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

TECHNICAL REPORT - ACTION B7

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

SUBJECT:

REHABILITATION PLAN
TECHNICAL REPORT

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Abbreviations

AHP: Analytic Hierarchy Process

DU: Demonstration Unit

ELFM: Enhanced Landfill Mining

LCT: Life Cycle Thinking

LF: Landfill

LFM: Landfill Mining

MCA: Multi-Criteria Analysis

MSW: Municipal Solid Waste

PL: Polygyros Landfill

RCM: Region of Central Macedonia

Chapter 1. EXECUTIVE SUMMARY

For engineering and infrastructure projects, the development of Rehabilitation Plans is important part of the overall project design phase. This report focuses on the design of a Rehabilitation plan for a Landfill Mining project, based on the Polygyros LFM project of LIFE reclaim. The report can be read as a manual for similar projects as it provides insight to the relevant legislation, the international and Greek experience of land fill and dump site rehabilitation, the special features of each project which should be taken into account, the several alternatives which can be examined as various rehabilitation options and the suggested method to choose the most suited alternative for a specific project.

In particular, the literature review on the rehabilitation of landfills presents an overview of all the relevant legislation, both national and European, on solid waste management and landfills. Furthermore, the recent revision of the National Waste Management Plan (EDSA, June 2015) is presented, showcasing its main purpose and objectives. The role of the national Solid Waste Management Bodies is also discussed, as they are the official agencies responsible for the landfills in each region of Greece and every decision about landfill operation, closing works or rehabilitation schemes must be approved by them. Finally, rehabilitation of landfills is approached at a theoretical level and some distinctive cases from the literature are presented.

To propose any rehabilitation plan, first of all, the main characteristics of each site must be examined. The next chapters of the report provide the necessary guidance through the process of identifying the important baseline conditions which will be used to point out the most relevant rehabilitation suggestions for every project. The distinction between three categories of projects is taken into account: operating landfills, closed landfills and sites after complete LFM projects. The particular characteristics of each one of these three situations are explored, as different rehabilitation approached need to be followed. This section also gives many examples of rehabilitation alternatives such as the creation of a solar park, a recreational area, a residential area and many more.

Specifically for the LIFE reclaim project, the report assumes that a complete LFM project was carried out at the Polygyros Landfill, thus a suitable rehabilitation plan should be designed. Drawing data from the earlier "*Technical Report on Baseline environmental and social conditions*" of Action A3 of the project, the key baseline characteristics of the surrounding area of the landfill are examined. After establishing the conditions of the region, all the potential rehabilitation options are explored and the five most suitable ones among them are chosen: Return to Natural state, Commercial/Industrial use, Recreational area, Composting Facility and Construction and Demolition (C&D) Waste Recycling and Disposal Facility.

Alongside the exploration of various alternatives, it is stressed that the process of deciding which option is the most suitable for each project can be made easier and streamlined with the use of Multi-Criteria Analysis. The MCA methodology uses specific criteria to guide the user through complex problems, in order to make the best and most objective decision. For rehabilitation plan alternatives, the creation of a MCA tool can ease the process and provide credibility as well as the stakeholders' insight when finding the best available option.

For every MCA method, the definition of the criteria to be used is very important. For the creation of a LFM oriented MCA tool to help with the decision-making of the most suitable rehabilitation plan, the selected criteria were the Environmental, the Financial and the Social impacts of each alternative. This is how the **RECLAIM-hab tool** was created, following the MCA methodology. The specific model which was followed was the Analytic Hierarchy Process (AHP) which uses a simple 1-9 scale to make pairwise comparisons between the qualitative criteria, leading to a hierarchy, so that each alternative option can be compared to one another. The tool is highly adaptable and its methodological approach as well as a complete step-by-step example are both presented in the report.

The RECLAIM-hab tool is put in use for the Polygyros Landfill case of the LIFE reclaim project. The five proposed rehabilitation scenarios are compared with each other using the presented methodology and analysed with respect to the three identified criteria: the Environmental, the Financial and the Social factors. To estimate the values for the qualitative criteria and the pairwise comparisons for the LIFE reclaim example, a DELPHI session was held with experts from the Reclaim Team, using a questionnaire developed for this reason, which can be adapted for use with any project and it can also be used during a public consultation. Among the five suggested alternative choices, the most fitting is found to be building a Composting Facility, which got the best score at the Social Factor and the second best at the Environmental and Financial factors.

The report goes on with the description of the actual rehabilitation works at the Polygyros Landfill, which were minimal as the landfill is still operating. Moreover, the selected rehabilitation alternative, the Composting Facility is presented in detail: after a complete LFM project, the landfill cell is transformed into a 3-level plateau where the Composting Facility will be built. The rest of the Landfill infrastructure is left untouched as it will serve the Facility's needs.

To summarise, the report elaborates on a complete Rehabilitation Plan design for the Polygyros Landfill and also serves as a manual to future projects for selecting the relevant alternatives and using a tool such as the RECLAIM-hab to facilitate and streamline the process. Apart from LFM projects, it can be useful to engineers and construction companies for mining developments, infrastructure projects and industry works, as the procedure is highly adaptable and very easy.

Chapter 2. INTRODUCTION

2.1. Action context and Objectives

This present report is the Deliverable of Action B7 of the LIFE reclaim Project "Landfill mining pilot application for recovery of invaluable metals, materials, land and energy", which is being funded by the European Commission through Life+ 2012 vehicle, under the contract LIFE12 ENV/GR/000427.

The scope of the action is to prepare a detailed manual for the clearance, consolidation and rehabilitation of landfills after landfill mining. The Project Team elaborated on the national experience of land fill and dump site rehabilitation and combine it with the specific problem at hand, taking into account the peculiarities of the project. The foreseen plan will be composed based on the following steps:

1. **Literature review** for rehabilitation plans related to landfill or waste mining
2. **Selection of alternatives** that are relative to the Greek reality for operational landfills and non-rehabilitated old unregulated dump-sites
3. **Development of a tool** for evaluating the most appropriate method, based on Multi-Criteria analysis
4. Selection of the **better** suiting **alternative** for the Polygyros Landfill
5. Creation of a **virtual rehabilitation**, by means of modern technological tools, as 3D design and virtual video. The selection of this approach owes to the fact that PL will still be in operation and it will not be possible to rehabilitate it in reality
6. **Presentation** of the virtual rehabilitation on the projects website.

2.2. General Information on LIFE+ reclaim

2.2.1. Project Objectives

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

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

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

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

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

2.2.2. Actions and Means

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

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

More analytically, the Project includes the following Actions:

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

6. Project management Actions

7. After-life communication plan

2.2.3. Expected Results

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

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

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

2.3. The Study Team

This Report has been elaborated by the following Life reclaim collaborators:

From the team of ENVECO S.A.

- Georgios Kotzageorgis, Biologist (University of Athens, Greece), Ph.D. in Ecology
- Yanis Katselis, Mineral Resources Engineer, Environmental Engineer MSc, Business Administration MBA

- Chrysanthi Papara, Environmental Scientist (University of Aegean)
- Nikolaos Mihas, Civil Engineer (AUTH), MSc in Environmental Engineering
- Zoi Gaitanarou, Mining Engineer NTUA, MSc Environmental Engineering and Business Management, Imperial College of London
- Emmanouilia Kalfaki, in Environmental Engineer (Technical University of Crete), MSc
- Panagiota Mprousti, Environmental Scientist (University of Aegean), MSc in Water Resources Science and Technology (NTUA)

2.4. Report Content

The scope of this Report is to act as a technical manual for future LFM projects, mainly in Greece but also abroad. It will provide the necessary information, both from the literature but also from the LIFE reclaim experience and it will also make suggestions for alternatives and propose a decision-making tool for Rehabilitation of Landfills after a completed LFM project.

The results from the desktop study around the main framework of LF rehabilitation, such as the legislative background, the rehabilitation of landfills and some case studies from Landfill Mining Applications are presented in **Chapter 3.**

Chapter 4 is an extensive presentation about potential alternative rehabilitation plans for different cases of LFM projects. It also makes some suggestions of alternative rehabilitation solutions for the Polygyros Landfill.

To make a careful selection among the alternatives, an MCA decision making tool is designed in **Chapter 5**, after examining the MCA methodology and the example of another MCA tool used for LFM projects.

Chapter 6 makes use of the MCA decision making tool developed in previous chapters to make a selection among the alternatives for the Polygyros Landfill. Then, **Chapter 7** demonstrates how this rehabilitation plan will be implemented in the LF.

Final conclusions and considerations are provided in **Chapter 8**.

Chapter 3. LITERATURE REVIEW FOR REHABILITATION PLANS FOR LANDFILLS

3.1. Legal framework

3.1.1. EU Framework and Legislation

The Greek Legislation about waste has been greatly influenced by the relevant EU Framework. In fact, the first legal action taken by the Council of the European Communities was the so called Waste Directive (75/442/EEC) of 1975, amended and corrected many times, until its newest review, revision and re-release in 2008, as the Waste Framework Directive (WFD) 2008/98/EC (OJ L312). The WFD sets out the definitions of many waste related terms, sets specific and strict rules for the characterization of waste materials, in order to enable up-cycling of certain streams and introduces the application of the waste hierarchy and the Life Cycle Thinking (LCT) into the waste management process. Its main scope (Art.1) is to lay down the necessary measures for environmental and human health protection by:

- Preventing adverse impacts of waste generation & management
- Reducing adverse impacts of waste generation & management
- Reducing overall impact of resource use
- Improving the efficiency of resource

Furthermore, effective waste management in the EU has strong roots in the Council Directive 99/31/EC of 26 April 1999 on the Landfill (LF) of waste (OJ L182/1/1999). The Directive Scope is to prevent or reduce the adverse effects of the landfilling of waste on the environment, in particular on surface water, groundwater, soil, air, climate and human health. The Directive has been supplemented by ancillary legislation relating to landfill of waste, mostly related to the establishment and smooth operation of landfills:

- Commission Decision 2000/738/EC concerning a questionnaire for Member States reports on the implementation of Directive 1999/31/EC on the landfill of waste
- Council Decision 2003/33/EC, of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 and of Annex II to Directive 1999/31/EC

3.1.2. National Framework and Legislation

The general guidelines for waste management policy formulated and determined by the Ministry of Environment, Energy and Climate Change (MEECC) in collaboration with the other Ministries and the collective instruments of local government aim at taking appropriate measures to promote: (i) the prevention or reduction of production and (ii) the harmfulness of waste, in particular the development of clean and more affordable technologies, that may lead to milder exploitation of natural resources, to the technical development and marketing of products designed for minimization of waste and hazards, (iii) the development of appropriate techniques for final disposal of dangerous substances contained in waste destined for recovery and (iv) the recovery of waste by means of recycling, re-use or reclamation or any other process, which aims at extracting secondary raw materials , or the use of waste as an energy source.

Measures taken include primarily training framework specifications and drawing general waste management plans referring mainly to:

- disposal methods;
- specifications for temporary storage of waste;
- eligibility criteria and site selection criteria of disposal or recovery of waste;
- general standards of disposal and recovery facilities;
- general specifications for remediation after closure or their related facilities;
- general specifications for remediation of uncontrolled disposal sites;
- criteria for determining the length of aftercare facilities or premises after the termination of their operation.

Furthermore, enforcing these measures, MEECC may cooperate with other Member States and the European Commission.

The legal framework governing the management of waste in Greece is now defined by:

- Law 2939/2001 (Government Gazette 179/A/06.08.2001) "Packaging and alternative management of packaging of other products - Establishment of the National Organisation for the Alternative Management of Packaging and Other Products (EOEDSAP) and other provisions" , as amended by:
- Law 3854 / 10 (GG 94/A/23.06.2010) "Amendment of legislation for the alternative management of packaging and other products , and the National Organization of Alternative management of Packaging and Other Products (NOAMPOP) and other provisions " and by
- Law 4042/2012 (GG 24/A/13-2-2012) "Criminal Protection of the environment - Compliance with Directive 2008/99/EC - Framework waste generation and management - Compliance with Directive 2008/98/EC - Setting matters of the Ministry of Environment, Energy and Climate Change ", which incorporates into national law Directive framework 2008/98/EE waste, and the specific provisions of Law 4014/11 (Government Gazette 209/A/21-9-11) ' Environmental licensing projects and activities , setting arbitrary in relation to creating environmental balance and other provisions concerning the Ministry of Environment "as amended and in force .

The national law also incorporated key EU directives on waste, such as:

- JMD 29407/3508/2002 the CMD (OG 1572 B) « Measures and conditions for the landfill of waste" for incorporation of Directive 1999/31/EC , and
- JMD 22912/1117/2005 (GG 759 B) « Measures and conditions for the prevention and reduction of environmental pollution from waste incineration " for incorporation of Directive 2000/76/EC, with immediate effect the European Waste Catalogue (EWC), in accordance with the Annex to Decision 2002/532/EC , as amended and in force.

To regulate specific issues has been a series of joint ministerial decisions, the most important of which are:

- JMD No. 50910/2727/2003 "Measures and Conditions for Solid Waste Management. National and regional management ", as amended by Law 4042/2012
- JMD 13588/725/2006 "Measures , conditions and restrictions for the management of hazardous waste in compliance with the provisions of Directive 91/689/EEC " Hazardous Waste "of the Council of 12 December 1991 ", as amended by Law 4042/2012 and
- JMD 146163 /2012 "Measures and conditions for Sanitary Waste Management Units 1991 ", issued delegated under Article 38, paragraph 7 of Law 4042/2012.
- MD 56366/4351/2014 - Defining the requirements and specifications for processing activities concerning the mechanical - biological treatment of mixed municipal waste and defining the features of resulting materials according to their uses, in accordance with part b of paragraph 1 of Article 38 of Law. 4042/2012 (24 /A)

3.1.3. Revision of the National Waste Management Plan (EDSA)

The revision of the National Plan for Waste Management (EDSA) came into force in June 2015. It was created by both the Ministry of Environment and Climate Change and the Ministry of Interior and Administrative Reconstruction. This Plan takes into consideration previous studies and the views and suggestions of agencies, organisations, stakeholders and citizens of a wide number and scope.

