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Rehabilitation of abandoned mine sites. Problems and trends

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Abstract

At the beginning of this century, the mining industry trends began to change, due to the new environmental regulations, not only referring to mining but to the general industrial sector and specifying in the mining sector, rehabilitation projects in the mine life-cycle end are becoming more and more important nowadays. There already are some countries that have specific legislation for that, which force the mining companies to have a specific mine closure project along with a rehabilitation project, and they have a fine that may be applied, and entails the loss of the exploitation. Nonetheless, there are still many abandoned mines around the world that are not rehabilitated, due to the country legislation where they are. Since each one has a different one, and could be said that this mining trend is a new one, which most countries not apply. The most remarkable problem of mining rehabilitation is the lack of funds, since the mine closure is the most expensive stage and when the mine is not in a very strict country in terms of legislation, almost all the mining companies decide not to rehabilitate the space. Despite that, some improvements in this field are being done over the time, but it is not known any specific guideline to carry out all the rehabilitation projects, since every mine is different both the land and the material, also the climate or the needs of the nearby population. At the moment all the available information is based on previous projects and studies.

Due to the fact that this issue is beginning to be a concern of many sectors, the research that is carried out on it, is becoming more important. However, the information that exists on the subject is quite subjective and variable, since there many valid options to carry out a mine rehabilitation depending on the area. For this reason it is necessary to prioritize the different activities that can be applied, and know which are the best methodologies for each mine depending on the area where it is located. Due to all the factors mentioned, this thesis try to find the barriers presented by the carrying out of mining rehabilitations in the different countries, the different techniques that exist in order to carry them out, and the factors that influence the process, such as environmental, technical and economic ones.

Finally has been known that, there is no guideline to follow at the time to carry out a rehabilitation project, due to each case is different and is influenced by many factors that depend on the area in which the mine is located. The same is happening with prioritization techniques, since those known today are based on past cases in which statistical techniques or GIS software have been used, where the results vary according to the area. On the other hand, due to the fact that the biggest problem is the lack of funds, it is necessary to make a balance taking into account the economic, environmental and quality factors, which implies a variability of the results depending on the needs of the area to be rehabilitated. So that neither the economic factors nor the different methodologies that exist can be evaluated in the same way in all cases.

1. Introduction

It is known that the mining and extractive industry plays an important role in different sectors of the society, creates jobs and it is necessary for the world development. Nevertheless, due to adverse environmental impacts such as water, underwater and air pollution, deforestation, biodiversity degradation, and surface deformation, mine rehabilitation is carry out at the end of mines life-cycle as one a stage more of it.

As an overall idea it is understood by land rehabilitation, the process of attempting to restore an area of land back to its natural state after it has been damaged or degraded, making it safe for wildlife and flora, as well as humans. It refers to any enhancement in regard with to ecosystem functioning and structure, independent of whether full restoration is achieved or not. (*Gastaue and*, *Ambio, Brazil 2019)* In contrast, restoration is defined as a complete restitution of ecosystem structure after degradation beyond its natural resilience threshold.

But the term mining restoration refers concretely to the rehabilitation of the area affected by the mining activities. Including recovering the landscape previously located in the area, and taking into account safety and health factors for nearby populations, guaranteeing a healthy and adequate state for the recovery of lost biodiversity. Even if, there is no an exactly number of abandoned mines per region, it is known that the industry is forcing the environment to their limit, which has side effects for the flora and fauna and for the humans too. So that it is necessary to sort out this environmental situation in order to avoid serious consequences.

For this reason, this research will try to clarify the problems and difficulties that mining restoration entails, together with the possible steps to follow in order to prioritize the work during the process

1.1 Approximation of abandoned mines worldwide

In spite of the fact that, recovering the land affected is the most important part of the rehabilitation process, it also has other convenient side effects in regard to the society, since is known that most community opposition to mining, is focused on the long-term impacts of mining activities in the environment. But due to this rehabilitation practices, is improving the public's perception of the mining industry. Nevertheless, there is still a lot work to do in this subject-matter, since there are so many abandoned sites which have not been rehabilitated yet.

Despite this environmental emergency situation, there is no international-wide inventory of abandoned sites due to the lack of information provided from the companies. However, is already known an approximate number of abandoned sites per region, which provide an overall idea of the abandoned mine sites worldwide.

