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

TECHNICAL REPORT - ACTION B6

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

SUBJECT:

TECHNICAL REPORT FOR MSW MINING, TREATMENT AND TESTS ASSESSMENT

ENVECO S.A. ENVIRONMENTAL PROTECTION MANAGEMENT & ECONOMICS

HELECTOR

Municipality of Polygyros

NTUA School of Mining & Metallurgical Engineering

With the contribution of the LIFE financial instrument of the European Union

ATHENS, SEPTEMBER 2015

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Abbreviations

AAS: Atomic Absorption Spectroscopy

BB: Big Bags

CAS: : Chemical Abstract Service Registry Number

ICP: Inductively Coupled Plasma Spectrometry

ICP – MS: Inductively Coupled Plasma Mass Spectrometry

LEL: Lower Explosive Limits

LF: Landfill

LFM: Landfill Mining

M.M.R.F.: Mobile Materials Recovery Facility

MSW: Municipal Solid Waste

NTUA: National Technical University of Athens

PB: Plastic Bags

PCBs: Printed Circuit Boards

PDU: Pilot Demonstration Unit

PL: Polygyros Landfill

PM: Particulate Matter

RCT: Rainwater Collection Tank

SCOEL: Scientific Committee on Occupational Exposure Limits

SLM: Sound Level Meter

SMME: School of Mining and Metallurgical Engineering

SPL: Sound Pressure Level

STEL: Short-term exposure limit

TSP: Total Suspended Particulate

TWA: Time-Weighted Average

UEL: Upper Explosive Limits

Chapter 1. EXECUTIVE SUMMARY

The present report analyses the operation of the Landfill Mining Pilot Demonstration Unit (PDU) of the Polygyros Landfill, which was installed within the context of the LIFE+ Reclaim project. The report analyses the processes which were used, the assessment of results from the pilot unit and provides the final conclusions from the unit's operation.

The waste excavation procedure followed the principles of surface (open-pit) mining using mainly a hydraulic excavator. The total amount of waste excavated and processed reached a volume of approximately 1300m^3 (580tn). 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. Special attention was paid to gas extraction wells and other fixed infrastructure found in the area. The haulage of the material was performed using standard dump trucks, which transported the excavated waste to a small pending area next to the PDU. The total number of working days with regard to the mining works was 34, while the average number of the trucks' routes per day was approximately 5.

The mined waste was then processed to separate the recyclable materials in the PDU. A Trommel Separation machine was placed at the entrance of the Pilot Demonstration Unit. Then, through hand-sorting facility allowed the recovery of glass, mixed hard plastics (PET, PP, HDPE), plastic film (mostly bags) and aluminium. A special magnetic device was placed after the end of the Mobile Materials Recovery Facility (M.M.R.F.) to remove any ferrous (magnetised) waste that was transported on the conveyor belt.

The project aimed also at processing electronic waste which was not found during the trial landfill mining in May 2014. A sample of 13.4 kg of Printed Circuit Boards (PCBs) was taken from old electronic waste was used for size reduction, treatment and retrieval of valuable metals, in the laboratory (beneficiation tests, flotation).

Finally, environmental monitoring works took place in order to assess the overall performance of the mining and processing operations as well as to evaluate the strains posed to the environment of the area. The environmental monitoring was conducted using a Continuous Ambient Particulate Mass Monitor - TEOM™, Personal Samplers and a Sound Level Meter to measure gas emissions/odors, dust and noise problems. Water samples were taken for further analysis, too.

The PDU Landfill Mining activities showed that there can be very important benefits from the method and that it can be an efficient tool for the recovery of materials, land and landfill space.

Chapter 2. INTRODUCTION

2.1. Action context and Objectives

The present report is the Deliverable of Action B6 of the LIFE Reclaim Project "Landfill mining pilot application for recovery of invaluable metals, materials, land and energy", which is funded by the European Union through Life+ financial instrument, under the contract with code LIFE12 ENV/GR/000427.

The Deliverable describes in detail the process of the Demonstration Unit's operation in Polygyros Landfill.

The objective of this action is the proper operation of the Demonstration Unit process, including:

- The waste mining on site,
- The field monitoring measurements,
- The beneficiation tests and
- The post-assessment of results.

The waste mining on site which is the core of the action realised from ENVECO's and HELECTOR's personnel while the field monitoring measurements were conducted by members of the National Technical University of Athens (NTUA) and ENVECO's team. Beneficiation tests were processed in the NTUA – School of Mining and Metallurgical Engineering (SMME) laboratories. The results of the waste mining process were analysed by ENVECO, under the consultation of NTUA.

The scope of Action B6 is to mine the waste from the Polygyros Landfill (PL), efficiently operate the Pilot Demonstration Unit (PDU) and conduct the necessary laboratory tests in order to analyse the results of the Landfill Mining Method.

2.2. General Information on LIFE+ reclaim

2.2.1. Project Objectives

The project aims at building a temporary pilot application on productive scale in order to 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 of management of past Landfill (LF) (controlled or uncontrolled) sites and create a useful tool for the recovery of:

- Useful materials, especially ferrous and non-ferrous metals,

- Space, which equals to extra landfill capacity and lifetime in cases of expansion,
- Soil material, which has been disposed off along with the waste and which is a natural resource valuable to local ecosystems as well as to landfill industry itself,
- Recyclable materials, 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.

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, Municipal Solid Waste (MSW) mining, operation and tests, Environment rehabilitation plan
3. Socioeconomics: Environmental Impact Assessment 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 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.

2.3. The Study Team

The Action and the present Report have been elaborated by the following Life reclaim associates:

From the team of ENVECO S.A.

- Spyros Papagrigoriou, Civil Engineer, Environmental Engineer, Dipl., MSc., MLitt

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- Nikos Tzimas, Mechanical Engineer
- George Koufodimos, Mechanical Engineer
- Spiros Sofianos, Civil Engineer
- Nikos Tsigas, Environmental Scientist
- Panagiota Konstantopoulou, Chemical Engineer
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- Dimitrios Kaliampakos, Professor of Mining Engineering and Environmental Mining at the SMME of the NTUA
- Konstantinos Tsakalakis, Professor of Mineral Processing at the SMME of the NTUA
- Dimitris Damigos, Associate Professor of Mining Engineering and Environmental Mining at the SMME of the NTUA

- Maria Menegaki, Assistant Professor of Mining Engineering and Environmental Mining at the SMME of the NTUA
- Andreas Benardos, Assistant Professor of Mining Engineering and Environmental Mining at the SMME of the NTUA
- Vasilis Protonotarios, Chemical Engineer
- Tasos Sotiroglou, Geologist

From the sub-contractors

- *RAM Europe Ltd staff*
- *Tsimerikas Bros staff*

2.4. Report Content

The present Report aims at presenting in detail the waste mining method including the machinery used and the results from the waste mining works (**Chapter 3**).

Chapter 4 describes the PDU operation process, the staff involved and the machinery used, as well as the difficulties appeared.

Chapter 5 presents the e-waste processing and specifically the beneficiation tests that took place in the laboratory. All three stages of the flotation tests and their results were analysed and the pulps obtained were investigated for the presence of metals and metalloids.

In **Chapter 6**, the environmental monitoring works are depicted, describing the implementation of the monitoring plan, as well as the results of air and water samples.

Finally, in **Chapter 7**, some general conclusions are presented, so as this report could serve as a reference for future application of the landfill mining method.

Chapter 3. WASTE MINING: PROCESS AND RESULTS

3.1. Description of Waste Mining Works

The target area for pilot application of the landfill mining, as it has been mentioned in the report of the **Action B2,** should be representative in terms of landfill's characteristics as well as waste content, easily accessible to the equipment and appropriately located in areas where the extraction works could not interfere with the daily waste disposal operations. The best possible arrangement, given the current state of the PL site, was to designate the mining area at the elevation of +622 m, at the central part of the disposal area.

In there the mining took place almost independently from the disposal operations. At the same time, the waste material found there covers a significant part of the PL's working life, from almost 2008 until 2014. Another advantage of the position is the minimization of the development works required for the setting up of the haulage road. The main internal access network of the PL was used, while only limited new road development is required at the level of +622. The area where the processing unit has been installed is located near the Leachate Collection Pond due to the proximity to electricity boards, while the entrance point of the disposal area, that has been proposed, **during Action B2,** as the best sitting placement for the DU, has been finally selected for the temporary storage of the processed material. The final arrangements, the designated mining and processing areas along with the proposed haulage access roads are presented in Fig. 3.1-1, 3.1.-2 and 3.1.-3.

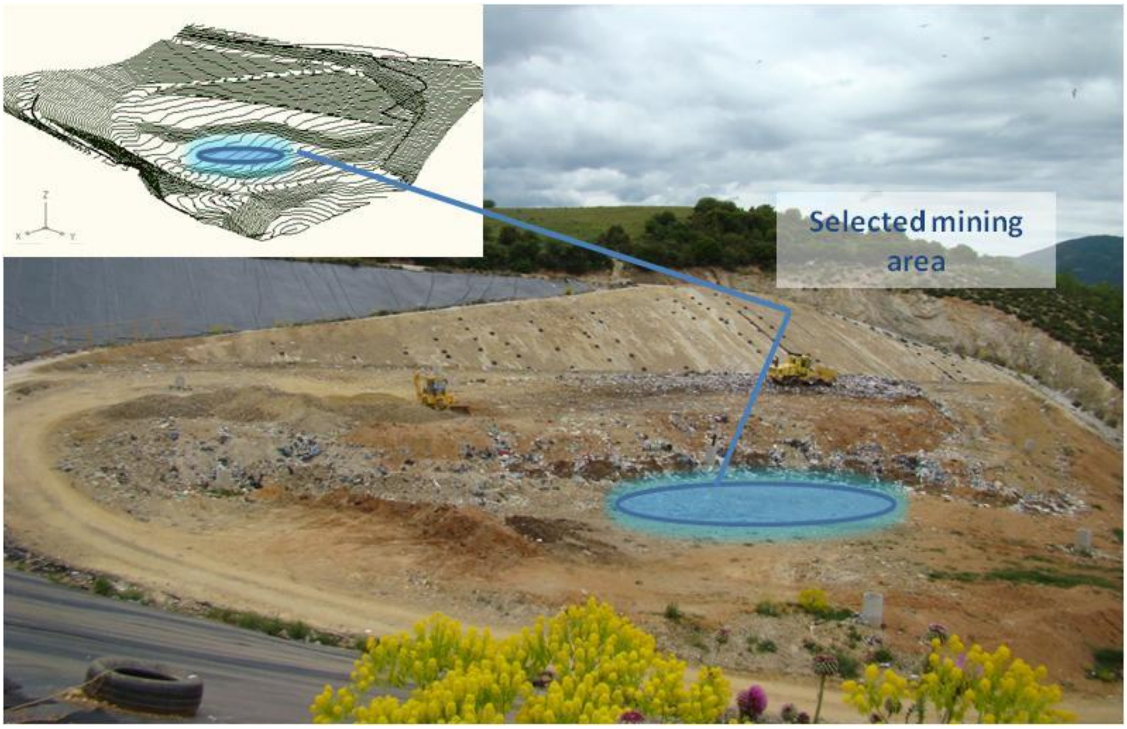


Figure 3.1-1: View of the proposed mining area in PL

Figure 3.1-2: Sitting of the selected mining area with regard to the processing unit

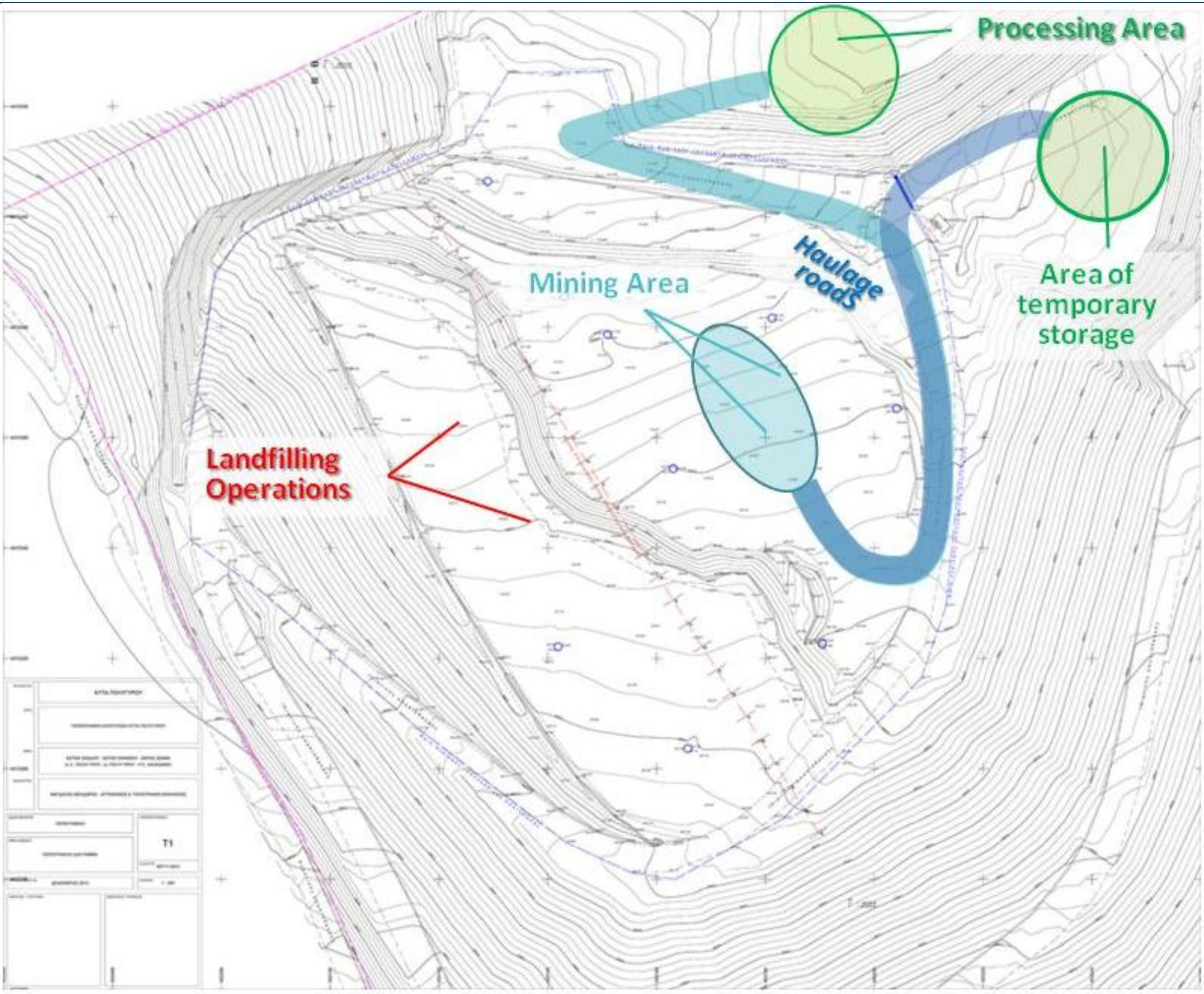


Figure 3.1-3: Location of the landfill mining area, with respect to the current landfilling operations and the proposed processing area and area of temporary storage

The total amount of waste excavated and processed reached a volume of approximately 1300 m^3 (loose material considering a swell factor ranging from 1.2 to 1.3). The required surface area for the mining activities is a relation of the extraction depth and the volume of the waste material required. Given that at the focus area the disposal depth is ranging between 7 and 8 m the excavation depth was set to 5 m, taking into consideration that a buffer of at least 2 m should be left form the base of the disposal area. The dimensions of the excavation area were 30 X 7 m, covering an area of 210 m^2.

3.1.1. Implementation of Waste Mining Plan (Action B2)

The excavation procedure, through which the waste is extracted from its place, 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 take place from the top (+622 m level) using a hydraulic excavator at the crest area (Fig. 3.1.-4), rather than making the extraction from the toe, using front-end loaders and by scraping the wastes, since the latter would require the development of an initial trench excavation and then the moving of the equipment (front loader and bulldozers) at the lower extraction level. This method could be applied successfully to a large scale mining scheme, but in the current mining application the development of the initial trench alone would have generated almost the majority of the required waste volume. Therefore, instead of making preparatory works, the direct mining approach selected for the Polygyros pilot LFM was simpler, straightforward and therefore less risky and more productive.

Figure 3.1-4: Application of the top excavation method in the landfill mining area

The excavator performed quite well with high productivity, extracting the loose waste found below, up to a depth 5 m. To be more specific, 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. 3.1.-5).

For flexibility reasons, during the pilot application a small volume of processed waste was need to be stored in a small stockpiling area, near the entrance point of the disposal area, as mentioned above.

Figures 3.1.-6 3.1.-7 and 3.1.-8 present the initial excavation and the sitting of the excavation works with regard to the disposal waste works, the processing unit and the temporary storage area, respectively.

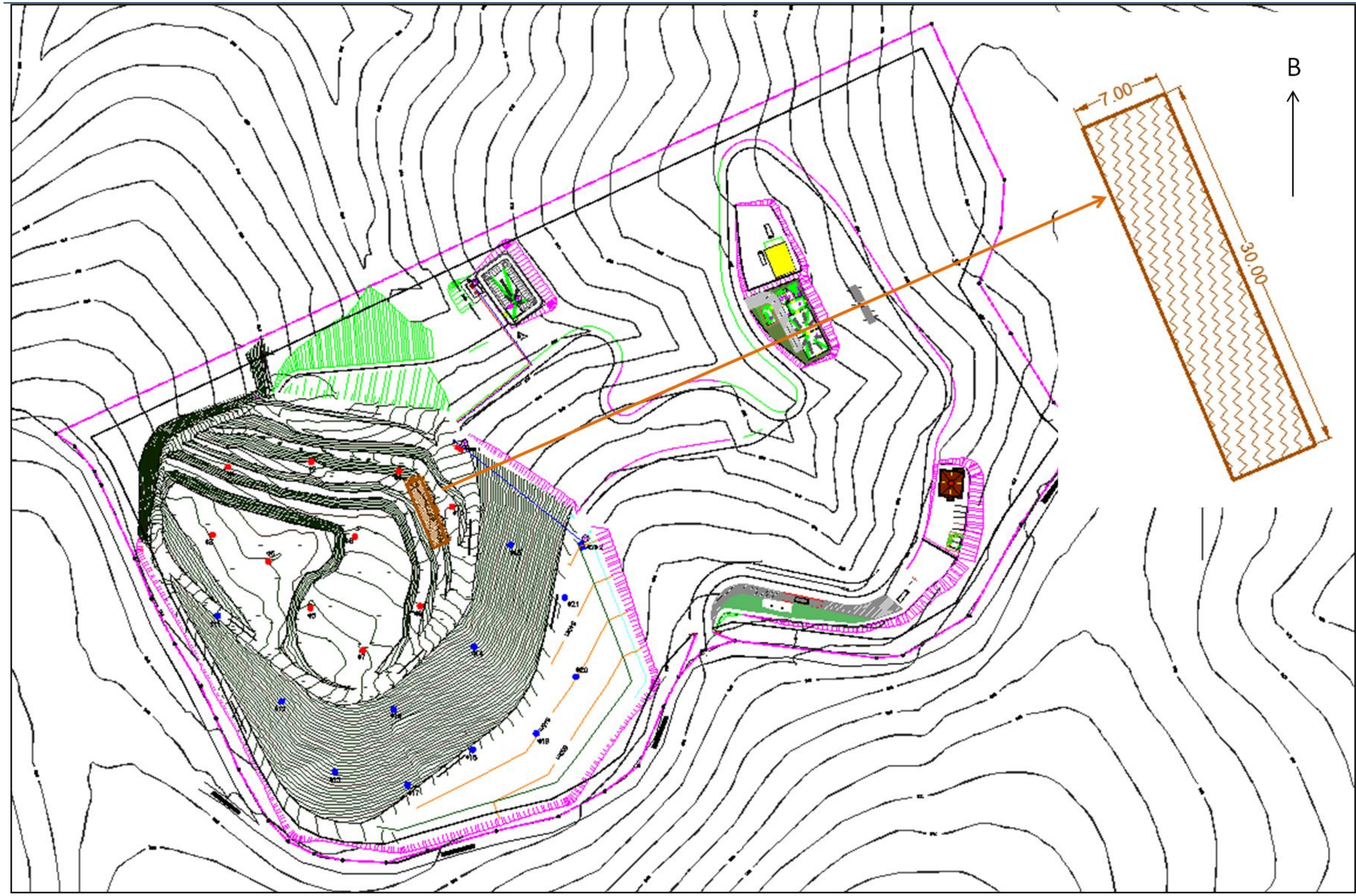


Figure 3.1-5: Sitting, orientation and dimensions of the final "box cut" of the landfill mining area

Figure 3.1-6: Initial excavation in the landfill mining area

Figure 3.1-7: Sitting of the excavation and the waste disposal waste works

Figure 3.1-8: Sitting of the excavation, the processing unit and the temporary storage area

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.

