%) | 11 | 13 | 10 | 5 | 8 | 0.2 | 3 | 2.0 |
| Textiles (%) | 4 | - | 9 | - | 5 | 2.3 | 7 | 1.6 |
| Wood (%) | 23 | 4 | 19 | 19 | 14 | 11.6 | 7 | 3.6 |
| Soil (%) | 14 | 18 | 20 | 17 | 19 | 40.1 | 44 | 54.8 |
| Other (%) | 7 | 27 | 9 | 15 | 19 | 34 | 10 | 27.1 |

**Table 5** - Typical composition of excavated waste

| Materials | Average waste composition (Incl. soil) (%) | Average waste composition (Excl. soil) (%) |
|---|---|---|
| Plastic | 4.6 | 10.3 |
| Paper and cardboard (P&C) | 5.3 | 11.8 |
| Glass | 1.1 | 2.5 |
| Total metals | 2.0 | 4.1 |
| - Ferrous | 1.7 | 3.7 |
| - Non Ferrous | 0.3 | 0.4 |
| Organic | 5.3 | 11.6 |
| Wood | 3.6 | 8.0 |
| Leather | 1.6 | 3.5 |
| Textiles | 1.6 | 3.6 |
| Construction-Demolition Waste (CDW) | 9.0 | 19.0 |
| Stones | 2.5 | 5.5 |
| Other | 5.8 | 12.8 |
| Non-MSW | 0.3 | 0.8 |
| Soil (diameter less than 24mm) | 54.8 | - |
| Inert | 2.6 | 5.8 |

Source: van Vossen and Prent (2011)

**Table 6** - Main assumptions under Scenario 2

| 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 |
| **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 | 40.00 | % |

The data of the typical composition of a Greek landfill (Table 6) represent the values taking into consideration the baseline scenario. In order to account for variations and uncertainty in 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%

Given the size of the landfill, it is assumed that LFM operations 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 selling the land, after complete reclamation have not been considered.

<u>Scenario 3: "Advanced" LFM project</u>

As already stated, Scenario 3 differs from Scenario 2 by taking into account the recovery of waste of electrical and electronic equipment (WEEE) contained in the municipal waste stream. However, for conciseness reasons only the normal productivity scenario is examined, assuming that LFM operations are carried out by means of own recourses (i.e. personnel and equipment).

In general, the percentage of WEEE found in MSW ranges from 0.5 to 2% on a weight basis. In Greece, according to UNU-IAS (2015) data, in 2014 the WEEE generation per inhabitant was around 15.2 kg. Taking into account that from 1990's there was a gradual increase in electrical and electronic goods market and that the WEEE recycling schemes were introduced in Greece in the mid 2000's, a range between 4 and 8 kg of WEEE per inhabitant per year was assumed to be generated and deposited in landfills. For the case of a Greek landfill covering the needs of 200,000 inhabitants for 25 years, this yields amounts from 20,000 to 40,000 tn of disposed WEEE. This value corresponds to 1% to 2% of WEEE content in the landfill waste, comparable to the values indicated in other EU countries (e.g. 1.5 % in UK and Ireland, 2% in Finland) (DEFRA, 2015). All in all, the weight content of WEEE in the typical landfill examined is assumed to be 1.5% in the baseline scenario (1% as a minimum and 2% as a maximum content values are also taken so as to include possible variations in content).

The portion of IT equipment and small household appliances are approximately 30% of the total WEEE weight (Zoeteman, 2006; Baldé et al., 2015; Eco3e, 2016). Furthermore, according to Oguchi et al. (2011), the weight fraction of PCB's ranges between 8% and 13%, in those WEEE categories. Thus it can be deduced that the PCB's weight deriving from small appliances and IT products is roughly equal to 0.03%.

Scenario 3 involves three different options as regards the recovered WEEE, as follows:

(a) WEEE devices are separated and, then, are sold “as is” without further treatment;

(b) WEEE devices are separated and, are dismantled in order to recover PCBs. In that case PCBs are sold without further processing at a different price compared to that of the rest WEEE quantities; and

(c) WEEE devices are separated and are dismantled in order to recover PCBs. Then, PCBs undergo a specific treatment in order to acquire the desirable size and separate metals and plastic particles. The latter are finally processed using froth flotation to recover valuable metals. Based on the size reduction and beneficiation tests that were carried out in the RECLAIM project, the estimated recovered quantities of materials from PCBs, on a weight basis, are presented in Table 7.

**Table 7** - Recovered materials from PCBs

| Composition | Value | Units |
|---|---|---|
| Mixed non-ferrous metals | 12.4 | % |
| Ferrous parts and detritus | 10.1 | % |
| Copper parts | 2.5 | % |
| Aluminium parts | 2.3 | % |
| Pulverized e-waste* | 70 | % |

*: The chemical composition of the pulverized e-waste and of the final concentrates is given in Annex I, as derived from the beneficiation tests

Finally, the main technical assumptions of Scenario 3 are presented in Table 8.

**Table 8** - Main assumptions under scenario 3

| 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 |
| Daily working period | 6.5 | hours/day |
| Working days (per year) | 250 | days/year |
| Productivity/year (normal/high)* | 19,500 / 40,600 | 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 |

| 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 | % |
| WEEE (1.5% @ 90% recov.) | 1.35 | % |
| Residuals | 38.75 | % |

*: Personnel required for treating WEEE is included in the cost of WEEE treatment

## 4.5. Financial assumptions

The cost and revenues data used in the estimates were mainly extracted by the Polygyros LFM pilot project. Wherever additional data were required, they were gathered by directly communicating with market experts. In Tables 9 and 10, capital and operating cost assumptions are given under two different operational models, namely operation with subcontractors, and operation with owned equipment and personnel.

**Table 9** - Capital and operating costs for LFM operations using subcontractors

| Description | Cost (€) |
|---|---|
| Site preparation & Development - Polygyros LFM scenario | 15,000 |
| Site preparation & Development - Greek typical case scenario | 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 10** - Capital and operating costs for LFM operations using owned equipment & personnel

| Description | Cost (€) |
|---|---|
| Site preparation & Development - Greek typical case | 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 |

Moreover, Table 11 illustrates the cost for processing WEEE devices under two different treatment scenarios. The first one includes only disassembly of WEEE devices to recover PCBs. The second one considers disassembly of WEEE devices and further processing of PCB's (as identified in Task B6), so as to recover ferrous, non-ferrous and precious metals. This distinction was necessary because there are considerable differences in the prices of the recyclable materials deriving from the WEEE resources and, thus, useful insights in the most promising processing level could be gained from a financial viewpoint.

**Table 11** - Cost of e-waste processing under different disassembly modes.

| Description | Cost (€) |
|---|---|
| E-waste disassembly to obtain PCBs per device | 1 |
| E-waste disassembly to obtain PCBs per tonne | 100 |
| PCB processing (size reduction and flotation process) per tonne | 350 |

Apart from the costs of LFM activities, there are significant benefits associated with the recovered materials and 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 12 presents the base prices of the recyclables that are used in the financial models, along with minimum and maximum estimates. The sell 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). The concentrate selling price is estimated at €700 per tonne, according to Annex I.

**Table 12** - Selling price (€/tn) of recyclables

| | Sell price (€/tn) | | |
|---|---|---|---|
| **Recyclable type** | ***Base estimate*** | ***Min estimate*** | ***Max estimate*** |
| Ferrous metals | 80 | 60 | 110 |
| Non-ferrous metals – Aluminium | 700 | 600 | 1000 |
| Non-ferrous metals – Copper | 1000 | 1000 | 2500 |
| Non-ferrous metals – Nickel, Lead | 750 | 700 | 1200 |
| Non-ferrous metals (mixed) * | 740 | 660 | 1200 |
| Glass | 10 | 10 | 15 |
| Plastics (mixed)** | 200 | 100 | 300 |
| Soft plastics | 0 | 0 | 0 |
| WEEE (mixed – no disassembly) | 80 | 70 | 110 |
| WEEE (PCB's) | 400 | 400 | 900 |
| Concentrate | 700 | 600 | 900 |

** The analysis is made taking into account a mix of 75% in aluminium, 15% in nickel, lead and 10% in copper.*
*** 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 are given in Table 12.

**Table 13** - 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 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%. The life span of the analysis covers a period of 10 years, except from Scenario 1 in which the operations last for two years due to the limited quantity of disposed waste.

## 4.6. Socioeconomic assumptions

Based on the social and environmental considerations and the methodological framework adopted, as discussed in previous sections, the external costs and benefits that are being taken into consideration in the analysis are related to the on-site environmental gains and risks of LFM operations (e.g. reclamation of land, removal of pollution sources, releases of air pollutants during the excavation and processing stages, etc.) (Hogland et al., 1997; Krook et al., 2007 & 2012; Fisher, 2013; Ford et al., 2013) and direct employment effects.

It should be mentioned that in order to avoid double-counting, 'secondary' benefits related to recovery of recyclable materials, such as energy savings, resources conservation, reduction in greenhouse gases emissions, etc., were not considered separately. The reason is that the primary valuation studies conducted at local and national level by means of the Contingent Valuation (CV) method, estimated society's willingness to pay (WTP) for LFM projects considering both direct and indirect environmental gains and losses associated of LFM. Moreover, as was already mentioned, indirect (i.e. on secondary markets) and wider effects (i.e. on public funds, regional growth, etc.) have been excluded from the analysis owing to methodological requirements.

To this end, the following socioeconomic assumptions have been taken into account:

<u>Scenario 1: Polygyros LFM project</u>

Concerning the social support of an LFM program in the area of interest, the results of the 'local' CV study were used. More specifically, the mean annual WTP of those who agreed to support LFM programs is around 47.5 € per household. Nevertheless, given that the elicited value was zero for 76% of the respondents, the mean annual WTP of the population is estimated at around 12 € per household. The population of the area of interest consists of 8,156 households.

In order to estimate the shadow wage, an unemployment rate of 25.5% was considered, based on the latest available data by the Hellenic Statistical Authority (HELSTAT, 2015) and an income tax rate of 22%. In addition, an income tax rate of 29% is used for subcontractors, assuming income from individual activities (i.e. non-permanent employees and freelancers).

Scenario 2: “Typical” LFM project

For this scenario, the results of the ‘national’ CV study were used. More specifically, the mean annual WTP of those who agreed to support LFM programs is around 70 € per household. Given that the elicited value was zero for 27.6% of the respondents, the mean annual WTP of the population is estimated at around 50 € per household.

In order to estimate the shadow wage, an unemployment rate of 24% was considered, based on the latest available data by the Hellenic Statistical Authority (HELSTAT, 2015) and an income tax rate of 22%. In addition, an income tax rate of 29% is used for subcontractors, assuming income from individual activities (i.e. non-permanent employees and freelancers). Moreover, in order to estimate the number of households in the hypothetical population of interest (i.e. 200,000 inhabitants), the average members per household in Greece (i.e. 2.6) was taken into account.

Scenario 3: “Advanced” LFM project

The socioeconomic assumptions of Scenario 3 are identical to those of Scenario 2.

# Chapter 5. FINANCIAL ANALYSIS OF LFM OPERATIONS

## 5.1. Financial analysis of Scenario 1

### 5.1.1. Deterministic analysis

Bearing in mind the assumptions of the "Polygyros" LFM scenario, only limited investment costs are required given that excavation and processing works are assigned to subcontractors.

Revenues (including avoided costs) are about €590,000. The projected cash flows are given in Table 13.

**Table 14** - Projected cash flows –Scenario 1

| | 0 | 1 | 2 |
|---|---|---|---|
| Capital costs | 15,000 | | |
| Waste processed | | 19,500 | 19,500 |
| Revenues | | 386,295 | 400,095 |
| *Benefit of recovered air-space* | | *193,830* | *193,830,0* |
| *Recycling metals, plastics and glasses* | | | |
| *- Ferrous metals* | | *16,714* | *16,714* |
| *- Non-ferrous metals* | | *37,902* | *37,902* |
| *- Glass* | | *585* | *585* |
| *- Plastics* | | *132,600* | *132,600* |
| *Avoidance of landfill cover material* | | *4,664* | *4,664* |
| Operating costs | | 823,397 | 823,397 |
| *Rental of mining equipment* | | *210,000* | *210,000* |
| *Rental of processing equipment* | | *550,000* | *550,000* |
| *Administrative costs* | | *10,000* | *10,000* |
| *Fuel / Energy* | | *50,020* | *50,020* |
| *Water* | | *3,377* | *3,377* |
| EBITDA | | -437,102 | -423,302 |
| Depreciation | | 600 | 600 |
| Earnings before taxes (EBT) | | -437,702 | -423,902 |
| Taxes (29%) | | 0 | 0 |
| NOPAT | | -437,702 | -423,902 |
| Cash flow | -15,000 | -437,102 | -423,302 |

Using a real discount rate of 6%, the NPV of the project is estimated at about €*-804,100*.

The total cost is approximately €42.2 per tn of waste and the benefits €19.8 per tn of waste, respectively. In present value terms, the LFM operations result in a net loss of around €20.5 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.

**Table 15** - Cost breakdown–Scenario 1

| 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 16** - Benefits breakdown–Scenario 1

| Category | Benefits (€/tn) | Percentage (% of total) |
|---|---|---|
| Ferrous metals | 0.86 | 4.3 |
| Aluminium cans | 1.94 | 9.8 |
| Glass | 0.03 | 0.2 |
| Plastics | 6.8 | 34.3 |
| Landfill cover material | 0.24 | 1.2 |
| ***Subtotal 1*** | ***9.87*** | ***49.8*** |
| Recovered air-space | 9.94 | 50.2 |
| **Total** | **19.81** | **100.0** |

### 5.1.2. Sensitivity analysis

The sensitivity analysis with respect to the profitability of the project focused on the most important parameters as regards the uncertainty in the range of values and the significance on the financial indices. To this end, the price of the recyclable materials (ferrous and non-ferrous metals and plastics) and the composition of the waste were taken into consideration. The results of the sensitivity of NPV to a ±20 percent change are given in Table 17 and illustrated in Fig. 7.

**Table 17** - NPV sensitivity analysis results (Euros) – Scenario 1

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | -852,719 | -828,408 | -804,097 | -779,786 | -755,476 |
| Plastics concentration | -852,719 | -828,408 | -804,097 | -779,786 | -755,476 |
| Non-ferrous metals price | -817,995 | -811,046 | -804,097 | -797,148 | -790,199 |
| Non-ferrous metals concentration | -817,995 | -811,046 | -804,097 | -797,148 | -790,199 |
| Ferrous metals price | -810,226 | -807,161 | -804,097 | -801,033 | -797,969 |
| Ferrous metals concentration | -810,226 | -807,161 | -804,097 | -801,033 | -797,969 |

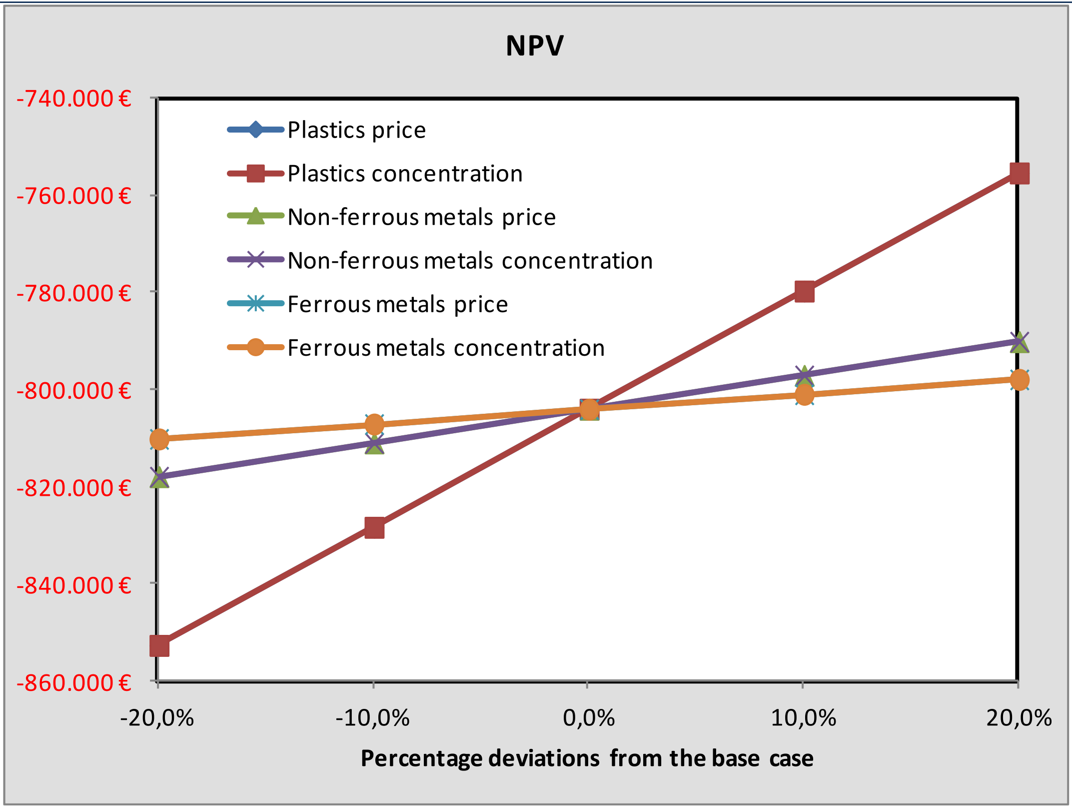



**Figure 7:** NPV sensitivity analysis – Scenario 1

The price and concentration of plastics have the same and the most significant result in the NPV of the project, followed by the non-metal price and concentration.

### 5.1.3. Stochastic analysis

As mentioned, sensitivity analysis quantifies the effects of specific variables on the profitability of the project on a ceteris paribus basis. To gain further insight into the financial results, probabilistic risk analysis was used, by means of random values from pre-selected probability distributions for critical input factors.

The parameters involved were 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 following assumptions were used:

- Price of ferrous metals (€/tn): min=60, most likely=80, max=110

- Price of non-ferrous metals - aluminium (€/tn): min=600, most likely=700, max=1000
- Price of plastics (€/tn): min=100, most likely=200, max=300
- Concentration of ferrous metals (%): min=0.5, most likely=1.1, max=2.0
- Concentration of non-ferrous metals - aluminium (%): min=0.1, most likely=0.3, max=0.5
- Concentration of plastics (%): min=2.5, most likely=3.4, max=4.5

Risk analysis was conducted using quantitative probability modelling, namely Monte Carlo simulation. The results of the simulation that was carried out by means of sophisticated software are presented in the following tables and figures.

**Table 18** - Monte Carlo simulation statistics – Scenario 1

| Variable | NPV |
|---|---|
| Mean | -783,476 |
| Median | -785,992 |
| Standard Deviation | 60,868 |
| Minimum | -933,223 |
| Maximum | -583,270 |
| Mean Std. Error | 1,925 |

**Table 19** - Monte Carlo simulation percentiles – Scenario 1

| Percentage | NPV (€) |
|---|---|
| 100% | -933,223 |
| 90% | -859,529 |
| 80% | -836,139 |
| 70% | -819,061 |
| 60% | -801,128 |
| 50% | -786,002 |
| 40% | -770,451 |
| 30% | -754,762 |
| 20% | -735,325 |
| 10% | -703,997 |
| 0% | -583,270 |

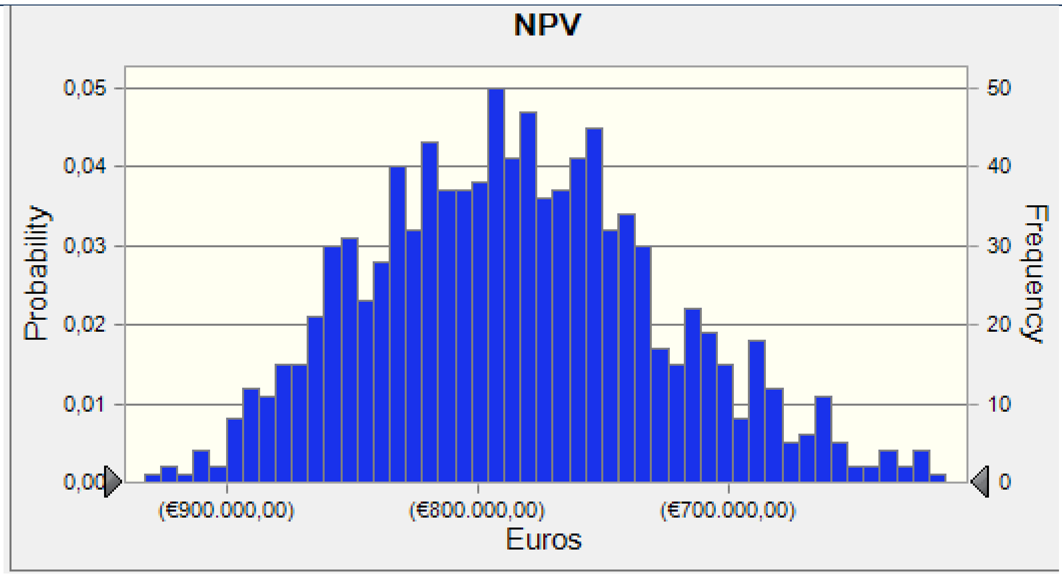



**Figure 8:** Histogram of NPV distribution – Scenario 1

The expected NPV is €-780,000 approximately. The minimum expected value is about €-933,000, and the maximum €-583,000, which means that the probability of accepting the project from a financial point of view is zero.

According to the sensitivity chart (Fig. 9), the value of the project is mainly affected by the price of plastics, followed by the concentration of plastics.

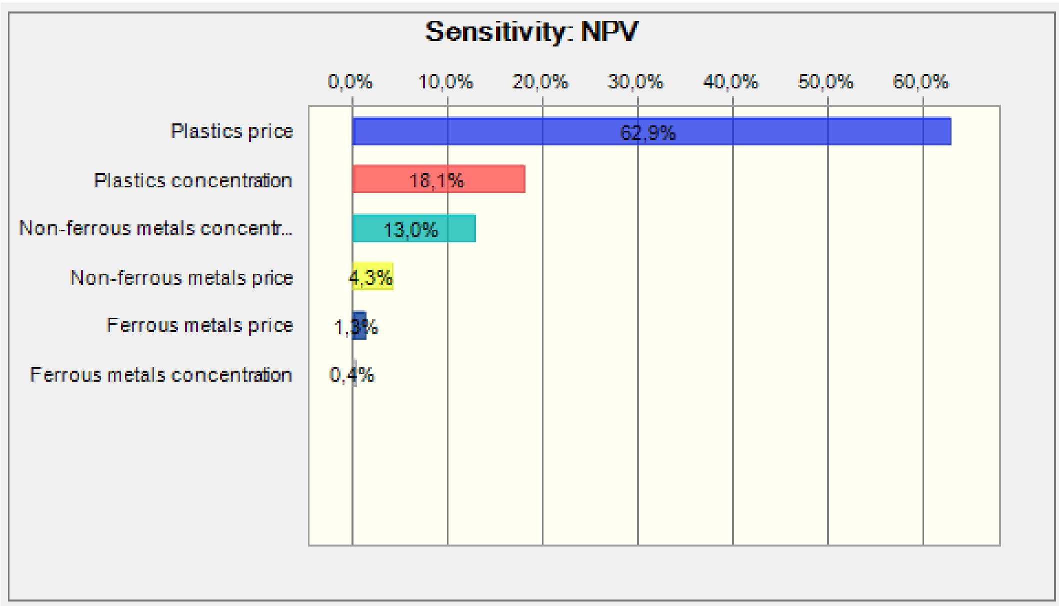



**Figure 9:** Sensitivity chart of NPV–Scenario 1

## 5.2. Financial analysis of Scenario 2

### 5.2.1. Deterministic analysis

As mentioned, this scenario involves the implementation of LFM process in a typical Greek landfill. To this end, three different sub-scenarios are examined. The first sub-scenario assumes that excavation and processing activities will be carried out by subcontractors, while the second and the third ones assume operation with owned equipment and personnel, with low and high productivity, respectively.

*2A. Subcontractor scenario*

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 20.

**Table 20** - Projected cash flows–Scenario 2A

| | **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.

**Table 21** - Cost breakdown–Scenario 2A

| 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 22** - Benefits breakdown–Scenario 2A

| 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** |

*B.1. "Own resources" scenario - Low productivity*

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 23.

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 and benefits on a per tn of waste basis are provided in the following tables.

**Table 23** - Projected cash flows –Scenario 2B1

| | 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 24** - Cost breakdown–Scenario 2B1

| 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** |

**Table 25** - Benefits breakdown–Scenario 2B1

| 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** |

*B.2. "Own resources" scenario- High productivity*

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 2.B.2. 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 26.

**Table 26** - Projected cash flows–Scenario 2B2

| | 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 |

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 costs and benefits on a per tn of waste basis are provided in the following tables.

**Table 27** - Cost breakdown–Scenario 2B2

| 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** |

**Table 28** - Benefits breakdown–Scenario 2B2

| 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** |

### 5.2.2. Sensitivity analysis

*A. Subcontractor scenario*

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. More specifically, the price of the recyclable materials (ferrous and non-ferrous metals and plastics) and the composition of the waste were taken into consideration. The results of the sensitivity of NPV to a ±20 percent change are given in Table 29 and illustrated in Fig. 10.

**Table 29** - NPV sensitivity analysis results (Euros) –Scenario 2A

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | -1,719,873 | -1,622,278 | -1,521,326 | -1,427,089 | -1,329,494 |
| Non-ferrous metals price | -1,614,278 | -1,569,481 | -1,521,326 | -1,479,886 | -1,435,089 |
| Ferrous metals price | -1,607,352 | -1,566,018 | -1,521,326 | -1,483,349 | -1,442,015 |
| Plastics concentration | -1,549,702 | -1,537,193 | -1,521,326 | -1,512,174 | -1,499,665 |
| Non-ferrous metals concentration | -1,535,574 | -1,530,129 | -1,521,326 | -1,519,238 | -1,513,793 |
| Ferrous metals concentration | -1,535,280 | -1,529,982 | -1,521,326 | -1,519,385 | -1,514,087 |

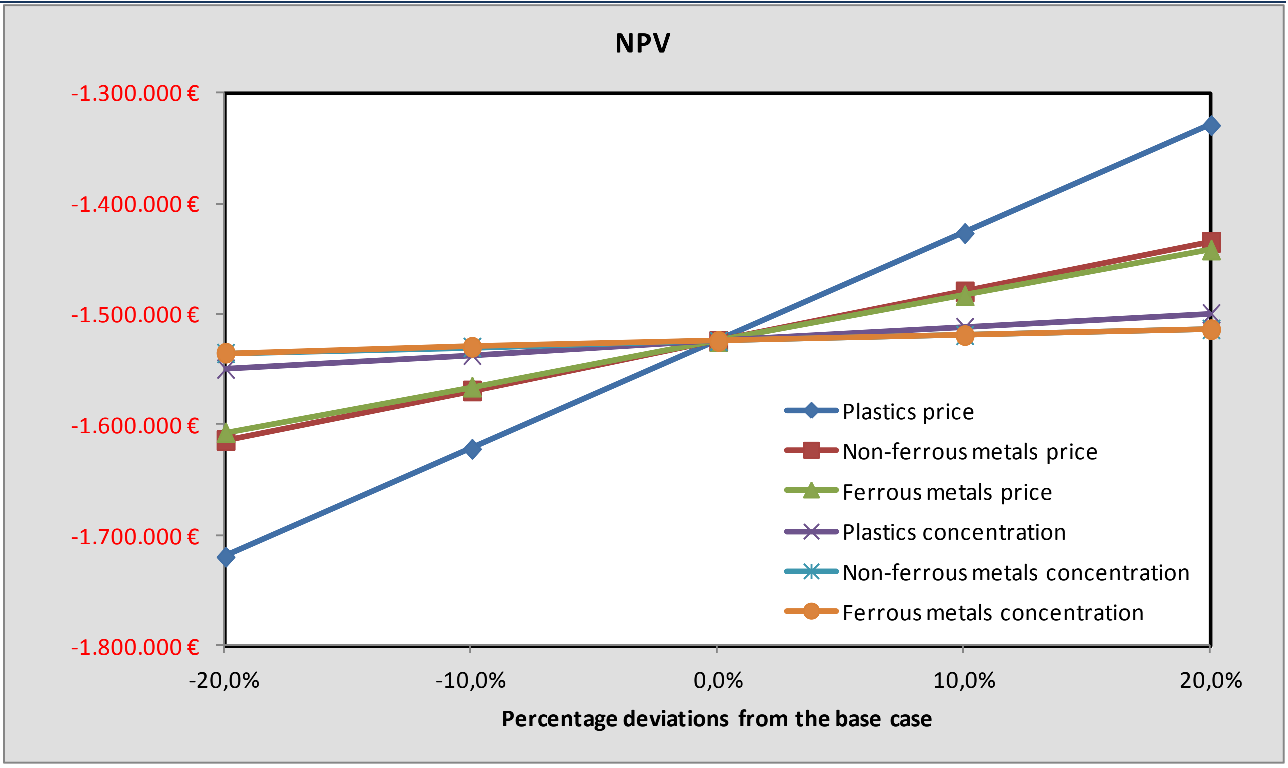



**Figure 10:** NPV sensitivity analysis–Scenario 2A

The price of plastics has the most significant result in the NPV of the project, followed by the non-metal price and the ferrous metals price.