Its main objective is the definition of the strategy, the political objectives and the actions for the sustainable management of waste at national level throughout the next six years (until 2020). The consultation that preceded and the organised large public dialogue events (KEDE, ENPE, TEE, EEDSA) enriched the content of the EDSA and created the conditions for a fruitful dialogue during the upcoming period in order for the Plan to specialize further in the regions and municipalities level, while many of its measures and guidelines will also be supported by law.

The new EDSA embodies the radically different political conception of the new governance towards an alternative waste management model, more modern and environmentally friendly. Its main priorities are:

- Decentralization of activities at municipal level,

- Qualitative and quantitative enhancement of recycling with a focus on separation at source,
- Separate collection and treatment of the organic fraction
- Supporting of small scale processing and recovery plants
- Encouraging social participation and
- Securing the public nature of waste management.

The ambitious goals of the EDSA fully embrace the concept of the hierarchy of waste management of the national and EC legislation, beyond the logic of centralized management units of mixed municipal waste, supporting the separate collection of recyclables and bio-waste and the reduction of the total volume of waste. Thus, addressing the current and pressing needs and the *acquis communautaire* so that the waste management in Greece can serve better the environment and the sustainable development, while drastically reducing management costs for the benefit of society and citizens. The new plan marks the reversal of some of the policies followed so far and leads to a zero waste economy and society that will convert waste to resources promoting the concept of Circular Economy.

Based on this framework, the national waste policy is focused to the following landmark goals for 2020: dramatic decrease of the waste generated per capita, preparation for re-use and recycling by separate collection of recyclables and biowaste at a 50% rate out of the total municipal solid waste, energy recovery as a complementary form of management when there is no recovery alternatives and landfilling as the last option, limited to less than 30% of all municipal solid Waste (MSW).

Besides MSW, the Plan also includes management of other waste streams, such as industrial waste, agricultural veterinarian, etc.

3.1.4. Solid waste management bodies

The public bodies responsible for landfills in Greece are the regional Solid Waste Management Bodies. The issues of waste management operators are regulated specifically by the following provisions:

- JMD 50910/2727/2003 (GG 1909 B) «Measures and Conditions for Solid Waste Management (National and regional)"as amended and in force.

- Law 3536/2007 (Government Gazette A 42/23.2.2007). Special Arrangements for migration policy and other matters concerning the Ministry of Interior, Public Administration and Decentralization (Article 30)

- Law 3852/2010 (Government Gazette An ' 87/7.6.2010). New Architecture of Government and Decentralised Administration - Program Kallikratis.

- Law 3854/2010 (Government Gazette 94/23.06.2010). Amend legislation on alternative management of packaging and other products and the National Agency for Alternative Management of Packaging and Other Products (NOAMPOP) and other provisions.

- Law 3979/2011 (Government Gazette A 138, 16.6.2011). E-Government and other provisions (Article 42).

- N.4071/2012 (Government Gazette 85/11.04.2012). Arrangements for local development, local government and decentralized administration Embed Directive 2009/50/EC.

3.2. Rehabilitation for Landfill Mining projects

After a LF has exhausted its useful life-time, eventually closure should take place, in order to protect public health and to rehabilitate the land. Closure of LF requires certain steps to materialize which involve (USEPA, 1993):

- Stabilization

The slope angle, slope length, and overlying soil load limit the stability of component interfaces (geomembrane with soil, geotextile, and geotextile/soil). Soil water pore pressures developed along interfaces also can dramatically reduce stability. If the design slope is steeper than the effective friction angles between materials, sliding instability generally will occur. Sudden sliding has the potential to cause tears in geomembranes, which require considerable time and expense to repair. Unstable slopes may require remedial measures to improve stability as a means of offsetting potential long-term maintenance costs. Methods to improve stability include using designs with flatter slopes, using textured material, constructing benches in the cover system, or reinforcing the cover soil above the membrane with geogrid or geotextile to minimize the driving force on the interface of concern.

- Waste terrain finalization

Modern theories of landscape design include the assessment of the balance of the natural ecology and the new ecosystem that will be installed on site, with the support of all necessary technical works will be constructed. The two main conditions for the final configuration are that the space will mix with the neighboring land and that will facilitate the natural runoff of stormwater. Thus, the final drainage system should be designed first and then the finalization of the terrain will follow.

- Final cover system

Design criteria for a final cover system should be selected to:

i. Minimize infiltration of precipitation into the waste;

ii. Promote good surface drainage;

iii. Resist erosion;

iv. Control landfill gas migration and/or enhance recovery;

v. Separate waste from vectors (e.g., animals and insects);

vi. Improve aesthetics;

vii. Minimize long-term maintenance;

viii. Protect human health and the environment; and

ix. Match final land-uses

The LF cap usually is designed in the same way as the LF liner. It includes (from top to bottom):

i. "Green" coverage with grass and low vegetation

ii. Natural mold or compost

iii. Infiltration layer, consisting of pebbles and gravel or from geo-synthetic materials

iv. Clay, or bentonite liner

v. Geotextile for HDPE membrane protection

vi. HDPE membrane

vii. Loose material for waste relief shaping

- Drainage control systems

Drainage layers are

- Leachate and gas management systems

The gas vent layer is usually 12 in. (30 cm) thick and should be located between the infiltration layer and the waste layer. Materials used in construction of the gas vent layer should be medium to coarse-grained porous materials such as those used in the drainage layer. Geosynthetic materials may be substituted for granular materials in the vent layer if equivalent performance can be demonstrated. Venting to an exterior collection point can be Biotic Layer provided by means such as horizontal pipes patterned laterally throughout the gas vent layer, which channel gases to vertical risers (or lateral headers. If vertical risers are used, their number should be minimized (as they are frequently vandalized) and located at high points in the cross-section.

Leachate management should be realized through the existing internal drainage network of the LF. The pumping station (if any) and the leachate treatment unit should be operational at all times after closure, until monitoring shows that the closed LF is inactive and no more leachate is created.

Rehabilitation of Landfill Mining projects can take a different direction, especially if it concerns removing the waste completely from an old landfill. In these cases there is no need for any covering or drainage system to be installed and usually no afterlife monitoring is needed. However, a careful examination of the soil must take place before any other rehabilitation activities take place, as the pollutants' content must be below the official limits that are established. More detailed information about soil remediation is provided in chapter 4.4.1. When the soil of the Landfill has being tested and treated if necessary, the area is ready to receive a landscaping configuration, designed by engineers and agriculturists, which can include: terrain shaping, planting trees, bringing fauna into the site, etc.

If the rehabilitation plans for a site aim only to bring it back to its natural state, the aforementioned steps conclude the rehabilitation. If the site is planned to be reclaimed for alternative uses such as industrial, commercial or even recreational purposes (presented in chapter 4.4.5), building works can start right after the successful soil remediation and landscaping activities.

3.3. Case Studies

The following projects have been selected to provide insight to different types of LFM and their different rehabilitation plans:

1) **Freshkills Dumpsite turned into a natural and recreational park, NY, US (Suflita et al, 1992, Yoneda, 2011)**

During its operation, Freshkills was World's largest landfill, amassing most of the household garbage collected in New York City and covering an area of 890 ha on Staten Island. The maximum amount of received waste was 29,000 tons per day and the four landfills cells of the site contain approximately 150 million tons of solid waste. The 50 year old dumpsite (opened in 1947) was closed in March 2001 due to pressure by the local community, with the support of the United States Environmental Protection Agency (EPA). During its operation, a small-scale LFM investigation project was conducted around 1992, but it is not known if it led to a fuller-scale LFM project. By 1997, two of the four landfill mounds were closed off and covered with an impermeable cap. New York City's garbage is now shipped to landfill locations in places such as Pennsylvania and Virginia.

Since its closure, the Freshkills dumpsite was planned to be reclaimed as a much needed new and massive green space. It is estimated that it will be transformed to a park almost three times the size of Central Park, available for recreational activities such as hiking, skiing, etc. The park will also offer ecological restoration and cultural and educational programming, including possible demonstrations teaching the public about renewable energy that will echo its environmental mission. Freshkills will also be a showcase for sustainable strategies such as advanced landfill gas collection infrastructure throughout the landfill to actively harvest methane from the buried decomposing waste, producing heating for almost 22,000 homes on Staten Island and producing additional $11 million annual revenue from the sale of the methane. The implementation of additional green technology to the park is being considered by introducing solar panels, wind turbines, solar thermal cells in water heating systems, geothermal heating and cooling, and following LEED building principles.

The full transformation and build-out will continue over the next 30 years, with phases over the next few years focusing on providing the public with the opportunity to see the interior of the site.

Figure 3.3-1: Panoramic view from Freshkills Park (source: Freshkills.org)

2) **Redevelopment of the Tagarades Landfill, Thessaloniki, Greece (FODSA of Central Macedonia, 2008)**

The landfill of Tagarades, at the location of Kalamaki, was operated since 1982 until August 2008, serving as the main landfill of Thessaloniki. At the preliminary stage of the rehabilitation of the landfill, an area of 10ha which contained waste from 1982 until 1984. The aim of the project was first to address all phenomena generated in an area of waste disposal and also the rehabilitation of the site in order to be visited and be useful to the public. The project cost was 1.034 billion drachmas. Specifically, the following activities took place:

- Landscaping earthworks
- Surface insulation with a clay layer and a topsoil material layer.
- Construction of 42 biogas wells with special equipment, a biogas collection network, connected to a pumping station and torch burner.
- Planting, irrigation, lighting and public use projects.
- Construction of four wells for leachate collection.

- Construction of rainwater drainage network.
- Construction of internal roads.
- Installation of remote control and monitoring system.

At its second stage, the rehabilitation of another 19ha of the eastern part of the landfill, operated between 1995 and 2004 took place, with the scope to unify this second part with the preliminary rehabilitated one and create a park which can be used as recreation and public education area to enhance environmental awareness. This part of the project has a total cost of 12.75 million euros. In particular, the main works included:

- Landscaping earthworks
- Surface insulation with clay
- Biogas management works,
- Flood control works,
- Vegetation projects,
- Internal roadworks, fencing, buildings and
- Environmental monitoring projects.

It should be noted that by the end of the rehabilitation works, the planting of 30,000 trees – shrubs is planned. After the final third stage of the redevelopment, which includes all the remaining surface of the landfill, a huge park of about 100ha will have been completed. The procedures to achieve this goal are progressing fast.

Figure 3.3-2: The rehabilitation works at the Tagarades Landfill (source: FOSDA of Central Macedonia, 2008)

3) Hague Landfill, New York, US (Nelson, 1994; Nelson, 1995)

The Hague LFM Project (1994) was the first successful effort in USA to dig up and entirely remove a 2.7 ha old landfill to return the site to its natural state (Nelson, 1995), for the purpose of using the land for recreational purposes. The project budget was $ 1.3 million which included removing 76,500 m3 of waste and recovering ferrous metal and soil fraction. Also, by composting on-site and re-screening a 31% weight reduction of the material was achieved. The reclaimed land was then used as a recreational space.

4) LFM for Metals, St. Helens, UK (Davison, 2008)

The St. Helens LFM project was first considered in 2000 following a site investigation and it involved the excavation and processing of 66,000tn of landfilled waste from this 1 acre historical site which mainly contained demolition waste from the 50's and the 60's. The landfill was in operation but in need of remediation. The operation was a completely self-funded by the recovery of metals from the disposed materials, as the metal commodity prices were on the rise at the time. The rehabilitation works after the project provided the necessary remediation of the landfill cell which also increased of the land value and removed the landfill liability.

Chapter 4. POTENTIAL ALTERNATIVE REHABILITATION PLANS IN GREECE

4.1. Overview

In general, the design of a rehabilitation plan for any project demands careful planning and considering various aspects of the site's location, surrounding environment and local community. Particularly for Landfill Mining, each case is different from the other so the approach to finding alternative rehabilitation plans will first answer a series of questions such as:

1. *Is the Landfill located in proximity to urban areas?* In general, reclaimed land near urban areas has added value as it can serve the community as a recreational space, as an industrial/commercial park, etc.

2. *Is it located near or into environmentally protected areas?* This particular characteristic of prohibits some land uses which might have a negative impact on the protected flora and fauna of the area.

3. *What was the reason/objective of the LFM project?* For some individual LFM projects, the main objective of the project points to a particular rehabilitation plan from the beginning of the works.

4. *What are the socioeconomic conditions of the area?* Employment of the broader area of the project, as well as the prevalent type of production might also point out to potential land uses which would be more positive financially than others. For example, an agricultural area has different needs than an urban or an area which is highly visited by tourists.

The answers to this series of questions must be used as guidelines to suggest the various alternative rehabilitation solutions that will be examined later on to distinguish the best one between them.

The rehabilitation of a site after a Landfill Mining project demands planning in advance, proper construction and testing. To reach to this rehabilitation plan, there are some factors necessary to be considered, similar to the ones examined by Martin and Tedder (2002) for the reclamation of the space of an old landfill :

- Site location and topography
- Character of the waste
- Closure requirements and maintenance of the closure system
- Monitoring and control of landfill gas
- Monitoring of water quality
- Structural stability of the landfill when used
- Human health and safety with the proposed use
- Economics of the use proposal

- Community involvement and support

In the next sections, different alternatives for various cases will be discussed in more detail.

4.1.1. Operating Landfills

Many Landfill Mining projects take place inside operating Landfills with a scope to:

a) *Prolong the life of the landfill by creating more space:* LFM can be a good way to expand the lifetime of an operating landfill, especially if it is known that it contains recyclable resources which can be removed to create more space for new incoming waste.

b) *Rehabilitate an older landfill part:* If there are issues with earth and groundwater contamination by poorly constructed or the lack of leachate drainage systems, it might be vital to excavate parts of a landfill to repair the damages. At the same time, the excavated waste can be processed to an LFM installation on site.

c) *Comply with current regulations:* Again, if the landfill faces serious issues with the regulating authorities, a short-term LFM project could be set up alongside any other construction works which are deemed necessary.