Special attention was paid to gas extraction wells and other fixed infrastructure found in the area. In terms of stability, the relatively shallow excavation did not create strains or problems to the slope. The final slope of the mined area did not exceed the 1:3 limit. Furthermore, a buffer distance of at least 10 m was kept between the mined area and the adjacent slope of landfilling operations. A safety distance was kept between the loading trucks and the trench's crest, with each truck stopping at least 2 - 3 m away from the working face.

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. More specifically, the mining face had been covering with soil on a daily basis, at the end of the working shift, so as to minimize odor issues, reduce windblown litter, etc.

The haulage of the material was performed using standard dump trucks (fig. 3.1-9). Their capacity was quite adequate to cover the capacity of the excavator and the processing unit, given the relatively small transport distance. The road network was periodically inspected and properly maintained. Water spraying has been applied in the road surface, with the use of tanker trucks, in certain periods in order to avoid dust problems.

Figure 3.1-9 Haulage of the excavated material

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. The processed waste has been loaded to trucks with front loader equipment and transported for their disposal in the landfill site, while the recovered soil has been used for covering purposes. Upon the completion of the materials processing and the end of the pilot application the closure of the mined space (trench) has been completed. More specifically, the closure has been made by the introduction of new waste material in the mined space, through standard landfilling operation. Within a period of 10 days the mined void has been re-filled with waste and brought back to its original condition (fig. 3.1-10).

Figure 3.1-10. The restored mining area

3.2. Used Machinery and Personnel

3.2.1. Machinery used

The PDU was placed on a pre-selected area nearby the existing PL leachate collection pond, which serves for the protection of ground and underground waters from wastewater coming from treated waste. The Separation Unit consisted of several machines placed in a layout conducive to the separation and the collection of selected materials.

A Trommel Separation machine was placed at the entrance of the PDU. This machine was suitable for processing, screening and separating of domestic waste as well as various materials and waste. Its technical characteristics have already been described in the preceding chapters. This separating machine produced two (2) fractions of landfill mined waste. The first (1st) fraction (<70 mm) consisted mainly of organic material, soil, small stones and debris (small particles made of plastic, glass, wood and metals), while the second (2nd) fraction (>70 mm) consisted of the rest of the waste (metals, plastics, glass, bigger stones, wood, fabric and residual waste). The produced fractions were coming out of the machine from different sides, in order to avoid mixing of the processed streams. Specifically, the separation of the streams is achieved through:

– A conveyor belt placed on the side of the machine (on the side of the rear edge of the drum) with some incline. Its length is 5,000 mm and its width is 800 mm, and it serves for unloading the screened material which has passed through the holes of the rotating screen (1st fraction).

– A rear unload conveyor belt, at the output of the drum, of 5.000 mm length and 800 mm width, serving for the unloading of the material which had not passed through the screen holes and was left in the drum (2nd fraction).

The 1st fraction was collected and stored in a specific area at the landfill cell for further treatment after the replacement of the 70mm holes drum with a 10mm holes drum. A truck was standing by the side belt in order to collect the 1st fraction and drive it to the storage area.

After the mechanical separation of the materials under 70 mm, the materials above 70 mm were forwarded to a moving elastic conveyor belt for the supply of waste of a length of 10 m and a width of 1.1 m and free workspace, while at various instances of the belt there were sideways working points enabling a manual sorting of the recyclable materials.

This sorting facility allowed the recovery of the following categories of materials:

- Glass
- Mixed hard plastics: PET, PP, HDPE
- Plastic film (mostly bags) and
- Aluminum

The materials were manually collected mostly in big-bags placed by the side of the conveyor belt.

A special magnetic device was placed before the end of the Mobile Materials Recovery Facility (M.M.R.F.) and vertically to the belt. This device was automatically removing any ferrous (magnetised) waste that was transported on the conveyor belt. As the waste passed underneath the magnet, its ferrous fragments were attracted and removed from the conveyor belt without the need of staff presence. As the waste reached the edge of the belt, it was thoroughly forwarded into a special collection bin.

After the manual removal of plastics, aluminium, glass at the M.M.R.F. and the automatic removal of ferrous material in the magnetic arrangement, all residual waste was carried through the conveyor belt to the end the belt where it was collected in a suitable bin.

Finally, the collected recyclables were washed in a metallic washing device (laundry). The laundry consisted of a rotary device, where the materials to be washed were placed manually. It was connected to the water supply from the water system and it was based on a metal base founded on the ground. When the materials were placed inside and the import gate was closed, the washing cycle began by pressing the start/stop button. The duration of the washing cycle depended on the kind of the materials.

Some additional machines were used for the landfill mining and the feeding of the separation unit. Firstly, an excavator was loading a truck with waste from a specific point of the landfill cell. The loaded waste was deposited in front of the Trommel separator machine. From this deposit a shipper was loading the trommel with waste. As mentioned above, another truck was loading from the side belt of the separation unit, with the 1st fraction. This fraction was deposited for further elaboration, with 10mm holes drum.

When the drum was changed, the 1st fraction was loaded to a truck and loaded again to the trommel. The result was: Solids <10 mm (29 t) biologically stabilized (anaerobically digested), with very little impurities (plastic, glass, metals etc.) and complying with most of the standards for soil used for daily coverage of MSW landfills in accordance with the Ministerial Decision 56366/4351/2014 (i.e. complies with the standards for heavy metals: Zn, Cu, Cd, Pb, Hg,Cr and As, apart from Ni, and also with the standard for Polyaromatic Hydrocarbons, PAH).

In summary, and as described above, for the appropriate procedure of excavation and separation of 1260 m^3 of waste a separation unit and two trucks, an excavator and a shipper for loading were used.

3.2.2. Personnel

The role of human factor was very important for the success of the landfill mining and separation process. During the planning phase and even more during the execution of the project work, all the team members had a constructive cooperation.

The greatest amount of human resources was required during the execution of the Landfill Mining process. As mentioned above, a host of different machineries were used for the success of the project work. There was the waste separation unit, two trucks, an excavator and a loader.

In more detail, after the mechanical separation of waste has been completed, a manual separation followed. There were 3 working posts on each side of the belt, and there were 6 workers (3 on each side) in total. There was also an engineer who was responsible for the management and the operation of the mechanical and manual separation unit. Nearby was another, technical support engineer who oversaw the function and the technical parts of the unit and was responsible for fixing mechanical problems. For the operation of the trucks there was a properly-licensed driver. The key team member who was responsible for the excavation of the waste and moreover for the loading of Trommel separation unit was the machine operator.

Apart from the working staff that participated actively in the landfill mining process, a number of people performed desk work. One person was responsible for keeping a daily record of activities. In that record, among others, he tracked the daily excavation volume and the weight of the separated materials. There were also a PDU manager and assistant manager who were commissioned for the appropriate operation of the whole process. Their duties were to monitor and control the procedures that were taking place in the landfill area. They indicated the places where the PDU was to be placed and also the excavation areas. In addition, they were responsible, during the planning phase, to suggest which machinery was appropriate for the project work.

During the execution or the project, they were also responsible for the health and safety for both the personnel and the machinery.

3.3. Results from the Waste Mining Works

As mentioned above, the rate of excavation was directly linked with the feeding capacity of the processing unit. This means in practice that the mining works were not performed on a daily basis in order to avoid the stockpiling of waste. The total number of working days with regard to the mining works was 34, while the average number of the trucks' routes per day was approximately 5. Figure 3.3-1 presents the number of dumps truck's routes per day. As it can be shown in the Figure 3.3-1 there is a linear increase in the number of trucks' routes during the progress of the pilot application, which is related with the optimization of the processing unit operations.

The total number of routes that have been carried out during the pilot application was 158. Given that the carrying capacity of each truck was 8 m^3, the total volume of excavated waste was estimated at 1264 m^3. This volume is very close to the volume of loose material estimated according to the swell factor used.

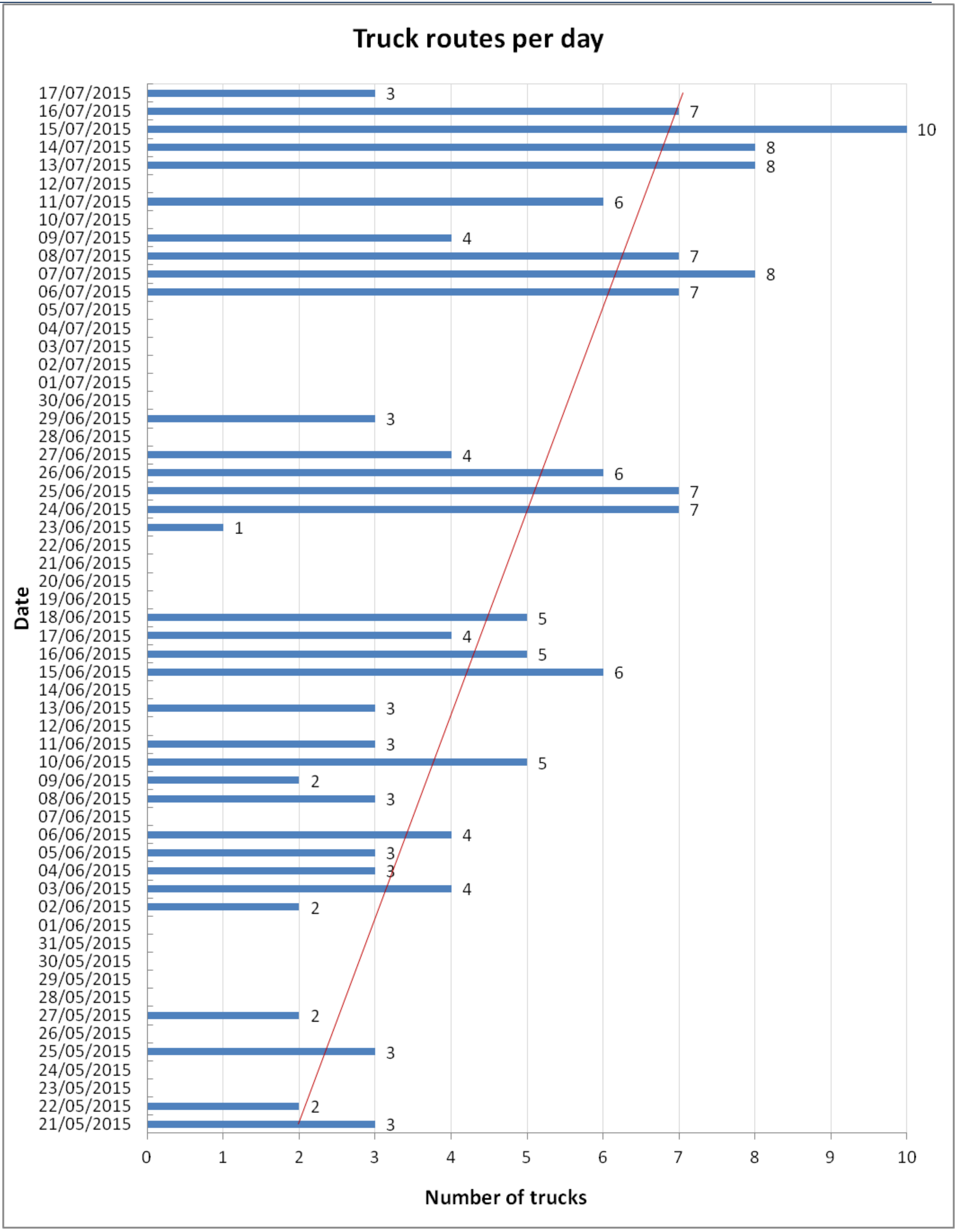


Figure 3.3-1: Number of dump truck's routes per day

The mean time of the load haulage cycle duration, including transportation to the weighbridge and back, was approximately 24 minutes. The total mass of waste was calculated at about 580.5 tons.

The cumulative volume of excavated waste on a daily basis is presented in Figure 3.3-2.

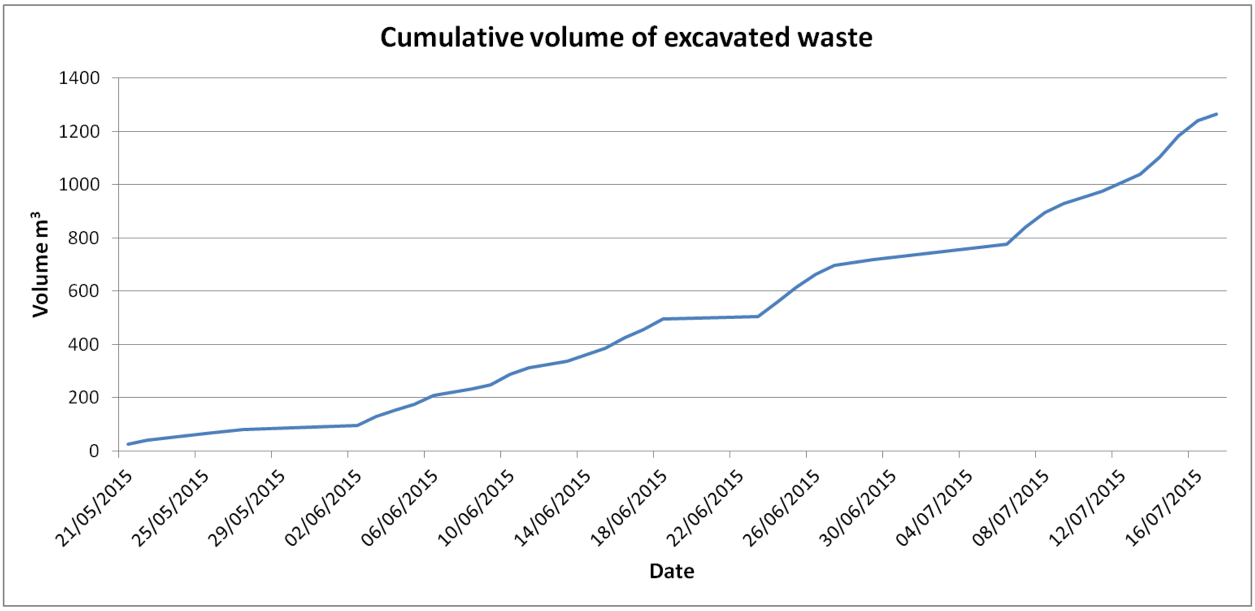


Figure 3.3-2: Daily cumulative volume of excavated waste

3.4. Difficulties – Deviations

During the first days of waste mining for the PDU, it became apparent that some changes were necessary to optimise the procedures and increase the speed of the excavation and processing of the waste. The most important of these changes was the utilisation of more assistant machinery. Initially, it was predicted that a Backhoe Loader and a Truck would only be necessary for the operation of the PDU but it was quickly apparent that more equipment was needed, thus, a **large Excavator** was also rented for the mining works, so that the Loader could be working constantly at the PDU site, feeding the Unit, moving materials, etc. The excavator was much more powerful and productive than the Backhoe Loader so it was better suited for the mining works. It was stationed by the excavation site and the excavated material would be loaded immediately to the truck of the Unit and forwarded to the stock pending area, in front of the PDU.

An important deviation to the previous plans of the PDU is the actual **final quantity of mined materials**. At the design period, during Action B3, it was proposed that the final quantity of processed waste would reach 2000m^3, instead of 1000m^3, which was mentioned in the LIFE reclaim Grant Agreement in the beginning of the project. This larger sample would serve to reach to firmer conclusions about the contents of the landfill and the operation of the PDU. However, even though the PDU was designed to process 2000m^3, due to many issues and delays during the processing of the waste, the productivity of the Unit was far lower than it was initially expected. To increase productivity, many changes to the machinery, adaptations and optimizations to the Unit were realised, whilst trying to keep the cost within the budget. These steps helped to reach up to a total of 1260m³ of mined and processed waste, a quantity which might be lower than the proposed one but it was decided amongst the experts of the Project Team that it would be sufficient so that specific conclusions about LFM could be drawn.

As the mining works were centered on a particular spot in the landfill cell, during the early days of mining and processing of the waste it was discovered that the soil and rock content was very high, causing problems with the PDU machinery. However, as the days passed and the excavator was digging vertically deeper into the cell, the soil material became less. This phenomenon was attributed to the «covering» of the waste during landfilling, as every ledge of landfilled waste should be sufficiently covered with a layer of soil material. The rocks were also used in purpose during landfilling to create better drainage of the waste.

The weather proved to be one of the most unexpected and productivity-lowering challenges of both the mining works and the PDU. Out of the 45 total days of operation (as per contract), from the beginning of June until mid-July, almost 20 of them had a smaller or bigger amount of rainfall, as it is shown in the chart of Figure 3.4-1 below. Rain would altogether halt the processing procedures, thus the mining works would have to be stopped as well. Also, the stock area should have been covered, at least during rainy days and for a few times a plastic sheet was used as temporary cover. Otherwise, the stock waste was also wet during the next day after heavy rainfall, causing many problems to the PDU and decreasing the productivity of the Unit.

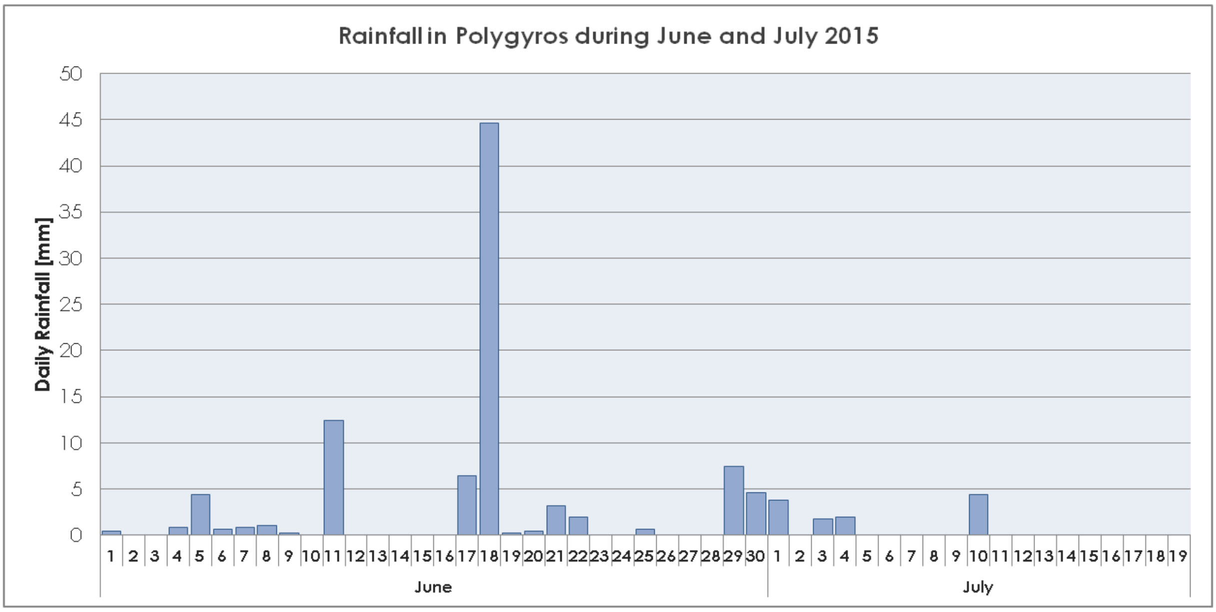


Figure 3.4-1: Rainfall in Polygyros during the operation of the PDU (June and July 2015, source: National Observatory of Athens)

On the other hand, the rainfall kept the waste humidity to an increased level, eliminating entirely any flying dust from the mining works and the need to wet down the mining pit or the landfill roads. Also, during the mining works, there were no issues concerning biogas emissions, as hardly any dangerous gases were detected by the environmental monitoring equipment, as it is analysed in Chapter 6. Finally, due to the fact that this pilot is taking place inside a modern landfill of compact and engineered structure, there were no issues regarding the stability of the waste during the mining works.

Chapter 4. PILOT DEMOSTRATION UNIT (PDU) OPERATION

4.1. Description of PDU Works

The PDU operation followed the steps below:

1) Waste excavation using a hydraulic excavator and placement of the buried waste into a truck.

2) Transport, weighing and deposition of the waste to the designed space next to the PDU (pending area).

3) Collection of a bucketful from the deposited waste and emptying it into the trommel.

4) Ripping of waste bags with incorporated in the trommel knives, while spinning waste to separate it to over and under 70 mm diameter.

5) Separation of the waste under 70 mm diameter into a platform tractor.

6) 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, aluminum.

7) 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. The procedure was time recorded for statistical analysis. A record sheet was created in the context of the Action B5 so as the consultant to be able to concentrate all the necessary information needed for the analysis.

4.1.1. Machinery and Personnel

The PDU operation was held by

- ENVECO's engineers/scientists who were supervising the procedure, recording quantities and time units, taking decisions and solving unexpected difficulties.

- HELECTOR's engineers/scientists who were inspecting the management of the LF and communicating with the competent authority.

- Sub-contractor's personnel, consisted of a mechanical engineer, a technician and eight people carrying out the hand sorting of the waste.

- Assistant machinery's operators (excavator, truck, platform tractor and backhoe loader operators).