*B.1. "Own resources" scenario – Low productivity*

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. More specifically, the price of the recyclable materials (ferrous and non-ferrous metals and plastics) and the composition of the waste were taken into consideration. The results of the sensitivity of NPV and IRR to a ±20 percent change are given in Tables 30 and 31 and are illustrated in Fig. 11 and 12.

**Table 30** - NPV sensitivity analysis results (Euros) –Scenario 2B1

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | -157,333 € | -88,041 € | -18,749 € | 50,544 € | 119,836 € |
| Non-ferrous metals price | -82,844 € | -50,796 € | -18,749 € | 13,299 € | 45,347 € |
| Ferrous metals price | -77,443 € | -48,096 € | -18,749 € | 10,599 € | 39,946 € |
| Plastics concentration | -157,333 € | -88,041 € | -18,749 € | 50,544 € | 119,836 € |
| Non-ferrous metals concentration | -82,844 € | -50,796 € | -18,749 € | 13,299 € | 45,347 € |
| Ferrous metals concentration | -77,443 € | -48,096 € | -18,749 € | 10,599 € | 39,946 € |

**Table 31** - IRR sensitivity analysis results (%)–Scenario 2B1

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 3.1% | 4.4% | 5.7% | 6.9% | 8.1% |
| Non-ferrous metals price | 4.5% | 5.1% | 5.7% | 6.2% | 6.8% |
| Ferrous metals price | 4.6% | 5.1% | 5.7% | 6.2% | 6.7% |
| Plastics concentration | 3.1% | 4.4% | 5.66% | 6.9% | 8.1% |
| Non-ferrous metals concentration | 4.5% | 5.1% | 5.66% | 6.2% | 6.8% |
| Ferrous metals concentration | 4.6% | 5.1% | 5.66% | 6.2% | 6.7% |

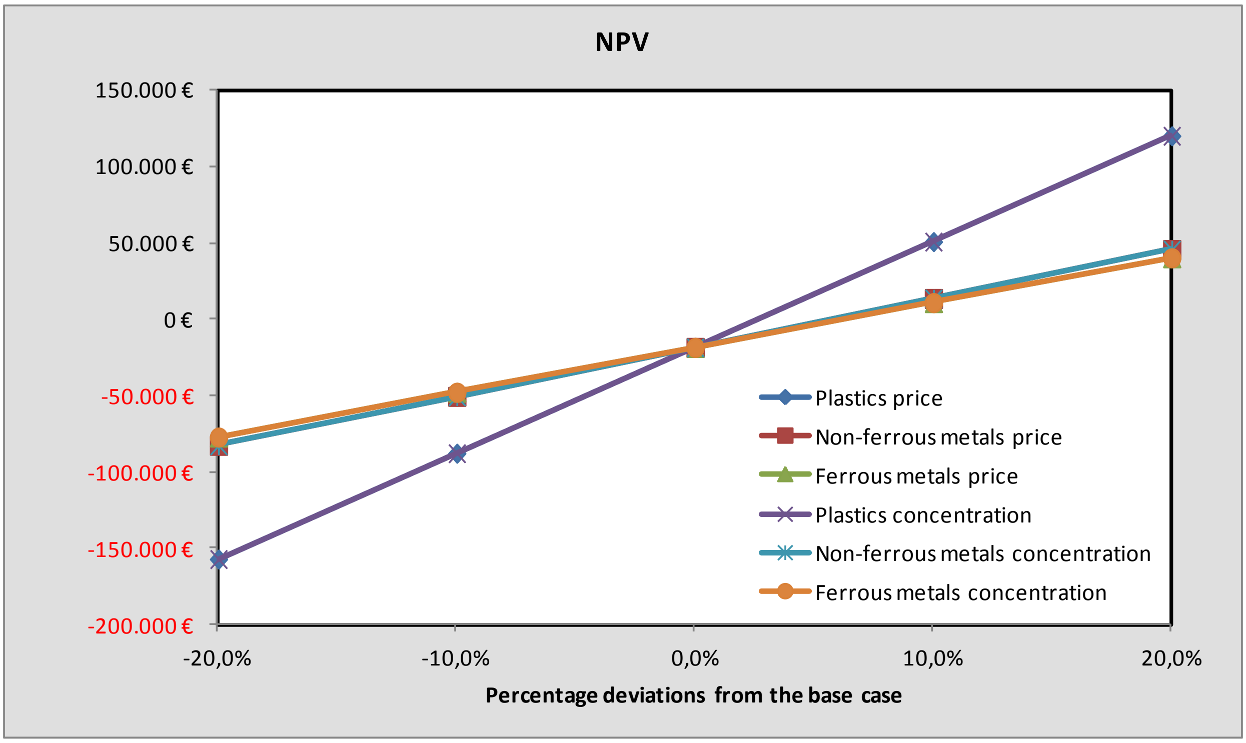



**Figure 11:** NPV sensitivity analysis–Scenario 2B1

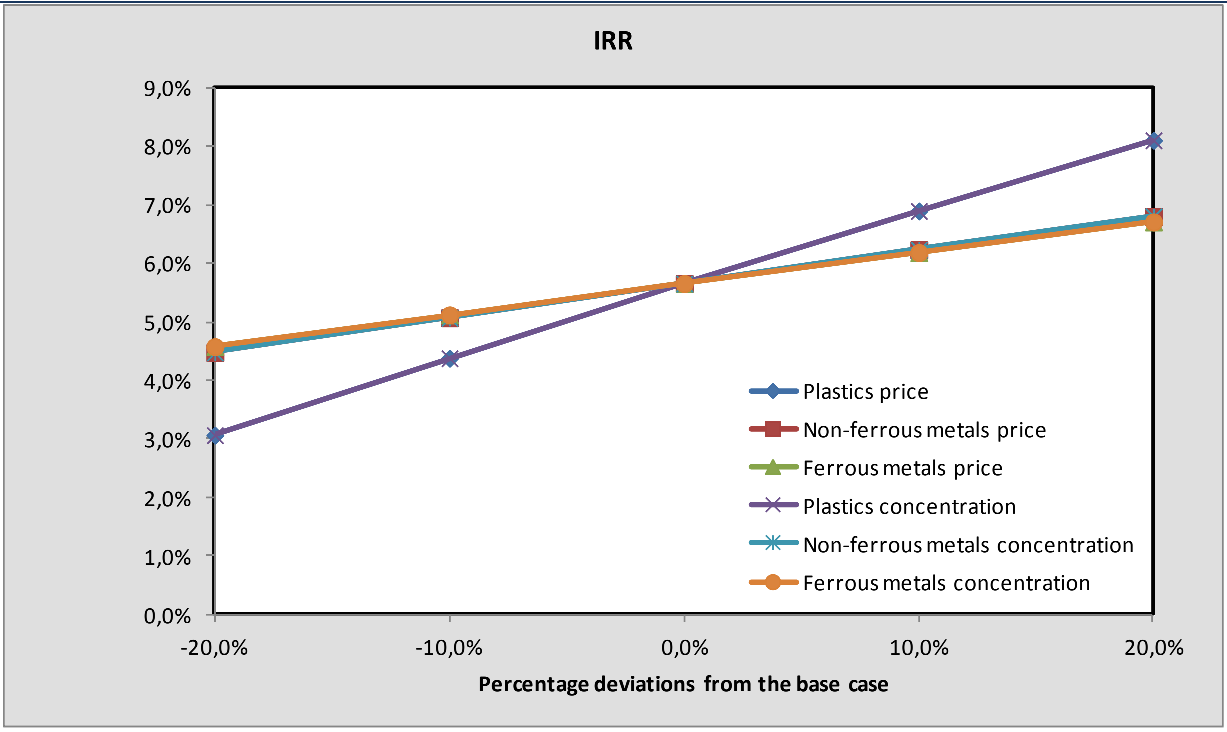



**Figure 12:** IRR sensitivity analysis–Scenario 2B1

According to the sensitivity analysis, the price of plastics and their content are the most significant factors influencing the NPV and IRR results of the project. Furthermore, the project 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%.

*B.2. "Own resources" scenario – High productivity*

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. More specifically, the price of the recyclable materials (ferrous and non-ferrous metals and plastics) and the composition of the waste were taken into consideration. The results of the sensitivity of NPV and IRR to a ±20 percent change are given in Tables 32 and 33 and are illustrated in Fig. 13 and 14.

**Table 32** - NPV sensitivity analysis results (Euros) –Scenario 2B2

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 1,734,336 € | 1,878,695 € | 2,023,054 € | 2,167,413 € | 2,311,772 € |
| Plastics concentration | 1,734,336 € | 1,878,695 € | 2,023,054 € | 2,167,413 € | 2,311,772 € |
| Non-ferrous metals price | 1,889,522 € | 1,956,288 € | 2,023,054 € | 2,089,820 € | 2,156,586 € |
| Non-ferrous metals concentration | 1,889,522 € | 1,956,288 € | 2,023,054 € | 2,089,820 € | 2,156,586 € |
| Ferrous metals price | 1,900,774 € | 1,961,914 € | 2,023,054 € | 2,084,194 € | 2,145,335 € |
| Ferrous metals concentration | 1,900,774 € | 1,961,914 € | 2,023,054 € | 2,084,194 € | 2,145,335 € |

**Table 33** - IRR sensitivity analysis results (%)–Scenario 2B2

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 20.2% | 21.2% | 22.3% | 23.3% | 24.3% |
| Plastics concentration | 20.2% | 21.2% | 22.3% | 23.3% | 24.3% |
| Non-ferrous metals price | 21.3% | 21.8% | 22.3% | 22.7% | 23.2% |
| Non-ferrous metals concentration | 21.3% | 21.8% | 22.3% | 22.7% | 23.2% |
| Ferrous metals price | 21.4% | 21.8% | 22.3% | 22.7% | 23.1% |
| Ferrous metals concentration | 21.4% | 21.8% | 22.3% | 22.7% | 23.1% |

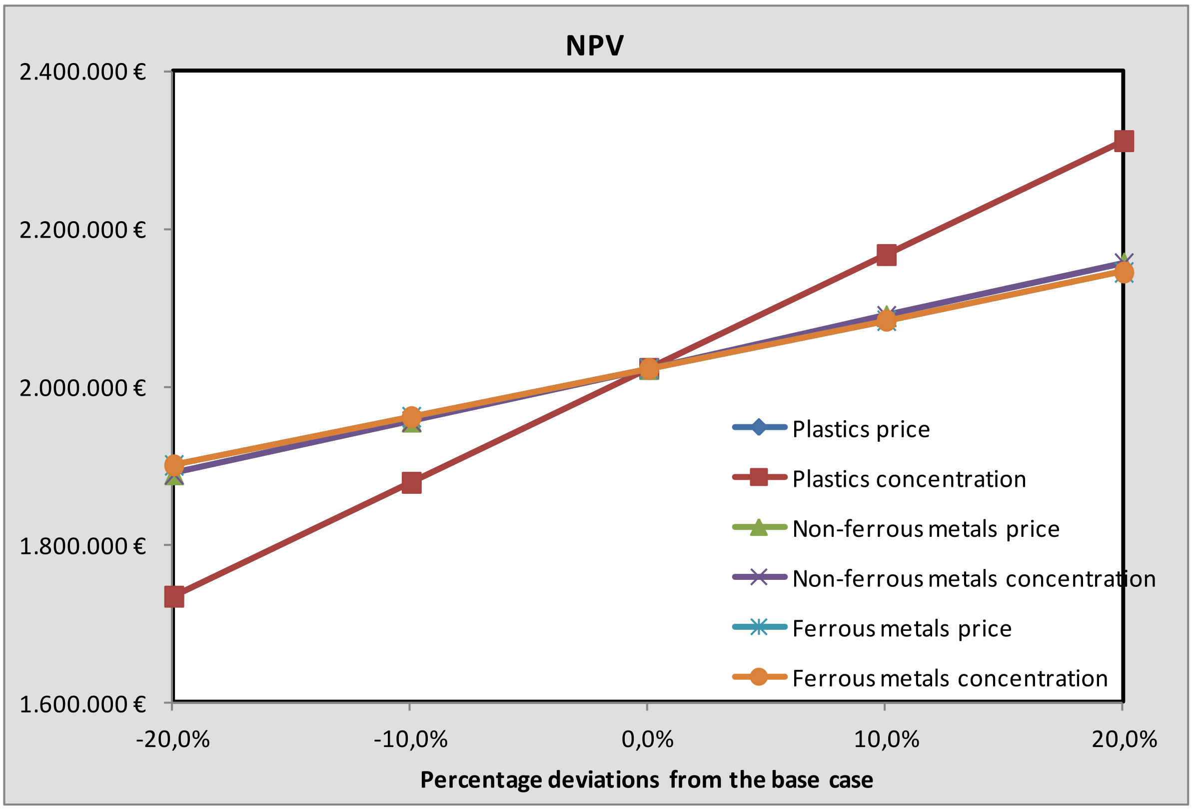



**Figure 13:** NPV sensitivity analysis–Scenario 2B2

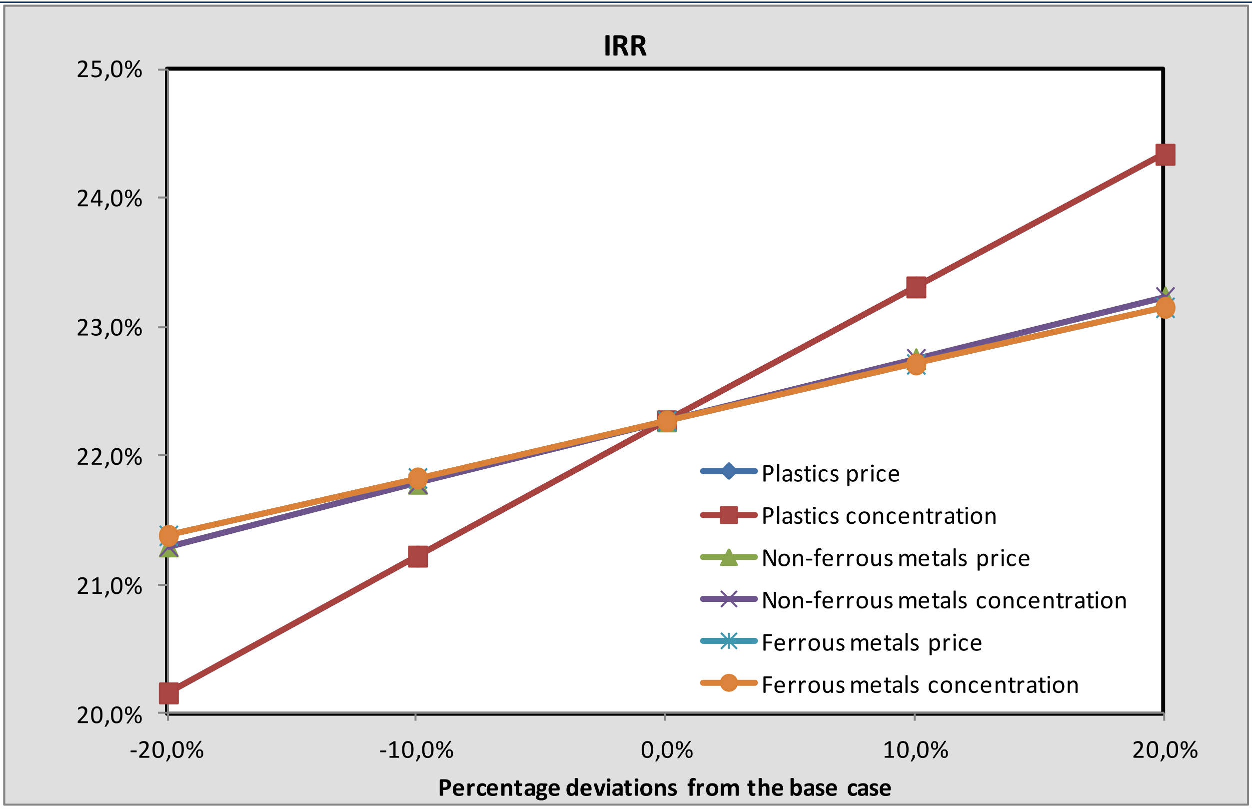



**Figure 14:** IRR sensitivity analysis–Scenario 2B2

According to the sensitivity analysis, the NPV and IRR indices of the project are affected by the price and the concentration of plastics. Furthermore, the project 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.

### 5.2.3. Stochastic analysis

The parameters involved were 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 following 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 - aluminium (%): min=0.3, most likely=0.5, max=0.9
- Concentration of plastics (%): min=3.0, most likely=3.4, max=8.5

*A. Subcontractor scenario*

The results of the simulation are presented in the following tables and figures**.**

**Table 34** - Monte Carlo simulation statistics–Scenario 2A

| Variable | NPV (€) |
|---|---|
| Mean | -1.338.995 |
| Median | -1.336.032 |
| Standard Deviation | 235,269 |
| Minimum | -1,930,697 |
| Maximum | -662,294 |
| Mean Std. Error | 7,440 |

**Table 35** - Monte Carlo simulation percentiles–Scenario 2A

| Percentage | NPV (€) |
|---|---|
| 100% | -1.930.697 |
| 90% | -1.650.131 |
| 80% | -1.543.239 |
| 70% | -1.474.837 |
| 60% | -1.400.831 |
| 50% | -1.336.115 |
| 40% | -1.280.528 |
| 30% | -1.219.745 |
| 20% | -1.135.122 |
| 10% | -1.037.485 |
| 0% | -662.294 |

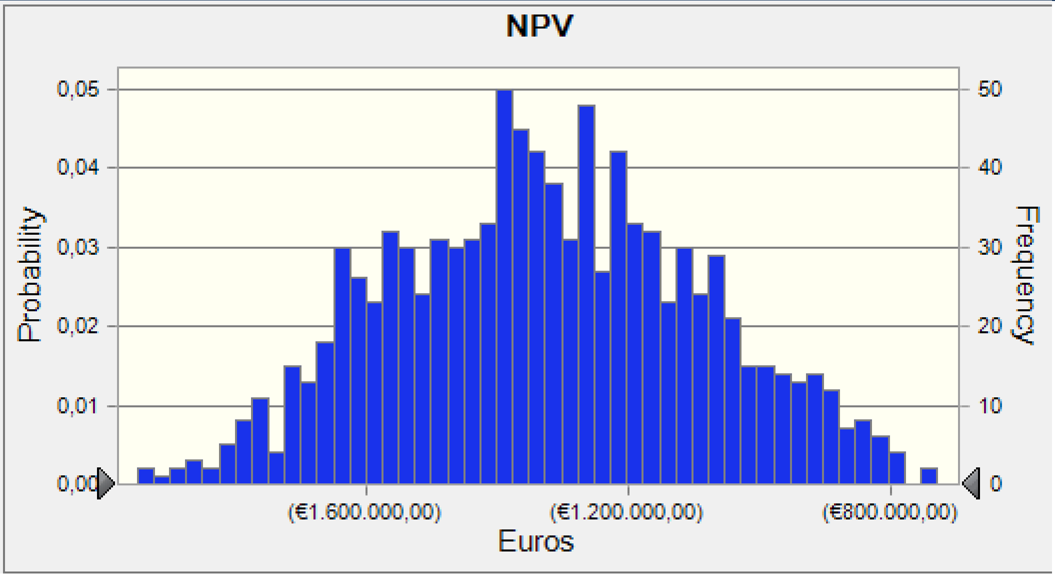



**Figure 15:** Histogram of NPV distribution–Scenario 2A

The expected NPV 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. Furthermore, according to the sensitivity chart (Fig. 14), the value of the project is affected by price of plastics at a great extent.

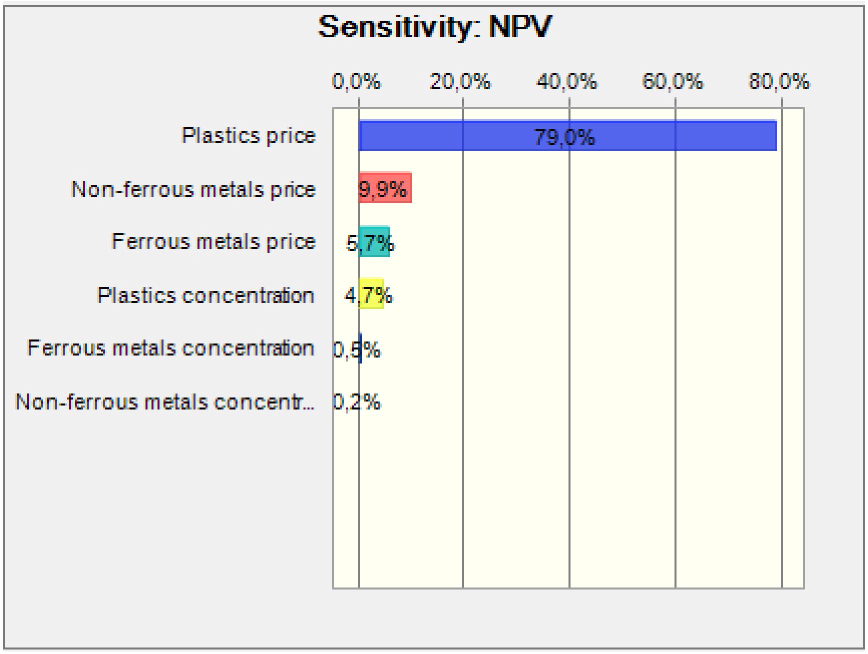



**Figure 16:** Sensitivity chart of NPV–Scenario 2A

*B.1. "Own resources" scenario – Low productivity*

The results of the simulation for the specific sub-scenario are given in the following tables and figures.

**Table 36** - Monte Carlo simulation statistics–Scenario 2B1

| Variable | NPV (€) | IRR (%) |
|---|---|---|
| Mean | 547,682 | 14.8 |
| Median | 509,768 | 14.5 |
| Standard Deviation | 356,786 | 5.4 |
| Minimum | -267,981 | 0.9 |
| Maximum | 2,174,073 | 37.3 |
| Mean Std. Error | 11,283 | 0.2 |

**Table 37** - Monte Carlo simulation percentiles–Scenario 2B1

| Percentage | NPV (€) | IRR (%) |
|---|---|---|
| 100% | -267,981 | 0.9 |
| 90% | 122,123 | 8.1 |
| 80% | 238,849 | 10.1 |
| 70% | 338,771 | 11.8 |
| 60% | 419,081 | 13.0 |
| 50% | 509,356 | 14.4 |
| 40% | 591,245 | 15.7 |
| 30% | 713,865 | 17.5 |
| 20% | 838,750 | 19.4 |
| 10% | 1,028,540 | 22.1 |
| 0% | 2,174,073 | 37.3 |

The expected NPV 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%.

Furthermore, according to the sensitivity charts (Fig. 19 & 20), the value of the project is affected to a great extend by the concentration of the plastics and to lesser one by the price of the plastics. The concentration and the price of ferrous and non-ferrous metals do not play a significantly role on the overall figures.

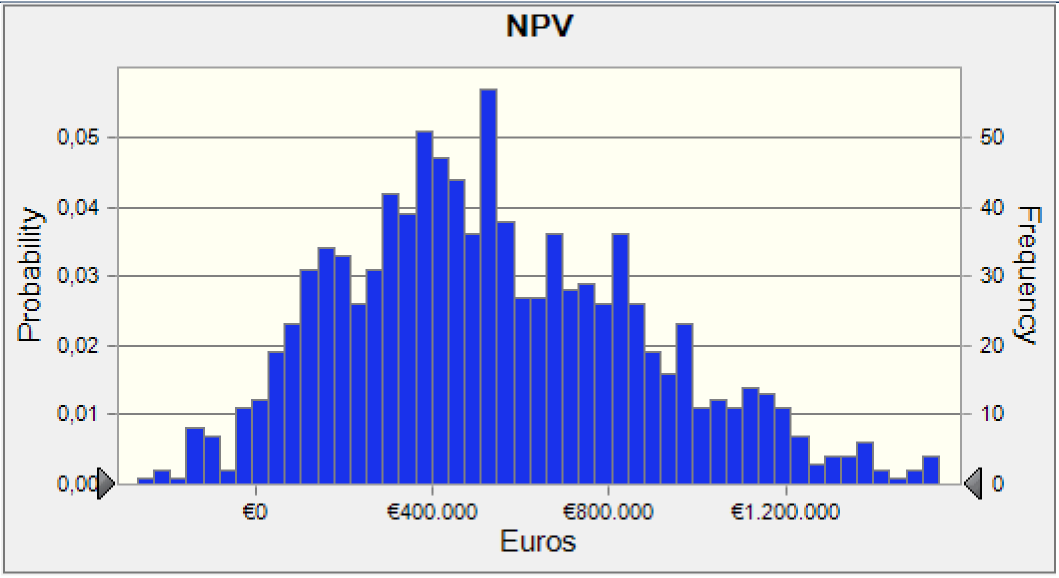



**Figure 17:** Histogram of NPV distribution–Scenario 2B1

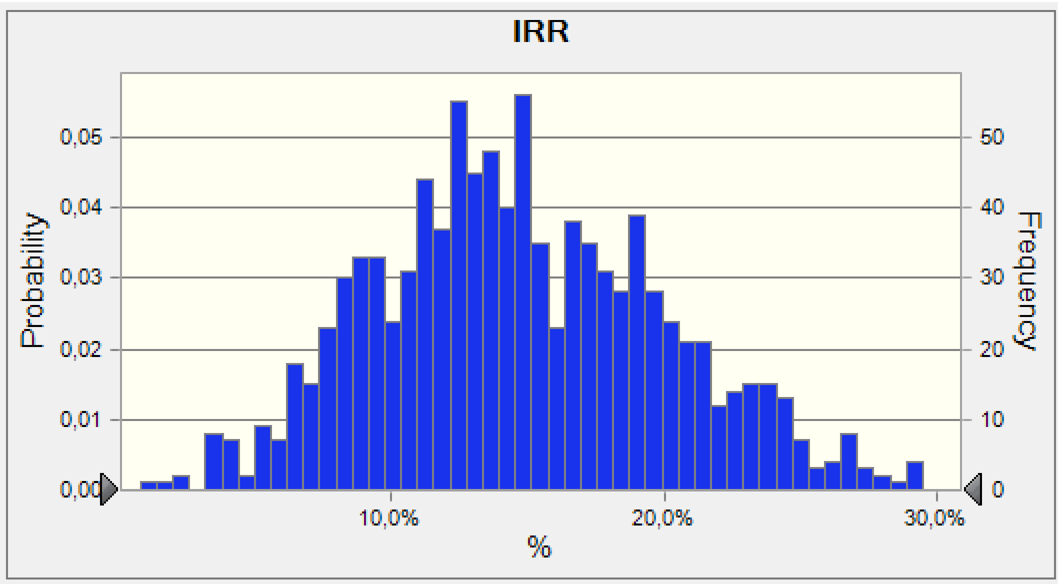



**Figure 18:** Histogram of IRR distribution–Scenario 2B1

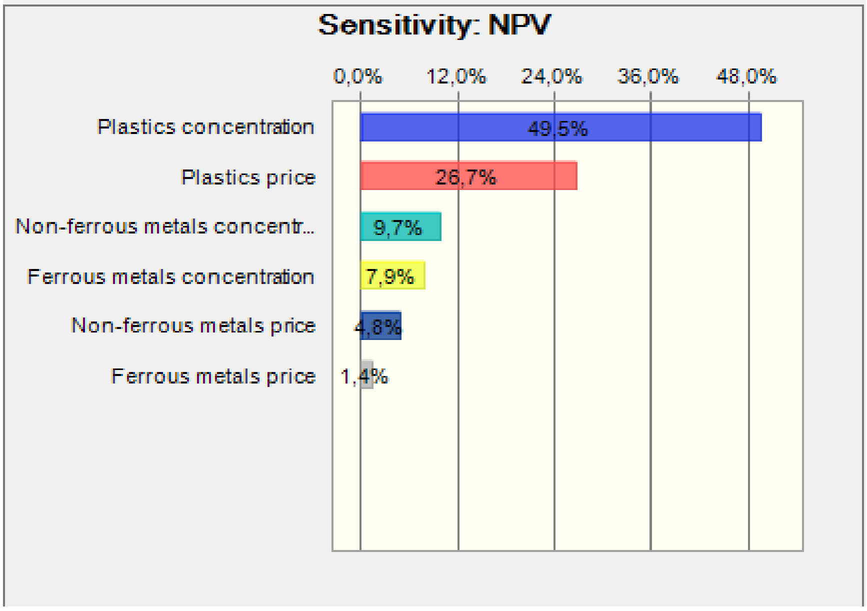



**Figure 19:** Sensitivity chart of NPV–Scenario 2B1

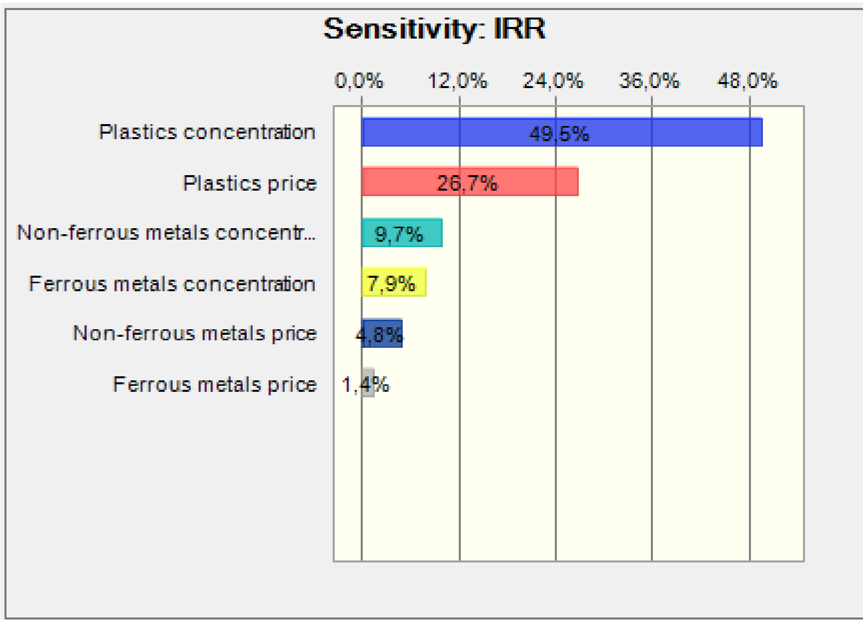



**Figure 20:** Sensitivity chart of IRR–Scenario 2B1

*B.2. "Own resources" scenario – High productivity*

The results of the simulation for the specific sub-scenario are given in the following tables and figures.