According with The New South Wales Department Mineral Resources, there are around 500 sites in Australia, but it is not a comprehensive list of all the sites *(Mining, Minerals and Sustainable Development, April 2002)*. In Canada there are some variable inventories which gather information about 10139 abandoned mines approximately, but most of them are not assessed. Moreover the British Geological Survey of abandoned mines data, from the Metallogenic Map of Britain 1996, listed 155 abandoned mines, and in the US is known that there are a large number of abandoned mines due to the legacy of the 16th century , the beginning of the industrial age. It is estimated that there is over than 557,5 abandoned hard rock mines in 32 states, such as in Arizona where is suggested by the State Mine Inspector's Office that there are as many as 27000 abandoned mines features in the State. South Africa also has many abandoned mines due to a long mining history, these include 134 abandoned asbestos mines and 400 asbestos dumps that are still contributing to the constant flow of asbestos dust to the surrounding areas creating a health hazard. In the European countries such as Ireland, the Environmental Protection Agency (EPA) has identified five sites that are or have the potential to cause environmental problems, and in Sweden is known a list of over 1000 abandoned mines, but only 70 environmentally significant. In addition, Japan has an approximately number of 5500 abandoned mines, specified by the national survey, and in Chile a survey by the National Geology and Mining Service in 1989/1990 found, that in northern and central Chile over 50% of the 665 tailings storage facilities studied had been abandoned without any cleanup or rehabilitation (*Clark et al., 2000*).

Due to the approximately number of mines found it is congested that, and look upon more abandoned sites than the approximate number, it is necessary to rehabilitate the land affected by mining activities. So as to recovered the flora and fauna, and decrease the visual impact of the area, bring a new use to the land taking into account the nearby populations, and improve the public's perception of the mining industry, since it is a crucial part for the world society development. However it is a long and hard procedure which needs specifics studies of the affected area, and the environment of the place surroundings including people needs. But not all parts of the rehabilitation process has benefits, that is why it is necessary to take into account the land rehabilitation advantages and disadvantages, before start the process.

1.2 *Problems and benefits of mining rehabilitation*

Mining rehabilitation stage takes place at the end of the mine cycle-life, so as to settle all the mining activities impact., But in most of the cases the land rehabilitation is not the solution of all the problems, since there are a lot of inconvenient issues which made the procedure harder, and create which is conceive as rehabilitation problems.

On the one hand, should be considered that, there is a problem of rehabilitation delay which before the procedure starts. The main reasons for the delay are the lack of clearly assigned responsibilities, the absence of criteria and the potential high cost of rehabilitation. The delay is produced because abandoned mine rehabilitation projects are invariably expensive, and they often have no clear view of where the necessary funds will come from as the economic phase of the mine will have ceased. In addition, there are other problems related with the proper rehabilitation process, since generally at the time of carrying out the restoration process, the major factors which contribute to the environmental problems are the type of mining method employed in the extraction of mineral resources, and the geographical location of the mine. Regarding the mining method, those underground mines do not have so many rehabilitation problems, since the visual impact is already minimize by the proper mining method. The only main points of the process are, to plan the future land use, prioritize the different rehabilitation works and recovered the affected land, in order to reduce pollution, balance pH levels, and restore the initial properties of the land so that its use is possible without any type of environmental danger or to human health.

However, open pit mines present greater problems due to the visual impact and the difficulties to restore the initial land properties in regard to the future land use. Apart from the initial properties, it is also necessary to recover the ground which sometimes is difficult to restore due to the loss of soil, harsh pH levels, areas of steep slopes changes in ground and surface water regimes, contaminated soils and aquatic sediments. Besides that, in several cases the visual impact is reduce by the rehabilitation activities, but the land composition and properties are still altered since the severity of the process, which prevents the field from being reused. Besides that, take into account mining rehabilitation literal meaning creates false expectations in the population, since it is known that the process of mining rehabilitation is necessary but, inevitably the final state achieved differs from the state prior to mining activities.

Regardless of the type of exploitation method used, it must be borne in mind that the biggest problem with the mining restoration is the lack of funds to carry it out. Besides that, sufficient legal responsibilities on the part of the owners and the lack of financial forecast at the beginning of the mining activities for the mine closure.