The Machinery used for the operation of the PDU consisted of the following equipment:

- Backhoe loader (JCB)
- Hydraulic excavator
- Truck
- Platform tractor
- Mobile Pilot Demonstration Unit (trommel, picking line, magnet)
- Washing machine
- Scale
- Continuous Ambient Particulate Mass Monitor - TEOM

4.2. Results from PDU Works

After five days of testing the PDU in late May, the official PDU operation started in the beginning of June and was concluded on the 19th of July 2015. Out of these days and excluding the days when the production was stalled due to the weather conditions or to machinery malfunctions, the **total days of work were 32.**

During the PDU operation, every action was recorded by the Project Team on a special template which was created for this purpose. Specifically, these records are showing:

- **The weighting of the mixed mined waste:** this table records the number of trucks filled with excavated waste, how many buckets of the excavator were employed to fill each truck, what time it was unloaded and the weight of each load, prior its transport to the pending area.
- **The Feeding of the Unit:** What time did the shift began each day, when there were brakes and what time it ended, how many buckets of the loader were fed to the Trommel, etc. Although these records were not kept closely throughout the day, they proved to be helpful in realising whether there were any delays in the process or if other adjustments could be made to the PDU to increase the overall productivity of the Unit.
- **The transportation of the <70mm material fraction:** This sheet was used to record the actions of the tractor platform; The time it was filled, the amount of time it took to be unloaded to a temporary storing area and return so that the PDU could restart with the processing, the number of times this was happening during each day, etc.
- **Changing Big Bags (BB):** This covered the time it took the loader to collect and put away the filled BB from the PDU or empty the Residues in the truck using a special bucket fitment. Again, these records were not kept at all times but they assisted in making necessary changes to further increase the productivity of the Unit.

- **Weighting Records:** Prior storing, all of the BB of the separated materials were being weighted using the truck. Apart from the weight and the number of BB, the records also marked the date and time when this process took place.

The analytic daily records are attached in Appendix 3. In the Table 4.2-1 below, a summary of the most important results is being presented:

Table 4.2-1: Summary of the PDU operation results

Mining Works			
Total No. of Trucks carrying excavated material	**Total Volume of excavated material per truck**	**Total Volume of excavated material**	**Total weight of excavated material**
160	8 m³	1264 m³	580547 kg
<70mm Material fraction			
Total No. of tractor and platform transporting <70mm material	**Total Volume of material per platform transportation**	**Total Volume of <70mm material**	**Mean weight of each load**
145	3 m³	435 m³	2670,9 kg
Weighting Records			
Aluminum	**Ferrous metallic materials**	**Plastic Bottles (PET, HDPE, etc)**	**Glass**
1612 kg	6220 kg	19470 kg	1680 kg
Soft Plastic (FILM, etc.)	**Residue material**	**<70 material fraction (approximate weight)**	**<10mm material fraction (soil)**
32570 kg	131710 kg	387285 kg	28700 kg

According to these data, an approximate mean content of the waste of the PL is presented in the chart below:

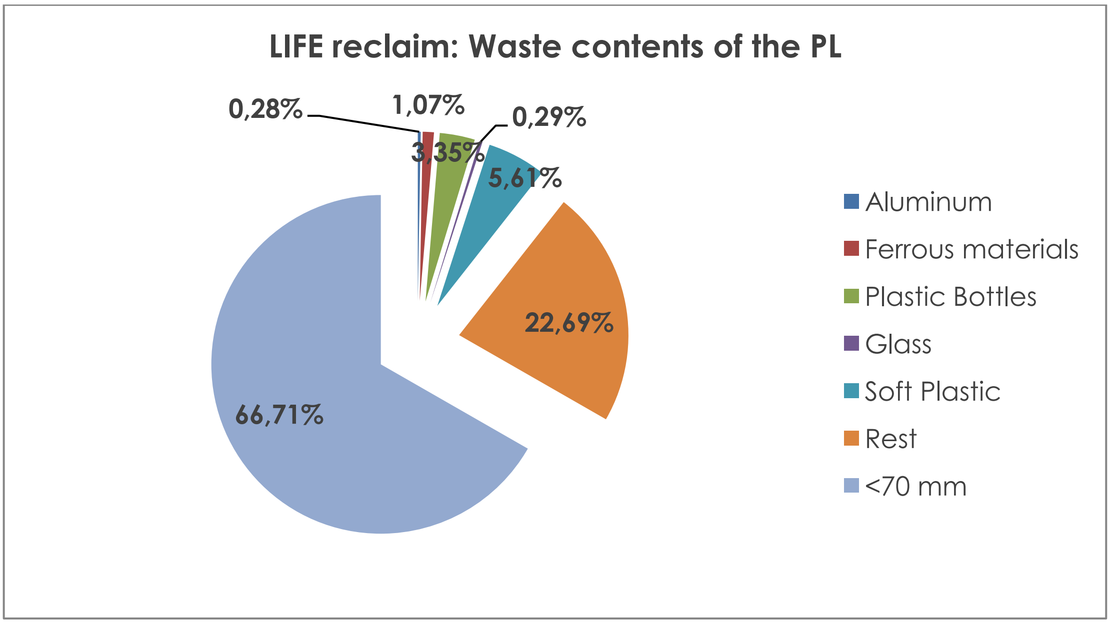


Figure 4.2-1: Presentation of the contents of the waste in the PL, w/w% comparison (LIFE reclaim project)

Thus, it is evident that the biggest fraction out of the excavated waste is the <70mm material fraction, which contained soil, rocks, organic material and smaller-sized waste particles. The second biggest waste stream at 22.69% is the "Rest" which is the residual materials. Out of the separated materials, the two biggest ones were the plastic: soft plastics were found to be the 5,61% of the waste whereas a 3,35% were the hard plastic components (PET, HDPE, etc.).

Further analysis on the <70mm material fraction indicates:

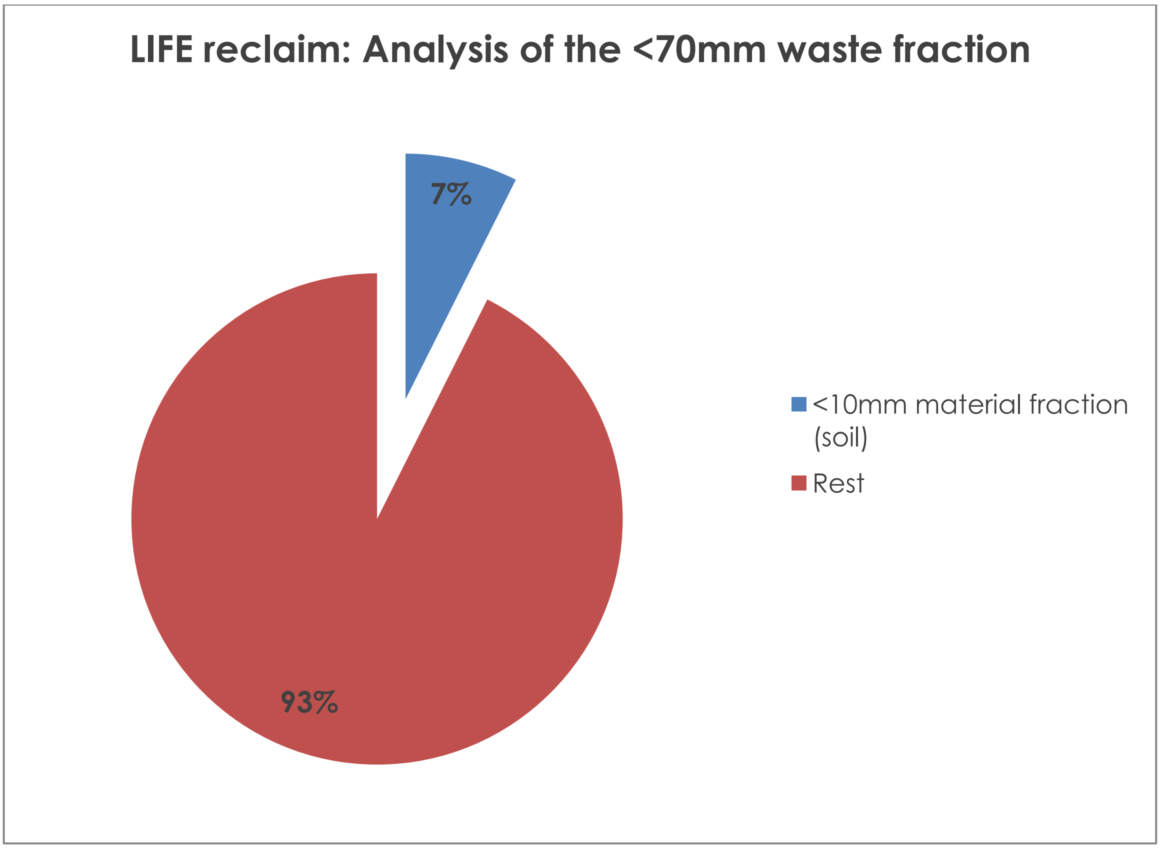
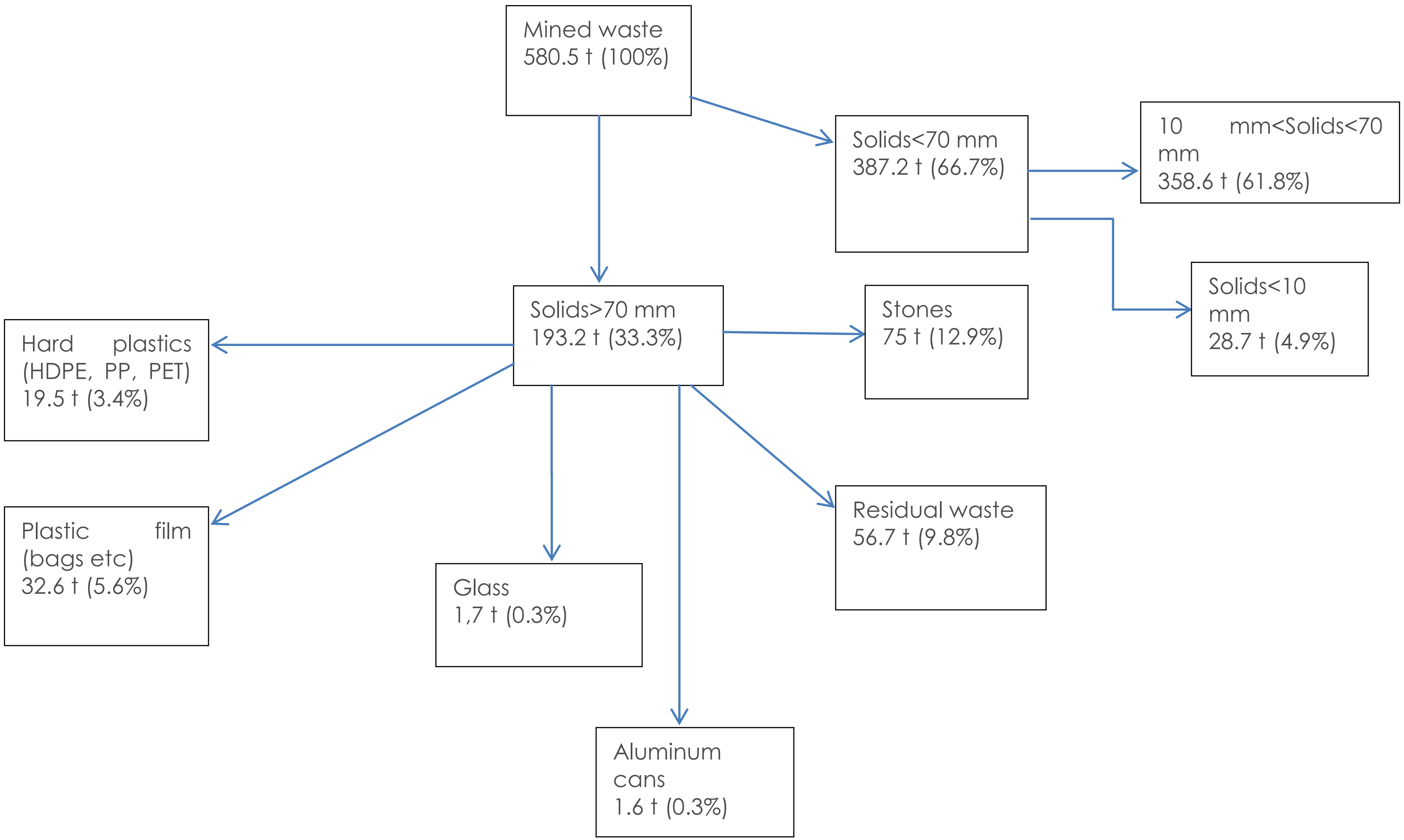


Figure 4.2-2: Presentation of the reclaimed soil content of the <70mm material fraction of the waste in the PL, w/w% comparison (LIFE reclaim project)

So, the reclaimed soil material (<10mm fraction) out of this process was 7% of the <70mm material fraction. Compared to the total amount of excavated waste, the **reclaimed soil fraction comes at 4,9%.**

Analysis of the material fraction <70mm

Flow diagram of mined waste treated and materials and residual waste produced



Solids undersize 70 mm that were produced after treatment in trommel were collected in a specific area in the landfill for further mechanical treatment and for lab analysis.

A representative sample of this part that weighed ~14 Kg was collected and sent to lab for a series of tests (solids fractional analysis, specification of impurities, biological stability etc) with the aim to find if this fraction of waste could be reused as material for landfill daily covering.

There are no specifications in Greek legislation for this specific material coming from mined waste (if wanted to be used for above purpose).

There is a national Common Ministerial Decision (56366/4352/2014) that contains technical specifications of compost and digestate produced in Mechanical Biological Treatment plants for Municipal Solid Waste that can be used as material for landfill daily covering, landfill and mines' restoration etc. but this does not apply, legally, for mined waste digestate.

According to this decision the compost/digestate produced in MBTs must be stabilized and contain maximum impurities 3% w/w (glass, metals, plastics) and must comply with a series of chemical and biological standards.

Lab analysis showed that the organic matter of mined waste (fraction<70 mm) from Polygyros landfill was biologically stabilized (SOLVITA test parameters: CO_2=6 και NH_3=4).

Lab analysis showed, also, that fraction<70 mm had 11.8% impurities and the fraction that complied with <3% w/w impurities (above legislative standard) was that undersize 10 mm.

Chemical analysis took place on the undersize 10 mm fraction and the results are compared with the limit values reported in above mentioned Ministerial Decision 56366/4352/2014 in the table below:

ANALYTICAL RESULTS				
Heavy metals				
Parameter	**Analytical Method**	**Result/Limit***	**LoQ**	**Units**
Zinc	TMECC 04.06 and TMECC 04.13B	191/1,200	0.5	mg/Kg dry
Copper	TMECC 04.06 and TMECC 04.13B	55.8/400	0.5	mg/Kg dry
Nickel	TMECC 04.06 and TMECC 04.13B	**382**/100	0.1	mg/Kg dry
Cadmium	TMECC 04.06 and TMECC 04.13B	0.17/3	0.05	mg/Kg dry
Lead	TMECC 04.06 and TMECC 04.13B	31.1/300	0.1	mg/Kg dry
Mercury	TMECC 04.13A	0.0067/2.5	0.00	mg/Kg dry

Chromium	TMECC 04.06 and nTMECC 04.13B	51.0/250	0.1	mg/Kg dry
Arsenic	TMECC 04.06 and HG - AAS	1.08/10	0.01	mg/Kg dry
***limit** value according to Ministerial Decision 56366/4352/2014, **LoQ :** Level of quantification				

ANALYTICAL RESULTS				
Polyaromatic hydrocarbons (PAHs)				
Parameter	**Analytical Method**	**Result**	**LoQ**	**Units**
Naphthalene	EPA Method 8310 (HPLC-Fl)	0.89	0.10	mg/Kg dry
Acenaphthalene		<LoQ(0.06)	0.10	mg/Kg dry
Acenaphthene		N.D.	0.10	mg/Kg dry
Fluorene		N.D.	0.10	mg/Kg dry
Phenanthrene		<LoQ(0.07)	0.10	mg/Kg dry
Anthracene		0.12	0.10	mg/Kg dry
Fluoranthene		N.D.	0.10	mg/Kg dry
Pyrene		N.D.	0.10	mg/Kg dry
Benzo (a) anthracene		N.D.	0.10	mg/Kg dry
Chrysene		N.D.	0.10	mg/Kg dry
Benzo (b) fluoranthene		N.D.	0.10	mg/Kg dry
Benzo (ι) fluoranthene		N.D.	0.10	mg/Kg dry
Benzo (a) pyrene		N.D.	0.10	mg/Kg dry
Indeno (1,2,3-c,d) pyrene		N.D.	0.10	mg/Kg dry
Dibenzoanthracene,		N.D.	0.10	mg/Kg dry
Benzo (g,h,i) perylene		N.D.	0.10	mg/Kg dry
N.D. : Not detectable, **LoQ** : Level of quantification **<LoQ** : result smaller than level of quantification (traces)				

According to Ministerial Decision 56366/4352/2014 the sum of PAHs concentrations must be <3 mg/Kg dry.

ANALYTICAL RESULTS			
Analytical Method: EPA 3550 C 2007+ EPA 8270D 2007			
Parameter	**Result**	**LoQ**	**Units**
PCB-28	N.D.	0.025	mg/Kg
PCB-52	N.D.	0.025	mg/Kg
PCB-81	N.D.	0.025	mg/Kg
PCB-77	N.D.	0.025	mg/Kg
PCB-95	N.D.	0.025	mg/Kg
PCB-101	N.D.	0.025	mg/Kg
PCB-99	N.D.	0.025	mg/Kg
PCB-110	N.D.	0.025	mg/Kg
PCB-123	N.D.	0.025	mg/Kg
PCB-118	N.D.	0.025	mg/Kg
PCB-114	N.D.	0.025	mg/Kg
PCB-105	N.D.	0.025	mg/Kg
PCB-126	N.D.	0.025	mg/Kg
PCB-151	N.D.	0.025	mg/Kg
PCB-149	N.D.	0.025	mg/Kg
PCB-146	N.D.	0.025	mg/Kg
PCB-153	N.D.	0.025	mg/Kg
PCB-138	N.D.	0.025	mg/Kg
PCB-128	N.D.	0.025	mg/Kg
PCB-156	N.D.	0.025	mg/Kg
PCB-157	N.D.	0.025	mg/Kg
PCB-169	N.D.	0.025	mg/Kg
PCB-187	N.D.	0.025	mg/Kg
PCB-183	N.D.	0.025	mg/Kg
PCB-177	N.D.	0.025	mg/Kg

PCB-180	N.D.	0.025	mg/Kg
PCB-170	N.D.	0.025	mg/Kg
PCB-189	N.D.	0.025	mg/Kg
PCB-167	N.D.	0.025	mg/Kg
PCB's SUM in according to DM 27/09/2010	N.D.	0.025	mg/Kg

N.D. : Not detectable **LoQ :** Level of quantification

<LoQ : result smaller than level of quantification (traces)

According to Ministerial Decision 56366/4352/2014 the sum of PCB number 28, 52, 101, 118, 138, 153 and 180 concentrations must be <0.4 mg/Kg dry.

From above analytical results it is shown that the landfill mined fraction undersize 10 mm is stabilized and complies with all physicochemical standards of Ministerial Decision 56366/4352/2014 for landfill daily covering etc. apart from Ni concentration.

It is proposed that this fraction will be used as material for waste daily covering as it resembles a lot to soil. Also, the Ministerial Decision does not legally apply for this material, and Ni concentration does not seem to be a problem in the specific use of material as daily covering. After all, the material will be landfilled again.

The percentage of the material undersize 10 mm is 5% and the percentage of stones collected manually from the fraction oversize 70 mm is 13%, as can be seen in above flow diagram. In this case, overall **28% w/w of landfill mined waste** is proposed to be used as material for landfill daily covering.

Future investigation is necessary to confirm above results and proposal.

4.3. Difficulties – Deviations

As mentioned extensively in chapter 3.4, **the weather** in Polygyros was the most difficult challenge that the PDU faced. Rainfall was detected at least 20 out of the total 45 days of the PDU. Due to the fact that the Unit was not designed to operate under such conditions, under heavy rain, the production had to stop. Also, the higher water content of the waste slowed down the processing and made hand-sorting much more difficult.

In the course of the first days of operation, it became apparent that the **collection of the residual material** was not running smoothly. At first, a BB was fixed at the end of the membrane to collect the residual waste, however, this was being filled too fast and it had to be removed and replaced up to 4-5 times each day (Figure 4.3-1 and 2). This moving included the halt of the motion of the membrane, the use of the backhoe loader for moving the BB and the assistance of up to 3 hand-sorting workers. It was an impractical method, delaying the production, thus, a different approach was used. The contactor provided 3 small skips with no extra charge. These skips bore a special fixture which could be easily used by the backhoe loader to lift them quickly and move them as necessary (Figures 4.3-3 and 4). When the skips were filled, they would be emptied into the truck, which would be weighted and then unload the residual material on the operating cell of the landfill. This method proved to be much quicker than the previous one, thus it was used until the end of the operation of the PDU.