In all three of the aforementioned cases, whether the LFM project is short-term or longer in duration, the rehabilitation plan remains almost the same; the end goal is an operational landfill which complies with current regulations and does not pose a threat to the immediate environment. Usually, during the LFM works, parts of the landfill are dug up, creating open areas in the landfill cell. Thus, aside any additional repairs necessary, such as the installation of a new bottom liner, the rehabilitation options are very limited. They mainly consist of filling up the empty space with fresh waste or residues from the processing of the previously excavated waste and if the cell is not operational any more, perhaps covering up the cell with soil material and vegetation.

4.2. Reclamation of Land

By definition (Cossu et al., 1996) Landfill Mining (LFM) is described as "*the excavation and treatment of waste from an active or inactive landfill for one or more of the following purposes: conservation of landfill space, reduction in landfill area, elimination of a potential contamination source, mitigation of an existing contamination source, energy recovery from excavated waste, reuse of recovered materials, reduction in waste management system costs and site redevelopment*". Thus, at the end of LFM projects, it might even be possible to reclaim the land anew and use it for various alternative uses, according to the needs of the local community.

This section explores the steps that should be followed after a LFM project has cleared all the waste off an old landfill site which mainly consist of remediating the soil, landscaping and transforming the site according to the needs of the surrounding natural and human environment.

4.2.1. Soil Remediation

In many cases though, after the end of the LFM operations, soil samples must be tested for heavy metal content and other pollutants, especially when there are suspicions of groundwater contamination (Hogland, 2002). To allow for alternative uses of the empty LF site, the soil samples must abide the pollutant limits, according to the current legislation. If not, soil remediation must precede any other activity on the site.

According to INTERGEO (2015), there are here are four (4) main categories of Soil remediation measures. These include:

A. Total excavation, processing/inactivation, reuse or disposal/destruction in special hazardous waste sites: this method is mainly applied in cases where the degree and type of pollution do not require complex and lengthy processing procedures, whether there is a high time constraint to restore the field (instant recovery) and of course there is the possibility to dispose a special place specific waste streams. Also the total excavation is usually feasible and economical when the volume of polluted soil is relatively small.

B. Treatment with physico-chemical and biological processes in situ (on the spot, without excavation), or ex situ (on site or off-site) and replacement of the soil to its original position: The treatment for decontamination of polluted soil is the method that most fully addresses the problem. Depending on the respective conditions prevailing in each contaminated site, processing can be applied both in situ and ex situ. The treatment of the contaminated soil can be achieved using physicochemical and biological methods aiming at complete elimination of the pollutant or its decrease at levels that do not pose a risk to human health and the environment. This is usually the most comprehensive solution to clean a contaminated site, and most times it is cheaper than the excavation.

C. Entrapment of the pollution (use of an impervious cover, construction of hydraulic impermeable dams, etc.): The entrapment of pollution is usually applied in combination with other soil treatment methods in order to ensure no further spreading of pollution to sensitive recipients through the air, or through groundwater. Also, similar pollution containment measures can be applied individually in areas where the predicted future use of land of the site and neighboring areas do not require high environmental limits on the state of the subsurface (industrial areas).

D. Simple monitoring of the physical biodegradation of the pollutants while limiting polluting activities: Simple monitoring of the condition of the site by limiting significantly or even eliminating the pollution sources is the final opportunity to intervene in a contaminated area. The simple monitoring is the most passive solution between the four of them as it is based solely on the natural processes of degradation of organic contaminants, thus keeping active the environmental risk for a long time. These countermeasures are applied to areas in which pollution is not particularly large, the contaminants are biodegradable and there is no immediate risk to human health and the ecological environment. It is the minimum measure which should be applied to contaminated sites.

In general, in most cases of soil pollution, a single remediation technique can not completely sanitize a contaminated area. Usually more than one technique are combined and applied progressively or simultaneously in a contaminated area, so as to generate a sequence of decontamination measures ("treatment train"). For example, a Soil Vapor Extraction system (SVE) can be combined with an Air Sparging system or pumping and processing of underground water (pump and treat), to completely clean up a polluted area of hydrocarbons. It is important to point out that the in situ and on site soil and groundwater remediation techniques are always considerably less expensive than the excavation and management of contaminated materials as hazardous waste and they provide a better solution to tackle such problems.

The soil remediation activities must also be accompanied by Landscaping activities to transform the site according to the needs of its future use. These landscaping activities may include:

- Land forming,
- terrain shaping and elevation
- Introduction of bodies of water and
- Incorporation of living elements (flora or fauna).

4.2.2. Alternative Uses

The reclamation of land after the end of a LFM project aims at altering the use of the land from a traditional waste disposal site to something else. This transformation must first and foremost address the needs of the local community and respect the surrounding environment. In fact, in the past, most landfills were installed near residential areas in order to cover smaller distance to dispose of the waste. With the expansion of the urban environment, many of these older landfills were surrounded by urban areas, both industrial and residential, raising health issues due to the proximity to these waste disposal sites, as well as the limited value of the surrounding land. Keeping the specific environmental and social criteria of each landfill site in mind, the LFM concept has provided solutions to these issues in the past which have been recorded in the relevant literature.

As mentioned in chapter 4.1, if a LFM project does not have a specific objective for its rehabilitation, before choosing between different proposed alternatives, the most important characteristics of the natural and socio-economic environment of the region must be considered, including:

- Site location
- Landscape topography
- Nearby protected natural areas or species
- Demographic data
- Production data of the region

- Regional Planning Designs
- Economics of the alternative proposal
- Human health and safety with the proposed use
- Stakeholder and community involvement and support

Some of the suggested ideas for alternative uses for remediated ex-landfill sites are:

1. Return to natural state: This is the most commonly proposed alternative, both for landfills located within urban areas and landfills in more isolated regions. In particular, the reclamation of land within the urban areas presents the opportunity to add some much needed green zones. This was the case for the Freshkills LFM project in New York, USA (Suflita et al, 1992) which is the most famous example of this category (Figure 4.2.2-1); what was once the biggest landfill of the world has now been transformed into a natural habitat and a recreational space for New Yorkers to enjoy (Yoneda, 2011). The same practice has also been applied to the old Tagarades landfill in Thessaloniki Greece. These alterations always include full scale rehabilitation and landscaping works according to the needs of every site to create a safe and beautiful environment for humans and wildlife to enjoy. Also, this is a popular alternative for landfills which are located outside urban areas, such as the Polygyros Landfill, as they are situated in forest areas and there is no need for any different land uses. In fact, an old site can be converted into natural habitats or wetlands to sustain the wildlife, especially if is inside or nearby natural protected areas. Finally, this option serves towards minimizing CO_2 emissions as vegetation will help in capturing it from the atmosphere.

Figure 4.2.2-1: Freshkills park, NY (source: Yoneda, 2011)

2. Recreational Uses: Apart from a natural park, an old landfill site could be turned into space for Recreational Activities, such as sports fields, playgrounds, open theaters, etc. A stunning example is Mount Trashmore in Virginia Beach, U.S. (Bender, 2014). Constructed in 1974 on a «man-made» mound of municipal refuse of over 240 meters, it is composed of two mountains, two lakes, two playgrounds, a skate park and vert ramp and multi-use paths. Other features include picnic shelters, volleyball courts, horseshoe pits and outdoor fitness stations. Another popular idea for reclaiming space for recreational areas is the creation of an open theatre for shows and concerts. This is a very common idea for reclaiming old mining spaces (Figure 4.2.2-3, Stergiopoulos & Taifakos 2010) but it could be used for the reclamation of an old landfill site as well.

Figure 4.2.2-2: Mount Trashmore in Virginia Beach, U.S. (source: Bender, 2014)

Figure 4.2.2-3: An open theatre at an old mining space (source: Stergiopoulos & Taifakos 2010)

3. Soft uses: The reclamation of the land after a LFM project could also host a temporary "soft-use" project until a more permanent option is chosen. These include temporary installations which can be taken down easily if the site is later to be used for any other purpose. Some examples are: installation of solar panels on the closed cell (Figure 4.2.2-4) and small greenhouses (e.g. for algae cultivation) (Antwerp landfill, Belgium), experimenting with horticulture activities and greenhouse growing systems (San Lin landfill, China, Kurian *et al*., 2004).

Figure 4.2.2-4: Solar panels, soft use for an old landfill (Antwerp landfill, Belgium)

4. Industrial Park: Another great scheme for repurposing the site of an old landfill is to create an area where a few industries and businesses could settle. A recent example of this option is the Del Valle Landfill in Austin, Texas (Beausoleil, 2014). This could be a very profitable solution especially if there is a shortage in space in the area. The best sites for this rehabilitation are those located near urban areas, where businesses might be attracted to.

5. Residential Areas: In densely populated places where there usually is lack of space, some sites could be even turned into residential areas if all the safety measures have been taken and it is proven that there are no reasons to fear that the area might be dangerous for landslides or any emissions from the ground. Also the groundwater must be tested for any pollution from the old leachates. Martin and Tedder (2002) are presenting four cases of residential use of old landfill sites in Florida U.S., albeit with some issues due to the fact that there was still waste buried underneath (Figure 4.2.2-5). An LFM project though which would empty the contents of an old site completely could provide a better and safer ground to build new homes.

Figure 4.2.2-5: Hampshire Homes Waste Excavation Area (source: Martin and Tedder, 2002)

4.3. Alternatives for the Polygyros Landfill

4.3.1. Assessment of the Polygyros Landfill site

To propose a number of suitable alternatives, an initial assessment will be made for the PL site, according to the guidelines given by Martin and Tedder (2002), as seen in Chapter 4.1 and the Technical Report on the Baseline Environmental and Social conditions of the LIFE reclaim project (Action A3) which examines the conditions inside and around the PL.

Site location and topography

The PL is located in Chalkidiki, an area of the Region Central Macedonia, in northern Greece. It is situated inside the Municipality of Polygyros (yellow area of Figure 4.3.1-1) at a distance of about 3,2km NW of the town of Polygyros. It is located behind the hill «Kastri», hidden from the main road from Thessaloniki leading to the town. The surrounding forest area is characterized by the presence of the mild mountainous mass of Mount Holomontas. These mountains give a special morphological quality to the landscape because of their natural beauty. Despite continuous and lengthy human activities taking place, the landscape of the immediate study area remains mainly untouched.

Figure 4.3.1-1: Determination of the study area (Image source: Google Earth, 2014)

The area around the PL has a very high conservation status, which is presented bellow. The protected areas within the study area or in the vicinity of it, include:

- The Special Protection Area (SPA) - GR 1270012 ‘Mount Cholomontas’ of the Natura 2000 network
- The Special Area of Conservation (SAC) GR1270001 ‘Mount Cholomontas’ of the Natura 2000 network
- The Special Protection Area (SPA) - GR1220009 ‘Lakes Volvi-Langada (or Koronia-Ag. Vasiliou) and Rentina Gorge (or Makedonika Tempi) of the Natura 2000 network
- The Corine land cover A00010018 ‘Mount Cholomontas’
- The Corine land cover A00060001 ‘Eastern Chalkidiki’
- The Important Bird Area (IBA) - GR033 ’Mount Cholomontas’
- The Important Bird Area (IBA) - GR032 ‘Lakes Volvi-Langada (or Koronia-Ag. Vasiliou) and Rentina Gorge (or Makedonika Tempi)’
- and the Controlled Hunting Areas:
    - K117 Zagliveri – Adam- Petrokerasa- Livadi (Law No. 673/B/85)
    - K819 Mpara Agiou Mama at the Lorida location, Municipality of Nea Moudania (Law no. 570/B/16-5-01)
    - K820 Petralona – Krini at the Katsika location, Triglia (Law no. 570/B/16-5-01)
    - K880 Poligiros, Municipality of Polygyros (decision 2528/18-4-2001, Law No .570B΄/16-5-2001)
    - K840 Chavria Municipality of Arnaia & Panagia (Law no. 469/B/04-04-05)

- K841 Cholomontas of the Municipality of Arnaia (Law no. 864/B/06-07-01)
- K821 Ag. Prodromou – Vavdou, Municipality of Arnaia (dec. 2530/16-3-2001, Law No. 570/B/2001).