On the other hand, there are so many benefits which make the rehabilitation process worth it. Mining rehabilitation allows recovering the topsoil of the altered zone, which entails the gradual and partial recovery of the flora and the fauna. This partial recovery is due to the fact that, in spite of recovering the initial state of the area, the same conditions will not return, therefore the species that can inhabit that space may change. Moreover, based on land new properties after the exploitation activities, it can be given a new use to the land different from the one that it had previously, be it agricultural use, forestry, of protected natural space, of leisure or even cultural. This planned future of the land must be studied and decided according to the needs and reclamations of nearby populations. Therefore it is considered a positive point to bring new claims to the area, which can lead to the creation of new jobs or simply attract tourism to the area.

As it was said, one of the greatest benefits of mining rehabilitation process is the recovery of an environmental state, suitable for human and animal and plant health. Due to that, is possible to include again the affected area in the environment, and give it a specific use or maybe simply increase the natural around area.

2. Rehabilitation projects carried out worldwide

As it was mentioned, rehabilitation activities are carrying out not only at the life cycle's mine end, since the altered land after conduct extractive activities, dumped hazardous wastes or polluted water, needs to be recovered. For this last case "Superfund" was carried out in USA in 1980 for the first time (*United States Environmental Protection Agency*) , due to the toxic waste dumps Love Canal and Valley of the Drums, which taken place in the Niagara Falls and Brooks, Kentucky respectively. The comprehensive Environmental Response, Compensation and Liability Act (CERCLA) informally called Superfund, is a project which allows EPA (Environmental Protection Agency) to clean up the contaminated sites including, manufacturing facilities, processing plants, landfills and mining sites. It also forces the parties responsible for the contamination to either perform clean-ups, or reimburse the government for EPA led clean up work, and when there is not responsible party the government gives EPA the funds and authority for clean up the contaminated sites.

Unless it was a very convenient and right environmental action, there are a lot of problems to carry out the land rehabilitation activities, and after fifteen years of activity, cleaned up is still too slow, and high costs and litigation plague the program. Besides that, investors and banks often refuse to lend money for the Superfund projects, which might have Superfund liability attach to them. But the strongest complaints about this initiative have been that few sites have been cleaned up, too much is spent on lawyers and administrative costs and cleanuos are too costly.

On one hand, unless the Environmental Protection Agency knows that the toxic trail which follows cleanup has serious side effects, the agency chooses not to quantify them. Thus the EPA cannot measure if the sites cleanup is worth it. On the other hand, EPA cleanup goals are in many cases unrealistic, since is required by the agency that the underground water should be treated until it is clean enough to drink. Nevertheless it is know that there are too many cases which could take around 500 years to recover the water completely, which does not correspond with EPA's requirements.

Due to the hardness to find any currently and available technology that will quickly and effectively clean these sites, an emerging solution among experts is allow the chemicals to break down naturally, being the most effective answer. It could be considered that the main problem of Superfund is that, the major decisions are left to private companies instead of being the government liability. The companies are the responsible parties to decide where they send the wastes, and the treated plants normally have well-documented histories of environmental violations. Moreover, if the technology used in the cleanup process does not work, the companies can be loath to change it since they have already invested in the infrastructure used previously.

Even with all the fund problems that can be find with respect of carrying out a land rehabilitation by Superfund, there are good few of cases which were taken place mostly in United States.

There is a list which collects all the Superfund sites located in United States, which was authorized by CERCLA for the United States Environmental Protection Agency (EPA) to create it, with the locations which are placed on the National Priorities List (NPL). According to this list, in 2014 there were 1322 Superfund sites located around the country , but there is no too many information about the rehabilitated sites nowadays, since Superfund is a lack of funds project which currently is practically paralyzed. Despite this, this year some filed project has begun to be review *(Emily Bender, The U.S Environmental Protection Agency, Boston, 2019)*.

Apart from the before mentioned project, there is another one that is being carried out in Canada and is called NOAMI (National Orphaned/Abandoned Mines Initiative). Unlike Superfund, this project is doesn´t clean directly the affected sites, rather it examines the legislative and policy framework in Canada for addressing the issue, and make recommendations for improving the situation of those abandoned mines which the owner can be found or for which the owner is financially unable or unwilling to carry out the clean up. The project is an example of a multi-stakeholder approach to a complex problem in the national framework of Canada ***(****Keith Cunningham, Senior Industry Analyst, Bulletin magazine, Canada, 2017).*

3. Worldwide mining legislation principals

The overall idea of the rehabilitation process which is followed in an international way is following:

According to the timing, the rehabilitation process or mine closure planning should begin early in the development planning phase and continue in the mining life cycle and closure phase. In addition mine closure planning should be integrated with environmental legislation and other assessment, such as environmental and social impact assessments. In some parts of the world, this planning must be reviewed and updated at least every three years. This reports should continue into the post-mining phases until formal closure is certified and the land is returned into government or community ownership, and the mining company has the greatest part of responsibility and for most of the others management actions. Furthermore, the mining closure planning should specify the final land use, which has to be consulted with local community and the other affected stakeholders.