**Table 38** - Monte Carlo simulation statistics–Scenario 2B2

| Variable | NPV (€) | IRR (%) |
|---|---|---|
| Mean | 3,215,759 | 30.5 |
| Median | 3,127,398 | 30.0 |
| Standard Deviation | 781,381 | 5.3 |
| Minimum | 1,732,006 | 20.1 |
| Maximum | 6,421,509 | 51.3 |
| Mean Std. Error | 24,709 | 0.2 |

**Table 39** - Monte Carlo simulation percentiles–Scenario 2B2

| Percentage | NPV (€) | IRR (%) |
|---|---|---|
| 100% | 1,732,006 | 20.1 |
| 90% | 2,266,856 | 24.0 |
| 80% | 2,508,144 | 25.7 |
| 70% | 2,733,010 | 27.3 |
| 60% | 2,964,147 | 28.9 |
| 50% | 3,126,641 | 30.0 |
| 40% | 3,314,090 | 31.3 |
| 30% | 3,560,505 | 32.9 |
| 20% | 3,878,159 | 35.0 |
| 10% | 4,286,578 | 37.7 |
| 0% | 6,421,509 | 51.3 |

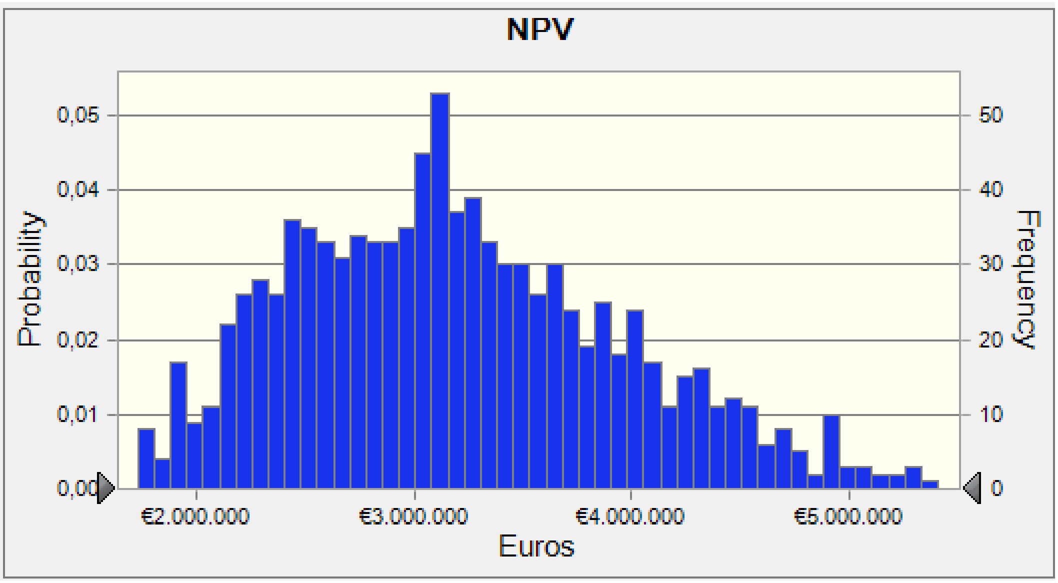



**Figure 21:** Histogram of NPV distribution–Scenario 2B2

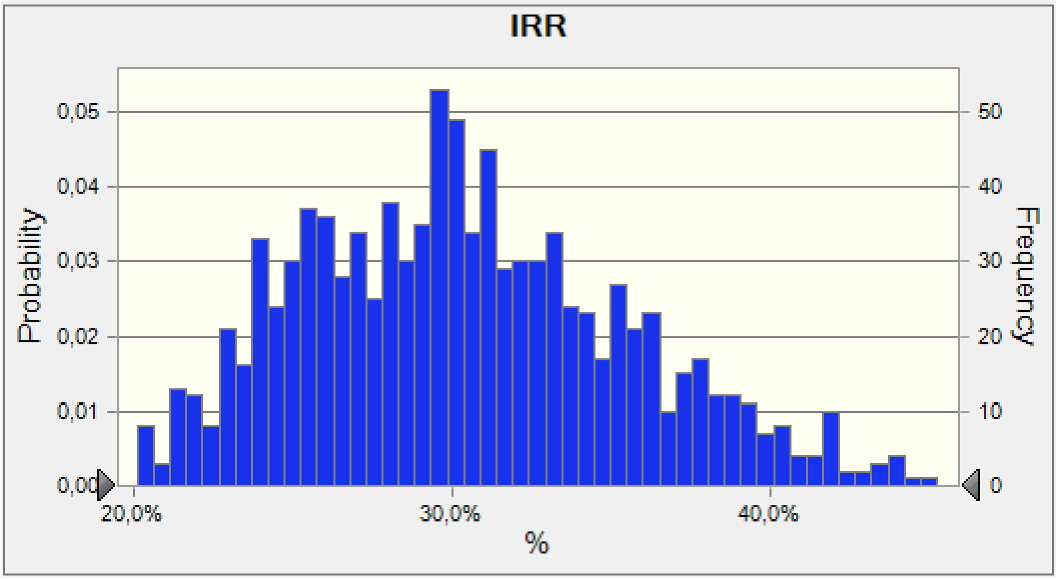



**Figure 22:** Histogram of IRR distribution–Scenario 2B2

The expected NPV 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 modelling 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%.

Furthermore, according to the sensitivity charts (Fig. 23 & 24), the value of the project is once again greatly affected by the concentration of the plastics and to lesser degree by the price of the plastics, while the price and concentration of ferrous and non-ferrous metals are much less significant under this scenario.

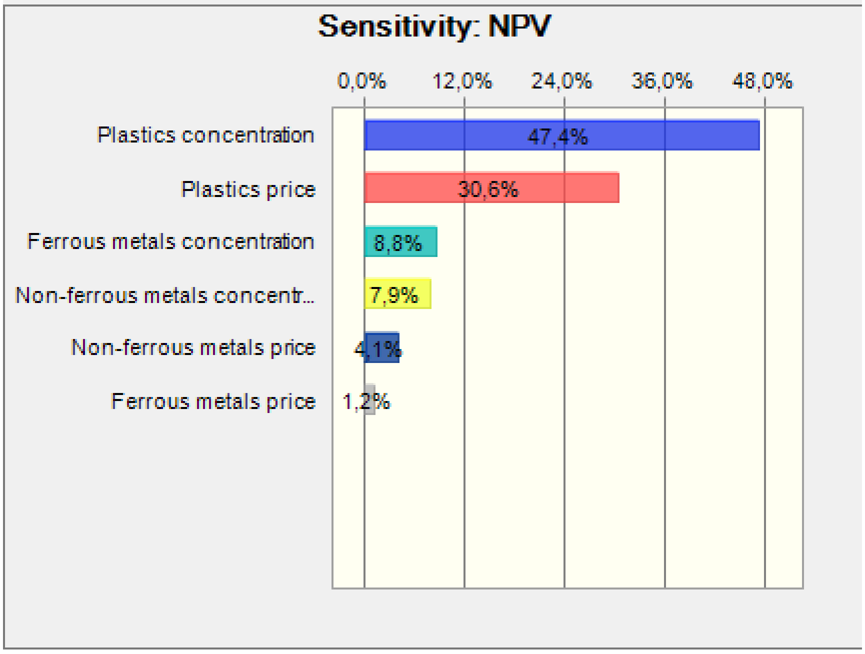



**Figure 23:** Sensitivity chart of NPV–Scenario 2B2

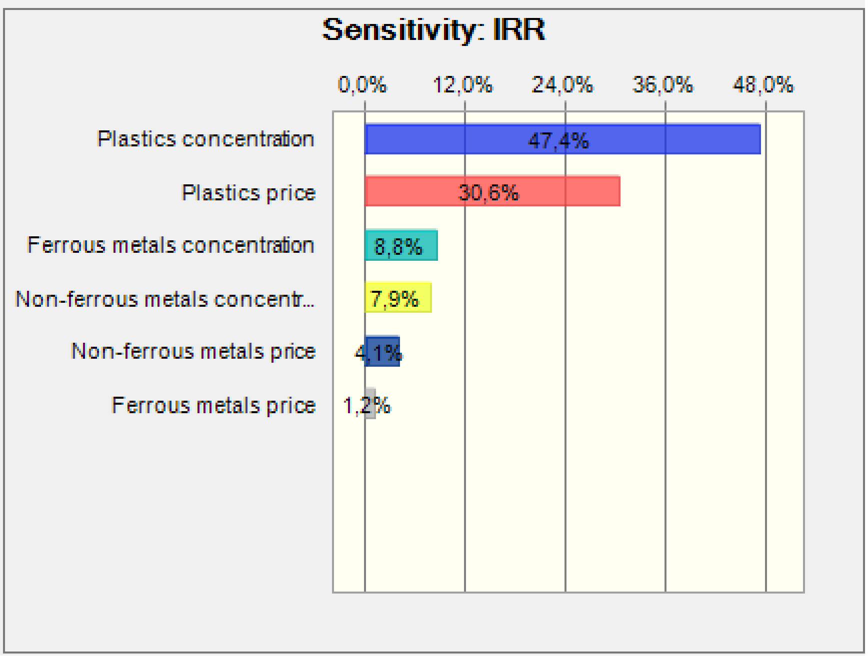



**Figure 24:** Sensitivity chart of IRR–Scenario 2B2

## 5.3. Financial analysis of Scenario 3

### 5.3.1. Deterministic analysis

This scenario involves the implementation of LFM process in a typical Greek landfill by taking into account the recovery of WEEE contained in the municipal waste stream. Scenario 3 involves three different sub-scenarios with respect to the recovered WEEE, as follows:

- Scenario 3A. WEEE devices are separated and, then, are sold "as is" without further treatment (Separation scenario).
- Scenario 3B. WEEE devices are separated and, are dismantled (IT and small electrical devices) in order to recover PCBs. In that case PCBs are sold without further processing at a different price compared to that of the rest WEEE quantities (PCB recovery scenario).
- Scenario 3C. WEEE devices are separated and are dismantled (IT and small electrical devices) in order to recover PCBs. Then, PCBs undergo a specific treatment in order to acquire the desirable size and separate metals and plastic particles. The latter are finally processed using froth flotation to recover valuable metals (Beneficiation scenario)

It is noted that in all scenarios examined, the excavation and processing works, as well as the dismantling of WEEE devices are conducted using own resources. In regards to the size reduction and the froth flotation of the fine PCBs pulverized material a total cost per unit is considered, based on actual costs incurred and direct communications with experts in the field.

*3A. Separation scenario*

The revenues gained under this scenario (including avoided costs) are about €640,000 per year, or roughly increased by €25,000 as compared to Scenario 2B1, where the WEEE material have not been taken into account. The projected cash flows are given in Table 40.

Using a real discount rate of 6%, the NPV of the project is estimated at about *€91.000* € or improved at around €110,000 when compared to the 2B1 scenario ($NPV_{2B1}$: *€-18,500)*. The IRR of this scenario is estimated at *7.6%.*

The total operating cost is approximately €22.3 per tn of waste and the benefits €32.9 per tn of waste, respectively. In present value terms, the LFM operations result in a net profit of around €0.5 per tn of waste. Details about the breakdown of benefits and costs on a per tn of waste basis are provided in the following Tables 41 and 42, respectively.

**Table 40** - Projected cash flows–Scenario 3A

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 1,160,000 | | | |
| Waste processed | | 19,500 | 19,500 | 19,500 |
| Revenues | | *640,919* | *640,919* | *670,919* |
| *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* |
| *- WEEE* | | *21,060* | *21,060* | *21,060* |
| *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 | | 191,023 | 191,023 | 221,023 |
| Depreciation | | 113,000 | 113,000 | 113,000 |
| Earnings before taxes (EBT) | | 78,023 | 78,023 | 108,023 |
| Taxes (29%) | | 22,627 | 22,627 | 31,327 |
| NOPAT | | 55,396 | 55,396 | 76,696 |
| Cash flow | -1,160,000 | 168,396 | 168,396 | 189,696 |

**Table 41** - Benefits breakdown–Scenario 3A

| **Category** | **Benefits (€/tn)** | **Percentage (% of total)** |
|---|---|---|
| Ferrous metals | 2.88 | 8.8% |
| Non-ferrous metals | 3.15 | 9.6% |
| Glass | 0.30 | 0.9% |
| Plastics | 6.80 | 20.7% |
| WEEE | 1.08 | 3.3% |
| Landfill cover material | 0.67 | 2.0% |
| ***Subtotal 1*** | ***14.9*** | ***45.2*** |
| Recovered air-space | 18.0 | 54.8 |
| **Total** | **32.9** | **100.0** |

**Table 42** - Cost breakdown–Scenario 3A

| 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** |

*3B. PCB recovery scenario*

The revenues gained under this scenario (including avoided costs) are about €644,000 per year, marginally increased as compared to Scenario 3A, where the WEEE were sold without any further processing. The projected cash flows are given in Table 43.

**Table 43** - Projected cash flows –Scenario 3B

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 1,160,000 | | | |
| Waste processed | | 19,500 | 19,500 | 19,500 |
| Revenues | | *644,078* | *644,078* | *674,078* |
| *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* |
| *- WEEE* | | *24,219* | *24,219* | *24,219* |
| *Avoidance of landfill cover material* | | *12,971* | *12,971* | *12,971* |
| Operating costs | | *457,794* | *457,794* | *457,794* |
| *Labour costs* | | | | |
| *- Skilled* | | *154,000* | *154,000* | *154,000* |
| *- Unskilled* | | *112,000* | *112,000* | *112,000* |
| *- WEEE processing* | | *7,898* | *7,898* | *7,898* |
| *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 | | 186,284 | 186,284 | 216,284 |
| Depreciation | | 113,000 | 113,000 | 113,000 |
| Earnings before taxes (EBT) | | 73,284 | 73,284 | 103,284 |
| Taxes (29%) | | 21,252 | 21,252 | 29,952 |
| NOPAT | | 52,032 | 52,032 | 73,332 |
| Cash flow | -1,160,000 | 165,032 | 165,032 | 186,332 |

Using a real discount rate of *6%*, the NPV of the project is estimated at about *€66,500*, almost *€25,000* lower when compared with Scenario 3A. This is mainly attributed to the increased processing cost of WEEE, which cannot be offset by the higher attained selling prices. The IRR of this scenario is estimated at *7.2%.*

The total operating cost is approximately €22.7 per tn of waste and the benefits €33.0 per tn of waste, respectively. In present value terms, the LFM operations result in a benefit of around €0.35 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 44 and 45.

**Table 44** - Cost breakdown–Scenario 3B

| Category | Cost (€/tn) | Percentage (% of total) |
|---|---|---|
| Ownership costs | 8.1 | 25.6 |
| Operating costs | 22.7 | 72.0 |
| Administrative costs | 0.8 | 2.4 |
| **Total** | **31.6** | **100.0** |

**Table 45** - Benefits breakdown–Scenario 3B

| Category | Benefits (€/tn) | Percentage (% of total) |
|---|---|---|
| Ferrous metals | 2.88 | 8.7% |
| Non-ferrous metals | 3.15 | 9.5% |
| Glass | 0.30 | 0.9% |
| Plastics | 6.80 | 20.5% |
| WEEE | 1.24 | 3.8% |
| Landfill cover material | 0.67 | 2.0% |
| ***Subtotal 1*** | ***15.0*** | ***45.5*** |
| Recovered air-space | 18.0 | 54.5 |
| **Total** | **33.0** | **100.0** |

*3C. Beneficiation scenario*

The revenues gained under this scenario (including avoided costs) are about €646,000 per year, almost the same as scenario 3B, in which the PCB's were separated from the WEEE materials and sold separately without any further treatment. The projected cash flows are given in Table 46.

Using a real discount rate of *6%*, the NPV of the project is estimated at about *€72,000*, almost *€20,000* lower when compared with Scenario 3A, but *€6,000* higher than scenario 3B. The IRR of this scenario is estimated at *7.3%.*

**Table 46** - Projected cash flows –Scenario 3C

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 1,160,000 | | | |
| Waste processed | | 19,500 | 19,500 | 19,500 |
| Revenues | | *645,895* | *645,895* | *675,895* |
| *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* |
| *- WEEE* | | *26,035* | *26,035* | *26,035* |
| *Avoidance of landfill cover material* | | *12,971* | *12,971* | *12,971* |
| Operating costs | | *458,584* | *458,584* | *458,584* |
| *Labour costs* | | | | |
| *- Skilled* | | *154,000* | *154,000* | *154,000* |
| *- Unskilled* | | *112,000* | *112,000* | *112,000* |
| *- WEEE processing* | | *8,687* | *8,687* | *8,687* |
| *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 | | 187,311 | 187,311 | 217,311 |
| Depreciation | | 113,000 | 113,000 | 113,000 |
| Earnings before taxes (EBT) | | 74,311 | 74,311 | 104,311 |
| Taxes (29%) | | 21,550 | 21,550 | 30,250 |
| NOPAT | | 52,761 | 52,761 | 74,061 |
| Cash flow | -1,160,000 | 165,761 | 165,761 | 187,061 |

The total operating cost is approximately €22.7 per tn of waste and the benefits €33.1 per tn of waste, respectively. In present value terms, the LFM operations result in a benefit of around €0.37 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 47 and 48.

**Table 47** - Cost breakdown–Scenario 3C

| **Category** | **Cost (€/tn)** | **Percentage (% of total)** |
|---|---|---|
| Ownership costs | 8.1 | 25.6 |
| Operating costs | 22.7 | 72.0 |
| Administrative costs | 0.8 | 2.4 |
| **Total** | **31.6** | **100.0** |

**Table 48** - Benefits breakdown–Scenario 3C

| Category | Benefits (€/tn) | Percentage (% of total) |
|---|---|---|
| Ferrous metals | 2.88 | 8.7% |
| Non-ferrous metals | 3.15 | 9.5% |
| Glass | 0.30 | 0.9% |
| Plastics | 6.80 | 20.5% |
| WEEE | 1.34 | 4.0% |
| Landfill cover material | 0.67 | 2.0% |
| ***Subtotal 1*** | ***15.1*** | ***45.7*** |
| Recovered air-space | 18.0 | 54.3 |
| **Total** | **33.1** | **100.0** |

### 5.3.2. Sensitivity analysis

*3A. Separation scenario*

The sensitivity analysis focused on the most critical technical and economic parameters relating to the uncertainty in the range of the estimates and their significance on the financial results. More specifically, the price of the recyclable materials and their composition were taken into consideration. The results of the sensitivity of NPV and IRR to a ±20 percent change are given in Tables 49 and 50 and are illustrated in Fig. 25 and 26.

According to the sensitivity analysis, the price of plastics and their content are the most significant factors influencing the NPV and IRR results of the project. Furthermore, the project is deemed acceptable from a financial point of view (i.e. NPV>0 and IRR>discount factor) in all the analyzed range.

**Table 49** - NPV sensitivity analysis results (Euros) –Scenario 3A

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 389,056 | 485,963 | 582,871 | 679,778 | 776,685 |
| Non-ferrous metals price | 487,245 | 535,058 | 582,871 | 630,684 | 678,496 |
| Ferrous metals price | 514,138 | 548,504 | 582,871 | 617,237 | 651,604 |
| WEEE price | 559,346 | 571,108 | 582,871 | 594,633 | 606,396 |
| Plastics concentration | 389,056 | 485,963 | 582,871 | 679,778 | 776,685 |
| Non-ferrous metals concentration | 487,245 | 535,058 | 582,871 | 630,684 | 678,496 |
| Ferrous metals concentration | 514,138 | 548,504 | 582,871 | 617,237 | 651,604 |
| WEEE concentration | 559,346 | 571,108 | 582,871 | 594,633 | 606,396 |

**Table 50** - IRR sensitivity analysis results (%)–Scenario 3A

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 12.6% | 14.1% | 15.6% | 17.0% | 18.5% |
| Non-ferrous metals price | 14.1% | 14.8% | 15.6% | 16.3% | 17.0% |
| Ferrous metals price | 14.5% | 15.0% | 15.6% | 16.1% | 16.6% |
| WEEE price | 15.2% | 15.4% | 15.6% | 15.8% | 15.9% |
| Plastics concentration | 12.6% | 14.1% | 15.6% | 17.0% | 18.5% |
| Non-ferrous metals concentration | 14.1% | 14.8% | 15.6% | 16.3% | 17.0% |
| Ferrous metals concentration | 14.5% | 15.0% | 15.6% | 16.1% | 16.6% |
| WEEE concentration | 15.2% | 15.4% | 15.6% | 15.8% | 15.9% |

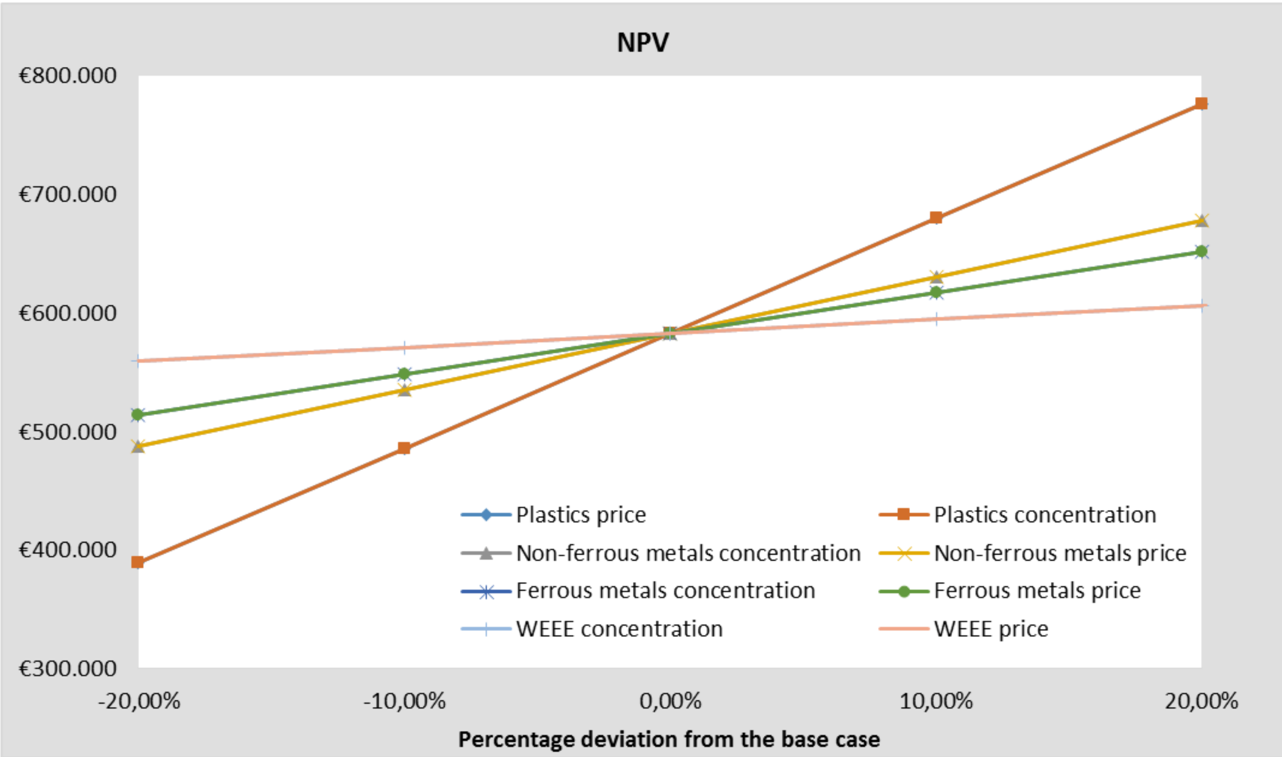



**Figure 25:** NPV sensitivity analysis–Scenario 3A

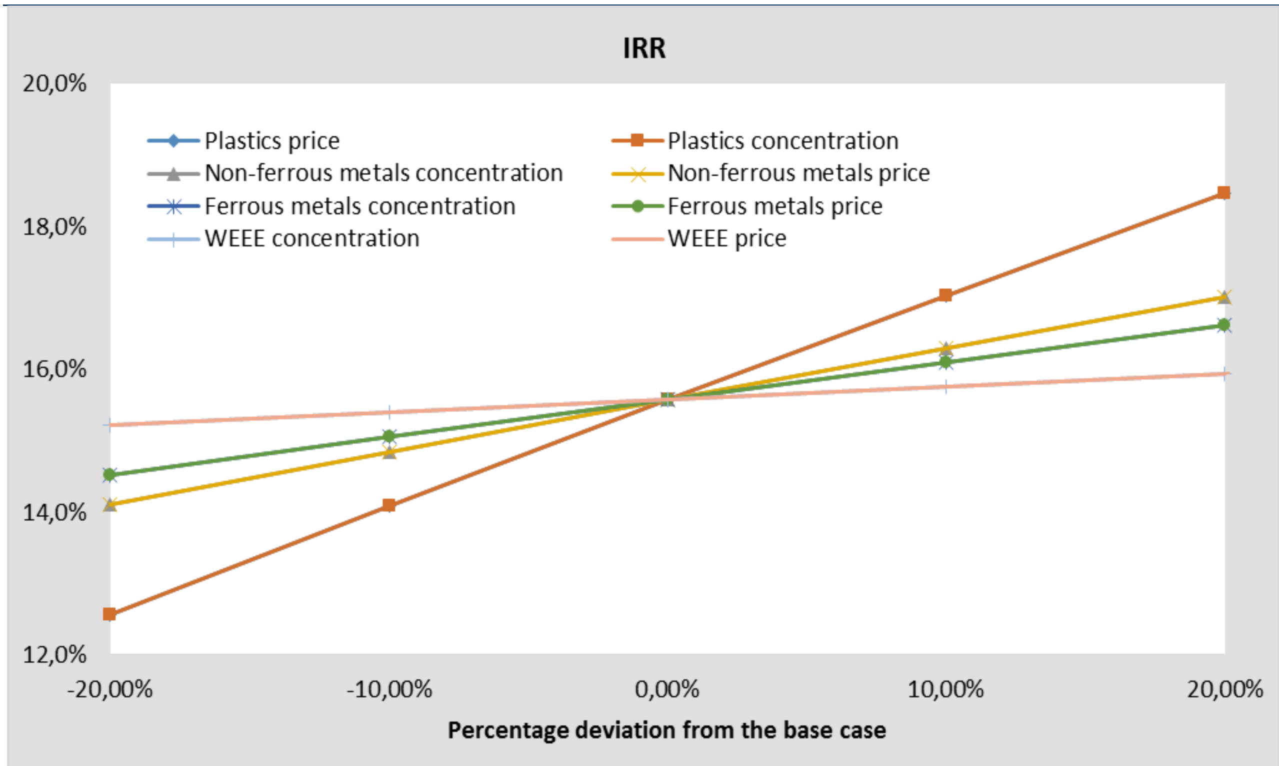



**Figure 26:** IRR sensitivity analysis–Scenario 3A

<u>*3B. PCB recovery scenario*</u>

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. More specifically, the price of the recyclable materials (ferrous and non-ferrous metals and plastics) and the composition of the waste were taken into consideration. The results of the sensitivity of NPV and IRR to a ±20 percent change are given in Tables 51 and 52; they are also illustrated in Fig. 27 and 28.