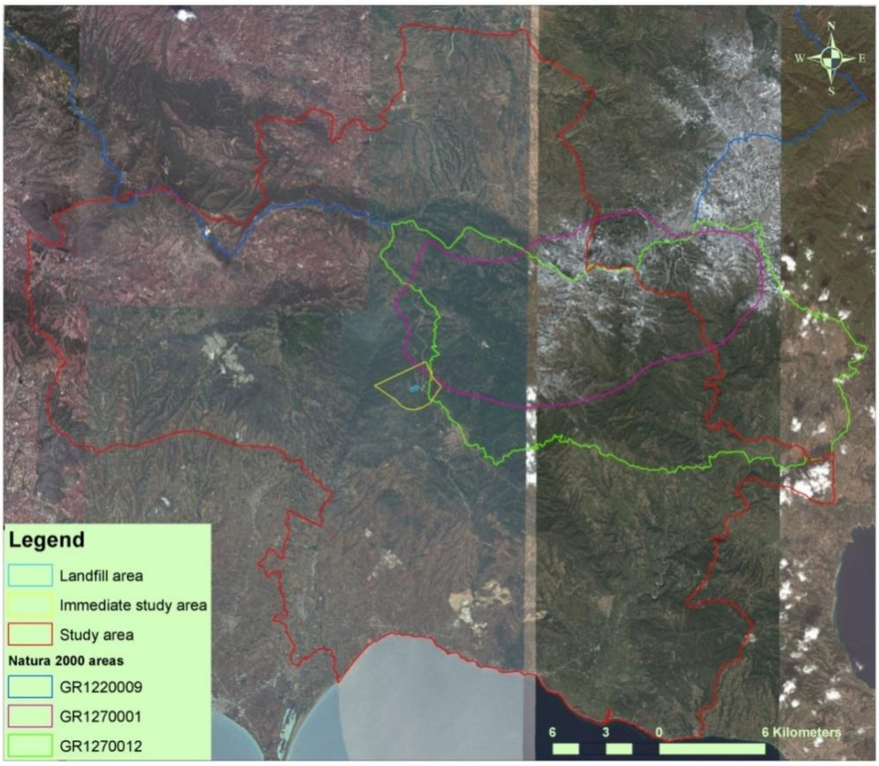


Figure 4.3.1-2 Natura 2000 sites in relation with the study area

Figure 4.3.1-3: Corine sites in relation with the study area

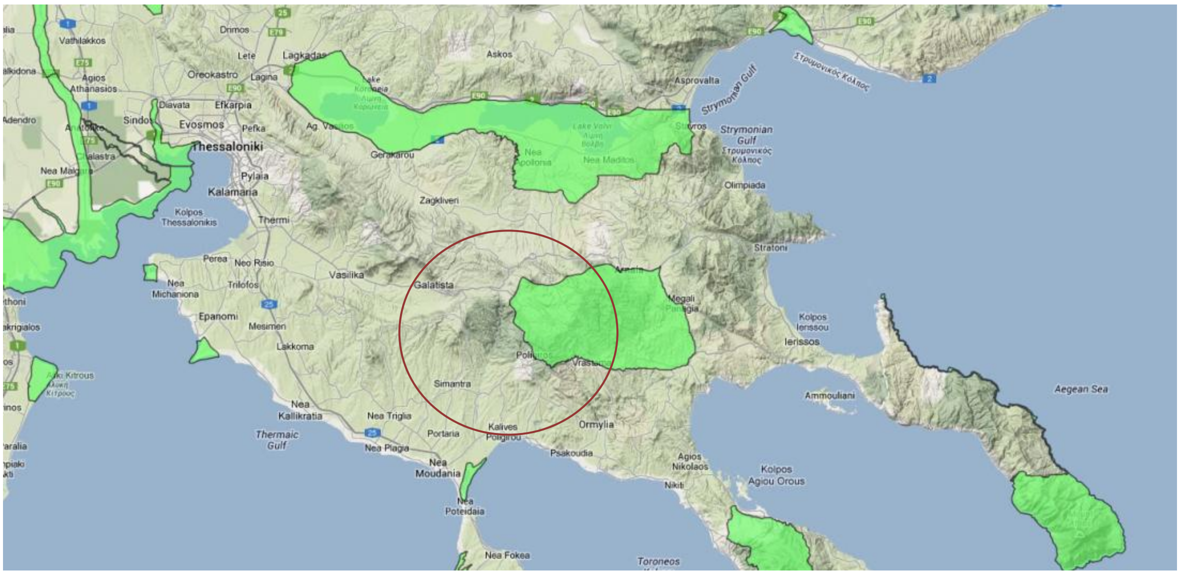


Figure 4.3.1-4 Important Bird Areas (IBAs)

As for the Land Use of the surrounding area of the Polygyros landfill, apart from a number of settlements (Town of Polygyros, Palaiokastro, Diastavrosi Palaiokastrou, Agios Prodromos, Vrastama, Gerakini, Plana, Sana, Taxiarches, Ormylia, Galatista, Simantra, Arnaia, and others), most of the immediate study area is covered by land of forest character. In Chalkidiki, the areas of agricultural character are particularly great in comparison with other regions of Greece (source: ELSTAT). Also, no Industrial Area (VIPE) has been established in the study area.

According to the Polygyros General Urban Plan (Government Gazette 243/21-06-2013), the area where the PL is located is characterised as part of an Area of Special Protection, at the Structural Plan of Spatial Organization Map (Figure 4.3.1-5) and as an area of Special Use inside a Forests and Woodland Protection Area, at the Land Use and Environmental Protection Map (Figure 4.3.1-6)

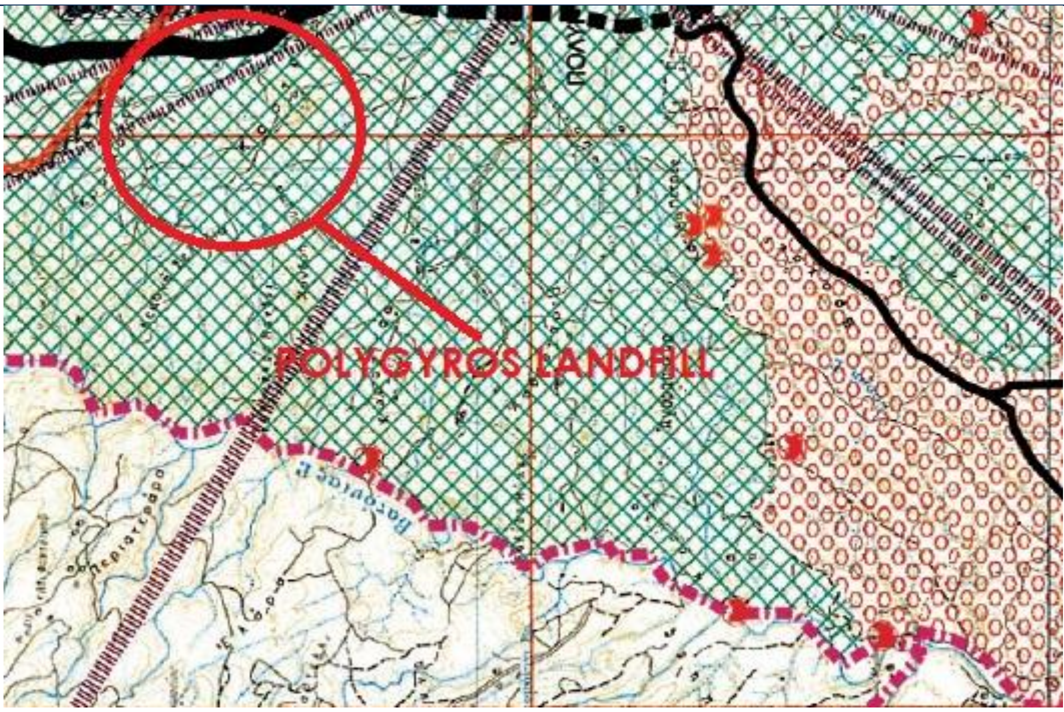
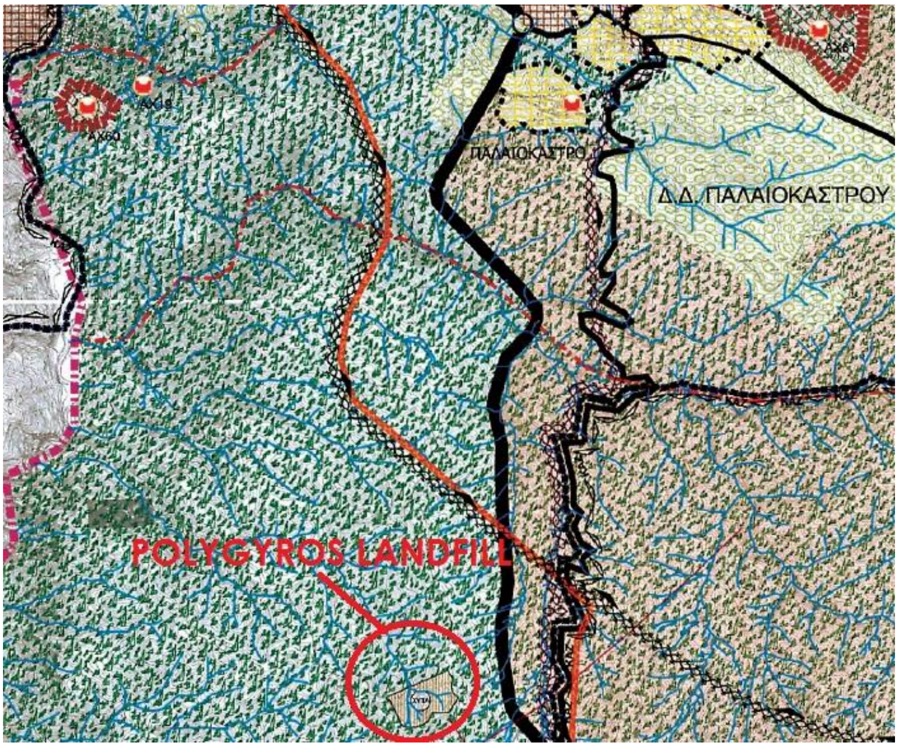


Figure 4.3.1-5: Structural Plan of Spatial Organization Map of Polygyros, PL area (General Urban Plan of Polygyros)



4.3.1-6: Land Use and Environmental Protection Map, PL area (General Urban Plan of Polygyros)

Character of the waste

As the PL is a relatively new sanitary landfill (operational since 2009) it is certain that it contains only Municipal Solid Waste, collected from the Municipality of Polygyros. Additionally, due to the lack of landfill disposal sites, the PL also receives the MSW from the nearby Municipality of Aristotelis and Municipality of Sithonia.

Polygyros established its first organized recycling system for packaging in 2013 and it is still a fairly new concept to the residents. Thus, many recyclable materials end up in the Landfill. The LFM pilot unit confirmed this; apart from decomposing organic waste (food scraps and prunings), plastic is the most commonly encountered material in the contents of the landfill. This includes:

- Hard plastics: PET and HDPE bottles, items made from Polypropylene, etc.
- Soft plastics: Film, plastic bags, membranes, etc.

The LIFE reclaim pilot unit also collected a great amount of metallic items, mostly aluminum cans and an assortment of various metallic items which contained iron and were consequently removed by the magnet of the unit. Moreover, glass bottles were also discovered. Also, many fabrics were unearthed and a few bulky items such as tires, mattresses and small furniture. Electronic waste (e-waste) was very little, as bulky appliances are collected in a container at the entrance of the landfill.

It is interesting though that the most prevalent in the PL cell, at around 50% was soil material: soil is used daily in the PL to cover the fresh waste. Many stones and rocks were also discovered, which are preferred when covering waste because of their increased permeability. In this way, rainwater penetrates the cell more easily but also leachate is collected without.

Figure 4.3.1-5: Pictures of separated waste streams from the PL contents: ferrous metallic waste, hard plastics, film and membranes and a few E-waste (LIFE reclaim project)

There is no construction and demolition waste or hazardous waste in the PL; this was also confirmed during the LFM activities of the pilot unit.

Monitoring and control of landfill gas

The PL has a complete biogas collection system installed, inside the waste cell. The waste are covered with permeable soil material so that it is properly aerated, which helps with the degradation of organic waste. The landfill gas is led to at the landfill's torch (Figure 4.3.1-6) for burning. However, Biogas generation is very low at the moment, expected to start rising at after 10 years from the beginning of operation landfill. Finally, if all the waste is removed, as was assumed in the previous chapter, there will not be any generation of landfill gas.

Figure 4.3.1-6: Torch for burning the biogas from the landfill cell, Polygyros Landfill

Monitoring of water quality

The PL cell is fully lined with geomembrane and has a complete leachates collection system installed which easily transports all excess liquid from inside the cell to the leachates reservoir. Then, with an automated pump, the leachates are forwarded to the PL's wastewater treatment plant which produces a good quality effluent which is then released to the environment. Also, the PL has a number of monitoring wells and checks the groundwater aquifer regularly for any sign of leaks and contamination. Again, if all the waste is removed, as was assumed in the previous chapter, there will not be any need for monitoring the water quality, unless initial water samplings have shown otherwise due to soil and groundwater contamination prior the LFM works.

Structural stability of the landfill when used

Even though the PL has been operated under the latest engineering standards and is considered to be very stable, if the rehabilitation plan includes the construction of any buildings or structures, the PL has to be tested for its stability and the possibility of any landslides. At any case, building big structures of more than one floor should be probably avoided.

Again, if all the waste is removed, as was assumed in the previous chapter, the remaining ground will be very stable and capable to carry almost any structure.

Human health and safety with the proposed use

According to the Technical Report on the Baseline Environmental and Social conditions of the LIFE reclaim project, the PL is located at a distance of 2,5km from the closest settlement, the village Palaiokastro, and 3,2km of the town of Polygyros. Thus, it is considered that the public health will not be affected by any of the rehabilitation plans. For even more caution, the air and water emissions from the PL site should be monitored during and after the rehabilitation works and building houses on the site should be avoided.

Again, if all the waste is removed, as was assumed in the previous chapter, and the ground is then remediated if samplings show any sign of contamination, the site will be safe for any potential future use.

Economics of the use proposal

For most of the LFM projects, it is difficult to build a solid business case as it has big installation costs and no immediate revenue from the process, apart from the selling of the recyclable materials, if there is a market in the area. However, a LFM project which aims at removing all the waste from a landfill is considered to gain from mitigating great monitoring costs.

As for the rehabilitation plan, after considering the alternatives for each case and developing a few proposals according to the needs of the surrounding natural and human environment, the financial costs should be taken into account as the most probable rehabilitation plan choice is usually the most cheap one.

Community involvement and support

During the course of the project, the LIFE reclaim project Team has been conducting a socioeconomic study which includes among others two surveys about LFM, both in Polygyros and at a National level. Even though the complete study has not been released yet, some early results have shown that interest about LFM is varied among the interviewees. Even worse, they have shown almost none intent to support any LFM financially through the municipal taxes. However, this intention is attributed to the Greek financial crisis and the unstable political environment almost entirely, as the surveys were conducted during the spring and summer of 2015, at an especially difficult period for Greeks. The uncertainty of their financial future made the interviewees unwilling to show any support to innovative technologies about waste.

The rehabilitation plans will probably receive the same reaction from the community unless it is proven that they are going to be very beneficial by providing new job positions, increasing the land value and bringing new income to local businesses.

4.3.2. Proposal of Alternatives for the Polygyros Landfill site

Taking into consideration the characteristics of the PL, the specific needs of the area, the proximity of the site to environmentally protected regions and the land use of the surrounding area, the LIFE reclaim Team is exploring all the aforementioned different alternatives for this specific case, keeping the assumption made in Chapter 4.3 that during the LFM works the landfill was fully excavated and the waste was removed completely.

- **Solar Park**

  Reclaiming the PL site to build a Solar Park seems to be a controversial idea. On the one hand, it is a very environmentally positive transformation and it will provide sustainable energy production for the region. The site is also conveniently located at a distance of around 10km to a nearby substation of the Public Power Corporation, which could ease its installation and access to the national power grid. However, a solar park needs a high capital investment which will be difficult to secure by the regional authorities and it is considered unlikely that any private investors would be interested in undertaking, due to the current low selling price of electrical energy. What is more, the terrain of the PL is very uneven, with many slopes and height differences, leaving only a small surface for installing the solar panels. Finally, the climate of the specific PL area is not ideal for a solar park, as it is a region with frequent rainfall and less sunshine than other nearby areas.