4. Current situation per region

4.1 Africa

It is known according with the literature consulted (*Alberts,R, 2016, Complexities with extractive industries regulation on the African continent*), that there are around 8000 mines and quarries with small mining activities, which are abandoned or were improperly closed, but the owners were not identified so as to carry out a rehabilitation program, so the database number of abandoned mines was finally reduced to 5445. From all the abandoned mines found, at least 1703 were found in South Africa and classified as high risk mines, on the other hand almost 729 were found in Limpopo a not well known area, of which there is practically no information about its nature and extent of problems. But there is no doubt that they are in deplorable state, and will certainly need to be given attention. As in the most of countries, the trend for mining rehabilitation in South Africa, is to give the first priority to public safety and then the environment.

To classify the different mines and quarries around the African continent and also in other parts of the world, are used hazard maps which are developed by the identification of all the abandoned mine features, and description of these mine features in terms of their associated potential physical and environmental hazards. The scoring of hazardous features take into consideration the magnitude of human and environmental hazards, based on their impact to human health, animal health and the environment. This method (using hazard maps) uses the Historic Mine Site Scoring System (HMS-SS). The system was developed and first used to rate abandoned mines in Ireland. It was developed based on the Abandoned and Inactive Mines Scoring System (AIMSS) that was used to rate abandoned mines at the State of Montana.

African law trends and funds

Regarding the laws trending, a comprehensive environmental governance regime has been established in many African nations over the last two decades, in conjunction with provisions for mine closure within mining legislation. Nevertheless, it has apparently not permeated effectively into avoiding or managing in abandoned mine closures. The primary foci of country and legislative reform is on improving governance, attracting investment, and associated opportunities for harnessing resource development. The apparent lack of discussion of mine site rehabilitation and closure planning, with in these vision building initiatives is a notable omission. However, there is a growing awareness of managing environmental resources to promote sustainable mining.

According with *(JP Casey, Mining Technology, 2018*) South African laws require mining companies to set outside funds at the beginning of a project, for the rehabilitation project once the mine life cycle is ended. If the company is unwilling to use those funds for rehabilitation activities after the mine closure, the government can opt to take the money and conduct it by itself through the “polluter pays” principal, which means that who pollute will pay. The International Financial Reporting Standards (IFRS) determines the extent of the financial information which the mining companies are obligated to provide, however it insists in present an unique and consolidated sum of money which reflects their ring-fenced funds. Thereby that contributes to a lack of information in the mining sector, since the responsibility is in the individual companies to disclose as much or as little of information as they want. Rather than on the government to ensure that all companies are legally obligated to provide detailed and enough information about their available funds.

4.2 Australia

It is said *(Vella & Vella, 2019)* that Australia is a country built on mining, since in 1980 was the gold rush and it continued until this days, where mining is the principal contributor to the country's PIB. Nevertheless it left approximately 50000 abandoned mines around the nation, of which 1700 are in Queensland, shared between private and public lands. It is known that this situation degrades local environments and creates hazards for local communities and animals. Furthermore, in 2013 cyclone Oswald caused wastewater from around 20 Queensland mines to rush into passing floods, disaster which made to took into consideration the issue severity and realized that abandoned mines are given to the society negative image from the mining industry.

Australian law trends and funds

As regards as the Australian law trending in mining rehabilitation, in 2012 the Western Australian government launched a new mining rehabilitation fund (MRF) to pay for the abandoned mines clean up. But, it is apparently not enough improve being that each region of the country is making their own rehabilitation laws instead of work together to solved a shared problem.

However the situation about this issue is improving over the years, although it is being so slowly. According with *(Laura Gartry and Ashleigh Stevenson, Australia 2018*) since two years ago, it is required by resource companies in Queensland to financially contribute to rehabilitate abandoned mines in that state of the country. Instead of being focus in one specific site, the companies are forced to allocate an amount of money to future abandoned mines if the owner goes bust. Therefor if in the future one mine fails, it will be rehabilitate by the funds, removing liability form the taxpayers, but in spite of that the future high risk project will should have to present a surety to the government to cover their rehabilitation costs.