Figure 4.3-1 and 2: Collection of the residual material at the end of the membrane, using a BB (LIFE reclaim project)

Figure 4.3-3 and 4: Updated collection of the residual material at the end of the membrane, using a special skip (LIFE reclaim project)

Furthermore, during the course of the project, a serious reason for production delays was the various **machinery malfunctions** that the Team faced. First of all, the backhoe loader, which was vital for the operation of the Unit as it was used constantly to feed the Trommel, suffered from many mechanical issues. The worst of them happened when one day it got a flat tire. As it was expensive to change these special tires, it was eventually mended but the production during that day was lost. Also, many problems with the moving membranes were caused, mainly due to the many heavy rocks contained in the extracted waste. To repair these damages, some more delays occurred (around 1-2 days).

Hiring locals as **hand-sorting workers** was also a bit challenging. Having 8 to 9 workers was important to keep the production running at a high pace. The Polygyros Landfill (PL) is located at a 5 minute drive away from Polygyros and two other small villages, all of which had very few workers. On the other hand, there were more people wanting to come and work at more remote villages. The commute to and from however proved to be a challenge, as most of them did not have a car. Also, most of the locals had only been working at seasonal agricultural jobs and were reluctant to come in contact with the waste. Finally, during the second week of operation, most of the workers had started to come every day and with 2 or 3 changes of workers due to a number of reasons, most of them stayed until the end of the PDU operation.

Figure 4.3-5: Hand-sorting workers: a difficult but most necessary job during LFM (LIFE reclaim project).

The aforementioned factors led to the change of processed waste goal, as was also mentioned in Chapter 3.3: even though at the design stage of the PDU it was mentioned that the final quantity of processed waste would reach 2000m^3, the **production of 1264 m^3** was achieved during the 45 days of operation of the PDU (as per contract). It was decided amongst the experts of the Project Team that would be sufficient to draw specific conclusions about LFM.

Chapter 5. E-Waste Processing: Beneficiation Stage

5.1. Description of Size-Reduction and Beneficiation Works

The size reduction and the beneficiation of the e-waste materials is an important step towards assessing the potential of these materials to be actively recovered, enriched and marketed in order to enhance the overall financial bottom line of the overall landfill mining endeavor. In the next sections the whole process is presented and the results obtained from the beneficiation stage are given in detail and assessed in terms of their efficiency to recover the valuable materials especially found in the printed circuit boards (PCBs).

5.1.1. Collection of E-Waste

The project expectations were 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 in May 2014 no electrical or electronic waste was found. In order to achieve the target of the project, a sample of e-waste (13,4 kg of electrical and electronic boards) was taken from dismantled old electrical and electronic waste, 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.

5.1.2. Size-reduction

The e-waste had to undergo specific treatment in order to acquire the desirable size. To perform this process, OIKOKYKLIOS S.A. was chosen, because of the company's specialization in the recycling of electronic devices, as well as their possession of appropriate equipment and knowhow.

Firstly, the collected electronic boards went through manual separation, in order to be cleansed of impurities and avoid further milling. Also, big parts constructed of the same material (e.g. aluminum) were dismantled and separated manually. Afterwards, the materials were separated by kind through a process including two types of shredders. First, the boards were placed in the crushing machine (pre-shredder) to start the size-reduction process; this downsized the granulometry of the incoming electronic boards to a range of 2 to 10mm. At a second stage, the outcome of the previous process was forwarded to a second shredder, which was a turbo-mill; this downsized the granulometry of the incoming material even further, to a range of 1 to 3mm. This latter fraction of produced materials was driven through closed pipe system to a vibratory sieve, where solid inert residues and dust were removed by an air-separator. The remaining product underwent further separation through a smaller-hole sieve and a magnetic separator.

The results of this procedure were several fractions of materials such as: Ferrous, Aluminum, Mixed metals and Plastic. More specifically, the incoming electronic boards of a weight of 13,4 kg, were transformed into:

- 1,6 kg of mixed metals
- 0,86 kg of ferrous detritus
- 0,32 kg of cooper parts

- 0,3 kg of aluminum parts
- 0,44 kg of ferrous parts and
- 9,34 of plastic

All of the above separated small metallic and plastic particles were given to NTUA for treatment and retrieval of valuable metals.

5.1.3. Beneficiation Stage: Sink Float tests

5.1.3.1. Introduction

The printed circuit boards (PCBs) found in the e-waste stream are rich in Cu content and fairly rich in precious metals (Pd, Au and Ag). Processing of these wastes for extracting and recovering a significant proportion of the metal values contained in PCBs and removing the non-metallic constituents (plastics, etc.) seems to be a challenge.

Froth flotation methodology was observed to be a promising technique for rejecting plastics from the PCBs comminution product. It has been shown that, nearly reagent-free flotation of relatively coarse size fraction (-1 mm) pulverized e-waste, is feasible with a reasonably good product at an acceptable yield and good recovery.

In this work, froth flotation processing of the fine PCBs pulverized material was investigated, through reverse flotation beneficiation in a scheme described as a natural hydrophobic response. Without reagents, the system uses the pH alteration, the particle size of the treated material, the kinetic parameters of the aeration rate and impeller (rotor) speed of the flotation machine to recover as "sink" product the metal values, contained in the fragmented and classified by sieving fraction of the PCBs material.

A sample of e-waste fine material (100% ≅ -1.5 mm) weighing about 10 kg was received from the initial raw material. Afterwards, with the help of a "Jones" mechanical splitter (sampling device), the feed was divided in smaller samples of about 200 g each, which will be used for the chemical analysis work and for the flotation tests.

Samples were stored and preserved for laboratory determinations by implementing ISO 18512/2007. Each sample was prepared for chemical analysis according to EUROPEAN STANDARD FINAL DRAFT prEN13657, "Characterization of waste – Digestion for subsequent determination of aqua regia soluble portion of elements".

Further analysis of each element was conducted according to DIN EN ISO 11885 and DIN EN ISO 17294, by utilizing Inductively Coupled Plasma Spectrometry (ICP – AES - Prodigy – Teledyne, Leeman Labs), Inductively Coupled Plasma Mass Spectrometry (ICP – MS) and Atomic Absorption Spectroscopy (AAS – Hitachi Z2000). Each measurement was replicated twice, for different samples and the difference between the two samples was less than 5%.

Following the aforementioned procedures, the elements Arsenic (As), Cadmium (Cd), Copper (Cu), Manganese (Mn), Lead (Pb), Iron (Fe), Nickel (Ni), Zinc (Zn), Chromium (Cr), Palladium (Pd), Silver (Ag), Platinum (Pt) and Gold (Au) were measured in each sample.

The chemical analysis of the original sample is given in the Table 5.1, which is shown also in Figures 5.1 and 5.2 for the common metals and the precious metals, respectively.

Table 5.1. Chemical Analyses of the original Sample

Element	Content %
As	-
Cd	-
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)	
Pd	3.73
Ag	250.59
Pt	<0.05
Au	19.27

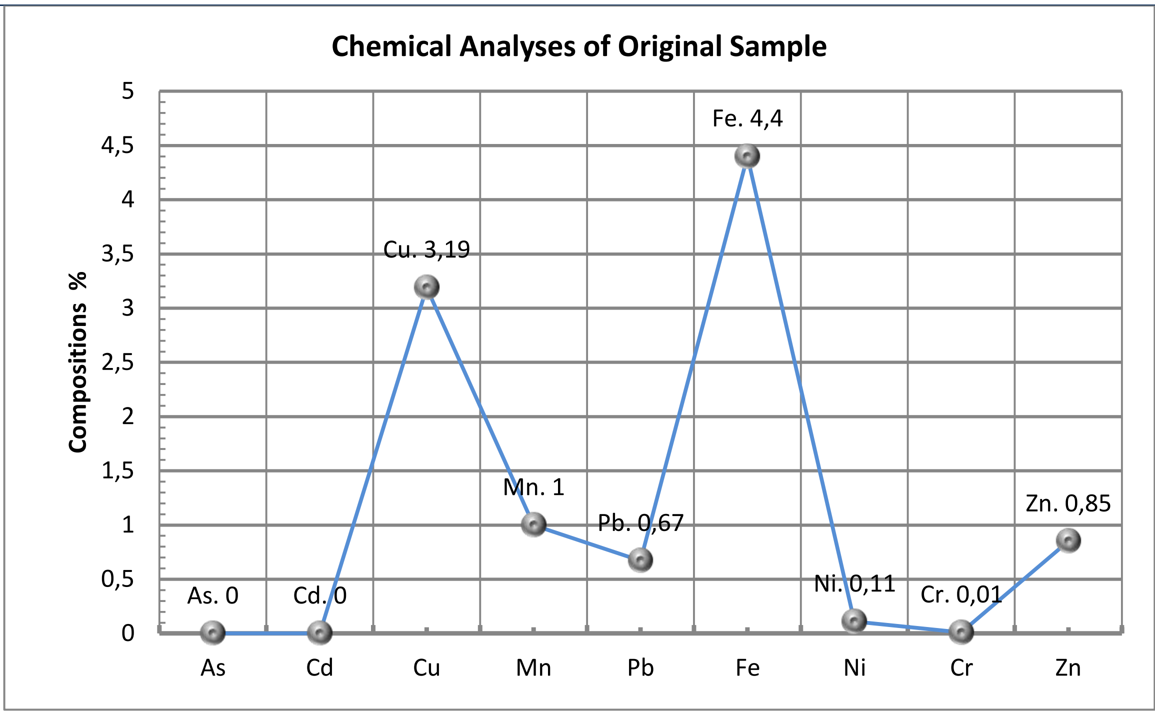


Figure 5.1. Metal content % in the original sample

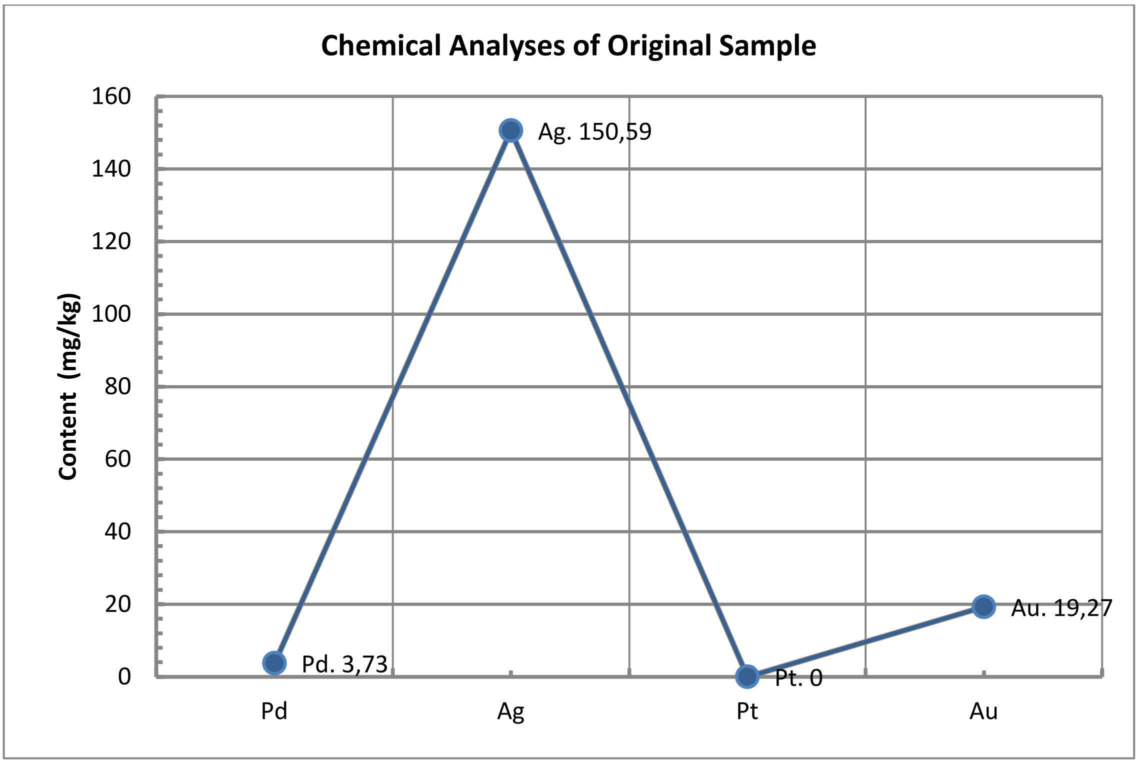


Figure 5.2. Precious metals content (mg/kg) of the original sample

5.1.3.1. Flotation Tests - Stages

The flotation tests were conducted using a Denver "Sub-A" flotation machine of the Laboratory of Mineral Processing (NTUA), Figure 5.3.

Figure 5.3. Denver "SUB-A" Laboratory flotation machine

The designed flotation tests were conducted in three different stages successively. The various process parameters (e.g. the slurry density, the stirring speed, the stirring time and the time of removal of the "float" product) were maintained constant. The test procedures applied are represented in Figure 5.4.

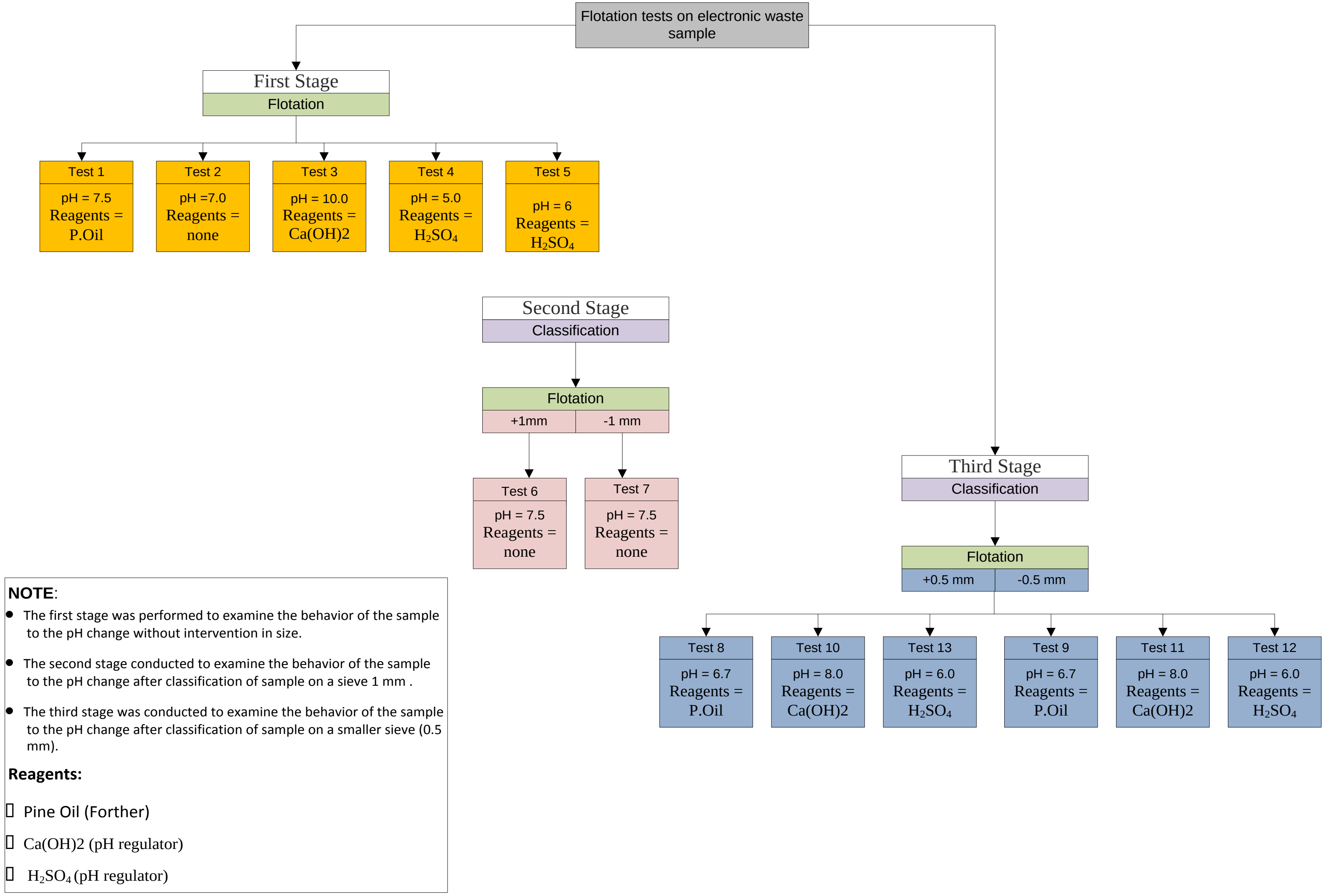


Figure 5.4. Different stages of the various laboratory flotation tests.

5.2. Results from Beneficiations

5.2.1. First Stage Tests and Results

The five (5) tests of this stage, were conducted under normal flotation conditions on original material feed, by changing solely the pH of the pulp. All other process variables (e.g. slurry/pulp density, machine rotor speed, stirring time) were maintained constant during the tests. The experimental results of each test are given in Tables 5.2 and 5.3, while the experimental conditions are shown in Tables 5.4, 5.5, 5.6, 5.7 and 5.8, respectively. From the above 5 tests, two of them (No 1 and 2 tests), considered as the most "promising", were analyzed in detail for the "floats" and the "sinks" and assessed for the metals presenting economic interest.

The flotation tests of the 1st stage were preliminary ("trial" tests) in order to study the behavior of the metal values and the non-metallic material associated with the PCBs fragmented material.

The parameters "c", "t", refer to the content (% or mg/kg) of the various metals in the feed, "floats" and "sinks", respectively, while R refers to the % recovery of the useful metal values in the products ("floats" and "sinks"), or their % distribution in the "coarse" (oversize) and the "fine" (undersize) products, after the size classification of the original feed.

Some primary comments, as deduced from the results are:

1. The precious metals, Au and Pd showed a tendency to report in the "floats", while high percentage of the other precious (Ag) reports to the "sinks" (Tables 5.2 and 5.3). The rest "high-concentration" metals Cu and Fe, reports in the "sinks" and the "floats", respectively.
2. Since, the chemical analysis of such complex flotation products is not only time consuming but expensive as well, it was decided to select the most representative tests, from the following two different experimental stages (2nd stage and 3rd stage), to perform complete chemical analysis of their products ("floats" and "sinks").