**Table 51** - NPV sensitivity analysis results (Euros) –Scenario 3B

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 370,338 | 467,245 | 564,153 | 661,060 | 757,967 |
| Non-ferrous metals price | 468,527 | 516,340 | 564,153 | 611,966 | 659,778 |
| Ferrous metals price | 495,420 | 529,786 | 564,153 | 598,519 | 632,886 |
| WEEE price (bulk) | 540,628 | 552,390 | 564,153 | 575,915 | 587,678 |
| WEEE price (PCBs) | 559,642 | 561,898 | 564,153 | 566,408 | 568,663 |
| Plastics concentration | 370,338 | 467,245 | 564,153 | 661,060 | 757,967 |
| Non-ferrous metals concentration | 468,527 | 516,340 | 564,153 | 611,966 | 659,778 |
| Ferrous metals concentration | 495,420 | 529,786 | 564,153 | 598,519 | 632,886 |
| WEEE concentration | 536,117 | 550,135 | 564,153 | 578,170 | 592,188 |

**Table 52** - IRR sensitivity analysis results (%)–Scenario 3B

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 12.3% | 13.8% | 15.3% | 16.8% | 18.2% |
| Non-ferrous metals price | 13.8% | 14.6% | 15.3% | 16.0% | 16.7% |
| Ferrous metals price | 14.2% | 14.8% | 15.3% | 15.8% | 16.3% |
| WEEE price (bulk) | 14.9% | 15.1% | 15.3% | 15.5% | 15.6% |
| WEEE price (PCBs) | 15.2% | 15.3% | 15.3% | 15.3% | 15.4% |
| Plastics concentration | 12.3% | 13.8% | 15.3% | 16.8% | 18.2% |
| Non-ferrous metals concentration | 13.8% | 14.6% | 15.3% | 16.0% | 16.7% |
| Ferrous metals concentration | 14.2% | 14.8% | 15.3% | 15.8% | 16.3% |
| WEEE concentration | 14.9% | 15.1% | 15.3% | 15.5% | 15.7% |

According to the sensitivity analysis, the price of plastics and their content are the most significant factors influencing the NPV and IRR results of the project. Furthermore, the project is deemed acceptable from a financial point of view (i.e. NPV>0 and IRR>discount factor) in all the analyzed range.

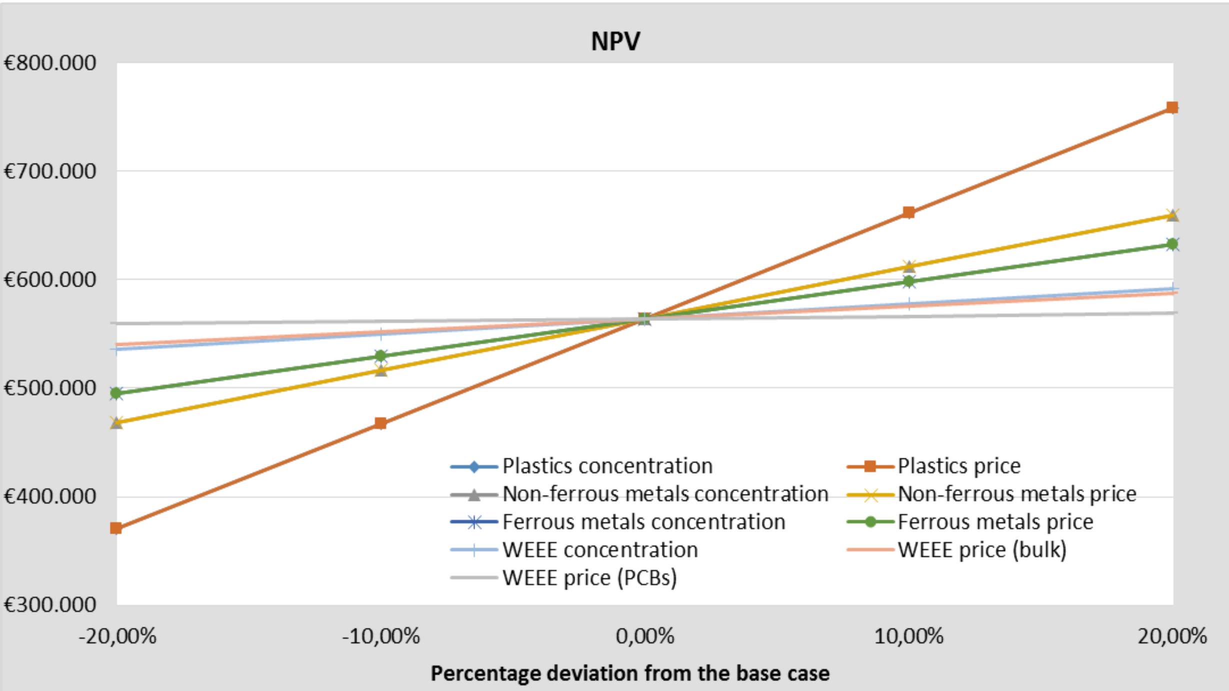



**Figure 27:** NPV sensitivity analysis–Scenario 3B

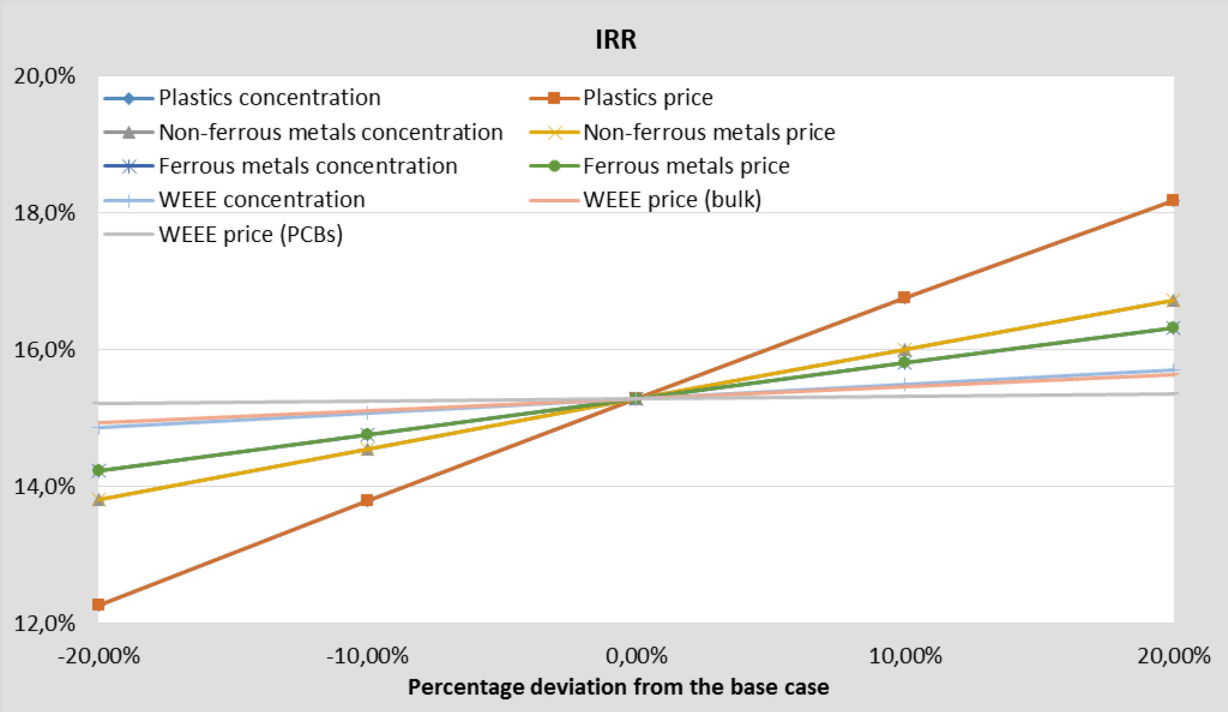



**Figure 28:** IRR sensitivity analysis–Scenario 3B

*<u>3C. Beneficiation scenario</u>*

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. More specifically, the price of the recyclable materials (ferrous and non-ferrous metals and plastics) and the composition of the waste were taken into consideration. The results of the sensitivity of NPV and IRR to a ±20 percent change are given in Tables 53 and 54 and are also illustrated in Fig. 29 and 30.

**Table 53** - NPV sensitivity analysis results (Euros) –Scenario 3C

| | **-20%** | **-10%** | **0%** | **10%** | **20%** |
|---|---|---|---|---|---|
| Plastics price | 373,559 | 470,467 | 567,374 | 664,281 | 761,189 |
| Non-ferrous metals price | 471,748 | 519,561 | 567,374 | 615,187 | 663,000 |
| Ferrous metals price | 498,641 | 533,008 | 567,374 | 601,740 | 636,107 |
| WEEE price (bulk) | 543,849 | 555,611 | 567,374 | 579,137 | 590,899 |
| WEEE price (concentrate) | 561,394 | 564,384 | 567,374 | 570,364 | 573,354 |
| Plastics concentration | 373,559 | 470,467 | 567,374 | 664,281 | 761,189 |
| Non-ferrous metals concentration | 471,748 | 519,561 | 567,374 | 615,187 | 663,000 |
| Ferrous metals concentration | 498,641 | 533,008 | 567,374 | 601,740 | 636,107 |
| WEEE concentration | 537,869 | 552,621 | 567,374 | 582,127 | 596,879 |

**Table 54** - IRR sensitivity analysis results (%)–Scenario 3C

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | 12.3% | 13.8% | 15.3% | 16.8% | 18.2% |
| Non-ferrous metals price | 13.9% | 14.6% | 15.3% | 16.1% | 16.8% |
| Ferrous metals price | 14.3% | 14.8% | 15.3% | 15.9% | 16.4% |
| WEEE price (bulk) | 15.0% | 15.2% | 15.3% | 15.5% | 15.7% |
| WEEE price (concentrate) | 15.2% | 15.3% | 15.3% | 15.4% | 15.4% |
| Plastics concentration | 12.3% | 13.8% | 15.3% | 16.8% | 18.2% |
| Non-ferrous metals concentration | 13.9% | 14.6% | 15.3% | 16.1% | 16.8% |
| Ferrous metals concentration | 14.3% | 14.8% | 15.3% | 15.9% | 16.4% |
| WEEE concentration | 14.9% | 15.1% | 15.3% | 15.6% | 15.8% |

According to the sensitivity analysis, the price of plastics and their content are the most significant factors influencing the NPV and IRR results of the project. Furthermore, the project is deemed acceptable from a financial point of view (i.e. NPV>0 and IRR>discount factor) in all the analyzed range.

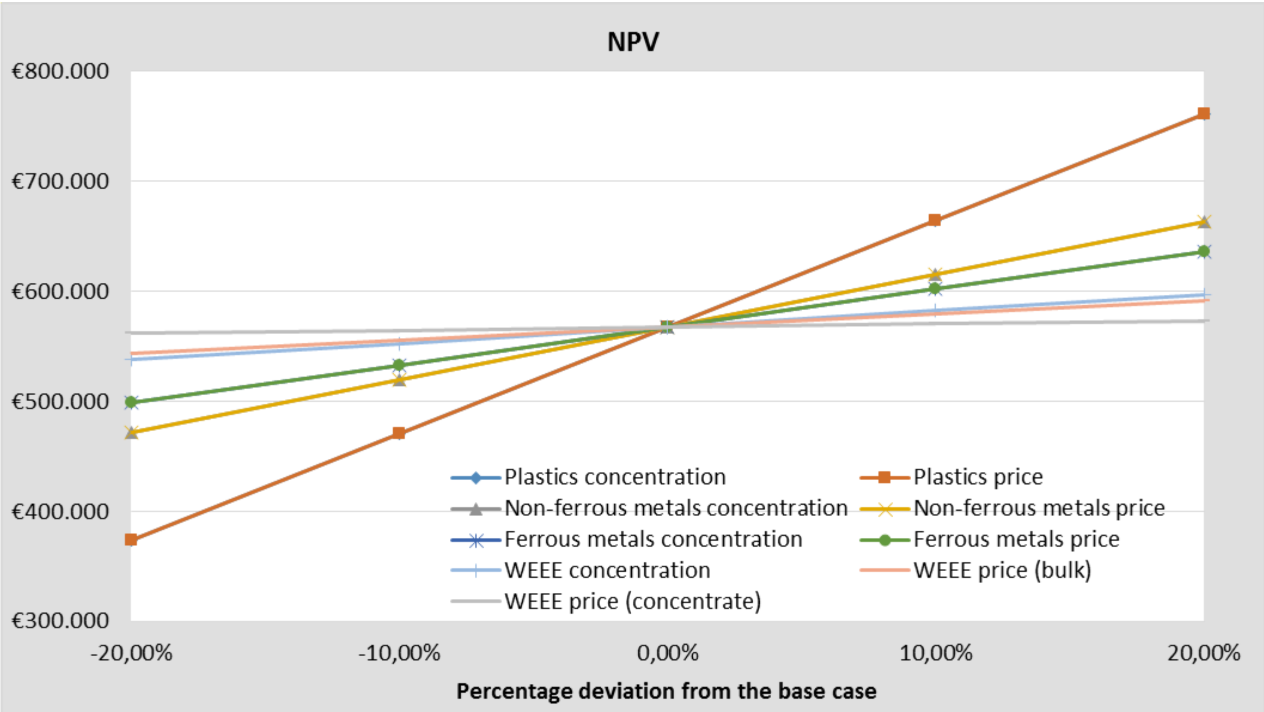



**Figure 29:** NPV sensitivity analysis–Scenario 3C

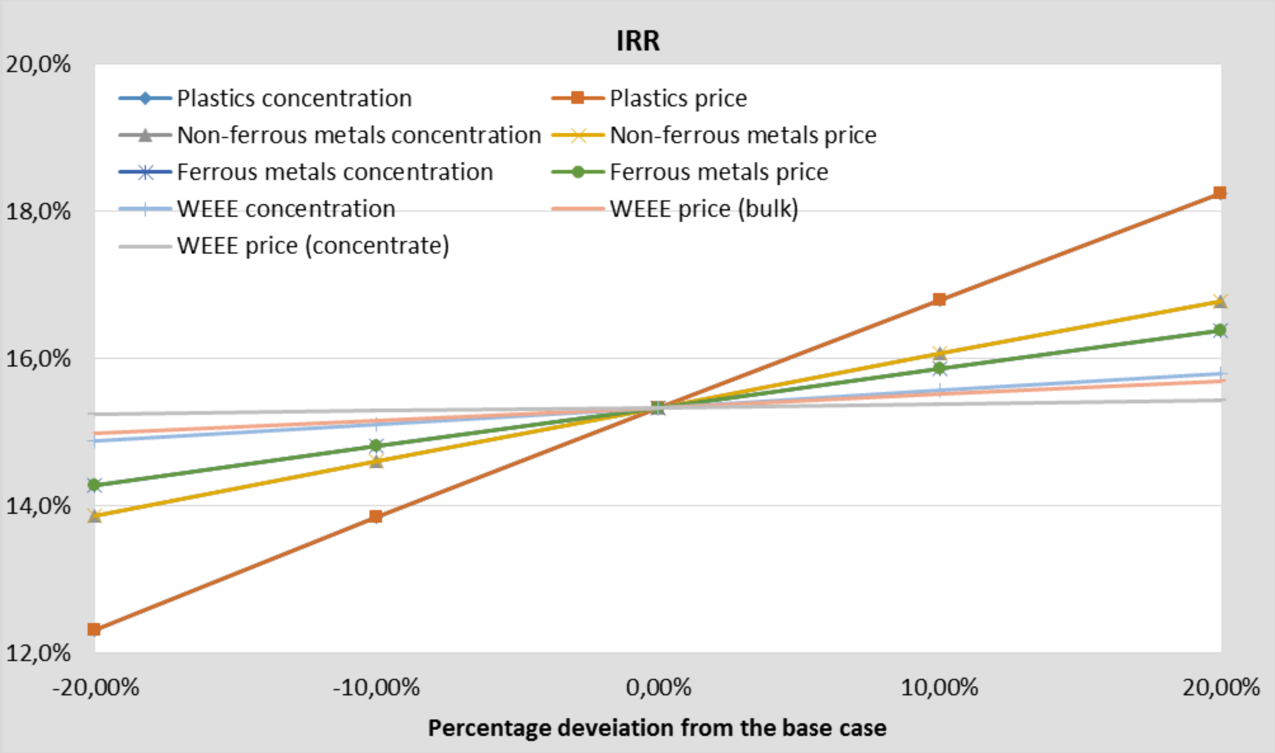



**Figure 30:** IRR sensitivity analysis–Scenario 3C

### 5.3.3. Stochastic analysis

The parameters involved were 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 following assumptions were used:

- Price of ferrous metals (€/tn): min=60, most likely=80, max=110
- Price of non-ferrous metals - aluminium (€/tn): min=600, most likely=700, max=1000
- Price of plastics (€/tn): min=100, most likely=200, max=300
- Price of WEEE (bulk) (€/tn): min=70, most likely=80, max=110
- Price of WEEE (PCBs) (€/tn): min=400, most likely=400, max=900
- Price of WEEE (concentrate) (€/tn): min=500, most likely=630, max=1,100
- Concentration of ferrous metals (%): min=1.8, most likely=3.6, max=7.2

- Concentration of non-ferrous metals - aluminium (%): min=0.3, most likely=0.5, max=0.9
- Concentration of plastics (%): min=3.0, most likely=3.4, max=8.5
- Concentration of WEEE (%): min=0.9, most likely=1.35, max=1.8

_3A. Separation scenario_

The expected NPV is around €660,000. The minimum expected value is about €-140,000 and the maximum value is €1,990,000. The probability of having a positive NPV value and thus accepting the project is estimated at 98.5%. The expected IRR attained under this scenario is 16.6%. The minimum expected value is around 3.5%, while the maximum value is around 35%. The results of the simulation for the specific sub-scenario are given in the following tables and figures.

**Table 55** - Monte Carlo simulation statistics–Scenario 3A

| Variable | NPV (€) | IRR (%) |
|---|---|---|
| Mean | 663,834 | 16.6 |
| Median | 612,782 | 16.0 |
| Standard Deviation | 376,510 | 5.6 |
| Minimum | -141,612 | 3.4 |
| Maximum | 1,986,729 | 34.9 |
| Mean Std. Error | 11,906 | 0.2 |

**Table 56** - Monte Carlo simulation percentiles–Scenario 3A

| Percentage | NPV (€) | IRR (%) |
|---|---|---|
| 100% | -141,612) | 3.4 |
| 90% | 215,254 | 9.7 |
| 80% | 333,822 | 11.7 |
| 70% | 438,557 | 13.3 |
| 60% | 520,497 | 14.6 |
| 50% | 612,728 | 16.0 |
| 40% | 713,706 | 17.5 |
| 30% | 828,055 | 19.2 |
| 20% | 970,631 | 21.3 |
| 10% | 1,179,120 | 24.2 |
| 0% | 1,986,729 | 34.9 |

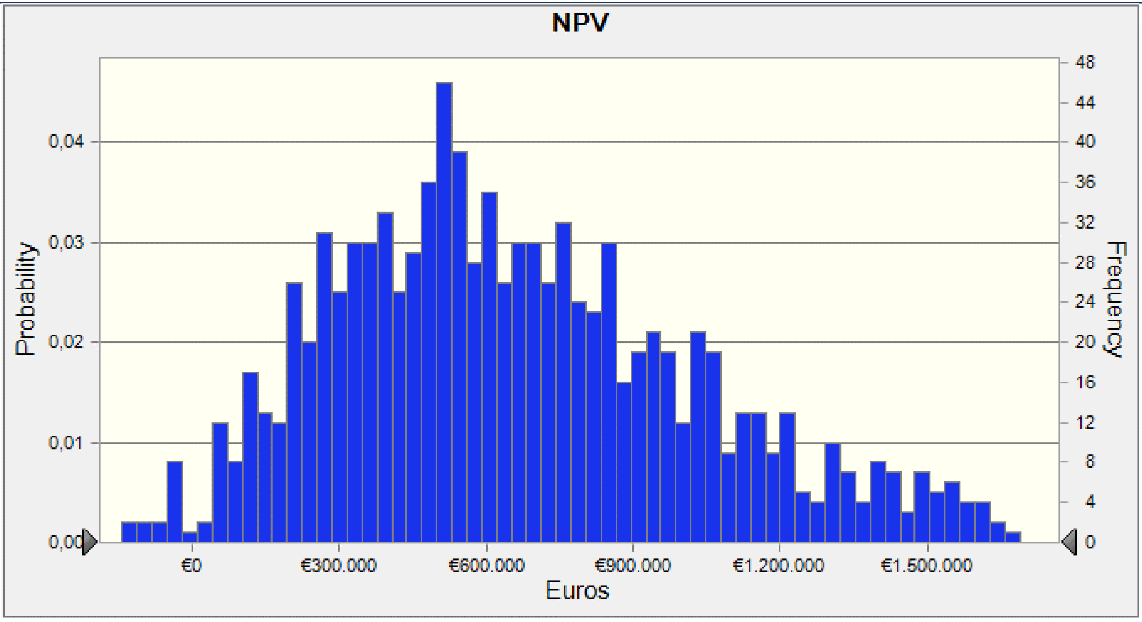



**Figure 31:** Histogram of NPV distribution–Scenario 3A

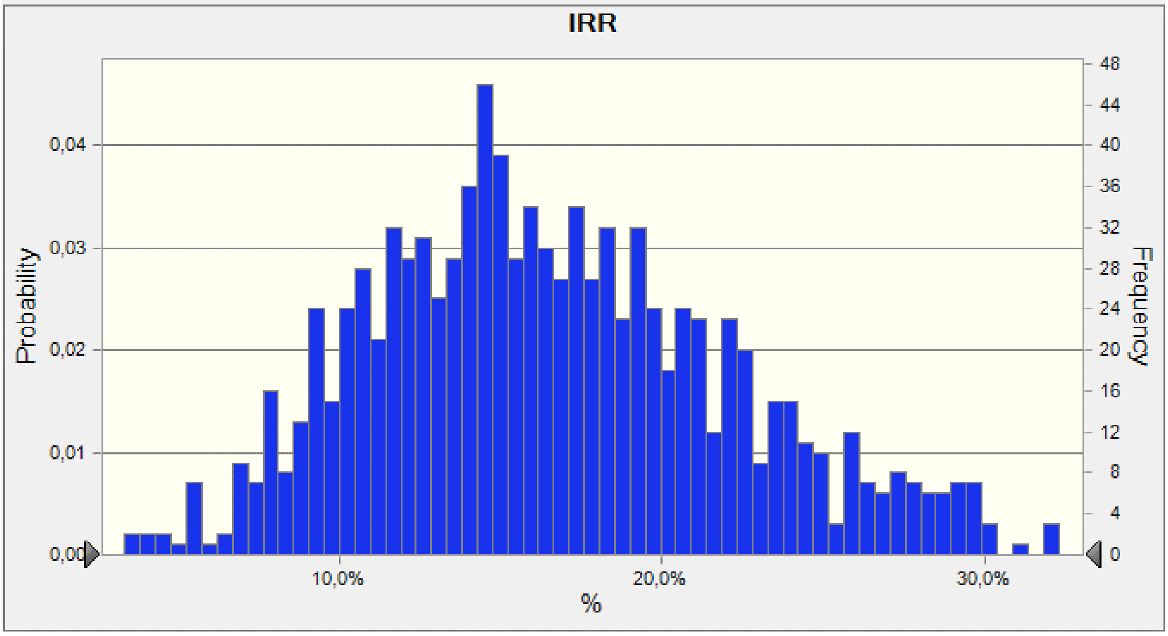



**Figure 32:** Histogram of IRR distribution–Scenario 3A

Furthermore, according to the sensitivity charts (Fig. 33 & 34), the value of the project is affected to a great extent by the concentration of the plastics as well as by the price of the plastics. The concentration and the price of ferrous and non-ferrous metals do not play a significantly role on the overall figures. As far as the WEEE concentration and price is concerned their effect practically insignificant to the overall results.

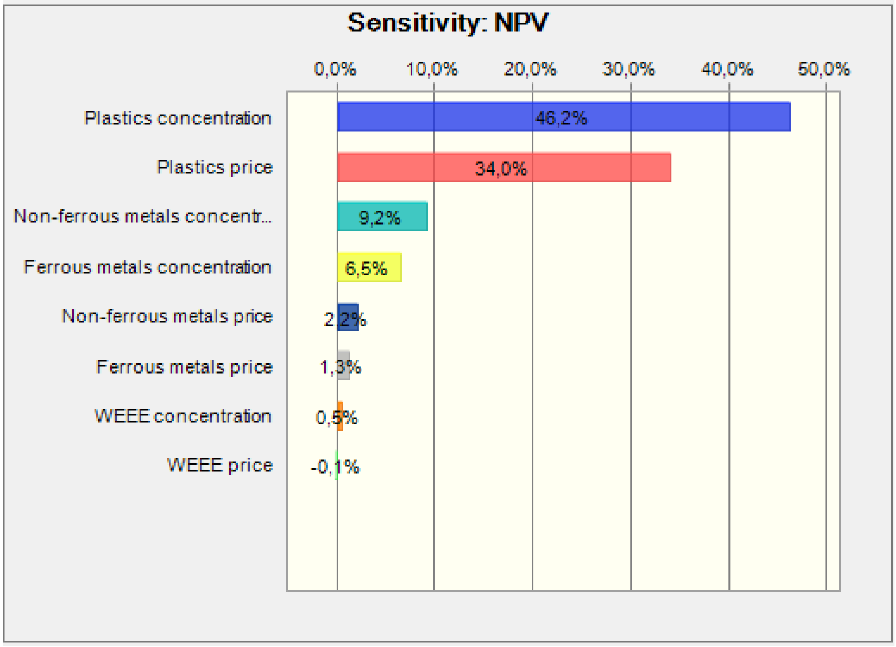



**Figure 33:** Sensitivity chart of NPV–Scenario 3A

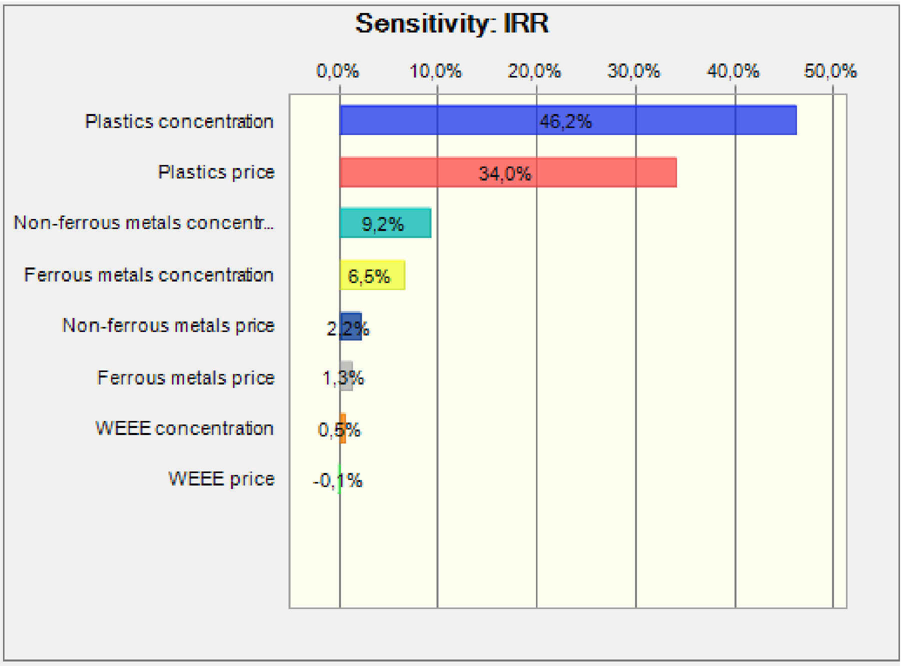



**Figure 34:** Sensitivity chart of IRR–Scenario 3A

*3B. PCB recovery scenario*

The results of the simulation for the specific sub-scenario are given in the following tables and figures.