It will be also required to have a rehabilitation project at the beginning of the extractive activities in each mine.

Nevertheless there are some law voids which are creating confronting situations between opposite parties, some of them are supporting the idea of apply the law in a retrospective way, while others are against that so as to let the mining companies left off the hook, and because of that the Queenslanders will be forced to pay all the rehabilitation work bills and the industry will be left off the hook.

4.3 Canada

It is known that there are mining sites in every part of Canada mine regions, but sites there are not well documented to respect either to the number of them, or the physical, health, environmental and liabilities associated, since there are many abandoned mines and orphaned mines, which means that mines which the owner cannot be found or for which the owner is financially unable or unwilling to carry out clean-up.

According with *(Keith Cunningham, Senior Industry Analyst, Bulletin magazine, Canada, 2017)* due to the lack of information and the severity of the problem, in 2002 following the stakeholders request to the different ministers of the country the National Orphaned/Abandoned Mines Initiative (NOAMI) was created. This organization is guided by Advisory Committee that brings together representatives from the Canadian mining industry, federal, provincial and territorial governments, non-government organisations (NGOs) and Aboriginal Canadians. NOAMI doesn´t clean directly the affected sites, rather it examines the legislative and policy framework in Canada for addressing the issue and make recommendations for improving the situation of this abandoned and orphaned mines, and prevent the occurrence of new abandoned and orphaned mines in the future.

Canadian law trends and funds

Respecting the environmental laws about mining rehabilitation, which are carrying out in Canada *(Abdel-Barr and MacMillan, Canada, 2018*), to bring to pass the mine closure project and restore properties after the exploitation activities, the approval of that project is provided for almost all the jurisdictions in the country. Generally is required that before any exploration and mining activity been undertaken the provincial government will have to approve the rehabilitation, restoration, reclamation or closure plan. As the proper rehabilitation word says, upon the mine closure the approved plans must be executed so as to restore the site to an acceptable condition.

4.3 United States

Even if it is 2019, in United States The General Mining Law of 1872, is still the principal law governing the locatable minerals on federal lands, which gives the citizens the opportunity to explore, discover and purchase valuable mineral deposits on federal lands. Regarding the environmental issues, NEPA, National Environmental Policy Act is the principal environmental law implicated by mining on federal lands. According with (*Evironmental Science*) the environmental law which is practiced in United States is the shortest law exists, since is less than 6 pages in length and was passed by Congress in 1969, signed into law on January 1 of 1970 by president Richard Nixon. Thus NEPA requires federal agencies to take a hard look at the environmental consequences of federal projects before action is taken *(Kahalley, Nichols and Nannini, 2017). ,* but it has to be taken into account that the overall NEPA process is to determine alternatives that would correct the environmental problems identified, study new potential environmental issues using various methods and regulations. Due to NEPA is a government initiative, it cannot interfere in the environmental consequences induced by mining activities, unless it does not have a recognized owner, in which case it would be designated as an abandoned mine. In that situation and when the mine's owner does not have enough funds to carried out the mine closure, and in consequence the rehabilitation project it is *Superfund* initiative which has the mining land liability. NEPA's limitations are due to the fact that US law generally permits foreign investments in US industries, including mining since the US government places few restrictions on such investments, unless they are deemed to have national security implications.

There is no that much information about mining rehabilitation legislation in United States and even over, since president Trump put all his effort to reform energy and environmental policies, recently aiming to decrease permitting barriers relating to the mining industry, it had begun to be more difficult to create environment laws related with mining rehabilitation. In spite of that fact, Superfund initiative is still working unless nowadays has significant fund problems which do not allow to carry out the mining land clean up, or to finish those projects that were started years ago and were finally filed.

4.5 South America

In spite of the fact that United States belong to the same continent, the different laws regarding mining are remarkable. There are some countries such as, Chile, Peru, Mexico, Argentina and Brazil that are more developed in mining than the others, since in Chile, for instance, the mining sector represents the 13 per cent of the GDP. This is due to Chuquicamata, the biggest cooper mine in the world, located in the Atacama Desert in Chile.

4. 5.1 Brazil

As in many countries, in Brazil the environmental legislation demands the rehabilitation of degraded areas to minimise the impact in the area. Unless this action, there is an important point which is not taking in account, since Brazilian law ignore the emergence of novel ecosystems due to large scale changes.