Table 5.2. Experimental results of the "float" product of the 1st stage (5 tests)

Element	Original sample	Test 1		Test 2		Test 3	Test 4	Test 5
		mean c % ("float")	R %	c % ("float")	R %	c % ("float")	c % ("float")	mean c % ("float")
As	-	-		-		-	-	n.a.
Cd	-	0.0008		0.0006		0.0005	0.0005	
Cu	3.19	0.72	8.8	0.61	7.6	0.43	0.89	
Mn	1.00	2.02		2.23		2.20	2.39	
Pb	0.67	0.89		0.72		0.52	0.61	
Fe	4.40	8.15	71.2	8.28	74.1	7.71	7.76	
Ni	0.11	1.64		0.85		1.87	1.83	
Cr	0.01	0.01		0.01		0.17	0.02	
Zn	0.85	1.55		1.66		1.55	1.83	
Element	Original sample mg/kg	c ("float") mg/kg	R %	c ("float") mg/kg	R %	c ("float") mg/kg	c ("float") mg/kg	c ("float") mg/kg
Pd	3.73	5.96	61.4	5.87	61.9	4.72	5.41	5,27
Ag	250.59	221	33.7	196.03	30.8	172.14	177.94	207.5
Pt	<0.05	<0.05		<0.05		<0.05	<0.05	<0,05
Au	19.27	36.5	72.9	39.43	80.5	30.06	37.73	32,80
Weight %		38.48		39.36		38.24	27.89	43.39

Table 5.3. Experimental results of the "sink" product (tailing) of the 1st stage

Element	Original Sample, %	Test 1		Test 2	
		t % ("sink")	R %	t % ("sink")	R %
As	-	0.0015		0.0006	
Cd	-	0.0041		0.0016	
Cu	3.19	4.73	91.2	4.86	92.4
Mn	1.00	0.33		0.20	
Pb	0.67	1.04		0.64	
Fe	4.40	2.06	28.8	1.89	25.9
Ni	0.11	0.31		0.20	
Cr	0.01	0.01		0.03	
Zn	0.85	0.72		0.32	
Element	Original Sample mg/kg	t ("sink") mg/kg	R %	t ("sink") mg/kg	R %
Pd	3.73	2.34	38.6	2.34	38.1
Ag	250.59	270.1	66.3	286	69.2
Pt	<0.05	<0.05		<0.05	
Au	19.27	8.49	27.1	6.18	19.5
Weight %		61.52		60.64	

Table 5.4. Experimental results of Test 1

Test 1
Test conditions:
Sample: Electronic waste from the original feed
Reagents : Pine Oil (Frother)
Particle size fraction: Original sample
Stirring Time: 2 min
Pulp % solids: 15%
pH: 7.5
Time of float removal : 1min
RPM : 900
Flotation cell volume: 1 liter

Content %					
Element	Original Sample	"Float"			"Sink"
		1	2	Mean	
As	-	-	0.0015	-	0.0015
Cd	-	0.0008	0.0006	0.0008	0.0041
Cu	3.19	0.74	0.68	0.72	4.73
Mn	1.00	2.22	1.50	2.02	0.33
Pb	0.67	1.02	0.55	0.89	1.04
Fe	4.40	8.85	6.26	8.15	2.06
Ni	0.11	1.83	1.11	1.64	0.31
Cr	0.01	0.01	0.02	0.01	0.01
Zn	0.85	1.70	1.14	1.55	0.72
Content (mg/kg)					
Pd	3.73	7.32	2.32	5.96	2.34
Ag	250.59	236.88	178.43	221	270.1
Pt	<0.05	<0.05	<0.05	<0.05	<0.05
Au	19.27	46.33	9.92	36.5	8.49
Weight %	100.00	28.01	10.47	38.48	61.52

Table 5.5. Experimental results of Test 2

Test 2 Test conditions: Sample: Electronic waste from the original feed Reagents : none Stirring Time: 2 min Pulp % solids: 15% pH: 7.0 Time of "float" removal : 1min RPM : 900 Flotation cell volume: 1 liter			
Content %			
Element	Original Sample	"Float"	"Sink"
As	-	-	0.0006
Cd	-	0.0006	0.0016
Cu	3.19	0.61	4.86
Mn	1.00	2.23	0.20
Pb	0.67	0.72	0.64
Fe	4.40	8.28	1.89
Ni	0.11	0.85	0.20
Cr	0.01	0.01	0.03
Zn	0.85	1.66	0.32
Content (mg/kg)			
Pd	3.73	5.87	2.34
Ag	250.59	196.03	286
Pt	<0.05	<0.05	<0.05
Au	19.27	39.43	6.18
Weight %	100.00	39.36	60.64

Table 5.6. Experimental results of Test 3

Test 3 Test conditions: Sample: Electronic waste from the original feed Reagents : Ca(OH)2 (pH regulator) Stirring Time: 2 min Pulp % solids: 15% pH: 10.0 Time of "float" removal : 1min RPM : 900 Flotation Cell volume: 1 liter			
Content %			
Element	Original Sample	"Float"	"Sink"
As	-	-	n.a.
Cd	-	0.0005	
Cu	3.19	0.43	
Mn	1.00	2.20	
Pb	0.67	0.52	
Fe	4.40	7.71	
Ni	0.11	1.87	
Cr	0.01	0.17	
Zn	0.85	1.55	
Content (mg/kg)			
Pd	3.73	4.72	n.a.
Ag	250.59	172.14	
Pt	<0.05	<0.05	
Au	19.27	30.06	
Weight %	100.00	38.24	61.76

Table 5.7. Experimental results of Test 4

Test 4 Test conditions: Sample: Electronic waste from the original feed Reagents: H2SO4 (pH regulator) Stirring Time: 2 min Pulp % solids: 15% pH: 5.0 Time of 'float" removal : 1min RPM : 900 Flotation Cell volume: 1 liter			
Content %			
Element	Original sample	"Float"	"Sink"
As	-	-	n.a.
Cd	-	0.0005	
Cu	3.19	0.89	
Mn	1.00	2.39	
Pb	0.67	0.61	
Fe	4.40	7.76	
Ni	0.11	1.83	
Cr	0.01	0.02	
Zn	0.85	1.83	
Content (mg/kg)			

Pd	3.73	5.41	n.a.
Ag	250.59	177.94	
Pt	<0.05	<0.05	
Au	19.27	37.73	
Weight %	100.00	27.89	72.11

Table 5.8. Experimental results of Test 5

Test 5 Test conditions: Sample: Electronic waste from the original feed Reagents : H2SO4 (pH regulator) Stirring Time: 2 min Solids: 15% pH: 6.0 Time of "float" removal : 1min RPM : 900 Flotation Cell volume: 1 liter					
Content %					
Element	original sample	"Float			"Sink"
		1	2	Mean	
As	-	n.a.	n.a.	n.a.	n.a.
Cd	-				
Cu	3.19				
Mn	1.00				
Pb	0.67				
Fe	4.40				
Ni	0.11				
Cr	0.01				
Zn	0.85				
Content (mg/kg)					
Pd	3.73	5.43	4.35	5.27	n.a.
Ag	250.59	216.90	154.08	207.5	
Pt	<0.05	<0.05	<0.05	<0.05	
Au	19.27	35.45	17.61	32.80	
Weight %	100.00	36.94	6.45	43.39	56.61

5.2.2. Second Stage Tests and Results

The flotation tests of the 2nd stage were conducted on the two products (+1 mm and -1 mm) produced after size classification of the original feed sample on a laboratory sieve of 1 mm aperture, producing two size fractions +1 mm and -1 mm, respectively.

The experimental results and their assessment are given in Table 5.9 and the conditions of the tests in Tables 5.10 and 5.11, respectively.

Table 5.9. Experimental results of the “Floats” and “Sinks” of the 2nd stage

Element	Original sample	Feed -1 mm	Test 6	Test 7 (-1 mm)			
			c % (”float”)	c % (”float”)	R %	t % (“sink”)	R %
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	n.a.	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	

Table 5.10. Experimental results of Test 6

Test 6 Test conditions: Sample: Size classified of the original Electronic waste feed Reagents : none Particle size fraction: +1mm Stirring Time: 2 min Pulp % solids: 15% pH: 7.5 Time of "float" removal : 1min RPM : 900 Flotation cell volume: 1 liter				
Content %				
Element	Original sample	Feed +1 mm	"Float"	"Sink"
As	-		n.a.	n.a.
Cd	-			
Cu	3.19			
Mn	1.00			
Pb	0.67			
Fe	4.40			
Ni	0.11			
Cr	0.01			
Zn	0.85			
Content (mg/kg)				
Pd	3.73		n.a.	n.a.
Ag	250.59			
Pt	<0.05			
Au	19.27			
Weight %	100.00	19.15	1.85	17.3

Table 5.11. Experimental results of Test 7

Test 7 Test conditions: Sample: Classification by size of the original Electronic waste feed Reagents : none Particle size fraction: -1 mm Stirring Time: 2 min Pulp % solids: 15% pH: 7.5 Time of "float" removal : 1min RPM : 900 Flotation Cell volume: 1 liter				
Content %				
Element	Original sample	Feed -1 mm	"Float"	"Sink"
As	-	-		-
Cd	-	-	0.0005	0.0007
Cu	3.19	3.55	0.70	6.38
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	2.37
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
Content (mg/kg)				
Pd	3.73	4.32	6.28	2.38
Ag	250.59	250.8	207.73	293.5
Pt	<0.05	<0.05	<0.05	<0.05
Au	19.27	22	38.64	5.5
Weight %	100.00	80.83	40.25	40.57

5.2.3. Third Stage Tests and Results

Detailed tests conducted by adjusting solely the pH of the pulp, on samples from the two products (+0.5 and -0.5 mm), which obtained after classification of the original sample in a finer, than previously, sieve aperture size (0.5 mm). The experimental conditions of these flotation tests are shown in the respective tables. Table 5.12 shows the size distribution of the original feed in the two fractions and the distribution % of the useful metal values between the oversize (**+0.5 mm)** and the undersize (-0.5 mm) material. It is obvious that over 80% percent of the various useful metals (Cu, Fe, Pd, Ag and Au) report to the fine fraction -0.5 mm.

Table 5.12. Size classification results of the original feed on sieve aperture 0.5 mm and % distribution (R %) of metal values.

Test 8 Test conditions: Conventional laboratory sieving (Ro-tap machine) Sample: Original Electronic waste feed Size classification of the original sample on sieve 0.5 mm (two products, +0.5 and -0.5 mm)					
Content %					
Element	Original sample	+0.5mm	R(+), %	-0.5 mm	R(-), %
As	-	-		-	
Cd	-	0.0005		0.0015	
Cu	3.19	1.71	18.9	3.99	80.1
Mn	1.00	0.062		1.51	
Pb	0.67	0.03		1.02	
Fe	4.40	0.19	1.52	6.71	98.48
Ni	0.11	0.04		0.15	
Cr	0.01	0.0005		0.02	
Zn	0.85	0.32		1.14	
Content (mg/kg)					
Pd	3.73	0.32	3.0	5.59	97.0
Ag	250.59	118.5	16.5	323.2	83.5
Pt	<0.05	<0.05		<0.05	
Au	19.27	8.75	16.0	25	84.0
Weight %	100.00	35.26		64.74	

Table 5.13. Experimental results of "floats" of the 3rd stage (+0.5 mm) and recovery of useful metal values in the "floats of the "coarse" (+0.5 mm) size fraction.

Element	Original sample	Feed +0.5 mm	Test 8		Test 10	Test 13
			c % ("float")	R %	c % ("float")	c % ("float")
As	-	-	-			
Cd	-	0.0005	0.0002			
Cu	3.19	1.71	0.30	0.19		
Mn	1.00	0.062	0.41			
Pb	0.67	0.03	0.17			
Fe	4.40	0.34	1.98	0.9		
Ni	0.11	0.04	0.36			
Cr	0.01	0.0005	0.01			
Zn	0.85	0.32	0.46			
Element	Original sample	Size fraction +0.5 mm	c ("float") mg/kg	R %	c ("float") mg/kg	c ("float") mg/kg
Pd	3.73	0.32	1.29	0.7	1.30	0.48
Ag	250.59	118.5	48.17	0. 4	42.31	17.60
Pt	<0.05	<0.05	<0.05		<0.05	<0.05
Au	19.27	8.75	12.25	1.28	11.35	12.93
Weight %	100	35.26	2.02		15.01	35.99

Table 5.14. Experimental results of the "sinks" of the 3rd stage (+0.5 mm) and recovery R %.

Element	Original sample	Feed +0.5 mm	Test 8		Test 10	Test 13
			t % ("sink")	R %	t % ("sink")	t % ("sink")
As	-	-	0.0003		0.0005	
Cd	-	0.0005	0.0004		0.0002	
Cu	3.19	1.71	1.82	19.0	1.75	
Mn	1.00	0.062	0.04		0.03	
Pb	0.67	0.03	0.09		0.05	
Fe	4.40	0.34	0.24	1.81	0.28	
Ni	0.11	0.04	0.06		0.05	
Cr	0.01	0.0005	0.02		0.02	
Zn	0.85	0.32	0.37		0.34	
Element	Original sample	Size fraction +0.5 mm mg/kg	t ("sink") mg/kg	R %	t ("sink") mg/kg	t ("sink") mg/kg
Pd	3.73	0.32	0.26	2.32		
Ag	250.59	118.5	121.8	16.15		
Pt	<0.05	<0.05	<0.05			
Au	19.27	8.75	8.45	14.6		
Weight %	100	35.26	33.24		29.97	22.57

Table 5.15. Experimental results of the "floats" of the 3rd stage (-0.5 mm) and recovery R %.

Element	Feed -0.5 mm	Test 9		Test 11		Test 12	
		c % ("float")	R %	c % ("float")	R %	c % ("float")	R %
As	-						
Cd	0.0015			0.0008			
Cu	3.99			0.56	6.4		
Mn	1.51			1.88			
Pb	1.02			0.52			
Fe	6.71			8.53	76.3		
Ni	0.15			1.33			
Cr	0.02			0.01			
Zn	1.14			0.88			
Element	Feed -0.5 mm (mg/kg)	c mg/kg	R %	c mg/kg	R %	c mg/kg	R %
Pd	5.59	5.72		7.87	83.0	6.63	
Ag	323.2	194.53		236.1	37.1	183.90	
Pt	<0.05	<0.05		<0.05		<0.05	
Au	25	38.06		39.4	80.5	36.48	
Weight %	64.74	36.21		39.36		38.72	

Table 5.16. Experimental results of the "sinks" of the 3rd stage (-0.5 mm) and recovery R %.

Element	Feed -0.5 mm	Test 9		Test 11		Test 12	
		t % ("sink")	R %	t % ("sink")	R %	t % ("sink")	R %
As	-	-		-			
Cd	0.0015	0.0006		0.0027			
Cu	3.99	8.2		9.3	74.0		
Mn	1.51	0.61		0.92			
Pb	1.02	2.61		4.02			
Fe	6.71	2.78		3.89	22.5		
Ni	0.15	0.54		0.77			
Cr	0.02	0.04		0.06			
Zn	1.14	1.84		1.95			
Element	Feed -0.5 mm (mg/kg)	t mg/kg	R %	t mg/kg	R %	t mg/kg	R %
Pd	5.59			2.03	13.8	n.a.	
Ag	323.2			458.2	46.4		
Pt	<0.05			<0.05			
Au	25			2.67	3.52		
Weight %	64.74	25.2		25.4		26.02	

Table 5.17. Experimental results of Test 8

Test 8

Test conditions:
Sample: Size classification of the original sample on sieve 0.5 mm
Reagents : Pine Oil (frother)
Particle size fraction: +0.5mm
Stirring Time: 2 min
Pulp % solids: 15%
pH: 6.7
Time of "float" removal : 1min
RPM : 900
Flotation cell volume: 1 liter

Content %				
Element	Original sample	Feed + 0.5 mm	"Float"	'Sink"
As	-	-	-	0,0003
Cd	-	0.0005	0.0002	0,0004
Cu	3.19	1.71	0.30	1.82
Mn	1.00	0.062	0.41	0,04
Pb	0.67	0.03	0.17	0,09
Fe	4.40	0.19	1.98	0,24
Ni	0.11	0.04	0.36	0,06
Cr	0.01	0.0005	0.01	0,02
Zn	0.85	0.32	0.46	0,37
Content (mg/kg)				
Pd	3.73	0.32	1.29	0.26
Ag	250.59	118.5	48.17	121.8
Pt	<0.05	<0.05	<0.05	<0.05
Au	19.27	8.75	12.25	8.45
Weight %	100.00	35.26	2.02	33.24
			35.26	

Table 5.18. Experimental results of Test 9

Test 9
Test conditions:
Sample Size classification of the original sample on sieve 0.5 mm
Reagents : Pine Oil (frother)
Particle size fraction: -0.5mm
Stirring Time: 2 min
Pulp % solids: 15%
pH: 6.7
Time of "Float" removal : 1min
RPM : 900
Flotation cell volume: 1 liter

Content %					
Element	Original sample	Feed -0.5 mm	"Float" 1	"Float" 2	"Sink"
As	-	-	n.a.	n.a.	-
Cd	-	0.0015			0.0006
Cu	3.19	3.99			8.2
Mn	1.00	1.51			0.61
Pb	0.67	1.02			2.61

Fe	4.40	6.71			2.78
Ni	0.11	0.15			0.54
Cr	0.01	0.02			0.04
Zn	0.85	1.14			1.84
Content (mg/kg)					
Pd	3.73	5.59	5.72	n.a.	n.a.
Ag	250.59	323.2	194.53		
Pt	<0.05	<0.05	<0.05		
Au	19.27	25	38.06		
Weight %	100.00	64.74	36.21	3.38	25.15

Table 5.19. Experimental results of Test 10

Test 10
Test conditions:
Sample: Size classification of the original sample on a sieve 0.5 mm
Reagents : Ca(OH)2 (pH regulator)
Particle size fraction: +0.5mm
Stirring Time: 2 min
Pulp % solids: 15%
pH: 8
Time of "float" removal : 1min
RPM : 900
Flotation cell volume: 1 liter

Content %					
Element	Original sample	Feed +0.5 mm	"Float" 1	"Float" 2	"Sink"
As	-	-	n.a.	n.a.	0.0005
Cd	-	0.0005			0.0002
Cu	3.19	1.71			1.75
Mn	1.00	0.062			0.03
Pb	0.67	0.03			0.05
Fe	4.40	0.19			0.28
Ni	0.11	0.04			0.05
Cr	0.01	0.0005			0.02
Zn	0.85	0.32			0.34
Content (mg/kg)					
Pd	3.73	0.32	1.30	0.43	n.a.
Ag	250.59	118.5	42.31	25.54	
Pt	<0.05	<0.05	<0.05	<0.05	
Au	19.27	8.75	11.35	1.88	
Weight %	100.00	35.26	1.62	3.67	29.97

Table 5.20. Experimental results of Test 11

Test 11
Test conditions:
Sample: Size classification of the original sample on a sieve 0.5 mm
Reagents : Ca(OH)2 (pH regulator)
Particle size fraction: -0.5mm
Stirring Time: 2 min
Pulp % solids: 15%
pH: 8
Time of "float" removal : 1min
RPM : 900
Flotation cell volume: 1 liter

Content %						
Element	Original sample	Feed -0.5 mm	"Float" 1	"Float" 2	Mean "Float" c %	"Sink"
As	-	-	-	-		-
Cd	-	0.0015	0.0008	0.0007	0.0008	0.0027
Cu	3.19	3.99	0.61	0.27	0.56	9.3
Mn	1.00	1.51	2.08	0.68	1.88	0.92
Pb	0.67	1.02	0.55	0.32	0.52	4.02
Fe	4.40	6.71	9.65	2.02	8.53	3.89
Ni	0.11	0.15	1.48	0.46	1.33	0.77
Cr	0.01	0.02	0.01	0.009	0.01	0.06
Zn	0.85	1.14	0.95	0.48	0.88	1.95
Content (mg/kg)						
Pd	3.73	5.59	8.5	4.37	7.87	2.03
Ag	250.59	323.2	246.4	176.52	236.1	458.2
Pt	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Au	19.27	25	45.08	6.4	39.4	2.67
Weight %	100.00	64.74	33.56	5.79		25.4
			39.36		39.36	25.4

Table 5.21. Experimental results of Test 12

Test 12
Test conditions:
Sample: Size classification of the original sample on a sieve 0.5 mm
Particle size fraction: -0.5 mm
Reagents : H2SO4 (pH regulator)
Stirring Time: 2 min
Pulp % solids: 15%
pH: 6.0
Time of "Float" removal : 1min
RPM : 900
Flotation Cell volume: 1 liter

Content %					
Element	Original sample	Feed -0.5 mm	"Float" 1	"Float" 2	"Sink"
As	-	-	n.a.	n.a.	n.a.
Cd	-	0.0015			
Cu	3.19	3.99			
Mn	1.00	1.51			
Pb	0.67	1.02			
Fe	4.40	6.71			

Ni	0.11	0.15			
Cr	0.01	0.02			
Zn	0.85	1.14			
Content (mg/kg)					
Pd	3.73	5.59	6.63	6.33	n.a.
Ag	250.59	323.2	183.90	204.39	
Pt	<0.05	<0.05	<0.05	<0.05	
Au	19.27	25	36.48	29.32	
Weight %	100.00	64.74	32.93	5.79	26.02

Table 5.22. Experimental results of Test 13

Test 13 Test conditions : Sample: Size classification of the original sample on a sieve 0.5 mm Particle size fraction: + 0.5mm Reagents : H2SO4 (pH regulator) Stirring Time: 2 min Pulp % solids: 15% pH: 6.0 Time of Concentrate removal : 1min RPM : 900 Flotation cell volume: 1 liter					
Content %					
Element	Original sample	Feed +0.5 mm	“Float” 1	“Float” 2	“Sink”
As	-	-	n.a.	n.a.	n.a.
Cd	-	0.0005			
Cu	3.19	1.71			
Mn	1.00	0.062			
Pb	0.67	0.03			
Fe	4.40	0.19			
Ni	0.11	0.04			
Cr	0.01	0.0005			
Zn	0.85	0.32			
Content (mg/kg)					
Pd	3.73	0.32	0.49	0.48	n.a.
Ag	250.59	118.5	18.15	17.60	
Pt	<0.05	<0.05	<0.05	<0.05	
Au	19.27	8.75	3.34	22.93	
Weight %	100.00	35.26	1.37	11.33	22.57

5.2.4. Environmental Characterization of Pulps

In order to proceed with the environmental characterization process, the pulps obtained, after filtration of the flotation products, were investigated for the presence of metals and metalloids (As, Cd, Cu, Mn, Pb, Fe, Ni, Zn and Cr). After sampling, all liquids were immediately stored below 4◦C, for purposes of adequate preservation and before any chemical analysis.

Namely six (6) samples were examined, according to DIN EN ISO 11885 and DIN EN ISO 17294 by utilizing Inductively Coupled Plasma Spectrometry (ICP – AES / Prodigy – Teledyne, Leeman Labs) and Atomic Absorption Spectroscopy (AAS – Hitachi Z2000). Results are presented in the following table (Table 5.23).