**Table 57** - Monte Carlo simulation statistics–Scenario 3B

| Variable | NPV (€) | IRR (%) |
|---|---|---|
| Mean | 647,697 | 16.3 |
| Median | 593,003 | 15.7 |
| Standard Deviation | 381,533 | 5.7 |
| Minimum | -303,968 | 0.1 |
| Maximum | 2,239,961 | 38.0 |
| Mean Std. Error | 12,065 | 0.2 |

**Table 58** - Monte Carlo simulation percentiles–Scenario 3B

| Percentage | NPV (€) | IRR (%) |
|---|---|---|
| 100% | -303,968 | 0.1 |
| 90% | 192,888 | 9.4 |
| 80% | 323,675 | 11.5 |
| 70% | 408,166 | 12.9 |
| 60% | 498,334 | 14.3 |
| 50% | 592,826 | 15.7 |
| 40% | 709,171 | 17.5 |
| 30% | 837,097 | 19.3 |
| 20% | 977,246 | 21.4 |
| 10% | 1,164,713 | 24.0 |
| 0% | 2,239,961 | 38.1 |

The expected NPV is around €650,000. The minimum expected value is about €-244,000 and the maximum value is €2,045,000. The probability of having a positive NPV value and thus accepting the project is estimated at 98%. The expected IRR attained under this scenario is 16.3%. The minimum expected value is around 0.1%, while the maximum value is around 38%. The histograms of the NPV and the IRR distributions are given in Figs. 35 and 36.

Furthermore, according to the sensitivity charts (Fig. 37 & 38), the value of the project is affected to a great extend by the concentration of the plastics and to lesser one by the price of the plastics. The concentration and the price of ferrous and non-ferrous metals do not play a significantly role on the overall figures. As far as the WEEE concentration and price (bulk or PCBs) is concerned their effect practically insignificant to the overall results.

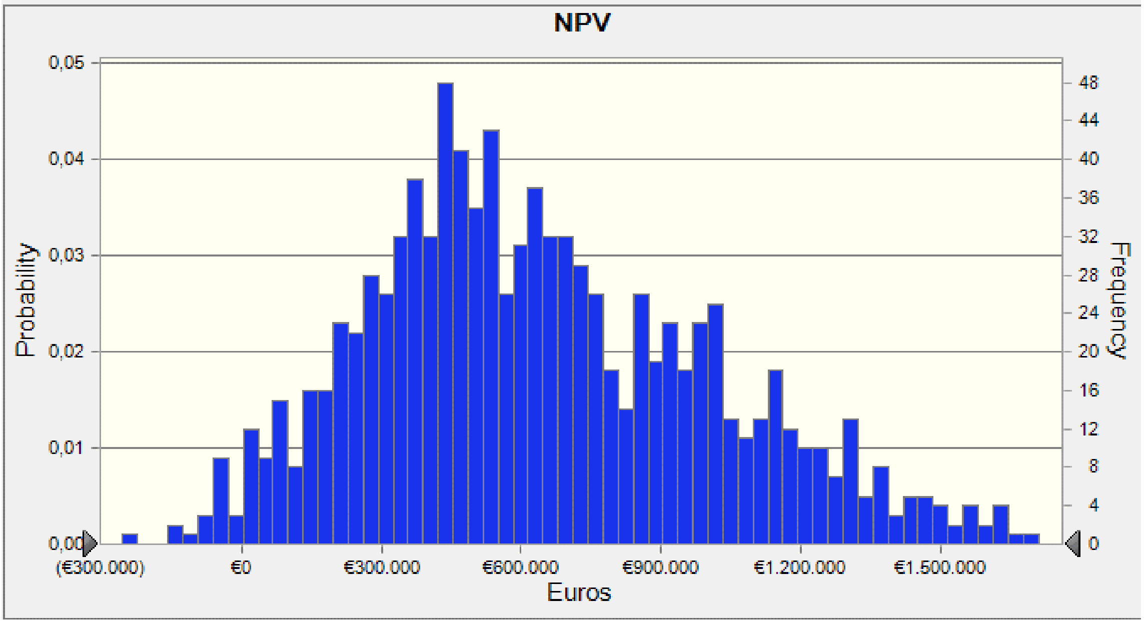



**Figure 35:** Histogram of NPV distribution–Scenario 3B

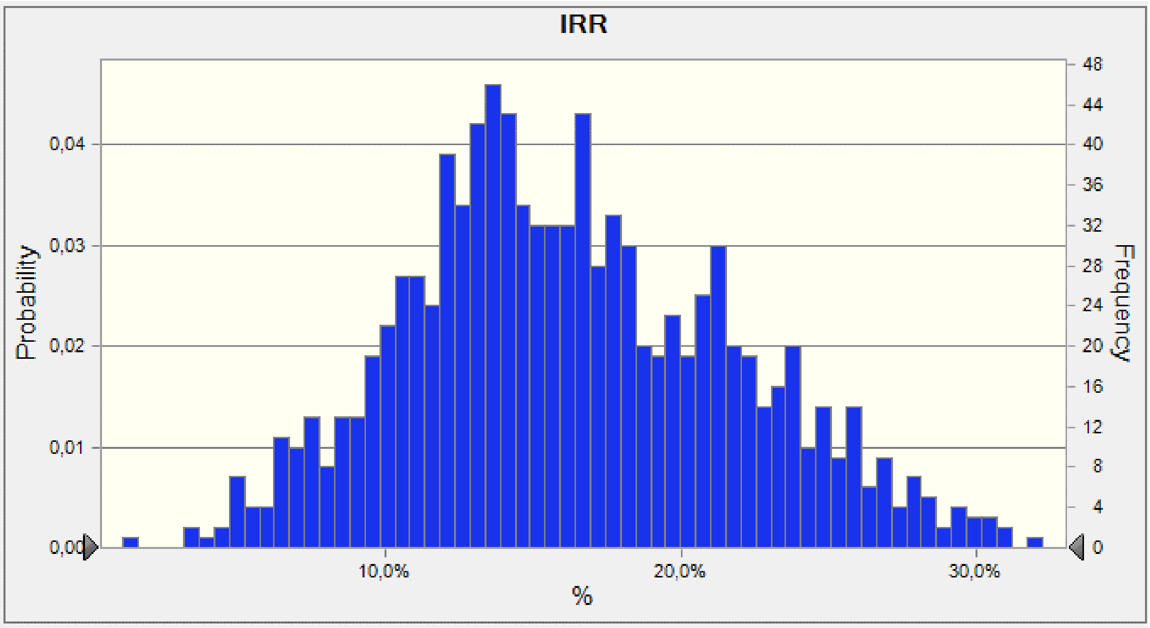



**Figure 36:** Histogram of IRR distribution–Scenario 3B

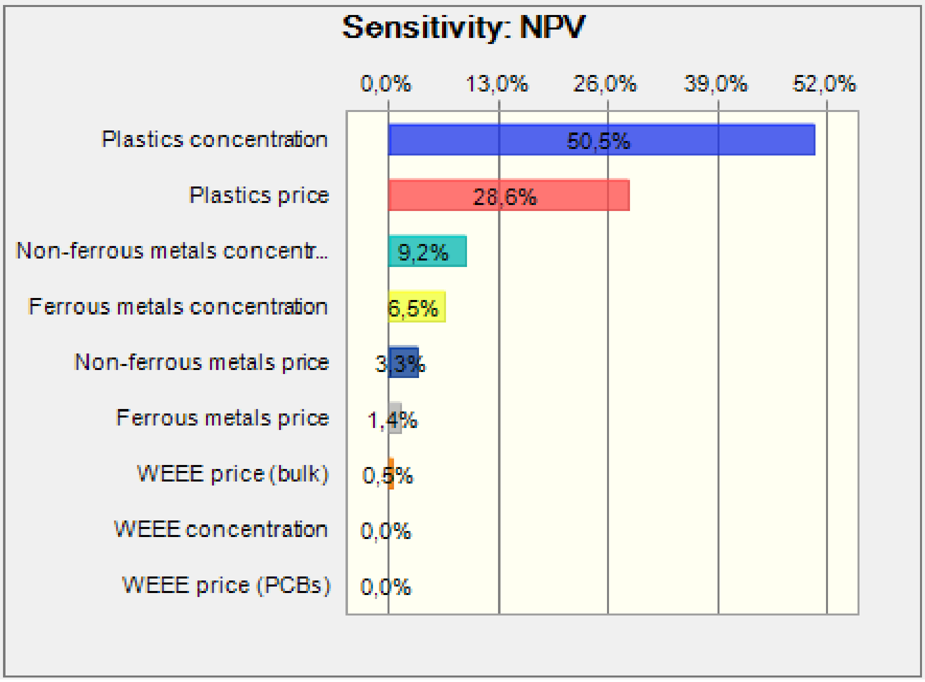



**Figure 37:** Sensitivity chart of NPV–Scenario 3B

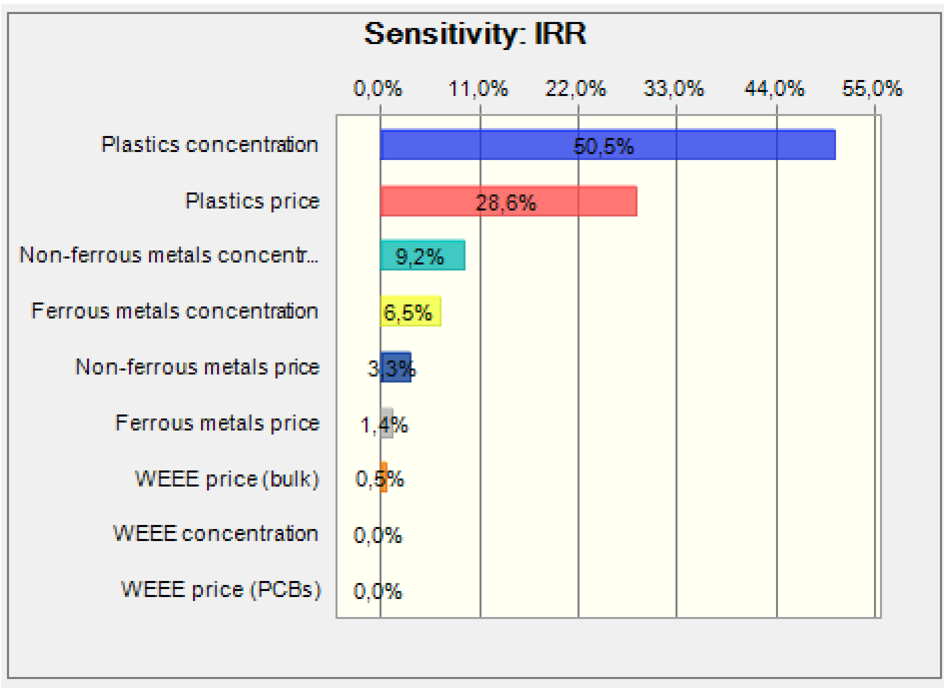



**Figure 38:** Sensitivity chart of IRR–Scenario 3B

*3C. Beneficiation scenario*

The results of the simulation for the specific sub-scenario are given in the following tables and figures.

**Table 59** - Monte Carlo simulation statistics–Scenario 2B1

| Variable | NPV (€) | IRR (%) |
|---|---|---|
| Mean | 647,608 | 16.3 |
| Median | 614,585 | 16.1 |
| Standard Deviation | 375,175 | 5.6 |
| Minimum | -281,406 | 0.6 |
| Maximum | 2,168,662 | 37.2 |
| Mean Std. Error | 11,864 | 0.2 |

**Table 60** - Monte Carlo simulation percentiles–Scenario 3C

| Percentage | NPV (€) | IRR (%) |
|---|---|---|
| 100% | -281,406 | 0.6 |
| 90% | 200,202 | 9.5 |
| 80% | 317,380 | 11.4 |
| 70% | 425,988 | 13.1 |
| 60% | 520,163 | 14.6 |
| 50% | 613,946 | 16.0 |
| 40% | 712,935 | 17.5 |
| 30% | 814,637 | 19.0 |
| 20% | 940,468 | 20.8 |
| 10% | 1,176,817 | 24.2 |
| 0% | 2,168,662 | 37.2 |

The expected NPV is around €650,000. The minimum expected value is about €-280,000 and the maximum value is €2,170,000. The probability of having a positive NPV value and thus accepting the project is estimated at 97.7%. The expected IRR attained under this scenario is 16.3%. The minimum expected value is around 0.5%, while the maximum value is around 37%.

Furthermore, according to the sensitivity charts (Fig. 41 & 42), the value of the project is affected to a great extend by the concentration of the plastics and to lesser one by the price of the plastics. The concentration and the price of ferrous and non-ferrous metals do not play a significantly role on the overall figures. As far as the WEEE concentration and price (bulk or concentrate) is concerned their effect practically insignificant to the overall results.

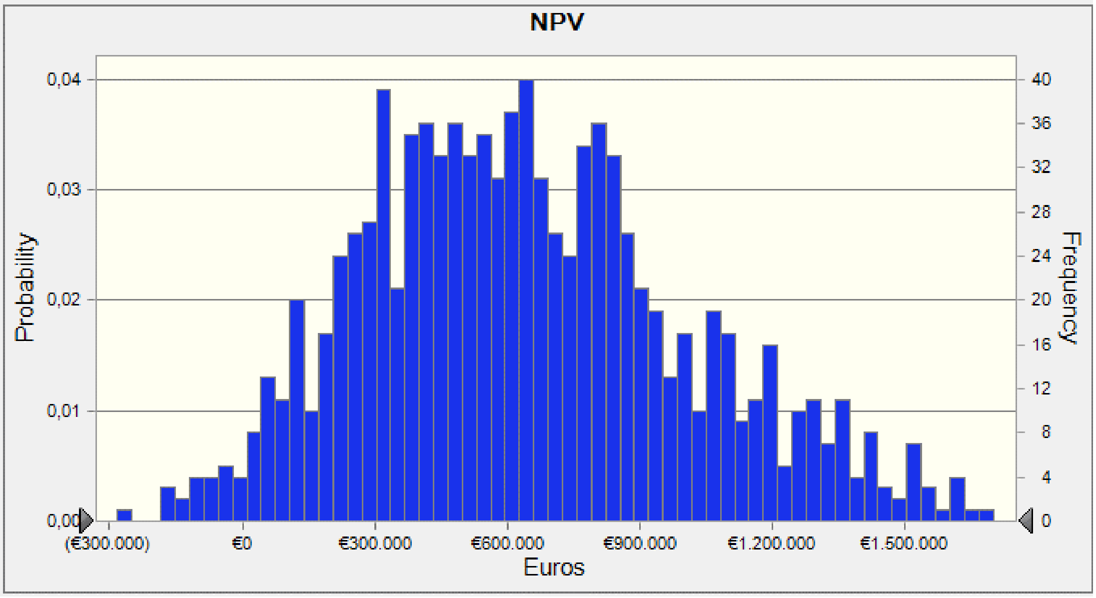



**Figure 39:** Histogram of NPV distribution–Scenario 3C

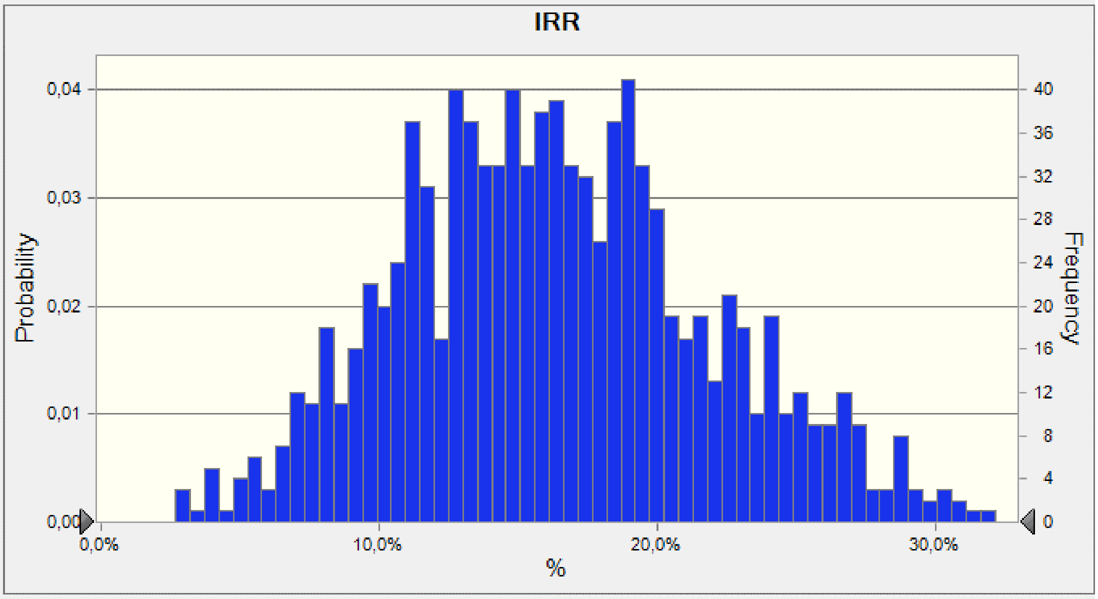



**Figure 40:** Histogram of IRR distribution–Scenario 3C

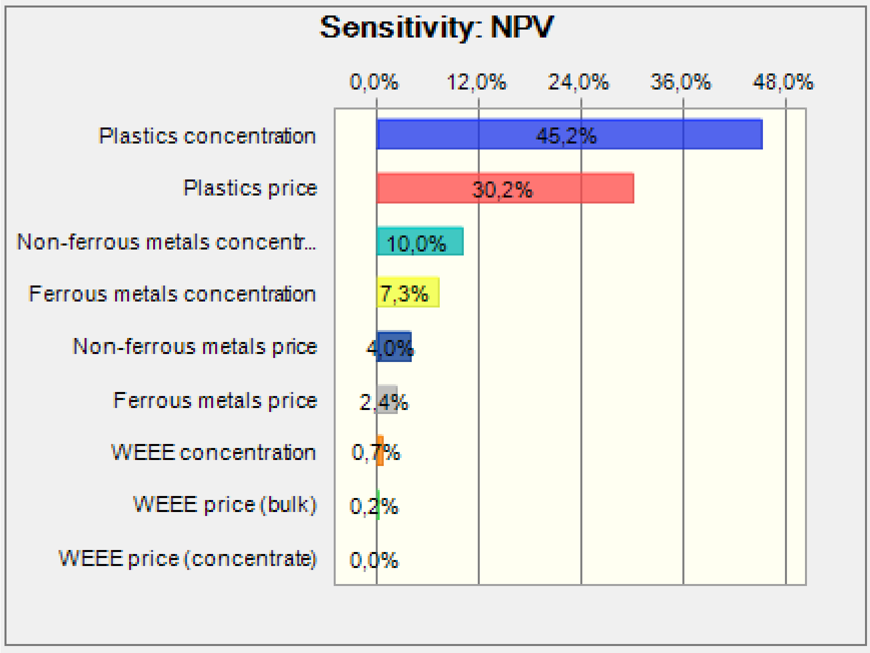



**Figure 41:** Sensitivity chart of NPV–Scenario 3C

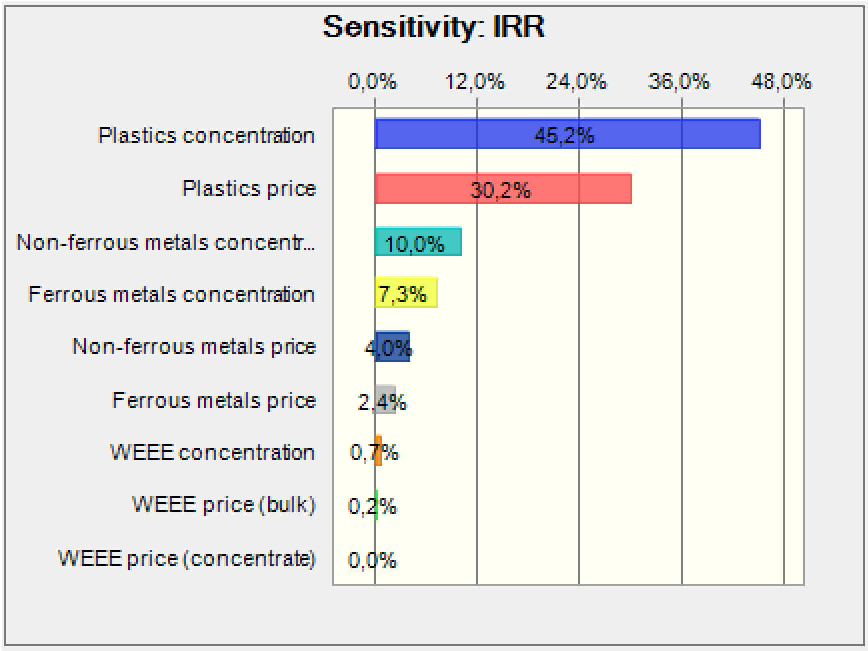



**Figure 42:** Sensitivity chart of IRR–Scenario 3C

# Chapter 6. SOCIAL COST BENEFIT ANALYSIS OF LFM OPERATIONS

## 6.1. Socioeconomic analysis of Scenario 1

### 6.1.1. Deterministic analysis

In order to estimate the social NPV and IRR of the "Polygyros" LFM project, the appropriate corrections were made, i.e. fiscal corrections, conversion of market prices to shadow prices and corrections for externalities. Given that the operating costs are mainly associated with the money paid to the subcontractors, it was assumed that the profit margin is around 30% and that the labour costs amount to 50% of the subcontractors' payment.

Finally, a social discount rate of 3.5% was adopted, which is lower than the proposed rate of 5% for Cohesion countries, since the project under evaluation is not a major one.

The projected social cash flows are given in Table 61.

**Table 61** - Projected social cash flows –Scenario 1

| | 0 | 1 | 2 |
|---|---|---|---|
| Capital costs | 15,000 | | |
| Total revenues | | 386,295 | 400,095 |
| Total costs | | 593,906 | 593,906 |
| Externalities | | 97,872 | 97,872 |
| Net Social Cash Flow | -15,000 | -109,739 | -95,939 |

The social NPV is estimated at about €-*210,000*. Furthermore, the LFM operations result in a net social loss of around €5.4 per tn of waste, in present value terms. Thus, the project is not justified from a social point of view.

### 6.1.2. Sensitivity analysis

Taking for granted, more or less, the market costs and benefits of the LFM project, a beak even sensitivity analysis was carried out to find the society's WTP (i.e. the external benefits of the project) that is required in order to achieve a zero NPV. According to the estimates, an average WTP per household equal to €26 per year is necessary (i.e. more than double than WTP estimated by the CV survey in the area).

Moreover, a sensitivity analysis by means of spider diagram was conducted in relation market and non-market costs and benefits. The results of the sensitivity of NPV to a ±20 percent change are given in Table 62 and are illustrated in Fig. 43.

**Table 62** - Social NPV sensitivity analysis results (Euros) –Scenario 1

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| Plastics price | -260,967 | -235,778 | -210,588 | -185,398 | -160,208 |
| Plastics concentration | -260,967 | -235,778 | -210,588 | -185,398 | -160,208 |
| WTP | -247,773 | -229,180 | -210,588 | -191,995 | -173,402 |
| Non-ferrous metals price | -224,988 | -217,788 | -210,588 | -203,387 | -196,187 |
| Non-ferrous metals concentration | -224,988 | -217,788 | -210,588 | -203,387 | -196,187 |
| Ferrous metals price | -216,938 | -213,763 | -210,588 | -207,412 | -204,237 |
| Ferrous metals concentration | -216,938 | -213,763 | -210,588 | -207,412 | -204,237 |

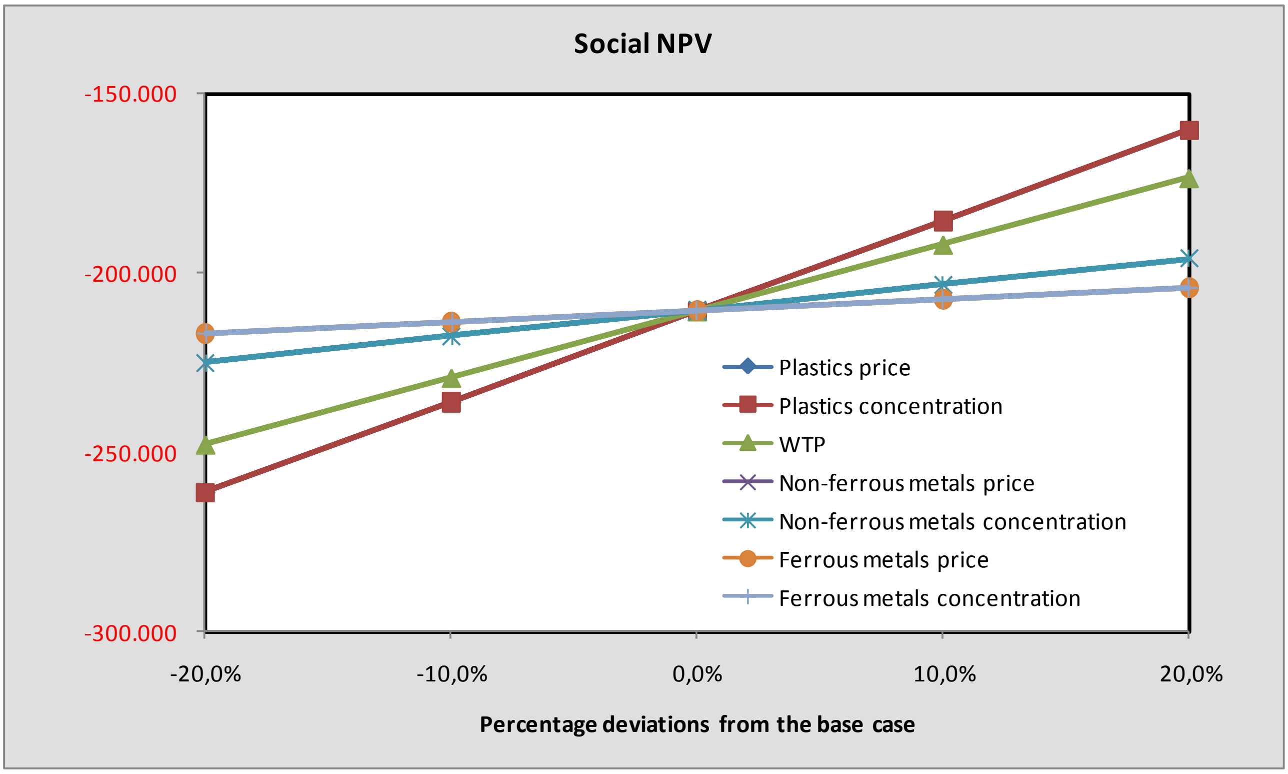



**Figure 43:** Social NPV sensitivity analysis–Scenario 1

According to the sensitivity analysis, the social NPV of the project is affected mainly by the price and the concentration of plastics, followed by the society's WTP for LFM programs. The project is rejected from a social point of view even in case that the prices or concentrations of recyclables, or WTP value increase by 20% on a ceteris paribus basis.

### 6.1.3. Stochastic analysis

The assumptions used for the market parameters (e.g. prices and concentrations of recyclable materials) were similar to those described in the financial scenarios. As regards the external benefits of the project, a triangular assumption was adopted with most likely value equal to €12 per household per year, and min and max values equal to €9.8 (i.e. the min WTP value found at Polygyros CV study) and €50 per household per year (i.e. the mean WTP value estimated from the national CV study), accordingly.

The results of the simulation are presented in the following tables and figures.