- **Return to Natural state**

  The PL is situated in a beautiful natural area, next to the dense forests of Tachiarchis and among many environmentally protected areas of the Natura2000 Network, of the Corine Land Cover, of the Important Bird Areas habitats and the national Controlled Hunting Areas. Thus, according to this plan, the PL could be transformed into a part of its surrounding environment, providing natural habitats for many wildlife species, some of which are protected. After the end of the works, it could also be suggested that the PL site could be added to the protected areas so that it remains untouched. This alternative also aids with carbon sequestration, the removal of greenhouse gas emissions from the atmosphere as it will include an extensive planting plan of trees and shrubs matching the vegetation of the general area. However, it includes several works which require a substantial financial input.

- **Recreational area**

  Alternatively, the PL could be turned into a multiple use recreational space. It is located very close to Polygyros and the villages of Palaiokastro and Agios Prodromos, so it could be turned into a park. This park can have a children's playground, a specific picnic space, a space reserved for social events such as weddings and parties, among other similar facilities. However, there already are several recreational parks within Polygyros and it is highly likely that the area will not be used as much.

- **Cultural Activities Space**

  Just like many other old industrial sites, the PL could also be reclaimed as a space dedicated to cultural activities. An open-air theatre for plays and music shows could be built on the landfill cell, which already has the best slope for an installation of this kind, or it could even be transformed into a music festival space, with special camping grounds and facilities to hold multiday events. This idea could be compatible to the Polygyros Municipal rich cultural activities programme, which holds multiple events throughout the year. However, the town already has the necessary infrastructure for these activities, including both an open-air theatre and a recently renovated music hall, both of which are conveniently located within the town limits.

- **Industrial Composting Facility**

  Polygyros is situated in the middle of Chalkidiki, a Region of central Macedonia which has vast agricultural areas and also provides intensive tourist facilities. Thus, the high organic content of the collected waste which ends up buried in the PL is justified. In recent years, home composting has been promoted by the municipalities, however, the larger volume of the organic waste (e.g. hotel food waste, seasonal clippings, etc.) is difficult to manage on-site. An industrial composting facility, where only organic waste would be processed could be a good alternative use for the PL site, providing a solution which meets the needs of the area and the demands of the National Waste Management Planning. This solution can also have a positive effect to the environment as it minimises the need for use of fertilisers and it provides a green alternative to the common practice of burning for the management of agricultural waste.

- **Construction and Demolition (C&D) Waste Recycling and Disposal Facility**

  Again, this is a different and more environmentally-friendly kind of waste processing facility which could be built on the PL site and it is required by the updated National Waste Management Planning, as it is prohibited to dispose of C&D waste by burying it in a traditional MSW landfill. Additionally, there is no other similar facility in the area and it would be very welcome by the inhabitants, as it would also provide job opportunities.

- **Commercial/Industrial use**

  The PL site, after it has been emptied from waste and fully remediated can be used as an Industrial or Commercial park. It is located right next to the Thessaloniki-Polygyros highway, and it is at a convenient distance of 45 minutes drive from the airport of Thessaloniki. It is far from any residencies (nearest settlement at 2,5km) and it is hidden from the street, thus there will be no noise or visual nuisance to the nearest inhabitants. Additionally, next to the PL are already two or three installed businesses. Finally, an industrial park could bring much needed new jobs and income to the area.

- **Residential area**

  Probably this is the least favorable rehabilitation alternative for the PL. Even though there exist many other similar projects where a landfill was repurposed into a housing district, this was always the case when the site was adjuscent to a densely populated urban area. The cituation around the PL is not similar, as the population of the nearest settlements might have increased during the last 20 years (source: *ELSTAT, census of 1991, 2001 and 2011*) but new residential areas have been built in Polygyros to satisfy the housing needs. The PL site is further away from the town and it does not offer the necessary infrastructure and amenities that a settlement does, such as access to drinking water, shops, school, etc. which will probably make it less appealing to permanent residents.

After the initial screening of all the available alternatives for the rehabilitation of the PL, it seems that there are five viable choices:

A. Return to Natural state

B. Commercial/Industrial use

C. Recreational area

D. Industrial Composting Facility

E. Construction and Demolition (C&D) Waste Recycling and Disposal Facility

The proposed alternatives A, B, C, D and E will be compared in the next chapters and the best one will be chosen for the PL site and it will be presented in detail in Chapter 7 of this report.

Chapter 5. MCA TOOL FOR ALTERNATIVES

5.1. Introduction to Multi-Criteria Analysis

Decision-making is the study of identifying and choosing alternatives to find the best solution based on different factors and considering the decision-makers' expectations. Every decision is made within a decision environment, which is defined as the collection of information, alternatives, values and preferences available at the time when the decision must be made. The difficult point in decision-making is the multiplicity of the criteria set for judging the alternatives. The objectives are usually conflicting and, in most of the cases, different groups of decision-makers are involved in the process. To facilitate this type of analysis, a family of tools referred to as Multi-criteria decision-making methods gained ground due to the need to have a formalized method to assist decision-making in situations involving multiple criteria (San Cristóbal, 2012).

According to Tsoutos *et al.* (2009) there are four reasons to use Multi-criteria methods:

(i) It allows for investigation and integration of the interests and objectives of multiple actors since the input of both quantitative and qualitative information from every actor is taken into account in form of criteria and weight factors;

(ii) It deals with the complexity of the multi-actor setting by providing output information that is easy to communicate to actors. The user-friendliness of the method lies on two aspects: the suggested criteria are estimated and given values that are consistent and comparable with the input data (as a measure of appropriateness); and the 'simple' format of the output of the method that makes the method's results meaningful and directly applicable for the interested actors;

(iii) It is well-known and applied method of alternatives' assessment that also includes different versions of the method developed and researched for specific problems and/or specific contexts and

(iv) It is a method that allows for objectivity and inclusiveness of different perceptions and interests of actor without being energy and cost intensive.

The MC-A methods are thus used to provide solutions to increasing complex management problems. They provide better understanding of inherent features of decision problem, promote the role of participants in decision-making processes, facilitate compromise and collective decisions and provide a good platform to understand the perception of models and analysts in a realistic scenario. The methods help to improve quality of decisions by making them more explicit, rational and efficient. Negotiating, quantifying and communicating the priorities are also facilitated with the use of these methods (Pohekar & Ramachandran, 2004)

The MCA methods are ideal for building models and tools to simplify decision making. The Flaminco decision support tool (an abbreviation for "Flanders landfill mining challenges and opportunities") is an example of using MCA for Landfill Mining projects. It was created in Flanders, Belgium, where a policy transition towards Sustainable Materials Management, including Landfill Mining, has been going on over the last years (Behets *et al*., 2013). Its main aim was to prioritise the potential for LFM of the landfill sites of the region and the risks due to contamination (remediation necessity), based on the multi-criteria analysis methodology.

Similarly, MCA could also be employed to choose between rehabilitation alternatives for a LFM project, as this report is aiming at.

5.2. Defining the Criteria

The MCA methodology presents a suitable option for the creation of a tool which will assess the different alternatives for an LFM rehabilitation project and suggest the best one. For the development of such a model, one of the most important steps is the definition of the criteria which will be used in the MCA as well as the weighing factors of each alternative.

First, the definition of the different aspects of a rehabilitation project must be defined. Most of these could be identified through an Environmental and Social Impact Assessment, which covers the following (Canter, 1996):

- <u>Environmental aspects:</u> Climate and meteorology, morphological and landscape characteristics, aquatic environment, conservation status, flora and fauna species, etc.
- <u>Socio-economic aspects:</u> Land use, regional and local development plans, industrial zoning, infrastructure, Archaeological sites and monuments, demographics, production and employment data, air quality, etc.
- <u>Financial aspects</u>

5.3. Our MCA Tool: RECLAIM-hab

The concept of MCA is followed by many different tool methodologies. For this application, the comparison between sets of choices using some qualitative weighing factors was necessary. Thus, it was decided to follow the more suitable Analytic Hierarchy Process (AHP) methodology.

The proposed AHP methodology by Richard Hodgett (2014) inspired the Reclaim-hab tool. This is based on a suggestion by Dr. Thomas Saaty which became very popular as it can make pairwise comparisons between qualitative criteria which constitute a hierarchy, so that each alternative option can be compared to one another using this structure. The method employs the following scale, described in Table 5.4-1:

Table 5.4-1: AHP 1-9 scale of comparison (source: *Hodgett,* 2014)

Scale	Verbal Expression	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one activity over another

5	Strong Importance	Experience and judgment strongly favour one activity over another
7	Very Strong Importance	An activity is favoured very strongly over another
9	Extreme Importance	The evidence farouring one activity over another is of the highest possible order of affirmation

Hodgett (2014) also introduces the concept of reciprocal matrixes, which are used in this method to enable the calculations with the pairwise comparisons. These matrixes, designed such as the one shown in table 5.4-2 below, present the comparison of the criteria which are used when making a selection. For the purpose of the Reclaim-hab tool and the selectin of the better suiting landfill rehabilitation plan, the defining factors identified were the **Environmental**, the **Social** and the **Financial** impacts of each alternative. To measure the importance of each factor, they are compared against one another with the help of the matrix where values are attributed according to the Scale given in table 5.4-1. When a criterion is compared against itself, the value **1** is entered into the matrix cell and also, the opposite value in the pairwise comparison must be **1 / value**. In the following example, we are using the variables X, Y and Z instead of real values. Thus, for the Reclaim-hab, the matrix reads: the Environmental Factor is X times the Financial (with regards to Saaty's scale) while the Financial is 1/X times the Environmental. In the same way, we also use the variable Y to symbolise that the Environmental Factor is Y times the Social and the variable Z for the Financial Factor being Z times the Social.

Table 5.4-2: RECLAIM-hab weighing criteria

PAIRWISE COMPARISON	**Environmental**	**Financial**	**Social**
Environmental	1	X	Y
Financial	1/X	1	Z
Social	1/Y	1/Z	1

Next, we have to examine the different alternative scenarios against each other, for each different Factor, thus, with respect to each criterion, three more similar tables of pair-wise comparisons are created, one for the Environmental, one for the Financial and one for the Social Factor. In this example, we are using three (3) alternative options for Rehabilitation plans: Alternative A, Alternative B and Alternative C. The alternatives will be compared pair by pair using the AHP method, as was conducted earlier for the three factors, using the values from the comparison scale of table 5.4-1.

Again, for the sake of this example, we are using variables X_E, Y_E, and Z_E for the Environmental table, X_F, Y_F and Z_F for the Financial and X_S, Y_S and Z_S for the Social Factor. Note that all these variables are not connected between them in any way but are produced individually via the comparison between the alternatives, using the scale of table 5.4-1. The resulting tables are presented below:

Table 5.4-3: Comparing matrix of Alternatives-Environmental Factor

ENVIRONMENTAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C
ALTERNATIVE A	1	X_E	Y_E
ALTERNATIVE B	$1/X_E$	1	$1/Z_E$
ALTERNATIVE C	$1/Y_E$	Z_E	1

Table 5.4-4: Comparing matrix of Alternatives-Financial Factor

FINANCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C
ALTERNATIVE A	1	X_F	Y_F
ALTERNATIVE B	$1/X_F$	1	$1/Z_F$
ALTERNATIVE C	$1/Y_F$	Z_F	1

Table 5.4-5: Comparing matrix of Alternatives-Social Factor

SOCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C
ALTERNATIVE A	1	X_S	Y_S
ALTERNATIVE B	$1/X_S$	1	$1/Z_S$
ALTERNATIVE C	$1/Y_S$	Z_S	1

As the criteria are all qualitative, the Project Team organised a DELPHI session to decide the X, Y and Z values of all the used comparisons in this methodology, both for the weighing factors but also for the three different tables of the Alternatives comparison for each factor. The Delphi Technique is a method used to estimate qualitative information, based on the exchange of views of a group of experts. Each expert individually gives estimates and assumptions to a facilitator who reviews the data and issues a summary report. The group members discuss and review the summary report individually, and give updated forecasts to the facilitator, who again reviews the material and issues a second report. This process continues until all participants reach a consensus. The aim is to clarify and expand on issues, identify areas of agreement or disagreement and reach a final agreement (*Haughey, 2015*).

In our case, the DELPHI session was organized with 8 experts from the Project Team, with diverse backgrounds: Engineers, environmental scientists, sociologists, economists, etc. Also, a Facilitator was chosen among the Management Team of the Project, to guide and coordinate the discussion. During the session, a questionnaire was introduced to help reach to firm conclusions about the comparisons between the participants. The template used during the session is attached in **Appendix 3**. The results of the session are further presented in **Chapter 6**.

For the sake of elaborating on the methodology of the RECLAIM-hab tool, this following generic **example** uses random values. Assume that we have a specific site after a complete LFM project. The randomly chosen values for the comparison of weighing factors and alternatives are:

Table 5.4-6: EXAMPLE: RECLAIM-hab weighing criteria

PAIRWISE COMPARISON	**Environmental**	**Financial**	**Social**
Environmental	1	0,5	3
Financial	2	1	4
Social	0,3333	0,25	1

Table 5.4-7: EXAMPLE: Comparing matrix of Alternatives-Environmental Factor

ENVIRONMENTAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C
ALTERNATIVE A	1	0.25	4
ALTERNATIVE B	4	1	4
ALTERNATIVE C	0.25	0.25	1

Table 5.4-8: EXAMPLE: Comparing matrix of Alternatives-Financial Factor

FINANCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C
ALTERNATIVE A	1	2	5
ALTERNATIVE B	0.5	1	3
ALTERNATIVE C	0.2	0.3333	1

Table 5.4-9: EXAMPLE: Comparing matrix of Alternatives-Social Factor

SOCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C
ALTERNATIVE A	1	3	2
ALTERNATIVE B	0.333	1	0.5
ALTERNATIVE C	0.5	4	1

The method of *Hodgett* (2014) goes on to calculating the factors' hierarchy and the results of the alternatives' comparison using Eigenvectors for the pair-wise matrixes. An Eigenvector (or characteristic vector of a linear transformation) used in linear algebra, is a non-zero vector, that does not change its direction when that linear transformation is applied to it. It is used in this case to calculate a specific score for each factor and a specific score for each alternative. The Eigenvectors are then normalised to reach to the clearest conclusion. These calculations are best handled with an Excel spreadsheet.