Table 5.23. Chemical Analysis of Pulps for purposes of environmental characterization (all values in mg/l)

Pulp Code	As	Cd	Cu	Mn	Pb	Fe	Ni	Cr	Zn
EpH 5	<0.01	0.01	<0.005	0.58	<0.01	<0.01	<0.005	<0.005	5.12
EA	<0.01	<0.005	<0.005	0.014	<0.01	<0.01	<0.005	<0.005	0.21
EpH 10	<0.01	<0.005	<0.005	<0.005	<0.01	<0.01	<0.005	<0.005	<0.005
E8	<0.01	<0.005	<0.005	<0.005	<0.01	<0.01	<0.005	<0.005	0.011
Ex	<0.01	<0.005	<0.005	0.014	0.018	<0.01	<0.005	<0.005	0.22
Eo	<0.01	<0.005	0.023	0.083	<0.01	<0.01	<0.005	<0.005	0.52

For purposes of adequate results interpretation, is critical to identify the conditions (pH and solvent) the flotation products were subjected to, prior to filtration. In Table 5.24, those conditions are illustrated.

Table 5.24. pH and Solvent used for elaborating flotation products, prior to filtration

Pulp Code	Average pH	Solvent Used
EpH 5	5.0	H2SO4
EA	7.0	Tap Water
EpH 10	10.0	Ca(OH)2 solution
E8	8.0	Ca(OH)2 solution (plus foaming)
Ex	7.0	Tap Water
Eo	6.0	H2SO4 (plus foaming)

As it is shown in Table 5.24, pH values are consistent with the solvent used for each sample (e.g acidic pH for when H2SO4 is used).

Generally, metals concentrations are presented low in all tested samples. Especially in EpH10 pulp, all metals concentrations (including Zn and Mn) are non-detectable. That was expected, due to the strongly alkaline pH conditions. Very low concentrations are also illustrated in alkaline sample E8, where only a small concentration of Zn (11 ppb) is detected.

Zinc and Manganese are the only metals with almost constant presence in all tested samples. As shown from Table 5.24, sample EpH5 possessing an acidic pH (= 5). That is the reason for relatively high concentrations of Zn and Mn in the liquid, since both metals present high dissolution rates under those pH conditions (Vogel et al., 2000). For both metals, their concentrations in the pulp are at least one order of magnitude higher than all other tested samples. A small portion of Cadmium (10ppb) is present in that sample, also attributable to the low pH environment (Vogel et al., 2000). Nevertheless, a small increase to pH value (from 5 to 6 for sample E0) decreases significantly both Zn and Mn concentrations. Copper is detected only in sample E0 (23 ppb) and Pb only in sample Ex (18 ppb). Iron, nickel, chromium and arsenic are not detected in any tested sample.

Greek legislation (Ministerial Decision 145116 / Official Gazette 354B'/8-3-2011: Determination of measures, terms and procedures for treated wastewater reuse) provides limit values for the presence of certain metals and metalloids in treated wastewater for purposes of possible reuse. Those values are presented in Table 5.25:

Table 5.25. Maximum allowable concentrations of metals and metalloids for treated wastewater prior any possible reuse

Element	Max Concentration (mg/l)
As	0.1
Cd	0.01
Cu	0.2
Mn	0.2
Pb	0.1
Fe	3.0
Ni	0.2
Zn	2.0
Cr	0.1

Comparing values presented in Tables 5.23 and 5.25, it is observed that only sample EpH5 may considered slightly problematic in terms of each further management, since Mn and Zn concentrations are exceeding the proposed limit values.

5.2.5. Conclusions from the float tests

From the preliminary work performed in the Laboratory of Mineral Processing (NTUA) under the frame of the present research work, it was verified that a natural hydrophobicity exists, a stable froth was observed even without the addition of any frother reagent.

The "report" of the useful metal values to the "floats" or the "sinks" could be effectively controlled during the flotation procedure, by pH alteration or the use of a flotation reagent. Thus, many of the metals were found to report to the foam (float) phase, while some other metals demonstrated a distinct preference for the sink product. Plastics and lightweight material are easily removed with the "floats", without the addition of any reagent, just by stirring and aeration of the pulp.

From the precious metals, Au and Pd showed an explicit "tendency" to report in the "floats" and Ag to the "sink", while the other metals of economic value (Cu and Fe) go to the "floats" or the "sinks", respectively.

The classification of the original sample into two size fractions (+0.5 mm and -0.5 mm) is helpful for the flotation, since the majority of the plastics and the lightweight material report in the "coarse" (+0.5 mm) fraction, while the metals report in the "undersize" or "fine" fraction (-0.5 mm), Table 5.12.

The distribution of the metals with economic value in the "fine" (-0.5 mm) fraction is Cu 80.1%, Fe 98.48%, Pd 97.0%, Ag 83.5% and Au 84.0%. After flotation of the "fine" fraction, the recovery of the metals is as follows: Au 80.5%, Pd 83.0%, Ag 37.5% and Fe 76.3% in the "floats", while for Cu 74.0% and Ag 46.4% in the "sinks".

It was noted that Ag presents an indifferent behavior between the "floats" and the "sinks". The higher values for Au 39.4 mg/kg and Pd 7.87 mg/kg were noted in the "floats" of the -0.5 mm size fraction, while the higher values for Cu and Ag were 9.3% and Ag 458.2 mg/kg, respectively, in the sink product of the same test (Test 11, Tables 5.15, 5.16 and 5.20).

The experimental results of the -1 mm treatment agree with the above findings (Tables 5.9 and 5.11). It is expected that, removing the ultrafine material (-0.045 mm, -45μm) prior of flotation, might be supportive to the success of the flotation procedure.

Finally, it was concluded that it is necessary to investigate the flotation more extensively as a method of recovery of the useful metals (Cu, Au, Pd and Ag) from e-wastes. Perhaps, applying a factorial design investigation of the tests, could clarify the "effect" of the various operating parameters on the process. This would lead to the optimization of the flotation process applied on the PCBs processing.

5.3. Presentation of the LIFE reclaim rehabilitation works

The Landfill Mining activities which took place at the Polygyros Landfill during the LIFE reclaim project were of small scale with around 1260m^3 of waste excavated and processed in the Pilot Demonstration Unit. Additionally, the PL is a rather new landfill, still operational and necessary to the area. Consequently, as far as rehabilitation was concerned, there was no other option than just closing the open pit and continue with the disposal of new waste.

The steps followed were simple:

1. **Cleaning the space - Moving**

   After the end of the LFM works at the PL, the workers cleaned up the space from any flyaway waste and made sure that there was no waste inside the machinery. The Pilot Demonstration Unit was disassembled by the contractor and moved using big trucks. Also, the reclaimed recyclables were stored in big bags at a dedicated space inside the LF.

2. **Closing the open pit**

   The pit which was excavated during the LFM works was filled up with some of the Remaining waste. Also, fresh waste coming into the Landfill for disposal was used to fill up the void.

   The whole process was documented in **Figures 5.3-1 through 4**.

Figure 5.3-1: Actual rehabilitation after the LFM works of the LIFE reclaim project: closing the pit

Figure 5.3-2: Actual rehabilitation after the LFM works of the LIFE reclaim project: closing the pit

Figure 5.3-3: Actual rehabilitation after the LFM works of the LIFE reclaim project: closing the pit

Figure 5.3-4: Actual rehabilitation after the LFM works of the LIFE reclaim project: closed pit

3. Reclaiming resources

The reclaimed materials from the LFM works were stored temporarily in Big Bags, on a specific site inside the Landfill (Figure 5.3-5). After the end of the works, the Reclaim Team came in contact with a number of Recycling businesses in the area to arrange the collection of the remaining materials. The most difficult issue during this process was the transportation of the materials to a recycling center, as the closest one is at least 50km away. Also, the unstable state of the economic market of Greece during the second half of the year 2015 presented an additional obstacle. Many of the recycling firms we contacted were not interested in collecting these resources as they required a lot of washing to reach to an acceptable state of quality. Finally, a local business was contacted which agreed to collect the waste and recycle the materials.

Figure 5.3-5: Temporary storage of the reclaimed materials from the LFM works of the LIFE reclaim project.

5.4. Difficulties - Deviations

The major difficulty that was encountered was the absence of e-waste quantities from the landfill excavated waste. Thus, the results obtained and presented in the above paragraphs were estimated using e-waste from other sources obtained especially for beneficiation process, in an attempt to assess the most promising method to recover/reuse the valuable materials.

Chapter 6. Environmental Monitoring

6.1. Description of the Environmental Monitoring Works

The monitoring process is a crucial step in order to safeguard the successful implementation of any LFM scheme and to minimise any potential impacts to the environment of the area. Thus, it is an essential task to document the findings of the pilot application, to assess the overall performance of the mining and processing operations as well as to evaluate the strains posed to the environment of the area. Finally, one of its most important aspects is to assist in the identification of solutions and measures to tackle, control or mitigate the impacts deriving from the LFM operations in the PL site.

The environmental monitoring in an LFM project is made by taking into consideration the following issues:

- release of landfill gases and odors
- release of liquids and leachates
- dust emissions
- noise emissions
- waste generation due to processing or valorisation
- excavation safety (subsidence / collapses)

The above threats, determine the type of measurements and specify to a great extend the design of the environmental monitoring campaign. In the case of the PL site, the monitoring is designed so as to be able to quantify the impacts and is mainly concentrated on the monitoring of the site's air quality (gas emissions/odors as well as dust problems), other nuisance issues (noise problems) and finally the waste generation relating to the processing and valorisation actions taken place there (waste sampling). Thus, special attention was given to the safety of the workers during the mining process and to the minimization of the impacts to the environmental condition of the neighboring areas.

This is made possible through the installation of fixed as well as mobile monitoring apparatuses and equipments capable of capturing the changes in the site's environmental characteristics as a result of the mining and the processing of the waste materials. A key element of the monitoring process is the identification of the site's background (ambient) data, which sets the baseline reference case for the assessment of the possible impacts.

A detailed list of the monitoring equipment and their capabilities and characteristics has already been given in previous project's reports (Technical Report of The Installation of the Pilot Demonstration Unit of Action B5), however a brief description will be made hereinafter in order to fully analyse the monitoring campaign and the work path adopted for the PL site. The monitoring equipment used on-site is:

- Continuous Ambient Particulate Mass Monitor - TEOM™ 1400ab (Rupprecht & Patashnick Co. Inc.), compatible with the EN12341 standard, which is used for the continuous monitoring of the air quality in the site and more particular the PM-10 concentration (particulate matters – dust concentration) in the atmosphere of the PL. Real-time monitoring of the PM-10 concentration is achieved, while the reporting is made available according to the relevant standards in hourly and daily (24h) intervals.

- Personal Samplers MultiRAE-Plus, QRAE-Plus (RAE Systems Inc.). These two (2) monitoring units are used to detect gaseous emissions during the excavation and the processing of the waste and ensure the safety of the personnel, under the EN482 guidance. The gases measured by the 2 devices are: O_2 (0%-30%), CO (0-500 ppm), CO_2 (0-20,000 ppm), CH_4 (0-100% LEL), NOx (0-250 ppm), H_2S (0-100 ppm).

- Sound Level Meter – SLM-116 (Norsonic AS), used for the monitoring of the noise and sound levels. In the PL site it will be used to assess the change in the acoustic environment inflicted by the activities taking place during the pilot scale landfill mining application.

6.1.1. Implementation of Environmental Monitoring Plan (Action B5)

The monitoring campaign commenced with the starting of the pilot application and the consequent excavation and processing of the waste materials. In Figure 6.1 the general layout of the PL facility is given, along with the areas where the main works related to the pilot LFM application were located. These particular zones, along with the internal route developed for the haulage of the waste, from the mining area to the processing plant, were the main targets areas of the monitoring campaign; the excavation and processing were taking place there, and also, the majority of the employees worked there.

Figure 6.1. Target areas (excavation and processing areas) of the monitoring campaign.

It should be noted that the results incorporate the impacts and the environmental burden deriving also from the use of heavy machinery and the operations that are carried out on a daily basis to facilitate the whole landfilling process of the municipal wastes at the PL site. This is a result of the concept used to for the identification of the background levels of the environmental indicators that were measured during the non-working days, usually during weekend times.

In Figure 6.2 the types and locations of the monitoring activities that were carried out at the PL site are given.

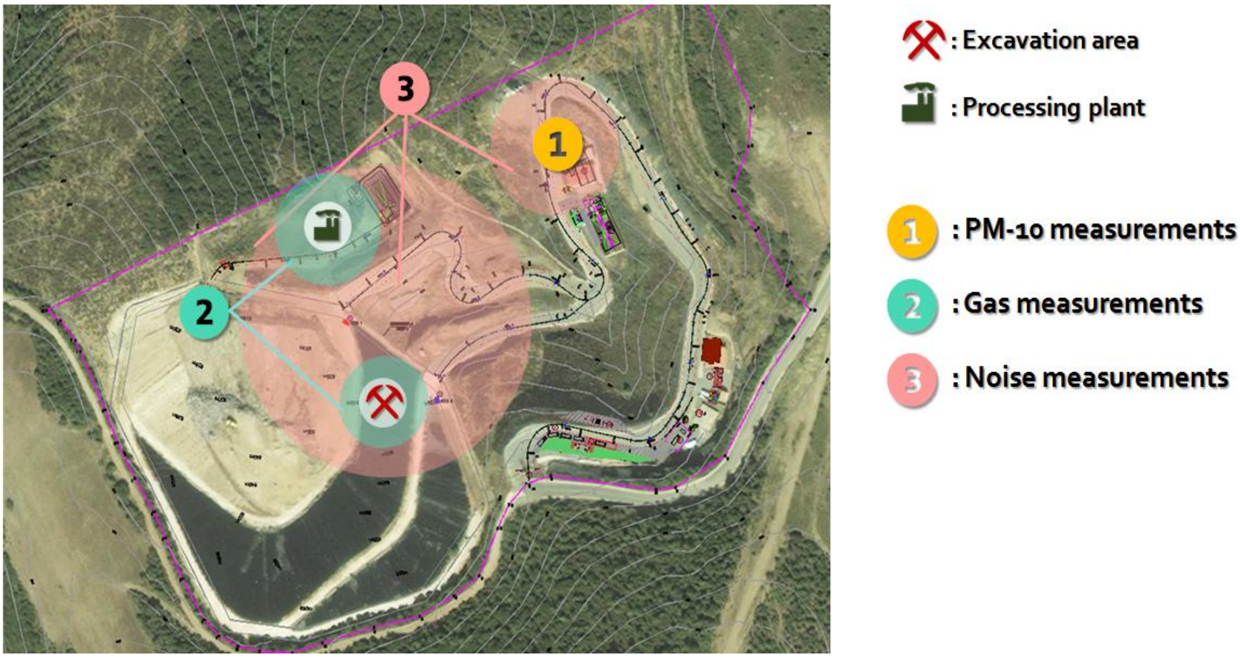


Figure 6.2. Locations and types of monitoring performed for the LFM pilot application at the PL site.

More specifically, the air-quality measurements (denoted as **1** in Fig. 6.2) related to the PM-10 concentration took place at the north-eastern part of the site, as at this particular location was the most well suited to facilitate the special requirements of the TEOM instrument. In there, the TEOM unit was located throughout the monitoring period, to assess in real time the concentration of dust releases to the atmosphere (Fig. 6.3).

The monitoring of gaseous emissions (denoted as **2** in Fig. 6.2) took place at the excavation stage of the waste as well as at the area of the processing plant. The monitoring was performed with portable units, as described, and were focused on the possible release of toxic or explosive gases (Fig. 6.4). The role of portable detectors was to identify the events and to warn personnel to timely leave the affected zone. The alarm limits for such detectors are directly related to exposure limits and are typically set at lower levels than instantaneous alarms for fixed detectors, to prevent injury.

Figure 6.3. Set-up location of the TEOM PM-10 monitoring unit.

Figure 6.4. Monitoring gaseous emissions at the waste excavation area.

Figure 6.5. Monitoring sound pressure level (SPL) at the waste processing area.

Finally, the sound pressure levels (noise) in the PL area were measured (denoted as **3** in Fig. 6.2) with portable equipment to identify the impacts to the workers and the nuisance to the surrounding area (Fig. 6.5). More particularly, measurements took place in the vicinity of the excavation and of the processing unit to record the sound levels for occupational hygiene purposes, as well as in the greater area of the site to assess possible impacts to the environment.

Besides the above measurements, that were implemented throughout the timeline of the pilot LFM application, a number of water samples were taken for further analysis. The samples were collected during the waste valorisation process, mainly involving the washing out of the waste, especially plastics (PET and/or HDPE), in an effort to enhance the quality of the material and attract higher sell values. The samples were analysed at a later stage and the results and their environmental characterization are provided in this report.

6.2. Results Air and Water Samples

In order to assess the environmental conditions the legislative framework describing the limits and thresholds of both national (Greek) and EU standards is briefly given.

6.2.1. Air quality - Particulate matter (PM-10)

Particulate matter is the term used to describe particles of solid or liquid state found in the air. Accordingly, PM-10 denotes the particles having a diameter of 10 μm - micrometers or less. The introduction of the PM-10 standard for the monitoring of the ambient air-quality was made at the end of the 1980's, replacing the Total Suspended Particulate (TSP) air quality standard. The PM-10 standard is focusing on smaller particles that have potential adverse health effects because of their ability to reach the lower regions of the human respiratory tract. Besides the PM-10 standards the EU directive 2008/EC/50 also introduces the use of PM-2.5 (fine particles) to assess the air-quality, including the limit value and exposure concentration obligation and exposure reduction targets.

Particulate matter can be characterized as either primary or secondary. Primary particles are released directly into the air from the sources (e.g. carbon PM from combustion, mineral PM from stone abrasion), while secondary particles are formed in the atmosphere by chemical reactions. The main sources of primary PM are road transport (combustion, braking and tyre wear by-products as well as dust mobilization from road surfaces); stationary combustion (mainly from domestic fuel burning); and industrial processes (production of metals, cement, lime, coke and chemicals, bulk handling of dusty materials, construction, mining and quarrying).

In EU the standards relating to the air quality are defined by the relative directive (2008/EC/50), entered into force on 11 June 2008. Through this standard the EU has set two limit values for particulate matter (PM-10) concentration, relating to the daily average and to the annual average concentration value. Their limits are as follows:

- the daily mean value concentration may not exceed 50 micrograms per cubic meter ($\mu g/m^3$) more than 35 times in a year

- the annual average concentration value that may not exceed 40 micrograms per cubic meter (μg/m^3)

The above standards have been also introduced to the Greek legislation regarding air-quality through the Ministerial Decision M.D. 14122/549/E.103/2011 (Official Gazette 488/B`/30.3.2011).

6.2.2. Air quality – Odors and Gaseous Emissions

The air quality in terms of odors and other gaseous emissions can be interpreted through the release of these substances to the atmosphere as well as to the issues raised to the health and safety of the personnel.

In terms of the air quality the limits are determined through the EU directive 2008/EC/50, which also provide limits for some of the gases found in the landfill site. These limits are:

- the hourly (1hr) mean value concentration of NO_2, not exceed the limit of 200 μg/m^3 more than 18 times a calendar year
- the yearly mean value concentration of NO_2, not exceed the limit of 40 μg/m^3
- the maximum daily eight hour (8hr) mean concentration of CO, not to exceed the limit of 10 mg/m^3

With respect to the air quality standards related to the exposure of the personnel to toxic gases, there are several EU directives dealing with such issues and propose indicative occupational exposure limit values. These are the directives 91/322/EEC, 2000/39/EC, 2006/15/EC and 2009/161/EU. These have been incorporated to the Greek legislation through the Presidential Decree P.D. 90/1999 (Official Gazette 94/A`/13.5.1999), as well as through the Greek Regulation of Mining and Quarrying Operations (Ministerial Decision M.D. D7/A/12050/2223/2011 - Official Gazette 1227/B`/14.6.2011).

Apart from the above, there is an ongoing investigation on the recommendations relating to the limits of several agents made by the Scientific Committee on Occupational Exposure Limits (SCOEL). These limits for the CO, NO, NO_2 and H_2S, are given in Table 6.1.

For the case of the methane (CH_4), the limits are not mainly related to the impacts to the human health, but the exposure limits are rather linked to the explosive characteristics of this particular gas. Hence, the presence of CH_4 in concentrations between its lower and upper explosive limits (LEL and UEL, respectively) can be a significant risk factor. The LEL and UEL values for the case of CH_4 is approx. 5% and 15% respectively, and consequently, extreme caution should be given when those limits are reached.

Table 6.1. Indicative limit values for occupational exposure (source: SCOEL)

CAS (1)	AGENT	INDICATIVE LIMITS - OCCUPATIONAL EXPOSURE				NOTES
		8 hour TWA(2)		STEL (15 mins) (3)		
		mg/m^3 (4)	ppm (5)	mg/m^3	ppm	
630-08-0	CO	23	20	117	100	SCOEL/SUM 57
10102-43-9	NO	2.5	2	-	-	SCOEL/SUM 89
10102-44-0	NO_2	0.955	0.5	1.91	1	SCOEL/SUM 53
7783-06-4	H_2S	7	5	14	10	SCOEL/SUM/124

(1) CAS: Chemical abstract service registry number.
(2) Measured or calculated in relation to a reference period of eight-hours time-weighted average (TWA).
(3) Short-term exposure limit (STEL). A limit value above which exposure should not occur and which is related to a 15-minute period unless otherwise specified.
(4) mg/m^3: milligrams per cubic metre of air at 20 °C and 101,3 KPa.
(5) ppm: parts per million by volume in air (ml/m^3).