**Table 63** - Monte Carlo simulation statistics–Scenario 1

| Variable | NPV (€) |
|---|---|
| Mean | -6.640 |
| Median | -28.597 |
| Standard Deviation | 158,183 |
| Minimum | -337.988 |
| Maximum | 534.468 |
| Mean Std. Error | 5,002 |

**Table 64** - Monte Carlo simulation percentiles–Scenario 1

| Percentage | NPV (€) |
|---|---|
| 100% | -337.988 |
| 90% | -196.765 |
| 80% | -147.280 |
| 70% | -106.255 |
| 60% | -72.250 |
| 50% | -28.720 |
| 40% | 19.781 |
| 30% | 71.060 |
| 20% | 138.003 |
| 10% | 208.464 |
| 0% | 534.468 |

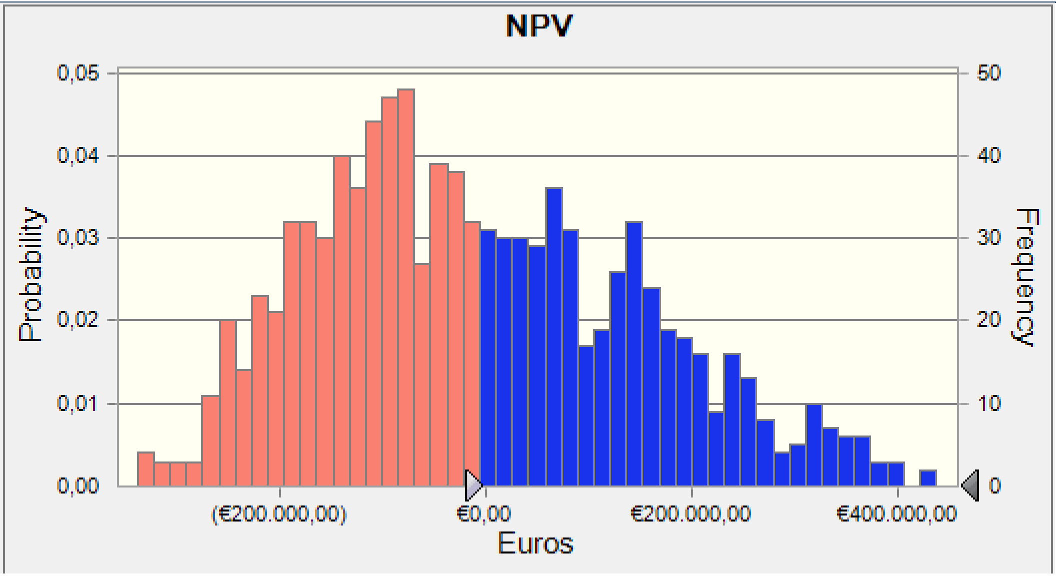



**Figure 44:** Histogram of NPV distribution–Scenario 1

The expected NPV is close to zero, €-6,600. The minimum expected value is about €-340,000 and the maximum value is €530,000. The analysis also indicates that the probability of accepting the project from a social viewpoint (i.e. social NPV>0) is around 45%. Furthermore, according to the sensitivity chart (Fig. 45), the social value of the project is almost entirely affected by the society's WTP for LFM programs.

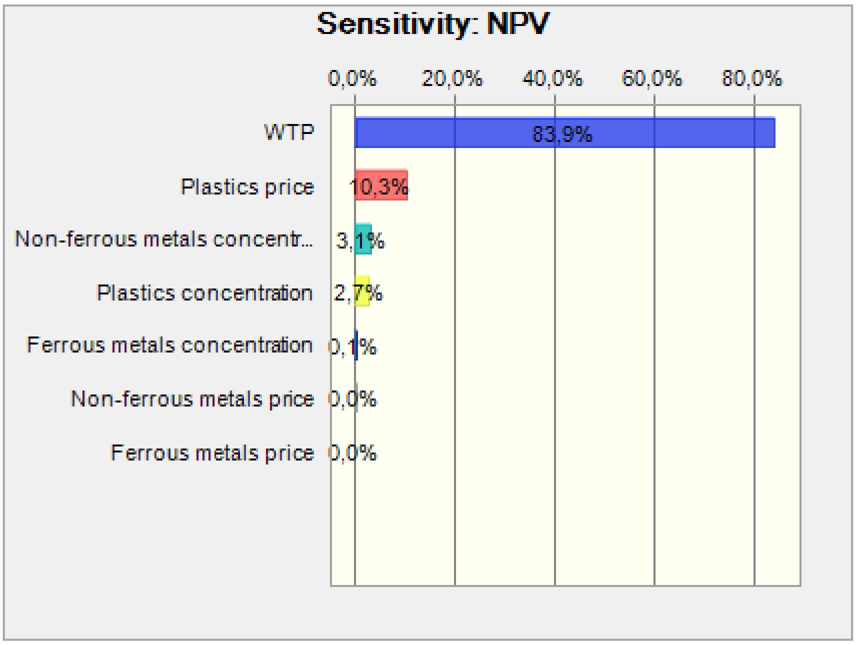



**Figure 45:** Sensitivity chart of NPV–Scenario 1

## 6.2. Socioeconomic analysis of Scenario 2

### 6.2.1. Deterministic analysis

Similarly to the financial analysis, two different sub-scenarios are examined.

*A. Subcontractor scenario*

In order to estimate the social NPV of the specific sub-scenario, the appropriate corrections were made, as previously described, and the same social discount rate was used.

The projected social cash flows are given in Table 65.

**Table 65** - Projected social cash flows –Scenario 2A

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 35,000 | | | |
| Total revenues | | 616,301 | 616,301 | 637,301 |
| Total costs | | 598,469 | 598,469 | 598,469 |
| Externalities | | 3,822,514 | 3,822,514 | 3,822,514 |
| Net Social Cash Flow | -35,000 | 3,840,345 | 3,840,345 | 3,861,345 |

The social NPV is estimated at about *€32,000,000*. This positive result is associated with the external benefits created by the LFM project. Furthermore, the LFM operations result in a net social benefit of around €160 per tn of waste, in present value terms. Thus, the project is totally justified from a social point of view.

*B.1. "Own resources" scenario - Low productivity*

The projected social cash flows are given in Table 66.

**Table 66** - Projected social cash flows –Scenario 2B1

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 1,160,000 | | | |
| Total revenues | | 619.859 | 619.859 | 649.859 |
| Total costs | | 335.473 | 335.473 | 335.473 |
| Externalities | | 3.822.514 | 3.822.514 | 3.822.514 |
| Net Social Cash Flow | -1,160,000 | 4.106.899 | 4.106.899 | 4.136.899 |

The social NPV is estimated at about *€33,000,000*, and, thus, the project is totally justified from a social point of view. Furthermore, the LFM operations result in a net social benefit of around €170 per tn of waste, in present value terms. Similarly to Scenario 2A, the high NPV is associated with the external benefits created by the LFM project.

*B.2. "Own resources" scenario - High productivity*

The projected social cash flows are given in Table 67.

**Table 67** - Projected social cash flows –Scenario 2B2

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 2,260,000 | | | |
| Total revenues | | 1.291.374 | 1.291.374 | 1.321.374 |
| Total costs | | 449.551 | 449.551 | 449.551 |
| Externalities | | 3.822.514 | 3.822.514 | 3.822.514 |
| Net Social Cash Flow | -2,260,000 | 4.664.336 | 4.664.336 | 4.694.336 |

The social NPV is estimated at about *€36,500,000*, and, thus, the project is totally justified from a social point of view. Furthermore, the LFM operations result in a net social benefit of around €170 per tn of waste, in present value terms. Similarly to Scenarios 2A and 2B1, the high NPV is associated with the external benefits created by the LFM project.

### 6.2.2. Sensitivity analysis

*A. Subcontractor scenario*

Given that the market costs and benefits of the LFM project are taken, more or less, for granted and, in addition, are less significant in the social cash flows, a break even sensitivity analysis was carried out to estimate the external benefits that are required in order to achieve a zero NPV. To this end both parameters determining externalities were examined, i.e. society's WTP per household and the number of households affected by the project. According to the estimates, the NPV of the project remains positive even when both parameters are set to zero, which means that the project is socially desirable after making appropriate fiscal corrections and estimating shadow prices.

Moreover, a sensitivity analysis by means of spider diagram was conducted in relation market and non-market costs and benefits. The results of the sensitivity of NPV to a ±20 percent change are given in Table 68 and are illustrated in Fig. 46.

**Table 68** - Social NPV sensitivity analysis results (Euros) –Scenario 2A

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| WTP | 25,590,054 | 28,769,088 | 31,948,122 | 35,127,155 | 38,306,189 |
| Plastics price | 31,727,565 | 31,837,844 | 31,948,122 | 32,058,400 | 32,168,678 |
| Plastics concentration | 31,727,565 | 31,837,844 | 31,948,122 | 32,058,400 | 32,168,678 |
| Non-ferrous metals price | 31,846,114 | 31,897,118 | 31,948,122 | 31,999,125 | 32,050,129 |
| Non-ferrous metals concentration | 31,846,114 | 31,897,118 | 31,948,122 | 31,999,125 | 32,050,129 |
| Ferrous metals price | 31,854,710 | 31,901,416 | 31,948,122 | 31,994,828 | 32,041,534 |
| Ferrous metals concentration | 31,854,710 | 31,901,416 | 31,948,122 | 31,994,828 | 32,041,534 |

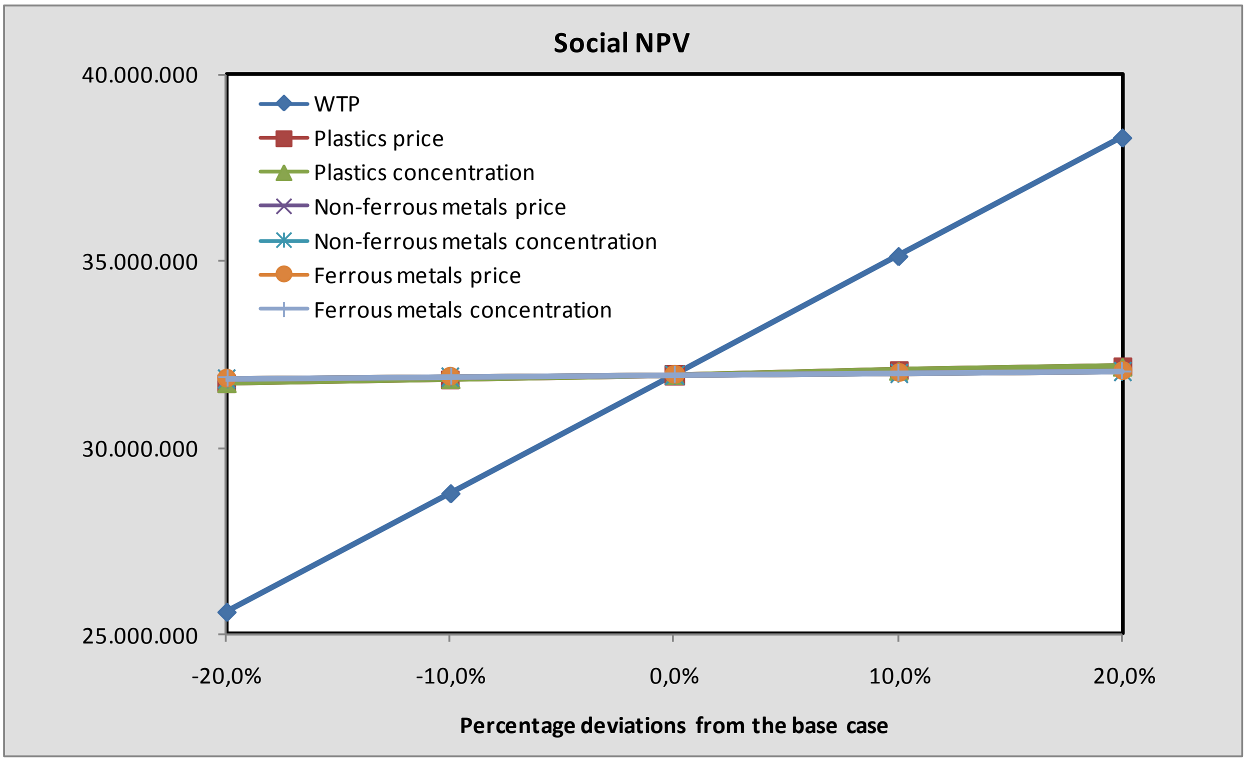



**Figure 46:**Social NPV sensitivity analysis–Scenario 2A

According to the sensitivity analysis, the social NPV of the project is heavily affected by the society's WTP for LFM programs. The project is always desirable from a social point of view even in all ceteris paribus changes.

*B.1. "Own resources" scenario - Low productivity*

A break even sensitivity analysis was carried out to estimate the external benefits that are required in order to achieve a zero NPV changing both the society's WTP per household and the number of households affected by the project. According to the estimates, the NPV of the project remains positive even when both parameters are set to zero, which means that the project is socially desirable after making appropriate fiscal corrections and estimating shadow prices.

Moreover, a sensitivity analysis by means of spider diagram was conducted in relation market and non-market costs and benefits. The results of the sensitivity of NPV to a ±20 percent change are given in Table 69 and are illustrated in Fig. 47.

**Table 69** - Social NPV sensitivity analysis results (Euros) –Scenario 2B1

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| WTP | 26,658,662 | 29,837,696 | 33,016,729 | 36,195,763 | 39,374,797 |
| Plastics price | 32,796,173 | 32,906,451 | 33,016,729 | 33,127,008 | 33,237,286 |
| Plastics concentration | 32,796,173 | 32,906,451 | 33,016,729 | 33,127,008 | 33,237,286 |
| Non-ferrous metals price | 32,914,722 | 32,965,726 | 33,016,729 | 33,067,733 | 33,118,737 |
| Non-ferrous metals concentration | 32,914,722 | 32,965,726 | 33,016,729 | 33,067,733 | 33,118,737 |
| Ferrous metals price | 32,923,317 | 32,970,023 | 33,016,729 | 33,063,435 | 33,110,141 |
| Ferrous metals concentration | 32,923,317 | 32,970,023 | 33,016,729 | 33,063,435 | 33,110,141 |

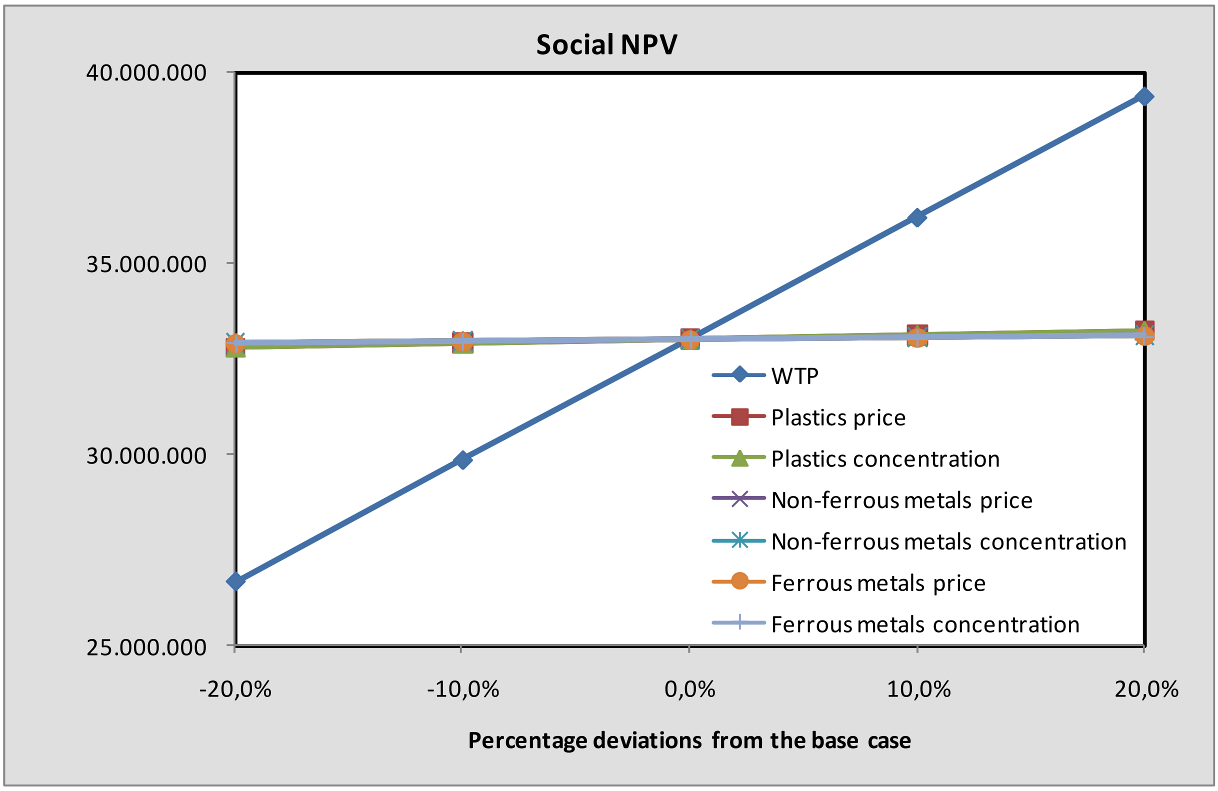



**Figure 47:** Social NPV sensitivity analysis–Scenario 2B1

According to the sensitivity analysis, the social NPV of the project is primarily affected by the society's WTP for LFM programs. The project remains socially desirable in all ceteris paribus changes.

*B.2. "Own resources" scenario - High productivity*

The NPV break even sensitivity analysis showed that the social NPV of the project remains positive even when both the society's WTP per household and the number of households affected by the project are set to zero.

Furthermore, a sensitivity analysis by means of spider diagram was conducted in relation market and non-market costs and benefits. The results of the sensitivity of NPV to a ±20 percent change are given in Table 70 and are illustrated in Fig. 48.

**Table 70** - Social NPV sensitivity analysis results (Euros) –Scenario 2B2

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| WTP | 30,194,640 | 33,373,674 | 36,552,708 | 39,731,741 | 42,910,775 |
| Plastics price | 36,093,215 | 36,322,962 | 36,552,708 | 36,782,454 | 37,012,200 |
| Plastics concentration | 36,093,215 | 36,322,962 | 36,552,708 | 36,782,454 | 37,012,200 |
| Non-ferrous metals price | 36,340,193 | 36,446,450 | 36,552,708 | 36,658,965 | 36,765,223 |
| Non-ferrous metals concentration | 36,340,193 | 36,446,450 | 36,552,708 | 36,658,965 | 36,765,223 |
| Ferrous metals price | 36,358,099 | 36,455,404 | 36,552,708 | 36,650,012 | 36,747,316 |
| Ferrous metals concentration | 36,358,099 | 36,455,404 | 36,552,708 | 36,650,012 | 36,747,316 |

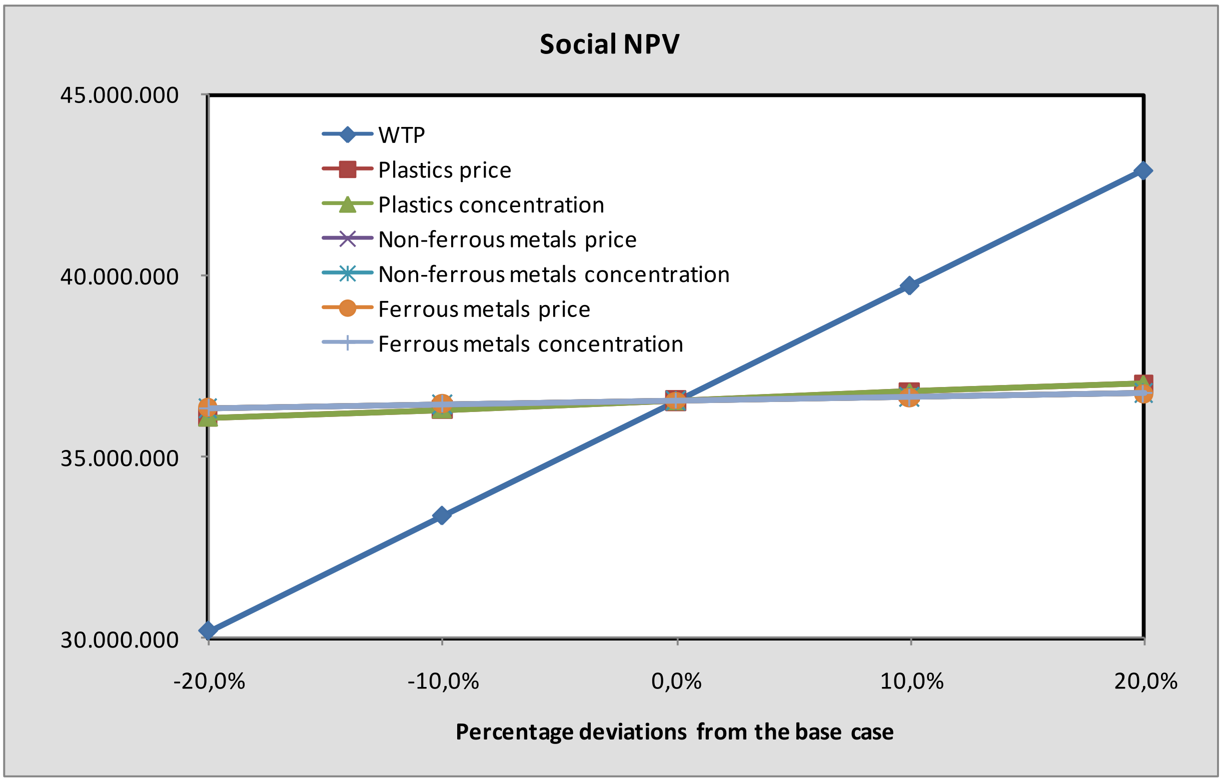



**Figure 48:** Social NPV sensitivity analysis–Scenario 2B2

According to the sensitivity analysis, the social NPV of the project is primarily affected by the society's WTP for LFM programs. The project remains socially desirable in all ceteris paribus changes.

### 6.2.3. Stochastic analysis

The assumptions used for the market parameters (e.g. prices and concentrations of recyclable materials) were similar to those described in the financial scenarios. As regards the external benefits of the project, a triangular assumption was adopted with most likely value equal to €50 per household per year, and min and max values equal to €12 (i.e. the mean value found at Polygyros CV study) and €52 per household per year (i.e. the max WTP estimated from the national CV study), accordingly.

*A. Subcontractor scenario*

The results of the simulation are presented in the following tables and figures.

**Table 71** - Monte Carlo simulation statistics–Scenario 2A

| Variable | Social NPV (€) |
|---|---|
| Mean | 25,044,716 |
| Median | 26,023,567 |
| Standard Deviation | 5,878,749 |
| Minimum | 8,994,409 |
| Maximum | 34,905,029 |
| Mean Std. Error | 185,902 |

**Table 72** - Monte Carlo simulation percentiles–Scenario 2A

| Percentage | Social NPV (€) |
|---|---|
| 100% | 8,994,409 |
| 90% | 15,957,816 |
| 80% | 19,601,400 |
| 70% | 22,233,968 |
| 60% | 24,124,740 |
| 50% | 26,019,806 |
| 40% | 27,675,570 |
| 30% | 29,173,016 |
| 20% | 30,652,334 |
| 10% | 32,050,925 |
| 0% | 34,905,029 |

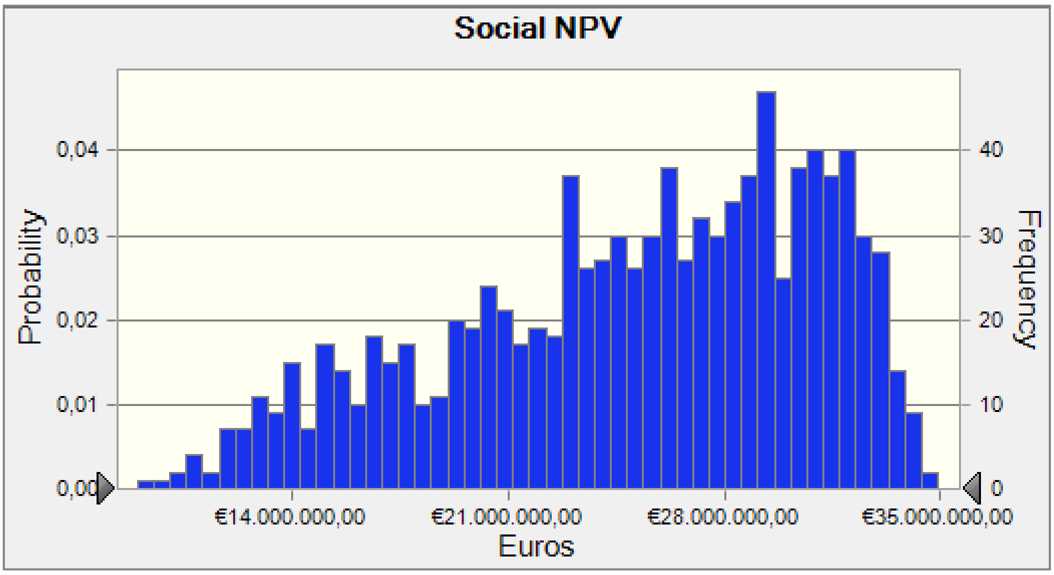



**Figure 49:** Histogram of Social NPV distribution–Scenario 2A

The expected NPV is around €25,000,000. The minimum expected value is about €9,000,000 and the maximum value is €35,000,000. The analysis also indicates that the probability of accepting the project from a social viewpoint (i.e. social NPV>0) is 100%. Furthermore, according to the sensitivity chart (Fig. 50), the social value of the project is practically affected only by the society's WTP for LFM programs.

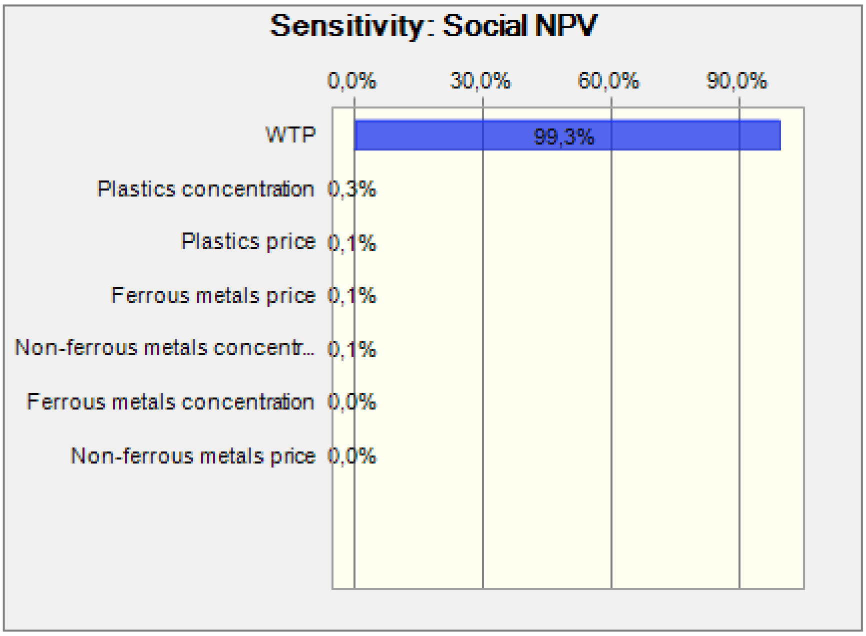



**Figure 50:** Sensitivity chart of Social NPV–Scenario 2A

*B.1. "Own resources" scenario - Low productivity*

The results of the simulation are presented in the following tables and figures.