In Brazil mining legislation and the mine closure plan varies within each jurisdiction, moreover a mine closure plan must be submitted as part of a series of studies in order to obtain an environmental license, and it must cover the minimizing of environmental degradation and negative impacts on the environment. This closure plan must be updated periodically, but the regularity of such update is not provided.

In oil well abandoned, during the exploration and development phases, oil companies must simply notify the situations to the Brazilian National Petroleum Agency (ANP), and during the production phase oil companies can abandon the exploitation as long as the Petroleum Agency authorized it. Nevertheless, oil wells cannot be abandoned if the mining operations had impacted neighbouring oil wells, unless the well to be abandoned represents a safety environmental threat to the environment. In this case of oil wells there is no closure plan required, but if the well abandonment is not done properly sanctions can be applied, as well in the mining exploitations, which range from a fine through to the termination of the license or concession agreements.

In this country there is a particular focus on health and safety regarding the mine closure, since the closure plan has to gather work health and safety rules that should be observed by mining companies.

Generally, across the region, it could be said that some form of closure or abandonment plan must be submitted to the government at the start of the project. Most jurisdictions require that this plan be updated over the course of the project. In Argentina, Chile and Peru there are proscribed times for updating the plan, however, in Colombia, it must be done only when there are variations in the mining operation and in relation to oil and gas, there are no specific time frames.

4. 5.2 Argentina

Mining legislation in Argentina is in silent regarding rehabilitation requirements following the mines closure. It only provides that the Environmental Impact Assessment may contain post-closure supervision of the operations. In the last two decades only two cases of mining closures are known *("CLOSURE OF NATURAL RESOURCES PROJECTS IN LATIN AMERICA", 2019)* in 1988 y 2012, but the latter is still in process since there is any formal requirement to obtain the closure certificate, and as any other cases in the country, it is expected to implement industry best practices in order to protect itself from potential liabilities in the future. Moreover there are no strict remediation requirements regarding the mine closure as long as the environmental impact do not be too aggressive, and the Environmental Impact Assessment may include post-closure supervision requirements, but it does not have to.

Regarding the oil wells Argentinian legislation considers two cases of abandonment, temporary and permanent, and both them must be treated depending on the characteristics of the area where the well is located. In all the cases, the land must be left free of liquid waste, all constructions must be demolished and auxiliary wells and basins must be filled. Finally, oil concessionaires may agree with land owners different methods to perform the final abandonment, as long as the spirit of conservation and preservation of the environment is maintained.

4. 5.3 Guarantees and amortization of closing costs

Guarantees are required in many jurisdictions as a form of insurance for carrying out the closing works in accordance with the requisite plans. The mining companies operating in Argentina, Chile, Colombia and Peru are required to have in place a deposit guaranteeing to closure work, an account allocated to that effect within the company’s own funds or an insurance policy covering this event in case the company cannot carry out the Works.

Argentina is the only one of those states that does not require a guarantee in respect of hydrocarbon reserves and a guarantee is not required for either mining or hydrocarbon reserves in Brazil.

4.4 Asia

In last decade, Asia becomes in one of one of the largest mineral producer in the world, such as rare earths, iron, manganese, zinc, cooper, and lead. In theory, is generally accepted that the earliest a mining company incorporates integrated environmental and social management into its closure planning, the more cost effective and efficient it will be *(Cesare, 2003).* Moreover it is also necessary an environmental impact assessment, due to in developing nations it is often difficult for mining companies to keep decommissioned sites under control, because the local communities, often indigenous, who would otherwise be unemployed, occupies the sites and works them as artisanal miners. Those activities may risk sabotaging rehabilitated and engineered structures, such as waste dumps, so that`s the reason why every mine has to use the land for other purposes after mining activities.

However, not everything is that simply since nowadays there is a lot of complexity regarding cultural and economic issues that complete the process of rehabilitated areas disturbed by mining. In the specific case of Indonesia, before 2000 there was no comprehensive law that dealt adequately with mine closure issues. In order to remedy this deficiency, in 2002 the Indonesian Government initiated a process to develop a policy. In that year there was a discussion about closure issues to conclude what are the principal points to carry out rehabilitation projects in the country, and they finally determined there was a lack of instructions and guidance form the Government. Besides that, they concluded there was also a lack of concerned and engagement in and participation of non-government organizations (NGO’s) in the mine closure process. In the light of these common points of interest, representatives of the mining industry agreed to establish the Industry Mine Closure Steering Committee (IMCSC).