6.2.3. Sound levels - Noise

In terms of the sound levels the respective legislative framework set by the EU is given in the 2003/10/EC directive. The directive establishes two indicators to assess the noise impacts at the workplace area. The daily noise exposure level ($L_{EX,8h}$) (dB(A) in relation to 20 μPa) is defined as the time weighted average of the noise exposure levels for a nominal eight-hour working day covering all noises present at work, including impulsive noise. Also the weekly noise exposure level ($L_{EX,8h}$) is defined as the time-weighted average of the daily noise exposure levels for a nominal week of five eight-hour working days. This directive is also included in the Greek legislation through the Presidential Decree P.D. 149/2006, and through the Greek Regulation of Mining and Quarrying Operations (Ministerial Decision M.D. D7/A/12050/2223/2011 - Official Gazette 1227/B`/14.6.2011).

According to the Directive the exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure are fixed at:

- exposure limit values: $L_{EX,8h}$ = 87 dB(A) and peak = 200 Pa (140 dB(C) in relation to 20 μPa) respectively;
- upper exposure action values: $L_{EX,8h}$ = 85 dB(A) and peak = 140 Pa (137 dB(C) in relation to 20 μPa) respectively;
- lower exposure action values: $L_{EX,8h}$ = 80 dB(A) and peak = 112 Pa (135 dB(C) in relation to 20 μPa) respectively.

Furthermore, industrial noise should conform with the guidelines set by the Presidential Decree P.D. 1180/81, where the upper noise levels are defined at 70 dB(A), measured at the border of the facility. However, for the cases where mobile equipment and machinery are operated, where in general, the noise produced is higher, the permissible noise limits are set by the 2000/14/EC directive. This has been incorporated to the Greek legislative framework with the Ministerial Decision M.D. 37393/2028/2003 (Official Gazette 1418/B`/1.10.2003)

6.3. Results of the On-Site Monitoring campaign

In this section the measurements and the data gathered from the environmental monitoring campaign are given. These are analysed and finally compared with the respective limits as proposed by the EU and Greek legislative framework.

6.3.1. Air quality (PM-10 measurements)

The PM-10 measurements were made over a total period of more than 1 month, in June and July of 2015. Based on the data from the Polygyros meteorological station, the prevailing wind direction at the wider area was the N-NE one, with an overall average wind speed of 6.8 km/hr. The details about the distribution of the wind direction and speed for the period of monitoring period (June and July 2015), are presented in Fig. 6.6.

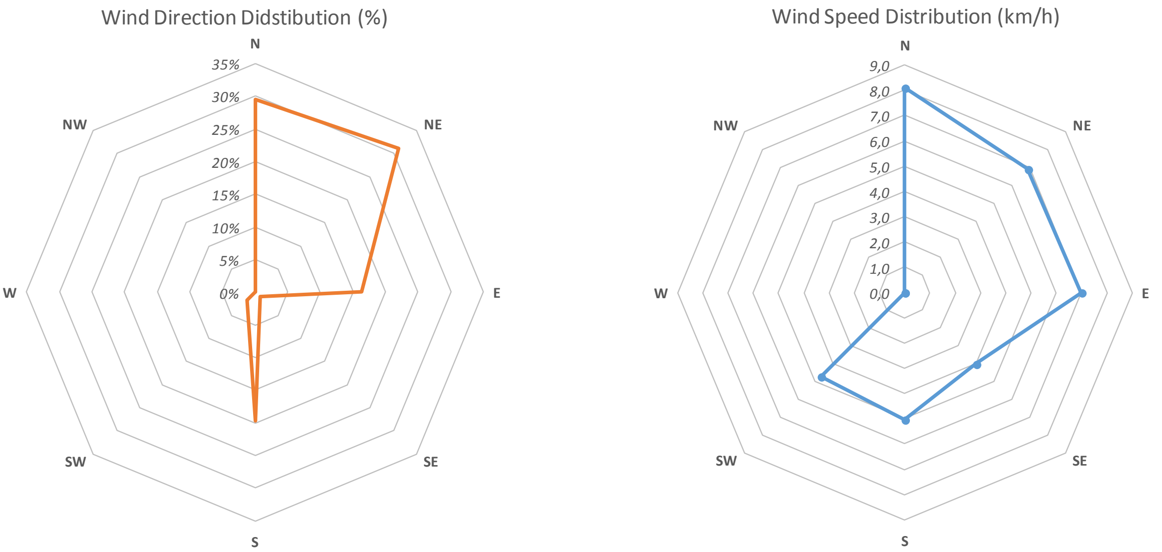


Figure 6.6. Details of the prevailing wind direction (a) and wind speed (b) during the monitoring period.

The background values of the area are taken from the weekend days, where no operation was taking place there. That included both the landfilling and the landfill mining or waste processing. In Figure 6.7 the results of the PM-concentrations (μg/m^3) throughout the duration of the measurement period are given in detail. In the diagram, the average daily (24h) results are depicted in yellow bars, while the green triangles represent the hourly (1h) average values. In the diagram, the background value as well as the total average PM-10 value measured on a daily basis are also depicted. The background value is rather low, at 8.2 μg/m^3, while the overall average daily value (24h) of particle concentration (PM-10) is also low, calculated at 9.3 μg/m3, almost 1 μg/m^3 more than the ambient values. The maximum daily PM-10 value recorded was 14.6 μg/m^3 (July 8th 2015), while the minimum was almost 4.8 μg/m^3 (June 18th 2015).

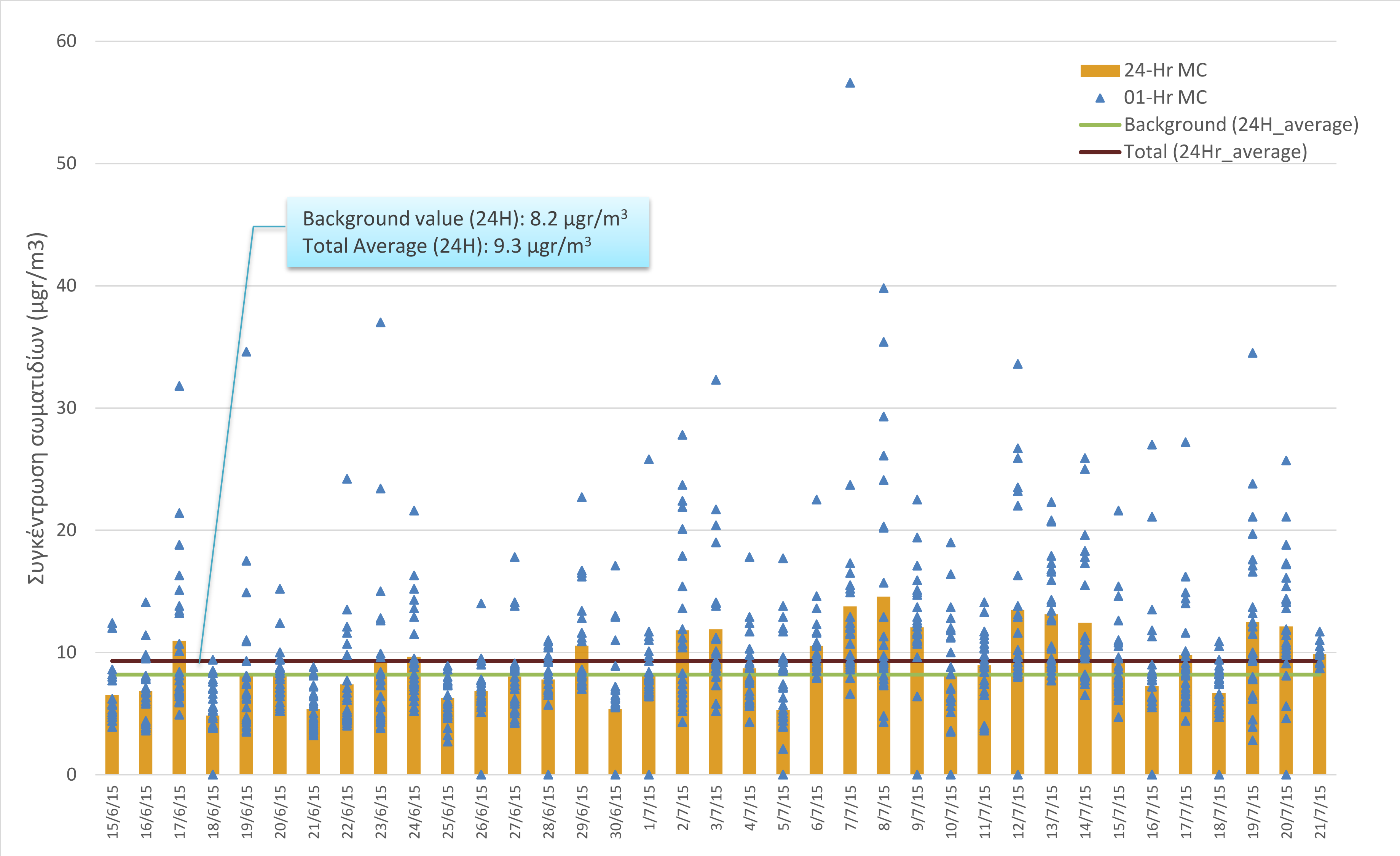


Figure 6.7. PM-10 concentration values recorded - 1hr and 24h average values (μg/m³) - during the LFM pilot application, at the PL site.

Even though the hourly (1h) values are not part of the standard, the research team has decided to include their values in the analysis in order to better depict the conditions at the PL site. In this manner, as seen from Fig. 6.7, fluctuations at an hourly basis do exist, with a PM-10 peak value at 56.6 μg/m³ recorder between 09.00 and 10.00 in July 7th. Nevertheless, the average daily PM-10 concentration is also low in the range of 9.3 μg/m³. The complete distribution of the hourly recorder values are given in Fig. 6.8. It can be see that the majority of the recorded values (approx. 55%) are found between 10 and 15 μg/m³, while values greater than 30 μg/m³ represent only a mere 2% of the sampling data.

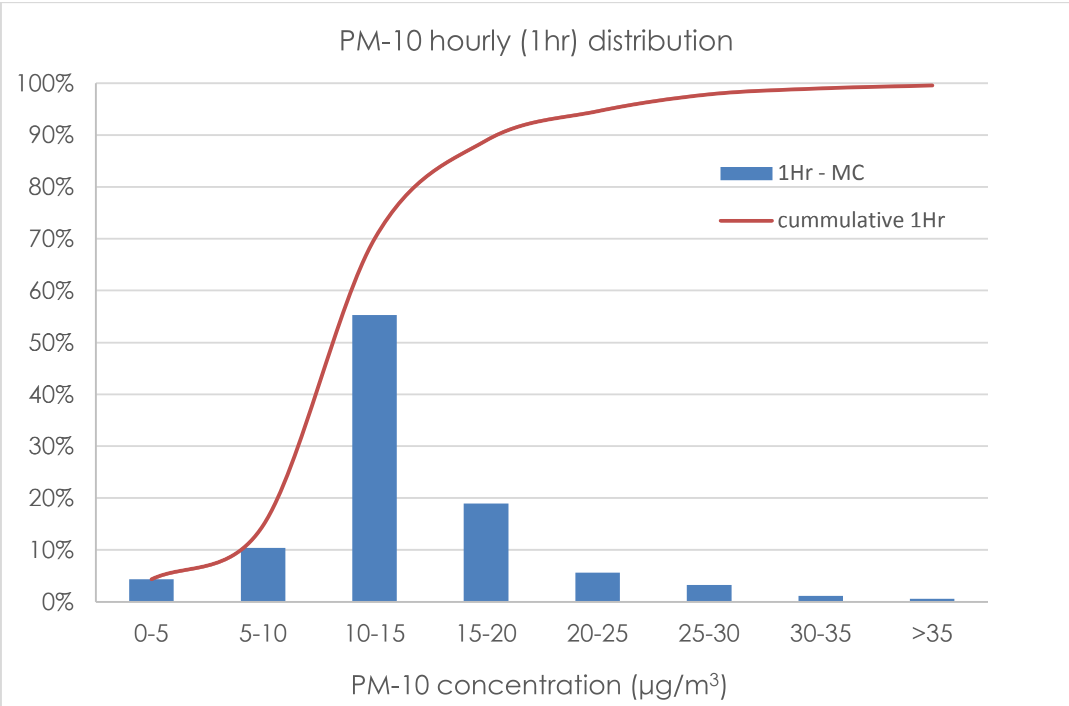


Figure 6.8. PM-10 distribution of the hourly (1hr) concentration values at the PL site.

In any case, in terms of the PM-10 daily values, the data gathered indicate that there isn't any significant impact in the deterioration of the air-quality of the site, as the average values recorder (9.3 μg/m³) are less than the 1/5th of the limit values as given in the 2008/EC/50 directive (50 μg/m³). The extremely small difference between the average background values and the average measured ones further indicates the extremely small impacts from the operations to the environmental conditions in terms of air-quality.

6.3.2. Air quality – Odors and Gaseous Emissions

The monitoring relating to odors and other gaseous emissions (CO, CO_2, CH_4, NO_x, H_2S), did not yield any significant results, even if there was a quick response from the monitoring team in the event of an odor problem, as identified by the personnel. Thus, even if there was a relevant direction to try and quickly transfer the portable sampling devices at the location where the odor was detected, the samplers haven't actually recorded any significant event. The odor problems at the pilot LFM application at the PL site were erratic in nature and rather small in both number of incidents and spread area and thus it can be deduced to have negligible impacts.

Figures 6.9a and 6.9b, show the graphical representation of the recordings of a case where the sampling units actually identified the presence of NO (Nitrogen oxide) at low levels of 0.5 ppm and the presence of NO_2 (Nitrogen dioxide) at 0.1 ppm. There are also some additional cases with NO recordings at low levels (0.4-0.5 ppm) but these instances are scarce, with the majority of recorded values to be 0. As far for the CO_2 concentrations, these were found to be in the range between 610 and 700 ppm. Apart from the above, no detection of hydrogen sulfide (H_2S) or methane gas (CH_4), was made. Especially the latter is of great importance as it can potentially result to the development of an explosive prone situation and consequently to high risk levels. Thus, the no detection during the operations is a positive issue for the safety of the workers and the operation itself.

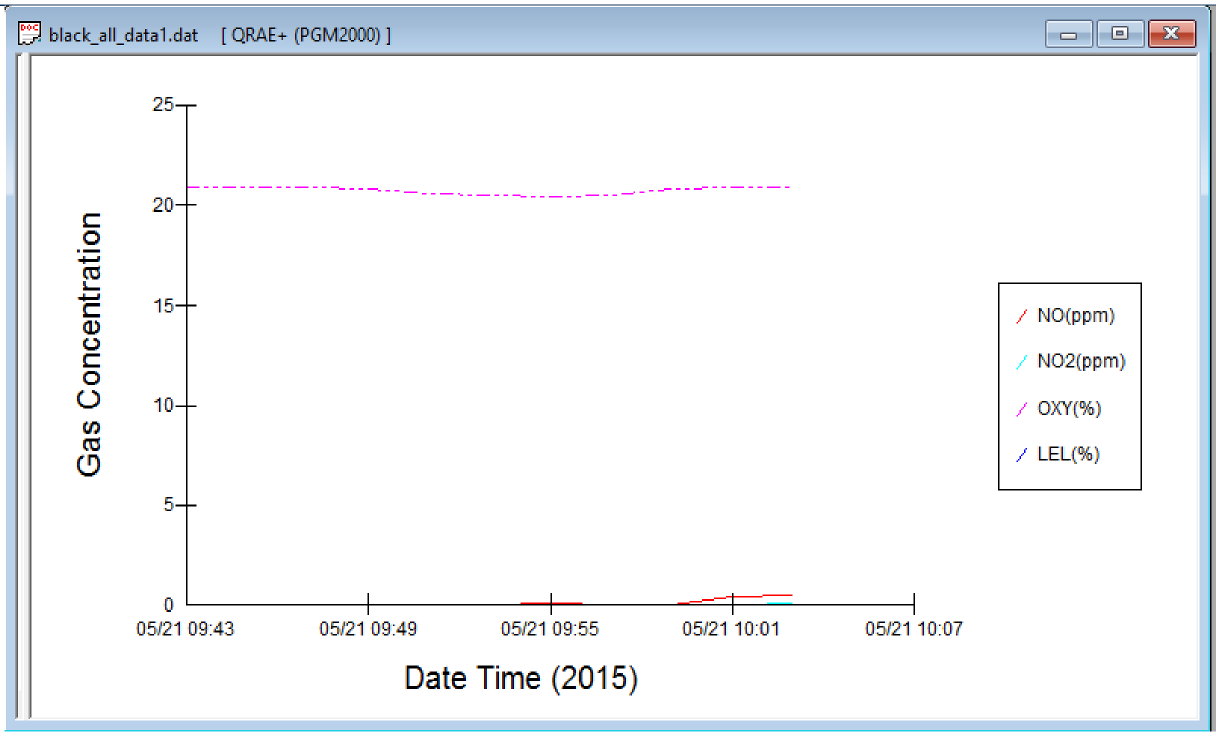
With respect to the exposure limits as indicated in section 6.2.2, the monitoring concentrated on the assessment of the short-term exposure limits (STEL). The values monitored were way below the thresholds indicated, as the peak values that were previously described are many times below these particular limits (NO_{Peak}=0.5 ppm – NO_{Limit}=2 ppm, NO_{2Peak}=0.1 ppm - NO_{2Limit}=1 ppm). Consequently, it can be deduced from the above data that the impacts to the workers due to the presence of gases are extremely limited.

6.3.3. Sound Levels - Noise

The sound level measurements were made to assess the overall noise from the LFM pilot application. The measurement of the background ambient noise was also performed, when no operation took place, during the day time, so as to be able to compare and benchmark the results. No measurements were executed during night time.

The background noise levels at the PL site can be characterized as "typical" for a rural area with L_{eq} values to be at around 58 dB(A). In the operation of the machinery, as it was expected higher noise levels were recorded. In Figure 6.10, two sound level measurements are presented, the background levels (lower) and the noise levels (upper) as monitored at a distance of about 2 to 5m from the operating mobile waste processing unit.

More particularly, the data presents two measurement types, the sound pressure level (SPL) and the equivalent continuous noise level (L_{eq}), which represents the average sound energy produced in the monitoring period. These measurements are made using the A and C weighting filter. The equivalent continuous noise level for the background noise is $L_{eq(A)\_back}$=58.6 dB(A), while for the operating unit is $L_{eq(A)\_oper}$=77.6 dB(A). The peak values are $L_{peak(C)\_back}$= 93.0 db(C) and the $L_{peak(C)\_oper}$= 107.6 dB(C). Figure 6.11 presents the data corresponding to the measurements performed in the vicinity of the operating mobile processing unit, as derived from the Norsonic Sound Level Meter (SLM-116).



Instrument: QRAE+ (PGM2000) Serial Number: 407407
User ID: 00000001 Site ID: 00000001
Data Points: 11 Data Type: Avg Sample Period: 120 sec
Last Calibration Time: 04/30/2015 14:52
Start At: 05/21/2015 09:43 End At: 05/21/2015 10:03

Sensor:	NO (ppm)	NO2 (ppm)	OXY (%)	LEL (%)
High Alarm Levels:	50.0	10.0	23.5	20.0
Low Alarm Levels:	25.0	1.0	19.5	10.0
STEL Alarm Levels:	25.0	1.0	-----	-----
TWA Alarm Levels:	25.0	1.0	-----	-----

Sensor:	NO (ppm)	NO2 (ppm)	OXY (%)	LEL (%)
Peak Data Value:	0.5	0.1	20.9	0.0
Min Data Value:	0.0	0.0	20.4	0.0
TWA Data Value:	0.0	0.0	-----	-----
AVG Data Value:	0.1	0.0	-----	-----

Figure 6.9.a,b. Graphical timeline of the measurements of the gaseous emissions performed and details of the event recoding the presence of NO (0.5 ppm) and NO_2 (0.1 ppm).

Several other sound level measurements were made in different operation phases and at various distances from the operating machinery and locations at the PL site. The data gathered expressed as equivalent continuous noise level (L_{eq}), can be seen in Figure 6.12.