The RECLAIM-hab tool is using Excel for the necessary calculations, even though the eigenvector of a matrix must be worked out step by step, as there is no function in Excel to estimate it faster. The calculations are following three steps: 1) the pairwise matrix is calculated 2) the sum of each row is calculated and normalised and 3) this process is repeated until the difference between the sums in the two consecutive calculations are smaller than a prescribed value (*Hodgett,* 2014).

The **RECLAIM-hab template excel file** incorporates this formula. To get started, the tables above are transferred to an Excel document, each to a dedicated sheet. A fifth sheet will be used later for the results of the comparison. Starting with the Criteria Weights, we square the matrix by selecting the cells C7:E9, inserting the formula '=MMULT(C3:E5;C3:E5)'and then using CONTROL + SHIFT + ENTER giving the table of Figure 5.4-1:

C7 {=MMULT(C3:E5; C3:E5)}

Pairwise Comparison	Environmental	Financial	Social
Environmental	1	0,5	3
Financial	2	1	4
Social	0,3333	0,25	1

2,9999	1,75	8
5,3332	3	14
1,1666	0,66665	2,9999

Figure 5.4-1: EXAMPLE: Calculation of the pairwise matrix of the RECLAIM-hab weighing criteria

Then, the rows are summed to normalise the matrix, by creating a sums column in F7 to F9. The total sum is then calc ulated in F10. To normalise the sums, they must be divided by the total sum, thus, in G7 '=F7FF10' is inserted and draged to G9. The sum of the normalised values must be then 1. After some formatting, the table looks like this:

F7 =SUM(C7:E7)

Pairwise Comparison	Environmental	Financial	Social
Environmental	1	0,5	3
Financial	2	1	4
Social	0,3333	0,25	1

			Sumed Rows	
2,9999	1,75	8	12,7499	0,319416
5,3332	3	14	22,3332	0,559501
1,1666	0,66665	2,9999	4,83315	0,121082
		TOTAL:	39,91625	1

Figure 5.4-2: EXAMPLE: Suming each row and normalising for the RECLAIM-hab weighing criteria

This process is then repeated three more times using the MMULT formula, summing and normalising the rows (Figure 5.4-3). The Eingenvectors (the normalised values of the matrix) are then taken as at the last two repeats, the values have remained the same, meaning that they are accurate to 6 decimal places. The values that we need to use afterwards are indicated in the figure with the red circle.

P19 fx

	A	B	C	D	E	F	G	H
1								
2		Pairwise Comparison	**Environmental**	**Financial**	**Social**			
3		**Environmental**	1	0,5	3			
4		**Financial**	2	1	4			
5		**Social**	0,3333	0,25	1			
6						**Sumed Rows**		
7			2,9999	1,75	8	12,7499	0,319416	
8			5,3332	3	14	22,3332	0,559501	
9			1,1666	0,66665	2,9999	4,83315	0,121082	
10					TOTAL:	39,91625	1	
11						Sumed Rows		
12			27,66530001	15,833025	72,4984	115,996725	0,319621	
13			48,33106668	27,6662	126,6642	202,6614667	0,55842	
14			10,55474446	6,041383335	27,66530001	44,26142781	0,121959	
15					TOTAL:	362,9196195	1	
16						Sumed Rows		
17			2295,797897	1314,055649	6016,857418	9626,710964	0,319619	
18			4011,13868	2295,872596	10512,44519	16819,45646	0,558427	
19			875,9868448	501,392335	2295,797897	3673,177077	0,121954	
20					TOTAL:	30119,34451	1	
21						Sumed Rows		
22			15812235,37	9050516,738	41440915,2	66303667,37	0,319619	
23			27626590,81	15812749,86	72404133,91	115843474,6	0,558427	
24			6033331,702	3453323,852	15812235,37	25298890,92	0,121954	
25					TOTAL:	207446032,8	1	
26								

Figure 5.4-3: EXAMPLE: Eigenvectors of the RECLAIM-hab weighing criteria

The Figures 5.4-4 to 6 below show summarise the estimated Eigenvectors for the Alternatives per each factor:

	B	C	D	E	F	G
2	**ENVIRONMENTAL**	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C		
3	ALTERNATIVE A	1	0,25	4		
4	ALTERNATIVE B	4	1	4		
5	ALTERNATIVE C	0,25	0,25	1		
6					**Sumed Rows**	
7		3	1,5	9	13,5	0,247423
8		9	3	24	36	0,659794
9		1,5	0,5625	3	5,0625	0,092784
10				TOTAL:	54,5625	1
11					Sumed Rows	
12		36	14,0625	90	140,0625	0,256173
13		90	36	225	351	0,641975
14		14,0625	5,625	36	55,6875	0,101852
15				TOTAL:	546,75	1
16					Sumed Rows	
17		3827,25	1518,75	9644,0625	14990,0625	0,255323
18		9644,0625	3827,25	24300	37771,3125	0,643353
19		1518,75	602,7539063	3827,25	5948,753906	0,101324
20				TOTAL:	58710,12891	1
21					Sumed Rows	
22		43941682,41	17438268,22	110726101,4	172106052	0,255317
23		110726101,4	43941682,41	279012291,5	433680075,3	0,64336
24		17438268,22	6920381,338	43941682,41	68300331,96	0,101323
25				TOTAL:	674086459,3	1

Figure 5.4-4: EXAMPLE: Eigenvectors of the Environmental Factor Alternatives Comparison matrix

	A	B	C	D	E	F	G
1							
2		**FINANCIAL**	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C		
3		ALTERNATIVE A	1	2	5		
4		ALTERNATIVE B	0,5	1	3		
5		ALTERNATIVE C	0,2	0,3333	1		
6						**Sumed Rows**	
7			3	5,6665	16	24,6665	0,581763
8			1,6	2,9999	8,5	13,0999	0,308963
9			0,56665	1,0666	2,9999	4,63315	0,109274
10					TOTAL:	42,39955	1
11						Sumed Rows	
12			27,1328	51,06403335	144,16365	222,3604834	0,581554
13			14,416365	27,13190001	76,5983	118,146565	0,308997
14			5,106403335	9,610308905	27,13190001	41,84861225	0,109449
15					TOTAL:	382,3556606	1
16						Sumed Rows	
17			2208,504322	4156,43166	11734,41537	18099,35135	0,581554
18			1173,441537	2208,431066	6234,830631	9616,703234	0,308996
19			415,643166	782,2454307	2208,431066	3406,319663	0,109449
20					TOTAL:	31122,37424	1
21						Sumed Rows	
22			14632150,45	27537882,89	77744801,92	119914835,3	0,581554
23			7774480,192	14631665,1	41308037,71	63714183	0,308996
24			2753788,289	5182662,636	14631665,1	22568116,02	0,109449
25					TOTAL:	206197134,3	1
26							

Figure 5.4-5: EXAMPLE: Eigenvectors of the Financial Factor Alternatives Comparison matrix

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	A	B	C	D	E	F	G
1							
2		SOCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C		
3		ALTERNATIVE A	1	3	2		
4		ALTERNATIVE B	0,333	1	0,5		
5		ALTERNATIVE C	0,5	4	1		
6						Sumed Rows	
7			2,999	14	5,5	22,499	0,500957
8			0,916	3,999	1,666	6,581	0,146531
9			2,332	9,5	4	15,832	0,352512
10					TOTAL:	44,912	1
11						Sumed Rows	
12			34,644001	150,222	61,8185	246,684501	0,49505
13			10,29528	44,643001	18,364334	73,302615	0,147105
14			25,023668	108,6385	44,653	178,315168	0,357845
15					TOTAL:	498,302284	1
16						Sumed Rows	
17			4293,709978	18626,52113	7660,748638	30580,97974	0,495106
18			1275,824883	5534,64879	2276,300354	9086,774027	0,147115
19			3102,765603	13460,08906	5535,889729	22098,74439	0,357779
20					TOTAL:	61766,49816	1
21						Sumed Rows	
22			65969631,88	286182491,2	117701649,2	469853772,2	0,495106
23			19602091,11	85035721,85	34973644,48	139611457,4	0,147115
24			47671660,41	206804163,4	85054787,94	339530611,8	0,357779
25					TOTAL:	948995841,5	1
26							

Figure 5.4-6: EXAMPLE: Eigenvectors of the Social Factor Alternatives Comparison matrix

Moving on *(Hodgett,* 2014), the results are calculated at the final sheet of the Excel file. The Table of Weights of the three Factors and the Table of Alternatives compared to Factor table are created (Table 5.4-7), from the normalized results that were derived by the Eigenvectors (the values indicated with the re circles in figures 5.4-3 to 6 above). The ending tables look like this:

Table 5.4-7: EXAMPLE: Weights of the RECLAIM-hab Factors and Alternative results per Factor

	Weights
Environmental	0,319619
Financial	0,558427
Social	0,121954

	Environmental	**Financial**	**Social**
ALTERNATIVE A	0.255317	0.581554	0.495106
ALTERNATIVE B	0.643360	0.308996	0.147115
ALTERNATIVE C	0.101323	0.109449	0.357779

The final calculations are worked out by creating a final Alternatives table which sums up the total score for each alternative multiplying with the respective factor weights. The Alternative with the highest score is the most preferable one. For example, the total score for Alternative A is [0,255317*0,319619+0,581554*0,558427+0,495106*0,121954]. Also, the final scores table enables the creation of a visual comparison chart. The results of the example are summarized in Figure 5.4-8.

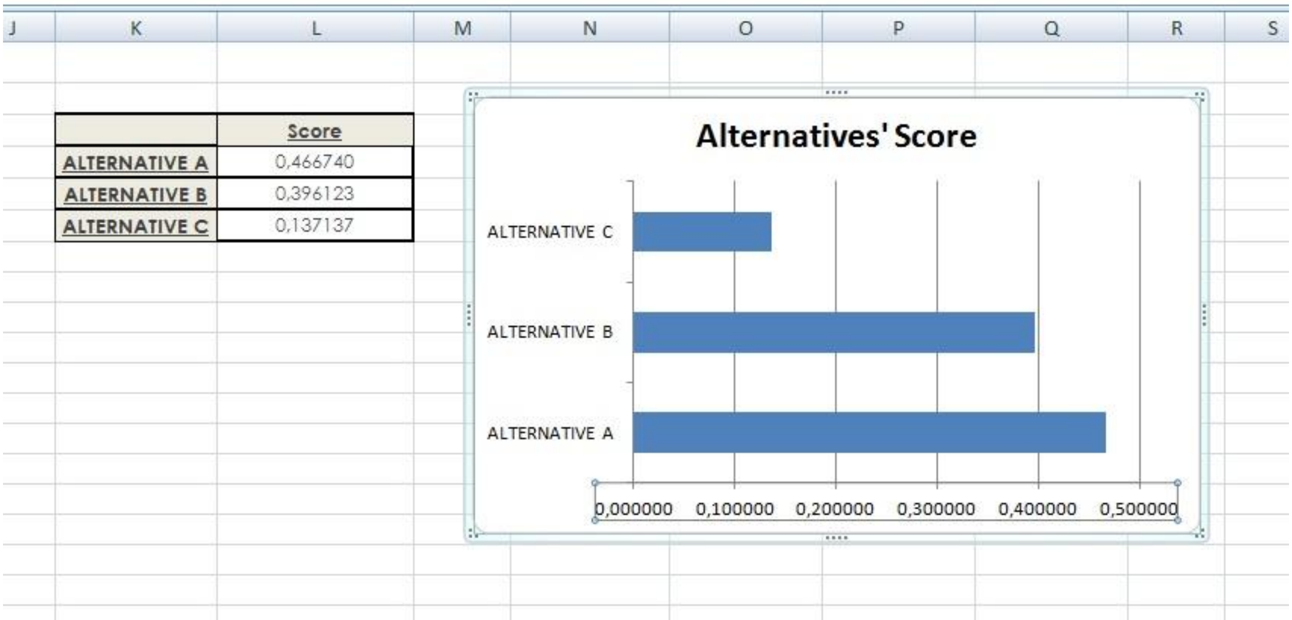


Figure 5.4-8: EXAMPLE: Results of the Alternatives Comparison

As mentioned before, the most preferable alternative is the one with the highest score. From this chart it is easy to see that for the given Example data, the best scenario is Alternative A followed by Alternative B and Alternative C.

Keeping this structure, the RECLAIM-hab tool can be adapted to different estimations of factors and comparison values. It can also be adapted to more alternatives or more weighing factors if this is what is necessary.

Chapter 6. SELECTION OF ALTERNATIVES FOR THE POLYGYROS LANDFILL

6.1. Choosing the best Alternative for Polygyros Landfill

In this section, the RECLAIM-hab tool will be used to decide which one of the five proposed Alternatives in Chapter 4 is the best for the Polygyros Landfill site. The Alternatives are all proposed under the aforementioned assumption that during the LFM works the landfill was fully excavated and the waste was removed completely.

The proposed alternatives A, B, C, D and E, as presented in detail in Chapter 4 are the following:

A. Return of the PL site to its natural state

B. Construction of a Commercial and/or Industrial park

C. Transforming the PL site into a recreational area

D. Construction of a Composting Facility

E. Construction of a Construction and Demolition (C&D) Waste Recycling and Disposal Facility

To follow the RECLAIM-hab tool methodology, the qualitative comparison estimation values must firstly be calculated. Thus, as mentioned in Chapter 5, a DELPHI session was held with experts from the Reclaim Team where the following estimations were agreed upon:

Table 6.1-1: RECLAIM-hab weighing criteria

PAIRWISE COMPARISON	Environmental	Financial	Social
Environmental	1	0.5	0.5
Financial	2	1	3
Social	2	0.3333	1

As depicted above, the participants of the DELPHI session agreed that the Environmental factor is less important than the Social and Financial ones, as the Polygyros Landfill is located amidst a natural forest area, far from the town of Polygyros and it is not visible from the road or any settlement. Also, due to the socioeconomic conditions of the area, the low employment rates and the few investment the Financial is the most important factor for choosing the best alternative. The Social factor is also important as the support of the residents and businesses of the area are very important for the realisation of the rehabilitation plan.