**Table 73** - Monte Carlo simulation statistics–Scenario 2B1

| Variable | Social NPV (€) |
| --- | --- |
| Mean | 26,415,667 |
| Median | 27,668,183 |
| Standard Deviation | 5,896,957 |
| Minimum | 10,182,259 |
| Maximum | 35,663,733 |
| Mean Std. Error | 186,478 |

**Table 74** - Monte Carlo simulation percentiles–Scenario 2B1

| Percentage | Social NPV (€) |
| --- | --- |
| 100% | 10,182,259 |
| 90% | 17,566,762 |
| 80% | 20,979,598 |
| 70% | 23,222,511 |
| 60% | 25,623,813 |
| 50% | 27,667,771 |
| 40% | 29,210,993 |
| 30% | 30,577,007 |
| 20% | 31,986,434 |
| 10% | 33,320,027 |
| 0% | 35,663,733 |

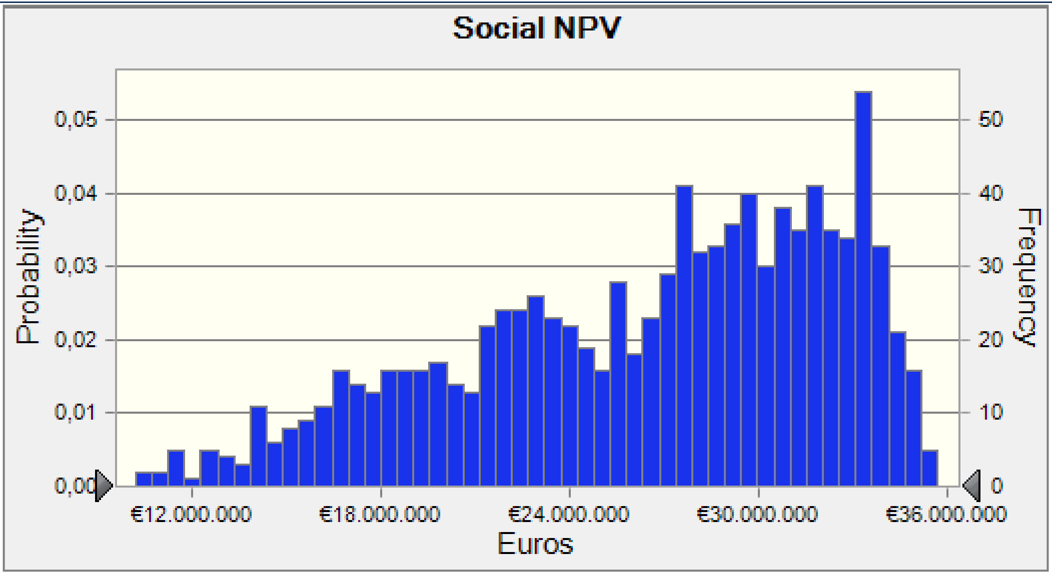



**Figure 51:** Histogram of Social NPV distribution–Scenario 2B1

The expected NPV is around €26,500,000. The minimum expected value is about €10,000,000 and the maximum value is approximately €36,000,000. The analysis also indicates that the probability of accepting the project from a social viewpoint (i.e. social NPV>0) is 100%. Furthermore, according to the sensitivity chart (Fig. 52), the social value of the project is practically affected only by the society's WTP for LFM programs.

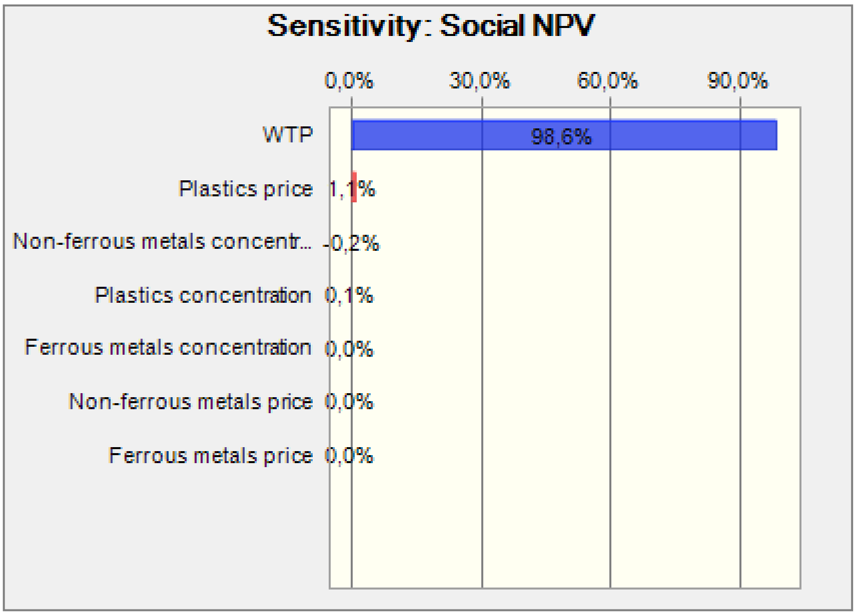



**Figure 52:** Sensitivity chart of Social NPV–Scenario 2B1

*B.2. "Own resources" scenario - High productivity*

The results of the simulation are presented in the following tables and figures.

**Table 75** - Monte Carlo simulation statistics–Scenario 2B2

| Variable | Social NPV (€) |
|---|---|
| Mean | 30,733,136 |
| Median | 31,494,741 |
| Standard Deviation | 6,135,448 |
| Minimum | 13,566,505 |
| Maximum | 42,637,013 |
| Mean Std. Error | 194,020 |

**Table 76** - Monte Carlo simulation percentiles–Scenario 2B2

| Percentage | Social NPV (€) |
|---|---|
| 100% | 13,566,505 |
| 90% | 21,675,748 |
| 80% | 25,128,794 |
| 70% | 27,790,200 |
| 60% | 29,529,200 |
| 50% | 31,487,486 |
| 40% | 33,434,841 |
| 30% | 35,117,897 |
| 20% | 36,618,296 |
| 10% | 37,950,355 |
| 0% | 42,637,013 |

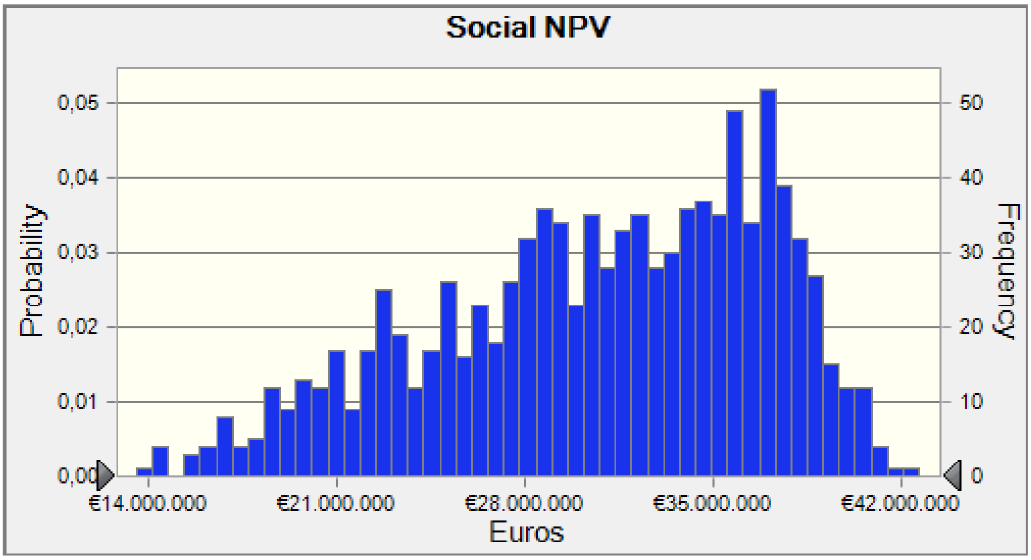



**Figure 53:** Histogram of Social NPV distribution–Scenario 2B2

The expected NPV is around €31,000,000. The minimum expected value is about €13,500,000 and the maximum value is €42,500,000. The analysis also indicates that the probability of accepting the project from a social viewpoint (i.e. social NPV>0) is 100%. Furthermore, according to the sensitivity chart (Fig. 54), the social value of the project is practically affected only by the society's WTP for LFM programs.

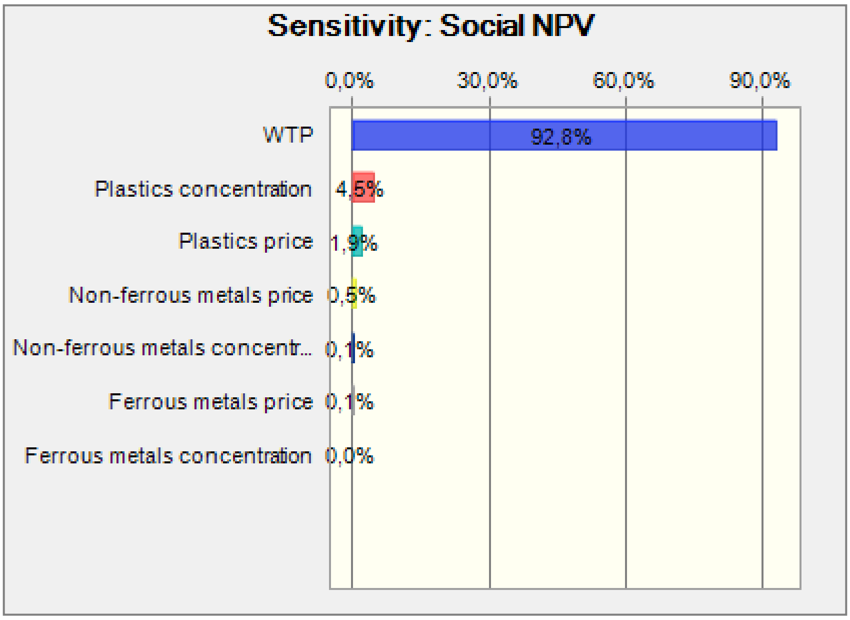



**Figure 54:** Sensitivity chart of Social NPV–Scenario 2B2

## 6.3. Socioeconomic analysis of Scenario 3

### 6.3.1. Deterministic analysis

Similarly to the financial analysis, two different sub-scenarios are examined.

*3A. Separation scenario*

In order to estimate the social NPV of the specific sub-scenario, the appropriate corrections were made, as previously described, and the same social discount rate was used.

The projected social cash flows are given in Table 77.

**Table 77** - Projected social cash flows –Scenario 3A

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 1,160,000 | | | |
| Total revenues | | 640.919 | 640.919 | 670.919 |
| Total costs | | 335.473 | 335.473 | 335.473 |
| Externalities | | 3.822.514 | 3.822.514 | 3.822.514 |
| Net Social Cash Flow | -1,160,000 | 4.127.959 | 4.127.959 | 4.157.959 |

The social NPV is estimated at about *€33,000,000*. This positive result is associated with the external benefits created by the LFM project. Furthermore, the LFM operations result in a net social benefit of around €150 per tn of waste, in present value terms. Thus, the project is totally justified from a social point of view.

*3B. PCB recovery scenario*

The projected social cash flows are given in Table 78.

**Table 78** - Projected social cash flows –Scenario 3B

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 1,160,000 | | | |
| Total revenues | | 644.078 | 644.078 | 674.078 |
| Total costs | | 340.155 | 340.155 | 340.155 |
| Externalities | | 3.822.514 | 3.822.514 | 3.822.514 |
| Net Social Cash Flow | -1,160,000 | 4.126.437 | 4.126.437 | 4.156.437 |

The social NPV is estimated at about *€33,000,000*, and, thus, the project is totally justified from a social point of view. Furthermore, the LFM operations result in a net social benefit of around €150 per tn of waste, in present value terms. Similarly to Scenario 3A, the high NPV is associated with the external benefits created by the LFM project.

*3C. Beneficiation scenario*

The projected social cash flows are given in Table 79.

**Table 79** - Projected social cash flows –Scenario 3C

| | 0 | 1 | 2…9 | 10 |
|---|---|---|---|---|
| Capital costs | 1,160,000 | | | |
| Total revenues | | 645.895 | 645.895 | 675.895 |
| Total costs | | 340.623 | 340.623 | 340.623 |
| Externalities | | 3.822.514 | 3.822.514 | 3.822.514 |
| Net Social Cash Flow | -1,160,000 | 4.127.785 | 4.127.785 | 4.157.785 |

The social NPV is estimated at about €*33,000,000*, and, thus, the project is totally justified from a social point of view. Furthermore, the LFM operations result in a net social benefit of around €150 per tn of waste, in present value terms. Similarly to Scenarios 3A and 3B, the high NPV is associated with the external benefits created by the LFM project.

### 6.3.2. Sensitivity analysis

*3A. Separation scenario*

a sensitivity analysis by means of spider diagram was conducted in relation market and non-market costs and benefits. The results of the sensitivity of NPV to a ±20 percent change are given in Table 80 and are illustrated in Fig. 55. Moreover, given that the market costs and benefits of the LFM project are taken, more or less, for granted and, in addition, are less significant in the social cash flows, a break even sensitivity analysis was carried out to estimate the external benefits that are required in order to achieve a zero NPV. To this end both parameters determining externalities were examined, i.e. society's WTP per household and the number of households affected by the project. According to the estimates, the NPV of the project remains positive even when both parameters are set to zero, which means that the project is socially desirable after making appropriate fiscal corrections and estimating shadow prices.

**Table 80** - Social NPV sensitivity analysis results (Euros) –Scenario 3A

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| WTP per household | 26,833,810 | 30,012,843 | 33,191,877 | 36,370,911 | 39,549,944 |
| Plastics price | 32,971,321 | 33,081,599 | 33,191,877 | 33,302,155 | 33,412,433 |
| Plastics concentration | 32,971,321 | 33,081,599 | 33,191,877 | 33,302,155 | 33,412,433 |
| Non-ferrous metals price | 33,089,870 | 33,140,873 | 33,191,877 | 33,242,881 | 33,293,884 |
| Non-ferrous metals concentration | 33,089,870 | 33,140,873 | 33,191,877 | 33,242,881 | 33,293,884 |
| Ferrous metals price | 33,098,465 | 33,145,171 | 33,191,877 | 33,238,583 | 33,285,289 |
| Ferrous metals concentration | 33,098,465 | 33,145,171 | 33,191,877 | 33,238,583 | 33,285,289 |
| WEEE price | 33,156,848 | 33,174,362 | 33,191,877 | 33,209,392 | 33,226,907 |
| WEEE concentration | 33,156,848 | 33,174,362 | 33,191,877 | 33,209,392 | 33,226,907 |

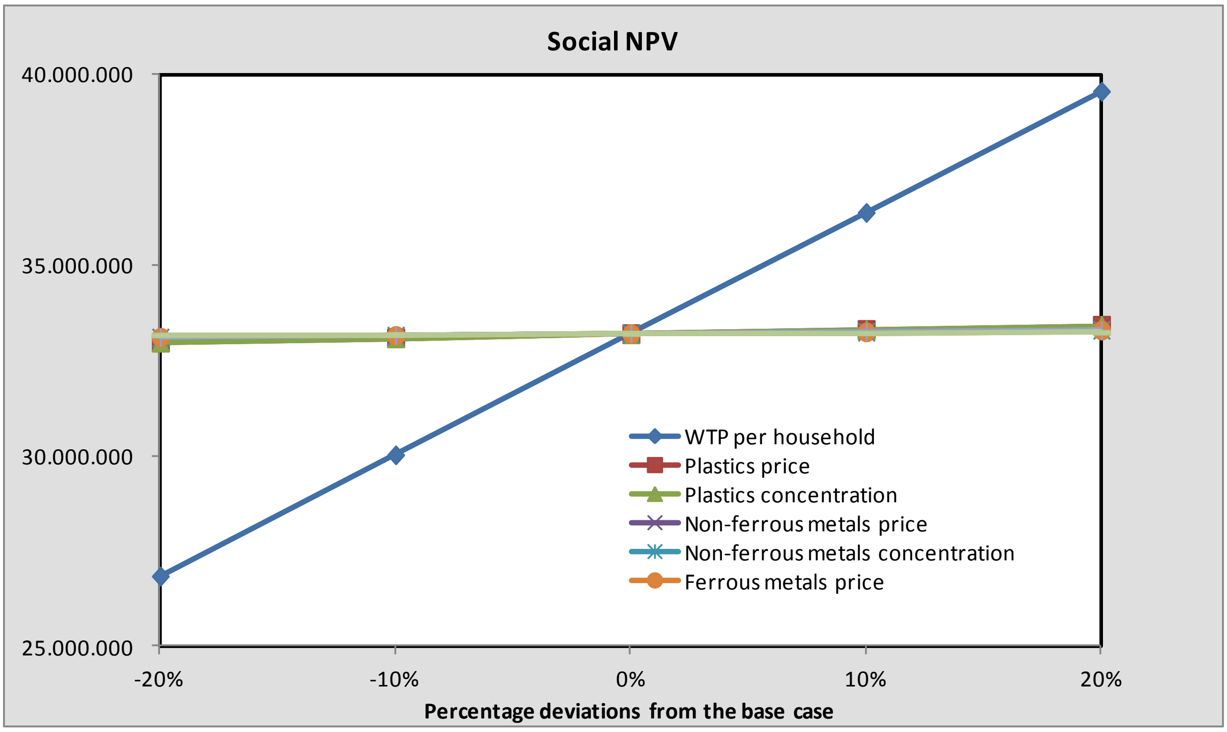



**Figure 55:** Social NPV sensitivity analysis–Scenario 3A

According to the sensitivity analysis, the social NPV of the project is primarily and heavily affected by the society's WTP for LFM programs. The project is always desirable from a social point of view even in all ceteris paribus changes.

*3B. PCB recovery scenario*

A break even sensitivity analysis was carried out to estimate the external benefits that are required in order to achieve a zero NPV changing both the society's WTP per household and the number of households affected by the project. According to the estimates, the NPV of the project remains positive even when both parameters are set to zero, which means that the project is socially desirable after making appropriate fiscal corrections and estimating shadow prices.

Moreover, a sensitivity analysis by means of spider diagram was conducted in relation market and non-market costs and benefits. The results of the sensitivity of NPV to a ±20 percent change are given in Table 81 and are illustrated in Fig. 56.

**Table 81** - Social NPV sensitivity analysis results (Euros) –Scenario 3B

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| WTP per household | 26,821,147 | 30,000,180 | 33,179,214 | 36,358,248 | 39,537,281 |
| Plastics price | 32,958,658 | 33,068,936 | 33,179,214 | 33,289,492 | 33,399,770 |
| Plastics concentration | 32,958,658 | 33,068,936 | 33,179,214 | 33,289,492 | 33,399,770 |
| Non-ferrous metals price | 33,077,207 | 33,128,210 | 33,179,214 | 33,230,218 | 33,281,221 |
| Non-ferrous metals concentration | 33,077,207 | 33,128,210 | 33,179,214 | 33,230,218 | 33,281,221 |
| Ferrous metals price | 33,085,802 | 33,132,508 | 33,179,214 | 33,225,920 | 33,272,626 |
| Ferrous metals concentration | 33,085,802 | 33,132,508 | 33,179,214 | 33,225,920 | 33,272,626 |
| WEEE concentration | 33,138,930 | 33,159,072 | 33,179,214 | 33,199,356 | 33,219,498 |
| WEEE price (bulk) | 33,144,184 | 33,161,699 | 33,179,214 | 33,196,729 | 33,214,243 |
| WEEE price (PCBs) | 33,173,959 | 33,176,587 | 33,179,214 | 33,181,841 | 33,184,468 |

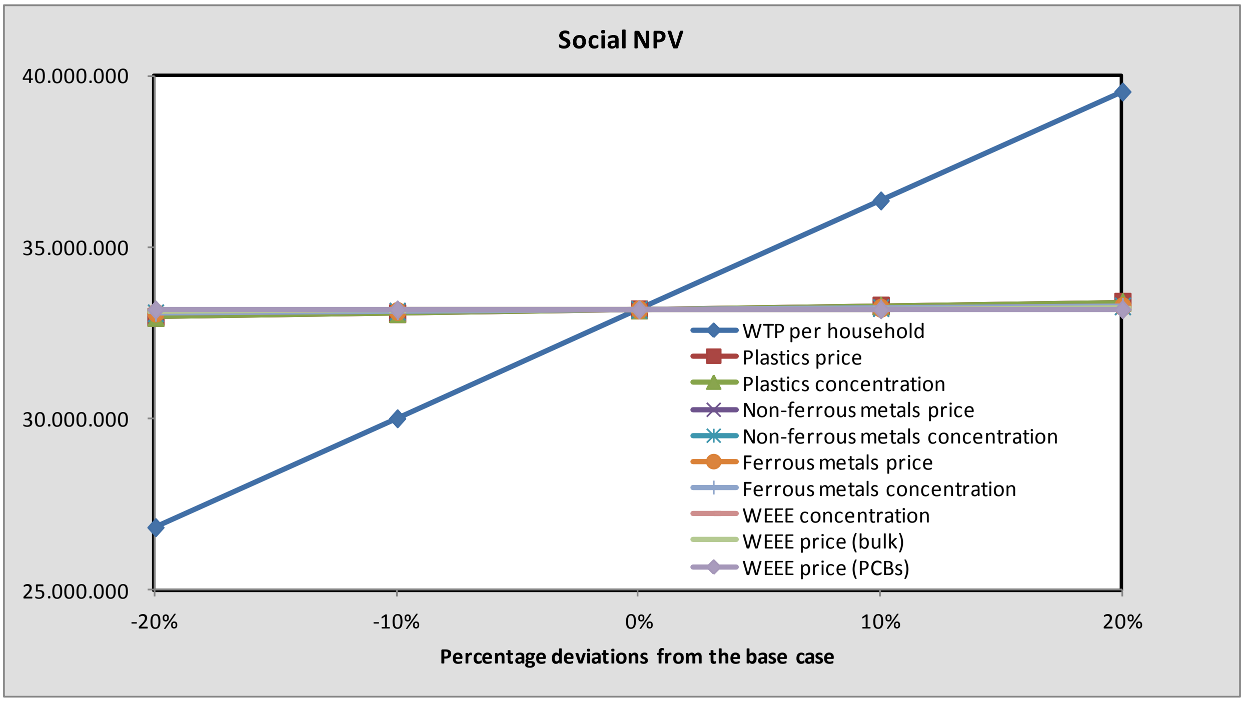



**Figure 56:** Social NPV sensitivity analysis–Scenario 3B

According to the sensitivity analysis, the social NPV of the project is primarily affected by the society's WTP for LFM programs. The project remains socially desirable in all ceteris paribus changes.

*3C. Beneficiation scenario*

The NPV break even sensitivity analysis showed that the social NPV of the project remains positive even when both the society's WTP per household and the number of households affected by the project are set to zero.

Furthermore, a sensitivity analysis by means of spider diagram was conducted in relation market and non-market costs and benefits. The results of the sensitivity of NPV to a ±20 percent change are given in Table 82 and are illustrated in Fig. 57.

**Table 82** - Social NPV sensitivity analysis results (Euros) –Scenario 3C

| | -20% | -10% | 0% | 10% | 20% |
|---|---|---|---|---|---|
| WTP per household | 26,832,360 | 30,011,393 | 33,190,427 | 36,369,461 | 39,548,494 |
| Plastics price | 32,969,870 | 33,080,149 | 33,190,427 | 33,300,705 | 33,410,983 |
| Plastics concentration | 32,969,870 | 33,080,149 | 33,190,427 | 33,300,705 | 33,410,983 |
| Non-ferrous metals price | 33,088,420 | 33,139,423 | 33,190,427 | 33,241,431 | 33,292,434 |
| Non-ferrous metals concentration | 33,088,420 | 33,139,423 | 33,190,427 | 33,241,431 | 33,292,434 |
| Ferrous metals price | 33,097,015 | 33,143,721 | 33,190,427 | 33,237,133 | 33,283,839 |
| Ferrous metals concentration | 33,097,015 | 33,143,721 | 33,190,427 | 33,237,133 | 33,283,839 |
| WEEE concentration | 33,147,122 | 33,168,774 | 33,190,427 | 33,212,079 | 33,233,732 |
| WEEE price (bulk) | 33,155,397 | 33,172,912 | 33,190,427 | 33,207,942 | 33,225,456 |
| WEEE price (PCBs) | 33,182,151 | 33,186,289 | 33,190,427 | 33,194,565 | 33,198,703 |

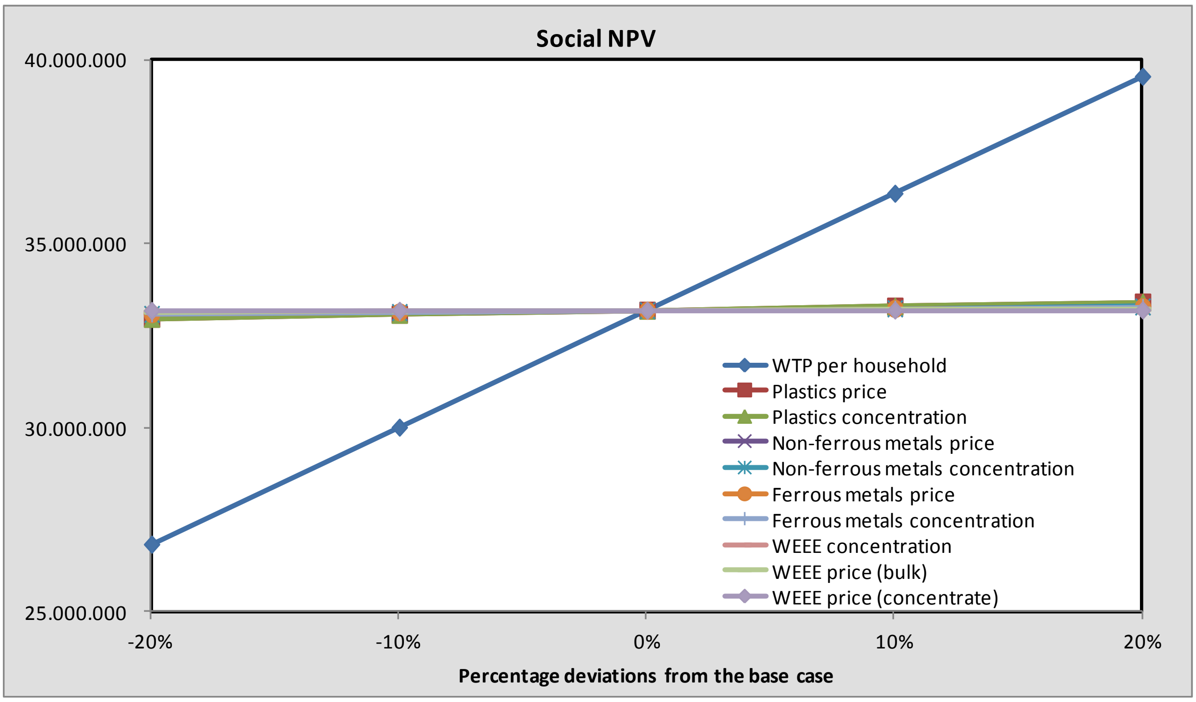



**Figure 57:**Social NPV sensitivity analysis–Scenario 3C

According to the sensitivity analysis, the social NPV of the project is primarily affected by the society's WTP for LFM programs. The project remains socially desirable in all ceteris paribus changes.

### 6.3.3. Stochastic analysis

The assumptions used for the market parameters (e.g. prices and concentrations of recyclable materials) were similar to those described in the financial scenarios. As regards the external benefits of the project, a triangular assumption was adopted with most likely value equal to €50 per household per year, and min and max values equal to €12 (i.e. the mean value found at Polygyros CV study) and €52 per household per year (i.e. the max WTP estimated from the national CV study), accordingly.

*3A. Separation scenario*

The results of the simulation are presented in the following tables and figures.

**Table 83** - Monte Carlo simulation statistics–Scenario 3A

| Variable | Social NPV (€) |
|---|---|
| Mean | 26,204,955 |
| Median | 27,121,625 |
| Standard Deviation | 5,958,296 |
| Minimum | 9,188,299 |
| Maximum | 35,858,450 |
| Mean Std. Error | 188,418 |

**Table 84** - Monte Carlo simulation percentiles–Scenario 3A

| Percentage | Social NPV (€) |
|---|---|
| 100% | 9,188,299 |
| 90% | 17,555,661 |
| 80% | 20,374,279 |
| 70% | 22,878,904 |
| 60% | 25,321,466 |
| 50% | 27,119,811 |
| 40% | 28,674,347 |
| 30% | 30,508,443 |
| 20% | 31,956,333 |
| 10% | 33,476,192 |
| 0% | 35,858,450 |

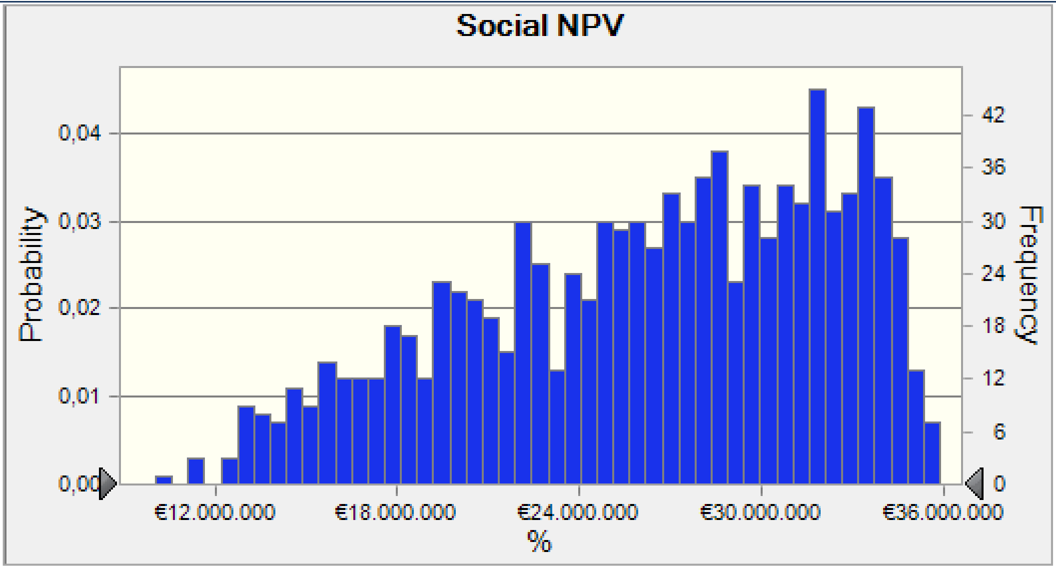



**Figure 58:** Histogram of Social NPV distribution–Scenario 3A

The expected NPV is around €26,000,000. The minimum expected value is about €9,000,000 and the maximum value is €36,000,000. The analysis also indicates that the probability of accepting the project from a social viewpoint (i.e. social NPV>0) is 100%. Furthermore, according to the sensitivity chart (Fig. 59), the social value of the project is practically affected only by the society's WTP for LFM programs.