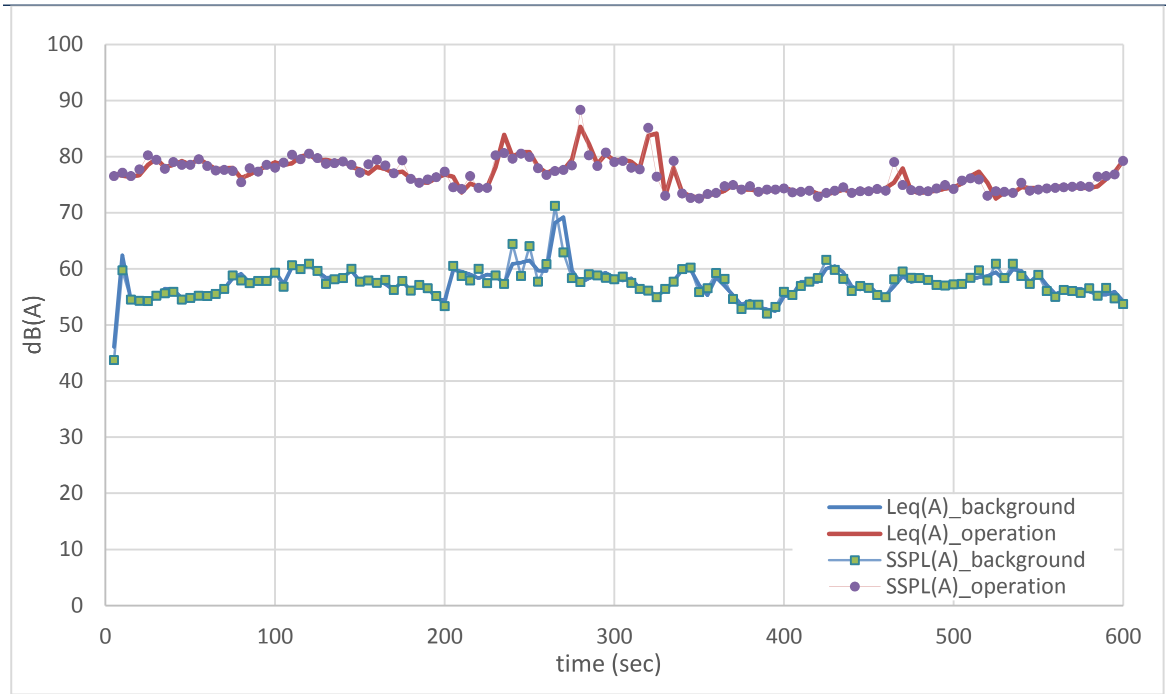


Figure 6.10. Measurement of the sound levels in the PL site (background noise and noise generated from the waste processing unit).

150521 15\05\21 12.31.52 LEV	TDATA 15\05\21 12.31.52	
Directory name	[150521]	
File number	[0005]	
Measurement mode	1 LEV	
Data type	3 TDATA	
Measurement date	15\05\21 12.31.52	
Measurement end date	15\05\21 12.41.52	
150521 15\05\21 12.31.52 LEV	TDATA 15\05\21 12.31.52	
Calibration factor	-26,1	dB
Measurement time	1000	00.10.00
Ovl status	0	Not Ovl!
A-weighted Leq	77,6	dB
A-weighted Leq Impulse	0	dB
A-weighted Max Fast	0	dB
A-weighted Max Slow	90,5	dB
A-weighted Max Impulse	0	dB
A-weighted Min Fast	0	dB
A-weighted Min Slow	71,2	dB
A-weighted Min Impulse	0	dB
A-weighted SEL	105,3	dB
A-weighted SEL Impulse	0	dB
A-weighted Peak	107,5	dB
A-weighted Tmax5 Fast	0	dB
A-weighted Tmax5 Impulse	0	dB
C-weighted Leq	87,6	dB
C-weighted Leq Impulse	0	dB
C-weighted Max Fast	0	dB
C-weighted Max Slow	92,8	dB
C-weighted Max Impulse	0	dB
C-weighted Min Fast	0	dB
C-weighted Min Slow	84,9	dB
C-weighted Min Impulse	0	dB
C-weighted SEL	115,4	dB
C-weighted SEL Impulse	0	dB
C-weighted Peak	107,6	dB
C-weighted Tmax5 Fast	0	dB
C-weighted Tmax5 Impulse	0	dB

Figure 6.11. Sound level monitoring data at the location of the mobile processing unit.

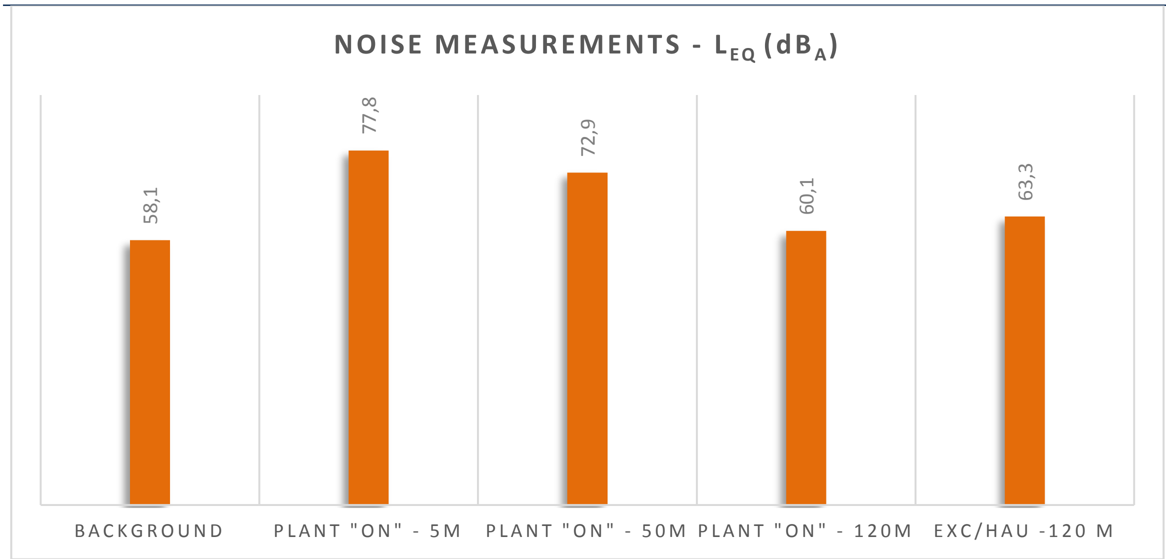


Figure 6.12. Noise measurements at the PL site for various scenario in terms of machine operation and distances from the monitoring source.

As it can be seen from Fig. 6.12, the sound levels from 78 dB(A) at a 5-m distance from the operating plant, drop to 73 dB(A) at a distance of 50 m from it, and to 60 dB(A) at a distance of 120 m. The latter is approximately the same with the ones recorded at the same distance (120 m) as result from the excavation and haulage operations taking place there to facilitate the LFM pilot operation. It is directly comparable though to the everyday normal landfilling operations taking place at the PL site, and 2 - 5 dB(A) higher from the background noise recorded there.

In terms of the conformity to the standards, the noise level measurements relating to the LFM pilot operation are considerably less than the ones dictated from the standards. They are measured almost 10 dB(A), lower than the LEX,8h (87dB(A)) and 80 dB(C) lower than the peak limits (200 dB(C)). They are also lower from the lower exposure action values (LEX,8h = 80dB(A), peak = 112dB(C)). Also, they monitored values are lower from the permissible ones set by the 2000/14/EC directive (the lowest limit is mandated at 83dB(A)).

6.4. Environmental Characterisation of Water Samples

6.4.1. General Details - Sampling and Experimental Procedure

For the purposes of the LIFE project, Recyclables Bottles (B) and Plastic Bags (PB) were washed in a metallic washing device (laundry), targeting on the examination of the possibility of materials re-use/recycling. Nevertheless, washing of waste coming from an operative landfill site, results in the production of a leachate that needs to be evaluated in terms of its further environmental management.

The washing procedure took place in a special laundry designed for that purpose consisted by a rotary device, where the materials were placed manually. The rotary device is powered by an electric motor of 5.5 kW and has a special gate for the materials import. It is connected to the water supply from the water system but there is also a choice of manual water supply. When the materials are placed and the import gate is closed, the washing cycle begins by the pressure of the start/stop button. The duration of the washing cycle depends on the kind of the materials. After the end of the wash the materials may exit manually from the same gate. More technical details about the laundry operation are given in "Technical Report of The Installation of the Pilot Demonstration Unit of Action B5".

Washing Tests were performed for seven different samples. The latter were either plastic bags (PB) containing waste or recyclable bottles (B) coming from the landfill. Different samples were washed first with water and then with a common detergent and leachates were collected from the laundry for further analysis and environmental characterization. A second series of samples were collected for purposes of metals determination and acidified in order to preserve metals in dissolution during to their transportation to the laboratory. All series of samples were immediately stored below 4◦C after sampling, for purposes of adequate preservation. The samples are coded as follows:

- PB: Plastic Bags
- W: Washed with water
- D: Washed with detergent
- B: Bottles

One sample (RCT 1) was also collected from the rainwater collection tank (RCT), situated in the area of the Pilot Demonstration Unit (PDU) preparation works. The purpose of investigating the particular sample was in order to identify if any leachate produced from the particular area may pollute the surface runoff collected in RCT. Collected samples are presented in the following Table 6.2.

Table 6.2. Identification of Samples Collected for Environmental Characterization.

Sample code	Sampling Date	Type of waste	Washing Agent
RCT 1	24/6/2015	-	-
PBW1	24/6/2015	Plastic Bags	Water
PBD1	24/6/2015	Plastic Bags	Detergent
PBW2	25/6/2015	Plastic Bags	Water
PBD2	25/6/2015	Plastic Bags	Detergent
BW1	25/6/2015	Bottles	Water
BD2	25/6/2015	Bottles	Detergent
BW2	27/6/2015	Bottles	Water

6.4.2. Materials and Methods of Analysis

Chemical analysis was performed focusing on some of the typical parameters that are usually monitored in leachate produced at landfill sites (Syed et al., 1994; Kjeldsen et al., 2002). In Table 6.3 typical values and range of some key leachate parameters are illustrated. Emphasis should be given to the age of waste, since there is a significant reduction of leachates pollution load for wastes remaining on a landfill site for more than 2 years. According to this approach, the parameters illustrated in Table 6.4 were measured. In the same Table, the respective standards and the analytical methods/devices used for each parameter are also presented.

Table 6.3. Key parameters of leachate composition according to landfill age (Syed et al., 1994; Kjeldsen et al., 2002).

Parameter	Range (mg/l)-Typical Values (mg/l) except pH	Landfill > 2 years
BOD	2000-30000/ 10000	100-200
COD	3000-60000/18000	100-500
TDS	200-1000/500	100-400
NH_4^+	10-800/200	20-40
NO_3^-	5-40/25	5-10
Total P	5-100	30
pH	5,3-8,5/6	7,5
Cl	100-3000/500	100-400
SO_4^{-2}	300-9000/1500	60-150
Fe	50-600/60	20-200

Table 6.4. Physicochemical Parameters measured in the leachates after waste washing

Parameter	*Standard*	*Analysis Device*
BOD	*DIN 38409T51, DIN 38409T52*	*OxiTop IS 6*
COD	*ISO 15705/2002*	*Titrimetric Analysis*
pH	*ISO 10523/2008*	*Mettler – Toledo pH Analyst*
Conductivity (μS/cm)	*ISO 8502-6/ISO 8502-9*	*Mettler – Toledo Conductivity Meter*
Total Dissolved Solids (mg/l)	*ISO 8502-6/ISO 8502-9*	*Mettler – Toledo Conductivity Meter*
Total P	*ISO 6878/2004*	*Orbeco – Hellige Series 942 – Water Analysis System*
SO_4^{-2}		*Gravimetric Analysis (Vogel et al., 2000)*
Cl^- *(mg/l)*	*Volhard Method*	*Volumetric (Titrimetric) Analysis (Vogel et al., 2000)*
NH_4^+ *(mg/l)*	*ISO 15923-1/2013*	*Orbeco – Hellige Series 942 – Water Analysis System*
NO_3^- *(mg/l)*	*ISO 15923-1/2013*	*Orbeco – Hellige Series 942 – Water Analysis System*
Pb, Cr, Ni, Mn, Fe, Zn, Cu, (mg/l)	*DIN EN ISO 11885*	*ICP – AES - Prodigy – Teledyne, Leeman Labs*

6.4.3. Results of the Water Samples

In Tables 6.5 and 6.6, the chemical analysis results of the water/leachate samples are illustrated, in terms of physicochemical parameters and metal concentration.

Table 6.5. Values of Physicochemical Parameters measured in leachate samples.

Sample	pH	Conductivity (μS/cm)	TDS (mg/l)	BOD	COD	SO_4^{2-}	Cl^-	NH_4^+	P	NO_3^-
RCT 1	8.3	2050	1027	50	115	292	391	216	35	25
PBW1	7.0	1090	546	100	510	163	320	302	20	<5
PBD1	8.0	1001	500	70	270	< 5	320	202	15	<5
PBW2	6.8	2880	1438	2200	5300	2022	355	360	45	<5
PBD2	7.0	1167	582	80	210	170	310	252	12	<5
BW1	6.5	5558	2760	2500	7800	907	480	504	75	<5
BD1	7.1	1050	530	55	125	363	320	209	15	<5
BW2	6.8	1480	738	70	190	129	340	288	25	<5

Table 6.6. Values of Metals Concentrations measured in leachate samples (in mg/l).

	Mn	Pb	Fe	Zn	Cu	Ni	Cr
RCT 1	0.25	<0.01	0.53	0.03	<0.005	0.21	<0.005
PBW1	0.46	<0.01	2.01	0.56	<0.005	<0.01	<0.005
PBD1	0.34	<0.01	0.34	0.28	<0.005	<0.01	<0.005
PBW2	0.21	<0.01	2.00	0.47	<0.005	<0.01	<0.005

Based on the above data, the following can be deduced for the collected samples:

RCT1: pH of water selected in the RCT is alkaline (Table 6.5), probably due to the interaction between the surface runoff and the sandy upper layer of the site insulation system. Values of BOD and COD are low, indicating a very small amount of organic load entering the RCT. Conductivity value is probably attributable to the presence of ions other than metals since the latter concentrations are very low (Table 6.6).

PBW1: pH value of the leachate produced under water effect is neutral (Table 6.5), indicating that waste are probably more than 2 years old, thus entering the methanogenic phase of decomposition. That is confirmed from the low BOD and COD values and BOD/COD ratio. Considering the age of the waste, the valued of the measured anions and cations are more or less expected.

PBD1: The leachate produced from washing the same waste sample with detergent presents slightly ameliorated attributes. In fact, pH value is becoming alkaline due to detergent effect, while notable is the significant decrease of the sulphates and iron load.

PBW2: Leachate produced from the second PB sample, indicates the presence of more recent waste, probably less than 2 years old. pH is acidic while BOD, COD, BOD/COD ratio and sulphates values are relatively high, as they should be for waste during the acid phase of decomposition.

PBD2: Leachate produced from washing the same waste sample (2) with detergent, presents significant reduction with respect to conductivity, TDS, BOD, COD and sulphates load. On the contrary, pH is very little affected.

BW1: The particular leachate was the one with the highest pollution load. pH indicates waste in the acidic phase of decomposition (i.e. less than 2 years old), while conductivity value is at least twice higher than the average of all other samples. The high values of BOD, COD, SO_4^{-2}, $NH_4^+$and Cl^-, confirm the problematic nature of the sample, with respect to its environmental management.

BD1: With respect to the previous sample (BW1), re-washing of the same bottle butch with detergent results in a leachate with low pollution load. pH is slightly alkaline, while conductivity and TDS are reduced more than 80%. All other measured parameters (especially BOD and COD), are significantly ameliorated.

BW2: The leachate produced after washing the second batch of bottles with water, is much less polluted than the BW1, indicating lower pollution levels in the second batch.

6.4.4. Leachate Management

Leachates produced from the washing of municipal waste (plastic bags and bottles) as described above, are considered as a waste water and require further management before entering soil or water bodies and before considering any possible reuse as mandated in the Directive 91/271/EEC concerning urban waste water treatment, as well as the Greek Ministerial Decision M.D. 5673/400 (Official Gazette 192B/14-3-1997). Greek legislation relative to landfill operation and management (M.D. 29407/3508 - Official Gazette 1572B'/16-12-2002) forbids any leachate, (produced in municipal waste landfills) release into soil or water bodies, without previous appropriate treatment. The obligatory stages of leachate treatment scheme depend on certain chemical and biological parameters of the liquid waste.

Nevertheless, many of the leachates and especially those produced under detergent effect, present improved quality compared to those typically produced in landfill sites. Bearing in mind the existed two-stage biological treatment plant at Polygyros Landfill Site, the leachates PBW1, PBD1, PBD2, BD1 and BW2, may enter directly to the secondary treatment stage, with no need of primary treatment. That is due to the relatively low BOD, COD and solids concentrations of the particular samples. On the other hand, PBW2 and BW1 need by all means to undergo a primary treatment stage (e.g. precipitation, coagulation) for reducing solids and BOD loads.

Generally, since the existing biological treatment plant operating at Polygyros Landfill Site, has two treatment stages, may accept all the leachates produced by the washing of plastic bags and bottles. It should be mentioned that metals concentrations are presented significantly low in all leachates examined. Thus, the implementation of a common biological treatment procedure for leachates management is feasible.

6.5. Difficulties - Deviations

The monitoring procedure related both to the on-site implementation of the measurements and to the implementation of the laboratory evaluation and characterisation of the water samples has not encountered any particular difficulties. On the contrary, the campaign can be characterised as a successful one, allowing a wide variety of measurements to take place. In this manner, the main characteristics of the prevailing environmental conditions and possible threats have been quantitatively assessed. Furthermore and more importantly though, the levels of the measured environmental indicators show that the impacts generated to the environment of the PL site and to the health and safety of the workers is minimal.

Nevertheless, it should be noted that the above are related to the impacts of the pilot LFM application and a possible transition from a pilot to a full scale operation should be examined with caution so as to mitigate and control any negative impacts.

Chapter 7. CONCLUSIONS

7.1. General Conclusions

During the course of this Action (B.6), all the necessary tasks and activities related to the operation of the PDU in the PL were completed through the collaboration of the sub-contractors appointed under Action B.4 and the Project Team. The sub-contractors successfully operated the agreed automobile and static equipment. The operation and monitoring took place inside the PL while the Beneficiation and sample testing was conducted in the SMME (NTUA) laboratory.

The organisation activities were also conducted as planned (i.e. roles and responsibilities for the Project Team members for the operational period of the PDU). Also, the actual day to day activities of the Unit followed the initial schedule apart from the cases that difficulties and deviations were affecting them, such as heavy rainfall and mechanical faults. Daily records were kept consistently and facilitated the execution of calculations about the PDU operation.

During the operation period, the Project Team overcame many difficulties, making some necessary deviations from the initial design of the Unit. The biggest difficulty of all was the weather: the rainfall this year was at its highest levels. The only solution to this issue was to be patient and waiting for the rain to stop. Also, to prevent any risk of damages or missing equipment, a security company was employed to inspect the PDU during the Operational period. At a longer-scaled project, it is suggested that the Unit should be covered at least with a shed and the excavated waste pending area as well as the mined area in the landfill cell should also be protected by the rain so that productivity can remain at its highest.

The total amount of waste excavated and processed reached a volume of approximately 1300 m^3 (580tn) and consisted of glass, mixed hard plastic, plastic film and aluminum (recyclable materials), as well as ferrous waste. Reclaim of glass proved to be less efficient, since the waste is pressed in order to be buried in the Landfill; so glass is usually broken into small fragments during the first phase of waste deposition. However all materials could potentially be recycled if they were forwarded to the right facility and they would even prove to be profitable if they were all washed in an industrial washing machine. Also, a great amount of soil was reclaimed by the excavated material. This was later tested and found to be compatible for use as landfill cover material, according to the current Greek regulations.

The Beneficiation tests were also completed successfully, although they were elaborated in the laboratory of SMME (NTUA) and the input material was not extracted from the mined waste of the PL but was gathered by an e-waste recycling point. The results showed that the metal concentrates from the PCBs were reclaimed at a satisfying rate with the float-sink tank method but much more tests are needed to maximise recovery efficiency and reach definite conclusions about this process.

Furthermore, the Environmental Monitoring of the LFM activities proved that the method does not have any significant negative impacts on the environment, especially for the PL, where the waste is rather new and the biogas production is still rather limited. However this might not be the same to different, older and bigger landfills, thus an efficient Environmental Monitoring system and the implementation of all the appropriate Health and Safety measures is important during every LFM project.

The PDU operation did work properly and ended up to the expected results. It is suggested that another test could be run in a larger scale, for a long-term period, using more staff, to determine the productivity and the recovery efficiency of the LFM method. Moreover, the design of the Unit should be slightly different, in order to avoid the difficulties from unpredicted factors, such as rain, and could be enhanced with some modifications in the machine array to include technology innovations and accommodate for the separation of more materials.

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APPENDICES

Appendix 1: Photographic Documentation


O&K


O&K


O&K


RAM
RAM ITALIA
112161


AFOI TSIMERIKA


80


80
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PIESTERITZ


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RAM


X.Y.T.A.
3ης Δ.Ε.
4013
BOMAG

Appendix 2: Demonstration Unit Lay Out Map
(Scale 1:200)