4.5 Europe

Tacking a quick look of the European geography, it is not the worst part of the world according with the natural degradation and impact after mining activities. There is no official inventory about how many abandoned mines can be found in the continent, but for instance, it is known that Slovakia has registered more than 17,000 old mining sites and Hungary has reported some 6,000. In Bosnia and Herzegovina the total area affected by mining exploration and exploitation is around 330000 hectares and in Czech Republic the devastated land mining area by mining operations reaches around 9500 hectares.

Regarding the European legislation according with mining closure, there is an environmental regulation which raises some types of environmental concerns: mining waste, nature protection, water protection, environmental liability… The mining waste directive (*Directive 2006/21/EC of the European Parliament and of the Council on the management of waste from* *the extractive industries)* introduce obligatory permits and setting requirements for building or modifying an extractive waste facility. Besides that, a document which includes the best available techniques (*BAT Reference Document, BREF*) was developed, on the management of waste from ore processing and waste-rock in mining activities. It covers activities related to tailings and waste-rock management of ores that have the potential for a significant environmental impact *("Mining Waste - Environment - European Commission", 2019)*.

With reference to water protection, mine water is covered by the Water Framework Directive, which introduces river-basin management with a focus on ecology, and requires that “good” status must be achieved for all EU water since 2015. It is complemented by the Groundwater Directive, which sets quality standards for underground water and introduces measures to prevent or limit the pollution of groundwater.

In the case of Nature protection, the habitats and birds Directives the EU nature conservation policy has a central element of which is the Natura 2000 network of ecological sites. Mining projects in and around Natura 2000 sites are not automatically ruled out, but they must be assessed in a proper way to have a significant effect on a protected site. If such effects are expected, mining projects must either be avoided or amended.