Subsequently, the five alternatives were compared to each other per each factor. For the Environmental Factor, the table below presents the pair-wise comparisons of the DELPHI session. To summarise, it was agreed that the most environmentally friendly option was Alternative A, as it presents the option of returning the site to its original natural state. Constructing a Composting Facility was also very high in the Environmental comparison score, as it is considered that it can help the area towards minimising its waste output and recycling resources. Alternative C (Transforming the PL site into a recreational area) was considered somewhat environmentally friendly as it would incorporate planting during the construction phase but would then be neutral during its operation. The Construction and Demolition (C&D) Waste Recycling and Disposal Facility is rather less friendly as it incorporates recycling of resources but also a disposal site, while it was decided that the Alternative B was the least friendly to the environment as it facilitated the creation of new sources of waste and even pollution with the establishment of new businesses or industries.

Table 6.1-2: Comparing matrix of Alternatives-Environmental Factor

ENVIRONMENTAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C	ALTERNATIVE D	ALTERNATIVE E
ALTERNATIVE A	1	7	3	2	5
ALTERNATIVE B	0.142857143	1	0.333333333	0.2	3
ALTERNATIVE C	0.333333333	3	1	2	4
ALTERNATIVE D	0.5	5	0.5	1	7
ALTERNATIVE E	0.2	0.333333333	0.25	0.142857143	1

Then, the Alternatives were compared as to their Financial potential. A Commercial and/or Industrial park (Alternative B) presents the biggest Financial opportunity as it is a way to bring more new businesses and investments in the area. Second in the line, Alternative D is also appealing as it can save money to the municipality through lessening the waste volume and thus minimising the disposal expenses. Alternative E is in the middle as it could generate a small income via the recycling of the materials. The Recreational Area could sometimes be profitable, but this would depend greatly on the weather conditions and it would vary. At the bottom of the comparison comes the Return to the Natural State (Alternative A) as it will only burden the authorities with the expenses of the rehabilitation without generating any profit.

Table 6.1-3: Comparing matrix of Alternatives-Financial Factor

FINANCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C	ALTERNATIVE D	ALTERNATIVE E
ALTERNATIVE A	1	0.142857143	0.5	0.2	0.333333333
ALTERNATIVE B	7	1	5	2	3
ALTERNATIVE C	2	0.2	1	0.333333333	0.5
ALTERNATIVE D	5	0.5	3	1	2
ALTERNATIVE E	3	0.333333333	2	0.5	1

The Social factor was then estimated for the comparison between the Alternatives. Alternative D presented the highest socially-friendly potential as it is seen as a healthy business opportunity for the area, which can stand for many years and provide for job opportunities for the local residents. For the same reasons, Alternative E comes next but the fact that it also has a disposal site might not be very appealing to some members of the community. Returning the site to its natural state might be appealing to some but it also doesn't add any social value in the longer term, so it was judged as a socially neutral option. Alternative B could potentially create job opportunities but could also be seen as very negative from the community, if the site become heavily industrialised. Finally, the lowest social score was gathered by Alternative C; even though it is about creating a recreational space for the local community, it is believed that due to its distance from the town of Polygyros, its specific location and the existence of similar infrastructure in the area, if it was created it would rarely host any events and it would be visited seldom, and thus it would slowly decline.

Table 6.1-4: Comparing matrix of Alternatives-Social Factor

SOCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C	ALTERNATIVE D	ALTERNATIVE E
ALTERNATIVE A	1	0.333333333	0.5	0.2	0.25
ALTERNATIVE B	3	1	2	0.142857143	0.5
ALTERNATIVE C	2	0.5	1	0.111111111	0.333333333
ALTERNATIVE D	5	7	9	1	3
ALTERNATIVE E	4	2	3	0.33	1

Then, the calculations of the Eigenvectors must be worked out, just like with the given example in Chapter 5. For these estimations, the end resulting tables were the following:

Table 6.1-5: Weights of the RECLAIM-hab Factors and Alternative results per Factor

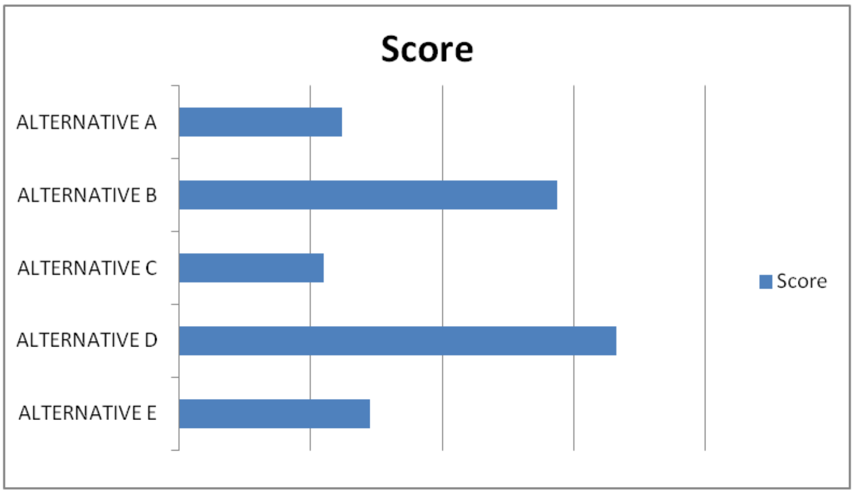
-	**Weights**
Environmental	0.189711006
Financial	0.547218574
Social	0.263070420

	Environmental	**Financial**	**Social**
ALTERNATIVE A	0.426222160	0.052390843	0.055899949
ALTERNATIVE B	0.072422617	0.444648144	0.116197374
ALTERNATIVE C	0.227192699	0.088678441	0.070908917
ALTERNATIVE D	0.228896268	0.261923177	0.554561317
ALTERNATIVE E	0.045266257	0.152359396	0.202432443

And the final results of the comparison are presented below:

Table 6.1-6: Results of the Alternatives Comparison of the Polygyros Landfill

	Score
ALTERNATIVE A	0.124233900
ALTERNATIVE B	0.287627183
ALTERNATIVE C	0.110281484
ALTERNATIVE D	0.332642047
ALTERNATIVE E	0.145215386



From the analysis of Table 6.1-6 and the accompanying chart, it seems that Alternative D (Composting Facility) gets the highest total score and thus is the best alternative rehabilitation plan for the Polygyros Landfill. It has the best score at the Social Factor and the second best of the Environmental factor, after Alternative A (Return to the natural state). Second comes Alternative B Commercial and/or Industrial park) which seems to have the best Financial factor score than all five options. Third is Alternative E (C&D Waste Recycling and Disposal Facility) due to its high financial score. Fourth comes Alternative A and last is Alternative C (Recreational space), which gets very low Financial and Social Factor Scores.

As it was the chosen option, Alternative D will be presented and discussed in detail in the following Chapter, as the proposed Rehabilitation Plan for the Polygyros Landfill.

Chapter 7. PRESENTATION OF THE PROPOSED REHABILITATION OF POLYGYROS LANDFILL

In this section, the Proposed Rehabilitation for the Polygyros Landfill will be presented, keeping the aforementioned assumption that the whole of the Landfill was mined. The appropriate Rehabilitation Plan for this LFM project was chosen using the RECLAIM-hab tool in Chapter 6.1 and it includes building a Composting Facility which can serve not only the Municipality of Polygyros but also the greater area of Chalkidiki, as no other similar facility exists in the region. The facility could receive the biodegradable waste of the town of Polygyros via a source-separating collection network to achieve the maximum possible quality of the compost. After the successful implementation of the biowaste collection system, it could be also applied to the rest of the settlements of Chalkidiki. As a result, the volume of the waste which is led to disposal would be reduced up to 30%. Most importantly though, Chalkidiki is a rural area and farming is one of the main activities, with vast olive groves throughout the region (source: Hellenic Statistical Authority). The majority of this waste could also be led to the Composting plant. Additionally, seasonal yard clippings which are a nuisance to collect and properly dispose of, could be useful to this facility.

This can be a very good rehabilitation option for the specific area and it is friendly to the Environment. Financially, the region’s landfill costs could be reduced due to the lower volumes of waste which would be directed for disposal. Also, a small profit from the composting product could be generated depending on its quality. What is more, the creation of full-time jobs for the local residents of the area and the environmentally-friendly nature of the Composting Plant make it a socially appealing choice and the support of the community is very important.

Thus, via LFM, the waste will be cleared off completely during the excavation works. The LFM procedure will follow the example of the LIFE reclaim project:

1) Surface mining of the waste using hydraulic excavators and transportation of the waste into trucks.

2) Weighing and deposition of the waste to the designed space next to the processing Unit at a designated pending area.

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

4) Ripping of waste bags 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.

8) Collection of the non recyclable waste into big bags or skips after the magnet.

9) Weighing of the sorted materials and placing in a spare location (storage space) by kind of materials.

10) Daily records of all incoming and outgoing materials of the Unit.

11) Provisions for the recycling of the materials and the disposal of the residue waste at a landfill site.

The Machinery which can be used for the operation of the Unit (see Technical report of Action B.5.) consist of: Backhoe loaders, Hydraulic excavators, Trucks, Platform tractor, Mobile Pilot Demonstration Unit (trommel, picking line, magnet), Washing machine, Scale, Environmental Monitoring equipment (such as the Continuous Ambient Particulate Mass Monitor – TEOM), etc.

Great care must be taken so that the impermeable geomembrane is not torn during waste mining. This issue must be addressed in the design of the Landfill Mining process by pointing out the depth of the waste and the exact position of the membrane so that most of the waste is removed without any tears.

Also, after the start of the operation of the processing of the excavated waste, the separated soil material should be analysed and tested for pollutants and heavy metals, as it might need to undergo soil remediation, or be handled and disposed of as hazardous waste. If the analysis shows that this material complies with the current legislation for the handling and use of aggregate and inert materials (Ministerial Decision 36259/1757/E103/2010), then this soil will be used for the purposes of the rehabilitation plan to construct the foundation for the Composting facility inside the landfill cell.

The specific design of the Composting Facility will be based on the relevant Ministerial Decision 56366/4351 of 2014 "*Defining the requirements and specifications for processing activities concerning the mechanical - biological treatment of mixed municipal waste and defining the features of resulting materials according to their uses, in accordance with part b of paragraph 1 of Article 38 of Law. 4042/2012 (24 /A)*". The aim of the Facility is to use source separated biowaste materials to produce high-quality marketable compost which can be used as a fertiliser for the agricultural and gardening activities of the area.

The preliminary stage of the Rehabilitation includes an in depth **desktop study**. This is essential to determine the detailed design of the rehabilitation plan, the sources and the exact amount of the incoming biodegradable waste, the out-coming compost quality and the market where it can be forwarded. In this case, the Composting Facility was designed to serve the entire Municipal area of Polygyros, in Northern Greece. Its incoming materials may include source-separated food waste and biowaste from the region's settlements which is nowadays sent to the Landfill, as well as agricultural waste. Taking into account the composition of the waste of the Polygyros Landfill, determined during the LFM pilot unit works of Action B6, the surface of agricultural activities of Chalkidiki (source: Agricultural Land, 2009, Hellenic Statistical Authority) and the production of green waste such as clippings, the Reclaim Team calculated that the Facility needs to be able to accept around **45.000tn** of biodegradable waste per year.

Once the design of the Facility is finalised, the construction begins. Apart from the landfill cell, all the remaining infrastructure of the Polygyros Landfill will remain as is and it will be used for the needs of the Composting Facility. This includes the offices, the weighbridge, the workshop, the wastewater treatment facility, etc. To achieve the maximum building surface, a three-tiered base will be constructed in the landfill cell on which the main Composting facilities will be built. As mentioned above, this construction could utilise the reclaimed soil material of the landfill, if it fulfills the criteria of the relevant legislation. The final design is depicted in Figures 7-1 and 7-2.

Figure 7-1: Virtual 3D view of the LIFE reclaim Rehabilitation Plan

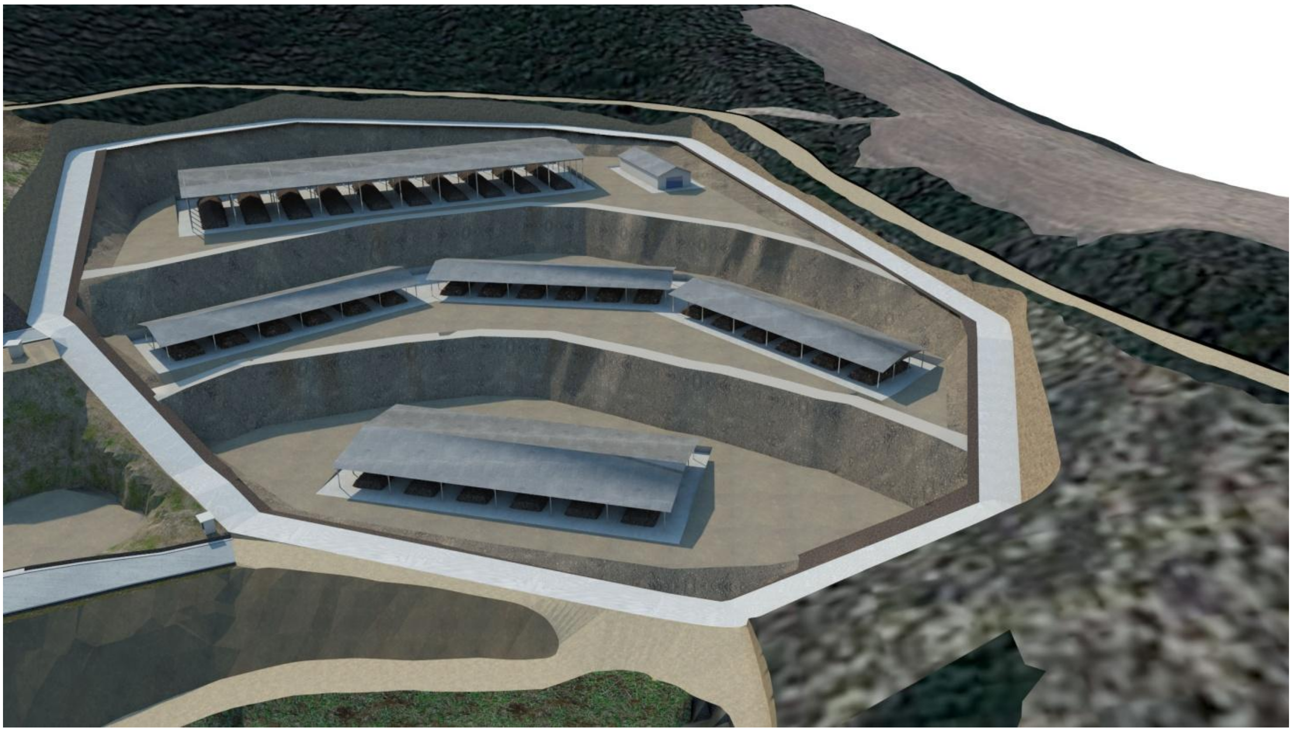


Figure 7-2: Zoom into the Virtual 3D view of the LIFE reclaim Rehabilitation Plan (Landfill cell modification and main Composting Facilities)

The main Composting Facilities will be built on these three levels A, B and C, as depicted in Figure 7-3.