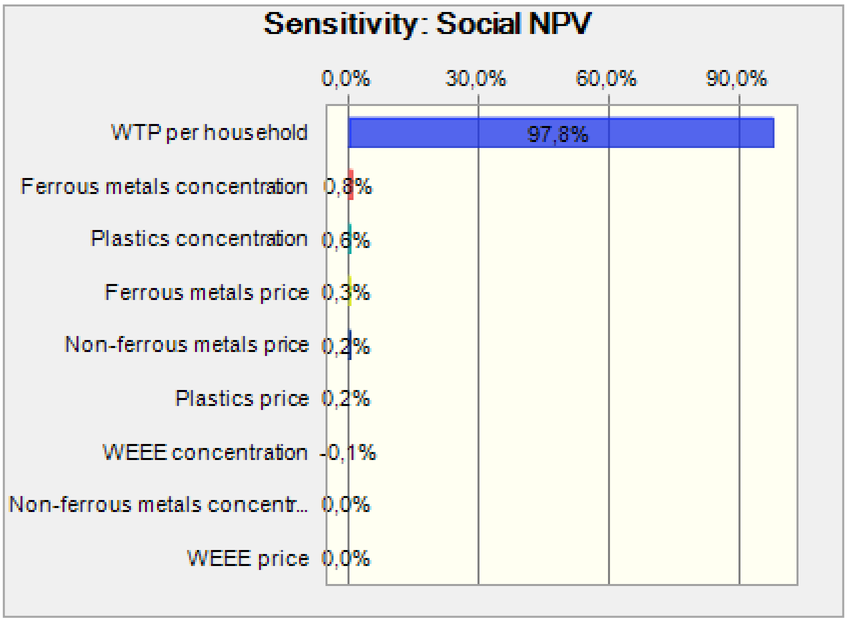



**Figure 59:** Sensitivity chart of Social NPV–Scenario 3A

*3B. PCB recovery scenario*

The results of the simulation are presented in the following tables and figures.

**Table 85** - Monte Carlo simulation statistics–Scenario 3B

| Variable | Social NPV (€) |
|---|---|
| Mean | 26,402,124 |
| Median | 27,455,809 |
| Standard Deviation | 5,890,694 |
| Minimum | 9,783,118 |
| Maximum | 36,879,916 |
| Mean Std. Error | 186,280 |

**Table 86** - Monte Carlo simulation percentiles–Scenario 3B

| Percentage | Social NPV (€) |
|---|---|
| 100% | 9,783,118 |
| 90% | 17,488,198 |
| 80% | 20,931,873 |
| 70% | 23,663,404 |
| 60% | 25,631,787 |
| 50% | 27,444,342 |
| 40% | 28,802,924 |
| 30% | 30,422,237 |
| 20% | 31,992,835 |
| 10% | 33,406,345 |
| 0% | 36,879,916 |

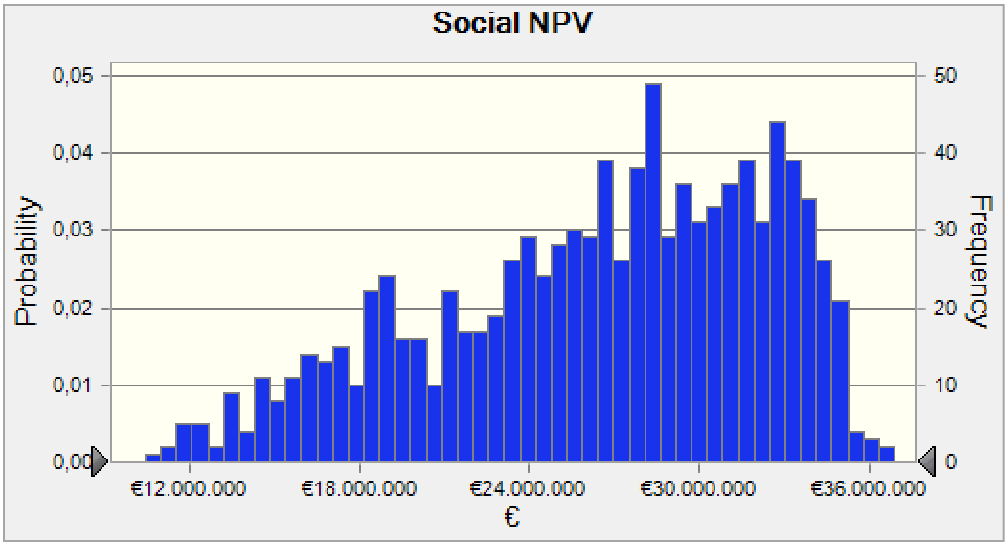



**Figure 60:** Histogram of Social NPV distribution–Scenario 3B

The expected NPV is around €26,400,000. The minimum expected value is about €9,800,000 and the maximum value is approximately €37,000,000. The analysis also indicates that the probability of accepting the project from a social viewpoint (i.e. social NPV>0) is 100%. Furthermore, according to the sensitivity chart (Fig. 61), the social value of the project is practically affected only by the society's WTP for LFM programs.

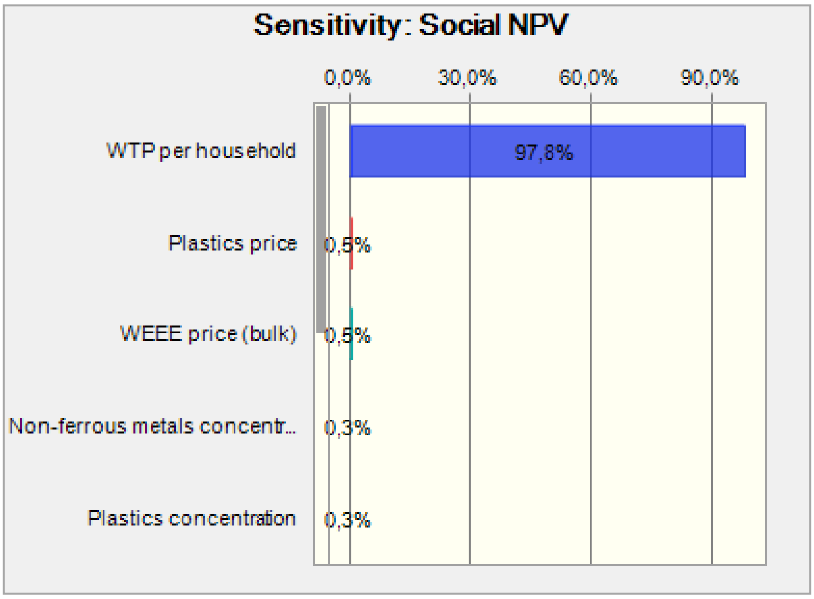



**Figure 61:** Sensitivity chart of Social NPV–Scenario 3B

*3C. Beneficiation scenario*

The results of the simulation are presented in the following tables and figures.

**Table 87** - Monte Carlo simulation statistics–Scenario 3C

| Variable | Social NPV (€) |
|---|---|
| Mean | 26,527,098 |
| Median | 27,534,459 |
| Standard Deviation | 5,741,096 |
| Minimum | 9,853,001 |
| Maximum | 36,258,579 |
| Mean Std. Error | 181,549 |

**Table 88** - Monte Carlo simulation percentiles–Scenario 3C

| Percentage | Social NPV (€) |
|---|---|
| 100% | 9,853,001 |
| 90% | 17,950,058 |
| 80% | 21,536,559 |
| 70% | 23,551,285 |
| 60% | 25,451,139 |
| 50% | 27,532,274 |
| 40% | 29,068,742 |
| 30% | 30,497,845 |
| 20% | 31,968,274 |
| 10% | 33,506,342 |
| 0% | 36,258,579 |

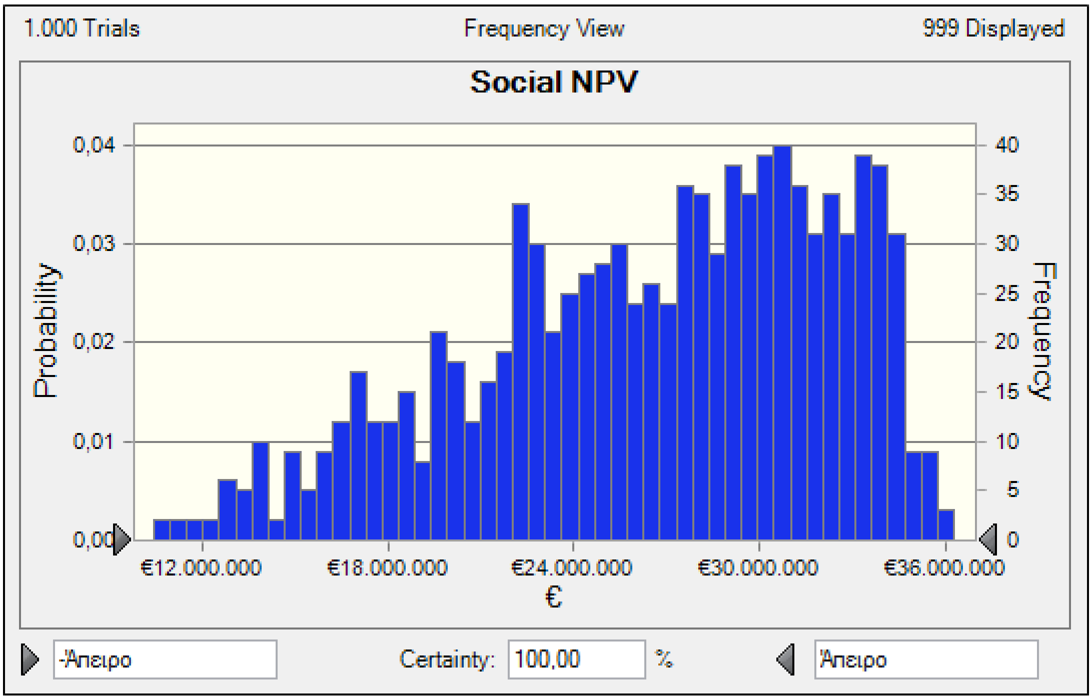



**Figure 62:** Histogram of Social NPV distribution–Scenario 3C

The expected NPV is around €26,500,000. The minimum expected value is about €10,000,000 and the maximum value is €36,000,000. The analysis also indicates that the probability of accepting the project from a social viewpoint (i.e. social NPV>0) is 100%. Furthermore, according to the sensitivity chart (Fig. 63), the social value of the project is practically affected only by the society's WTP for LFM programs.

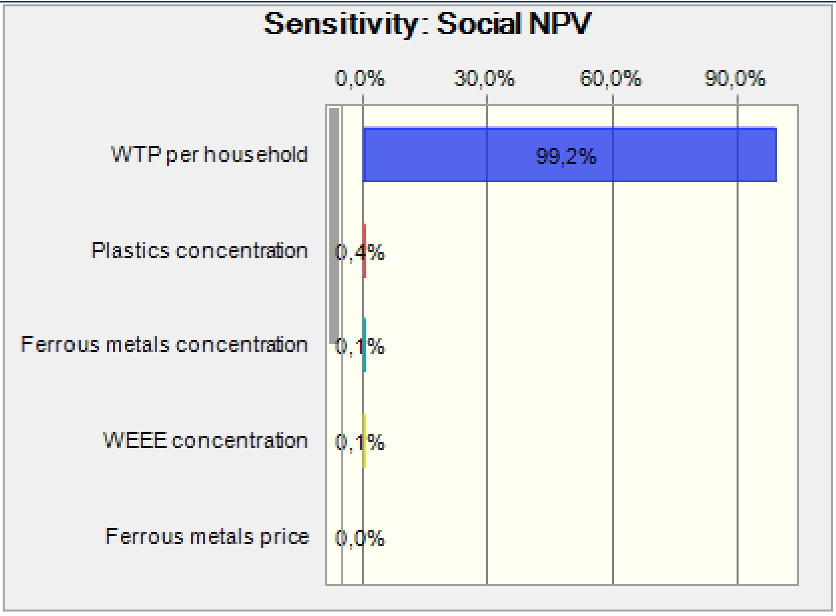



**Figure 63:** Sensitivity chart of Social NPV–Scenario 3C

# Chapter 7. CONCLUSIONS

Based on the results for the financial and socioeconomic analyses, the following conclusions can be drawn:

The financial success of LFM projects is not assured in all cases, and this stands especially when assigning the excavation and processing works to subcontractors. Nevertheless, there is an improvement on the financial indices when own resources in terms of equipment and personnel are used. In these cases, the total cost of the process is reduced to half and less than half, as well. As regards expected revenues from recyclable materials, hard plastic materials seem to have a dominant role. The separation of WEEEs adds to the financial benefits of the project. Nevertheless, the dismantling of IT equipment in order to retrieve and sell separately PCBs or the froth flotation processing of PCBs pulverized material in order to reject plastics and recover Cu and precious metals (Pd, Au and Ag), do not significantly impact the financial results owing to the small quantities of IT equipment that are reasonably anticipated to be found. Hence, the overall revenues are significantly affected by the recovered air-space. In addition, it has to be pointed out that in all scenarios examined a number of (significant) benefits, including energy recovery, redevelopment of the landfill area, 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.). This means that the financial results could be positively affected and could be different, if one or more of the abovementioned benefits were considered. From a socioeconomic viewpoint, the LFM projects seem to be socially justified. This derives primarily from society's WTP towards supporting LFM policies. In this case, however, the size of the population affected is crucial, especially when the WTP value lies in the lower part of the primary estimates (i.e. those derived from the two CV surveys in the context of RECLAIM project) or of the range of published values.

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) Under examined conditions, it seems that LFM works with low processing effort are likely to be more attractive from a financial viewpoint than processes with high processing effort, e.g. WEEE utilization 'as is' vs. IT equipment dismantling in order to retrieve and further process PCBs.

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

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# ANNEX I

## Economic Assessment of PCBs Concentrates

Pricing of the concentrates or the "useful materials", incorporating metals and precious metals, produced from beneficiation processes. The price of the raw materials sold to "smelters" shall be the sum of the values of the payable metals less the sum of the deductions.

In general smelting business consists of the following gross profit elements:

- Treatment Charge and Refining Charge for copper
- Refining Charges for other precious metals
- Free metals
- By product credits
- Metal premiums

Normally, the concentrate's buyers pay for about 95.0% of the final metal content, subject to minimum deductions of 1.0% unit or 1.0 g depending on the metal species, to compensate for the smelting or hydrometallurgical processing cost.

As regard the potential value of the concentrate as deriving from the beneficiation tests of the PCB's, this is analyzed in the detail in the following paragraphs. The analysis is based on the concentration of the initial feed (Table 1) and the recovery attained as well as on metal prices taken in the December of 2015 and represent the average monthly prices (Figs 1, 2).

**Table A1.** Chemical analysis of the original PCBs feed

| **Composition of the original Sample** | |
|---|---|
| **Element** | **Content %** |
| Cu | 3.19 |
| Mn | 1.00 |
| Pb | 0.67 |
| Fe | 4.40 |
| Ni | 0.11 |
| Cr | 0.01 |
| Zn | 0.85 |
| **Precious metal content (mg/kg or ppm)** | |
| Pd | 3.73 |
| Ag | 250.59 |
| Pt | <0.05 |
| Au | 19.27 |

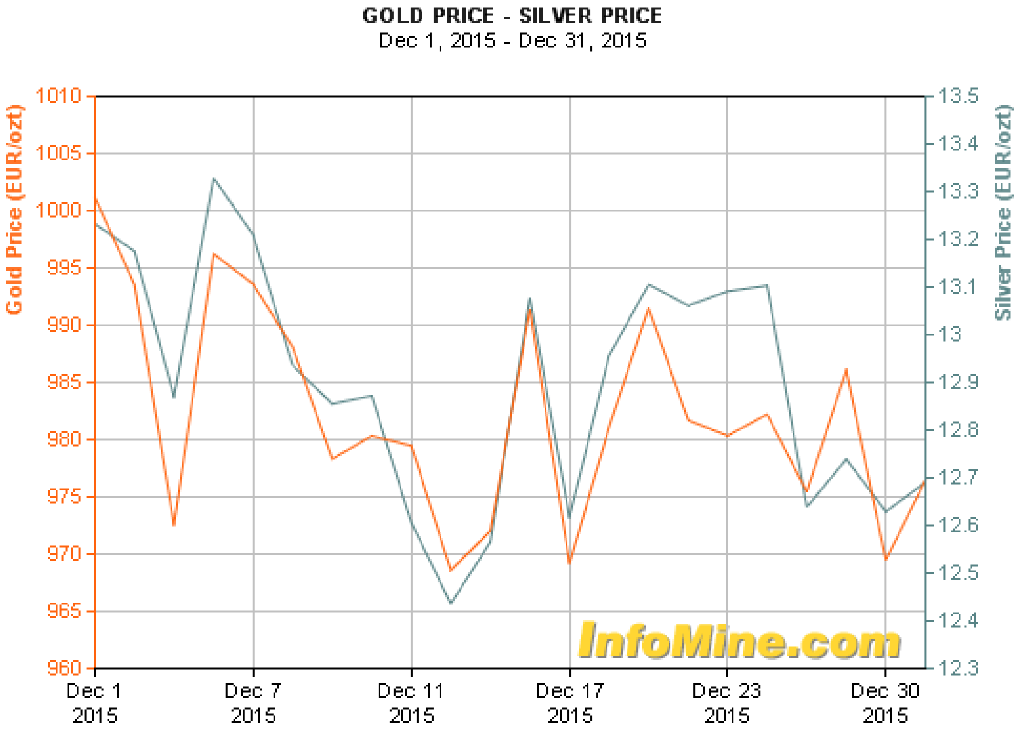


***Figure 1.*** *Gold and Silver prices for December 2015 (€/oz). (Source: Infomine)*

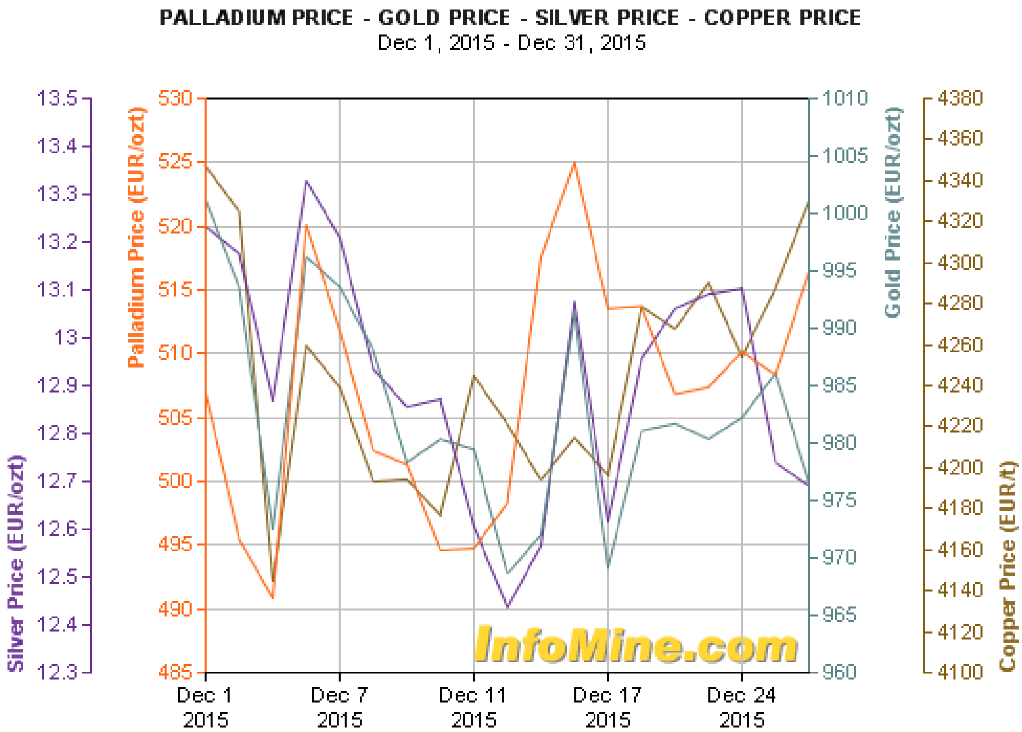


***Figure 2.*** *Palladium (€/oz) and Copper (€/t) prices for December 2015 (Source: Infomine).*

Based on the above metal prices the average monthly prices (Dec. 2015) were obtained as follows:

- Copper (Cu) price: 4,250 €/metric tonne
- Palladium (Pd) price: 505 €/tr oz (16.3 €/gr)
- Silver (Ag) price: 12.8 €/tr oz (0.41 €/gr)
- Gold (Au) price: 980 €/tr oz (31.5 €/gr)

The metal values in 1 metric tonne PCBs feed (according to Table A1) are calculated accordingly:

Value/metal (Cu) : 4,250 €/metric tonne × (31.9/1000) = 135.6 €
Value/metal (Pd) : (505 €/tr oz) × (3.73/31.15) = 60.5 €
Value/metal (Ag) : (12.8 €/tr oz) × (250.59/31.15) = 103.0 €
Value/metal (Au) : (980 €/tr oz) × (19,27/31.15) = 606.3 €
Total value of metals contained in 1 metric tonne PCBs : 905.4 €

***Table A2.*** *Experimental results of the "floats" and "sinks" of the -1 mm size fraction (80.83%) treated by flotation*

| Element | **Original sample** | **Feed -1,0 mm** | **Test 7** (Feed -1 mm) | | | |
|---|---|---|---|---|---|---|
| | | | c % ("floats") | $R_c$ % overall | t % ("sinks") | $R_t$ % overall |
| As | - | | | | - | |
| Cd | - | | 0.0005 | | 0.0007 | |
| Cu | 3.19 | **3.55** | **0.70** | **8.8** | **6.38** | **81.1** |
| Mn | 1.00 | 1.06 | 2.24 | | 0.39 | |
| Pb | 0.67 | 1.55 | 0.91 | | 2.16 | |
| Fe | 4.40 | 5.32 | 8.29 | **75.8** | 2.37 | **21.8** |
| Ni | 0.11 | 0.99 | 1.64 | | 0.33 | |
| Cr | 0.01 | 0.012 | 0.01 | | 0.014 | |
| Zn | 0.85 | 1.58 | 1.64 | | 1.51 | |
| | | | c ("float") mg/kg | | t ("sink") mg/kg | |
| Pd | 3.73 | **4.32** | **6.28** | **67.8** | **2.38** | **25.9** |
| Ag | 250.59 | **250.8** | **207.73** | **33.4** | **293.5** | **47.5** |
| Pt | <0.05 | <0,05 | <0.05 | | <0.05 | |
| Au | 19.27 | **22** | **38.64** | **80.7** | **5.5** | **11.6** |
| Weight % | 100 | **80.83** | **40.25** | | **40.57** | |

The metal values in "float" product (according to Table A2) are calculated as:

Value/metal (Cu): 0.088 ×135.6 €= 11.9 €

Value/metal (Pd): 0.678 × 60.5 € = 41.0 €
Value/metal (Ag): 0.334 × 103.0 € = 34.4 €
Value/metal (Au): 0.807 × 606.3 € 489.3 €
Total value of metals in "float": 576.6 €

Also, the values in "sink" product (according to Table A2) are calculated as:

Value/metal (Cu): 0.811 ×135.6 €= 110.0 €
Value/metal (Pd): 0.259 × 60.5 € = 15.7 €
Value/metal (Ag): 0.475 × 103.0 € = 48.9 €
Value/metal (Au): 0.116 × 606.3 € 70.3 €
Total value of metals in "sink": 244.9 €

The total values of the metals in in 0.8083 metric tonne PCBs of -1 mm feed (according to Table 2) are:

Value/metal (Cu): (0.088 + 0.811) ×135.6 €= 121.9 €
Value/metal (Pd): (0.678 + 0.259) × 60.5 € = 56.7 €
Value/metal (Ag): (0.334 + 0.475) × 103.0 € = 83.3 €
Value/metal (Au): (0.807 + 0.116) × 606.3 € 559.6 €
Total value of metals contained in 0.8083 metric tonne PCBs: 821.5 €

The distribution % by wt and the values of the products produced from PCBs by flotation is shown in Fig. 3.

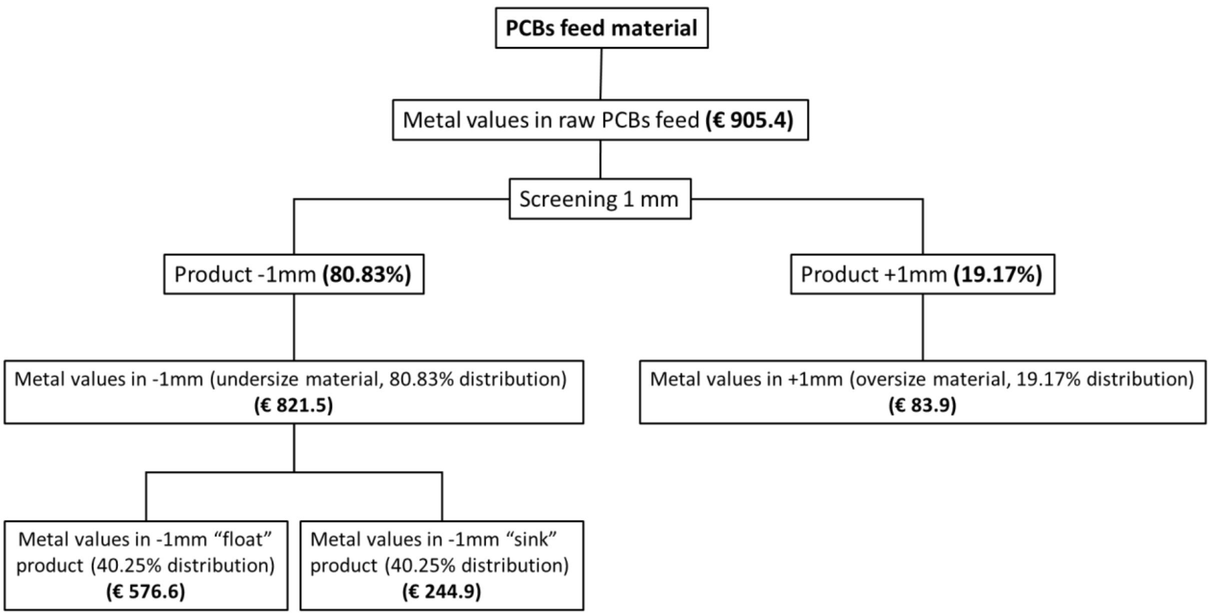


***Figure A3.*** *Distribution % by wt and metal values in the useful products.*

From the above calculations it is evident that, the metal values, recovered by flotation of the -1 mm PCBs size fraction, are € 576.6 in the "float" and €244.9 in the "sink" product, respectively, yielding a total value of € 821.5

The value payable from the concentrate buyer (-1mm feed) is estimated at around € 700. The analysis is given in Table A3 taking into account the deductions of a minimum of 1% or 1gr/tn for the metal products.

***Table A3.*** *Analysis of the payable values of the PCB's concentrate.*

| | Metal Prices | Initial Concentration | Payable Concentration | Recovery (%) | Price reduction | Payable Price (€) |
|---|---|---|---|---|---|---|
| **Cu** | 4,250 €/t | 3,2 % | 2,2 % | 0,899 | 5% | 79.5 |
| **Pd** | 505 €/oz | 3,7 gr/t | 2,7 gr/t | 0,937 | 5% | 39.4 |
| **Ag** | 12,8 €/oz | 250,6 gr/t | 248 gr/t | 0,809 | 5% | 78.3 |
| **Au** | 980 €/oz | 19,3 gr/t | 18,3 gr/t | 0,923 | 5% | 504.0 |
| ***Total payable*** | | | | | | ***701.2*** |