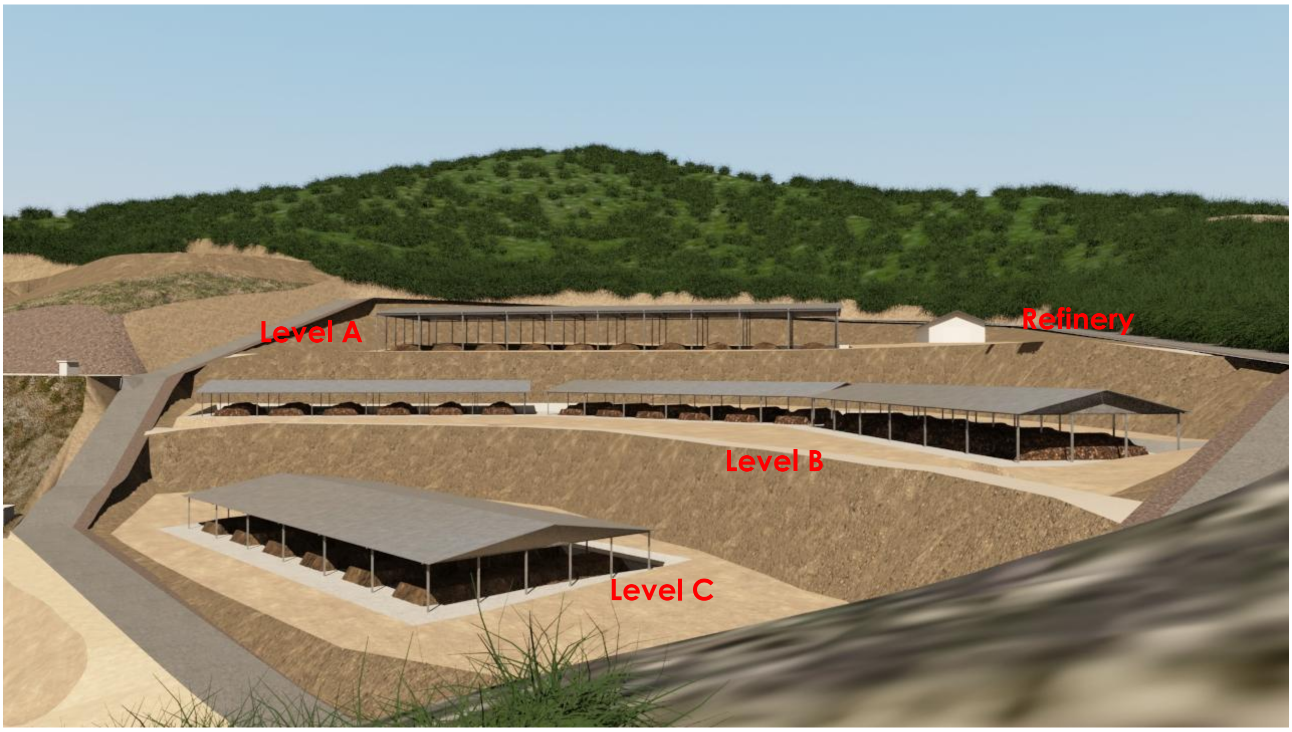


Figure 7-3: Zoom into the Virtual 3D view of the LIFE reclaim Rehabilitation Plan (Landfill cell modification and main Composting Facilities), a different angle

In particular, the main Composting Facilities consist of:

- **Reception:** the three sheds of LEVEL B will serve as the reception point of the biowaste. The incoming waste will be unloaded here, waiting to be processed.
- **Maturing:** The biowaste is piled under the tall shed of LEVEL A, were it will be turned regularly by compost turners, in order to speed up the degradation process. The waste remains at this stage for some weeks, until it is turned into compost.
- **Refinery:** This building is part of the post-processing of the compost. Using screens and air separation, the several contaminants of the compost such as wood, plastic, glass, etc. are removed from the final product to increase its ending quality.
- **Storing:** The shed in LEVEL C is used for storing the final marketable compost as long as necessary.

Alongside the 3D Virtual views of the rehabilitation Plan, the Reclaim Team has created a Virtual video to show the transformation of the Landfill. The video tracks the Landfill site from before the

Landfill was built in 2008, through its future closing, after the Landfill cell has been filled, and up to the complete landfill mining of the site and the rehabilitation of the site into a Composting Facility. You may find this virtual Video on the project's website www.reclaim.gr.

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APPENDICES

Appendix 1: RECLAIM-hab Questionnaire (DELPHI Session)

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

ENVIRONMENTAL REHABILITATION PLAN-Action B7

RECLAIM-hab QUESTIONNAIRE

DELPHI Session

Introduction

This questionnaire was created to assist with the DELPHI session of the procedure of the RECLAIM-hab tool. It was designed to assist each expert in this group to express their individual opinion about the pair-wise comparisons that the RECLAIM-hab tool uses.

Please, during the session keep in mind the specific characteristics of the **Polygyros Landfill**, which this RECLAIM-hab tool application is going to address to find the best alternative for its rehabilitation after a complete Landfill Mining project.

After completion of the questionnaire, a discussion on the results will follow until most of the participants all reach to an agreement on the estimates.

Let's start!

A) Comparison of the Weighing Factors

The weighing Factors of the RECLAIM-hab are three:

- The **ENVIRONMENTAL** factor
- The **FINANCIAL** factor
- The **SOCIAL** factor

Keeping in mind the specific characteristics of the region, please complete the sentences below:

1. *(Choose among three)* I believe that the **ENVIRONMENTAL/FINANCIAL/SOCIAL** factor is the most important one among the three.
2. *(Cross out)* I believe that the **ENVIRONMENTAL/FINANCIAL** is *(choose from a scale of 1 to 9)* **X times** more important than the **ENVIRONMENTAL/FINANCIAL** factor
3. *(Cross out)* I believe that the **ENVIRONMENTAL/SOCIAL** is *(choose from a scale of 1 to 9)* **X times** more important than the **ENVIRONMENTAL/SOCIAL** factor
4. *(Cross out)* I believe that the **FINANCIAL/SOCIAL** is *(choose from a scale of 1 to 9)* **X times** more important than the **FINANCIAL/SOCIAL** factor

B) Comparison of the Rehabilitation Alternatives

The proposed rehabilitation Alternatives for the Polygyros Landfill are five:

ALTERNATIVE A. Return of the PL site to its natural state

ALTERNATIVE B. Commercial and/or Industrial park

ALTERNATIVE C. Recreational area

ALTERNATIVE D. Composting Facility

ALTERNATIVE E. Construction and Demolition (C&D) Waste Recycling and Disposal Facility

These comparisons will be made separately for each of the three Factors. Thus, like before, keeping in mind the specific characteristics of the region, please complete the sentences below:

ENVIRONMENTAL Factor

5. *(Choose among five)* I believe that the **ALTERNATIVE A / B / C / D / E** is the best one among the five, in terms with the Environmental factor.

6. *(Cross out)* I believe that the **ALTERNATIVE A / B** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / B** , in terms with the Environmental factor.

7. *(Cross out)* I believe that the **ALTERNATIVE A / C** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / C** , in terms with the Environmental factor.

8. *(Cross out)* I believe that the **ALTERNATIVE A / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / D** , in terms with the Environmental factor.

9. *(Cross out)* I believe that the **ALTERNATIVE A / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / E** , in terms with the Environmental factor.

10. *(Cross out)* I believe that the **ALTERNATIVE B / C** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / C** , in terms with the Environmental factor.

11. *(Cross out)* I believe that the **ALTERNATIVE B / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / D** , in terms with the Environmental factor.

12. *(Cross out)* I believe that the **ALTERNATIVE B / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / E** , in terms with the Environmental factor.

13. *(Cross out)* I believe that the **ALTERNATIVE C / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE C / D** , in terms with the Environmental factor.

14. *(Cross out)* I believe that the **ALTERNATIVE C / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE C / E** , in terms with the Environmental factor.

15. *(Cross out)* I believe that the **ALTERNATIVE D / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE D / E** , in terms with the Environmental factor.

FINANCIAL Factor

16. *(Choose among five)* I believe that the **ALTERNATIVE A / B / C / D / E** is the best one among the five, in terms with the Financial factor.

17. *(Cross out)* I believe that the **ALTERNATIVE A / B** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / B** , in terms with the Financial factor.

18. *(Cross out)* I believe that the **ALTERNATIVE A / C** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / C** , in terms with the Financial factor.

19. *(Cross out)* I believe that the **ALTERNATIVE A / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / D** , in terms with the Financial factor.

20. *(Cross out)* I believe that the **ALTERNATIVE A / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / E** , in terms with the Financial factor.

21. *(Cross out)* I believe that the **ALTERNATIVE B / C** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / C** , in terms with the Financial factor.

22. *(Cross out)* I believe that the **ALTERNATIVE B / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / D** , in terms with the Financial factor.

23. *(Cross out)* I believe that the **ALTERNATIVE B / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / E** , in terms with the Financial factor.

24. *(Cross out)* I believe that the **ALTERNATIVE C / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE C / D** , in terms with the Financial factor.

25. *(Cross out)* I believe that the **ALTERNATIVE C / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE C / E** , in terms with the Financial factor.

26. *(Cross out)* I believe that the **ALTERNATIVE D / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE D / E** , in terms with the Financial factor.

SOCIAL factor

27. *(Choose among five)* I believe that the **ALTERNATIVE A / B / C / D / E** is the best one among the five, in terms with the Social factor.

28. *(Cross out)* I believe that the **ALTERNATIVE A / B** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / B**, in terms with the Social factor.

29. *(Cross out)* I believe that the **ALTERNATIVE A / C** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / C**, in terms with the Social factor.

30. *(Cross out)* I believe that the **ALTERNATIVE A / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / D**, in terms with the Social factor.

31. *(Cross out)* I believe that the **ALTERNATIVE A / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE A / E**, in terms with the Social factor.

32. *(Cross out)* I believe that the **ALTERNATIVE B / C** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / C**, in terms with the Social factor.

33. *(Cross out)* I believe that the **ALTERNATIVE B / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / D**, in terms with the Social factor.

34. *(Cross out)* I believe that the **ALTERNATIVE B / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE B / E**, in terms with the Social factor.

35. *(Cross out)* I believe that the **ALTERNATIVE C / D** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE C / D**, in terms with the Social factor.

36. *(Cross out)* I believe that the **ALTERNATIVE C / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE C / E**, in terms with the Social factor.

37. *(Cross out)* I believe that the **ALTERNATIVE D / E** is *(choose from a scale of 1 to 9)* **X times** more important than the **ALTERNATIVE D / E**, in terms with the Social factor.

Thank you for participating!

The Reclaim Team.

Appendix 2: RECLAIM-hab Tool

Excel spreadsheet

(available for download **HERE**)

Scale	**Verbal Expression**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong Importance	Experience and judgement strongly favour one activity over another
7	Very Strong Importance	An activity is favoured very strongly over another
9	Extreme Importance	The evidence farouring one activity overa another is of the highest possible order of affirmation

Pairwise Comparison	**Environmental**	**Financial**	**Social**		
Environmental	1	X	Y		
Financial	1/X	1	Z		
Social	1/Y	1/Z	1		
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
			TOTAL:	#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
			TOTAL:	#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
			TOTAL:	#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
			TOTAL:	#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
			TOTAL:	#VALUE!	#VALUE!

ENVIRONMENTAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C		
ALTERNATIVE A	1	Xe	Ye		
ALTERNATIVE B	1/Xe	1	1/Ze		
ALTERNATIVE C	1/Ye	Ze	1		
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
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				#VALUE!	#VALUE!
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	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!

FINANCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C		
ALTERNATIVE A	1	Xf	Yf		
ALTERNATIVE B	1/Xf	1	1/Zf		
ALTERNATIVE C	1/Yf	Zf	1		
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!

SOCIAL	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C		
ALTERNATIVE A	1	Xs	Ys		
ALTERNATIVE B	1/Xs	1	1/Zs		
ALTERNATIVE C	1/Ys	Zs	1		
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!
				Sumed Rows	
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
				#VALUE!	#VALUE!

	Environmental	Financial	Social
ALTERNATIVE A	#VALUE!	#VALUE!	#VALUE!
ALTERNATIVE B	#VALUE!	#VALUE!	#VALUE!
ALTERNATIVE C	#VALUE!	#VALUE!	#VALUE!

	Weights
Environmental	#VALUE!
Financial	#VALUE!
Social	#VALUE!

	Score
ALTERNATIVE A	#VALUE!
ALTERNATIVE B	#VALUE!
ALTERNATIVE C	#VALUE!