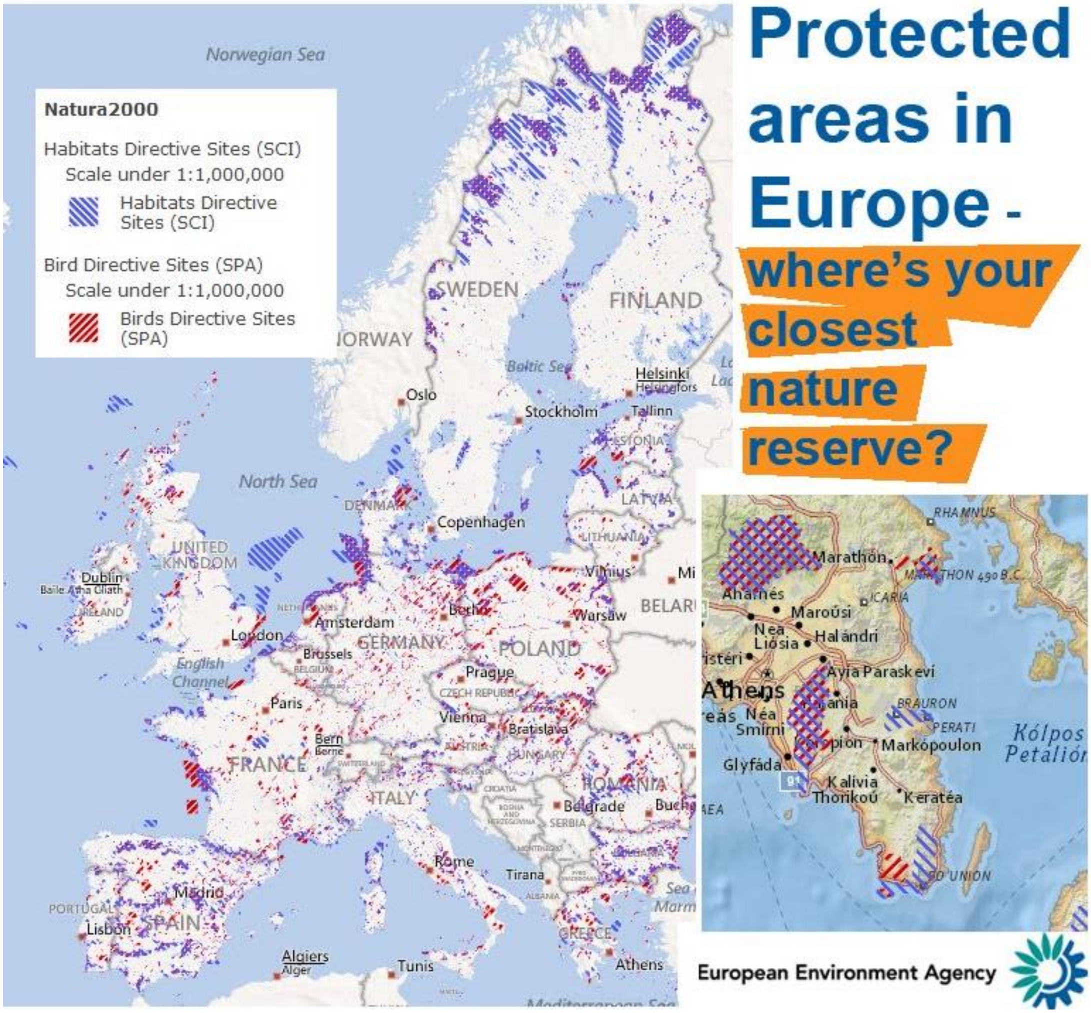

Fig 1. Natura 2000 network of protected ecological sites in EU

The mining industry is affected by the Environmental Liability Directive which is based on the “polluter pays” principal. Operators have a duty to avert environmental damage or take or finance restorative measures if such damage occurs due to their negligence or fault. Finally but not less important, health and safety issues have to be taken into account. Mining and quarrying has one of the highest rates of accidents at work and of work related health problems, thus *the Health and Safety at Work Directive* sets the general principles for prevention and protection of workers against occupational hazards.

Regarding the industrial framework, it is known that the industry is affected by general legislation, rules controlling pollution form industrial installations are covered in the legislation on industrial emissions, and the *Environmental Noise Directive* must be also respected and the use of chemicals in mining by the REACH legislation too.

Spanish laws and funds

According with the 1982 approved mining law in Spain, based on the restoration of natural space affected by mining activities, write a restoration plan and its approval by the competent authority is required, and its non-compliance can lead the mine closure. The restoration plan project has to contained, a memory describing the environment where the mine activities taken place, the geology, hydrology, climate, the socioeconomic situation of the nearby populations, and justification of the recovered system chosen, with planned measures for the restoration. Besides that, it is also needed all the blueprints of the area where the restoration will take place, specifying such as the pits place, the slopes, etc.… At the end it is also needed a social-economic study which has to developed all the budgets of the company that ensure compliance with the restoration plan. Apart from all the required information which has to be in the restoration plan, it must take into account that the restoration activities have to be included in the full mining project, which the company has to present before starting the extractive activities.

5. Successful and innovative rehabilitation projects worldwide

To achieve a successful rehabilitation project it is need to be planned through the future uses which will have the restore mine or quarry, such as exposing the geological structures of didactic interest for observation, to give a naturalistic, or forestry, or cultural employment ... to the mining area. For take that decision it has to be considered the weather, the nearby population, the flora and fauna, the economy, the land properties, close areas interests and the sustainability of the whole project. Afterwards, taking in consideration the information mention before, the rehabilitated space project can be used for industrial, agricultural, leisure activities or natural and forestry habitats.

Finally even if there are a lot of voids laws in every country regarding to mining rehabilitation, there are some successful rehabilitation projects around the world which had had enough funds to been carried out. Some examples of them are presented.

5.1 Eden project

The Eden project is a popular visitor's attraction located in Cornwall, England in a reclaimed china clay pit around 50 hectares which is inspired in nature and sustainable growth. It is formed by two greenhouses which are developing two different biomes with diverse kind of plants. One of the greenhouses simulates a rainforest environment forming the biggest tropical greenhouse in the world, while the other one reproduce a Mediterranean environment. The attraction also has an outside botanical garden which is home to many plants and wildlife native to Cornwall and the UK in general.

Fig 2. Kaolin mine before rehabilitation

The clay pit where the attraction is located ,was working for over 160 years and the initial idea for the Eden project began in 1996, but it was not until 1998 when the constructive activities began and finally the full sited opened the 17 of March, 2001. According with *The Eden Project* they needed an approximately 56 million investment to carried out the land rehabilitation, and nowadays their funding is coming from major sources like the European Union and Southwest Regional Development Agency (some £50 million between them, including £26 million towards capital funding from the EU) and £20 million of commercial loans.

Fig 3.Final outward appearance of Eden project

The Eden Park has almost 400 employers, and it offers 300 more places for volunteers. Since its opening in 2001, the park has attracted more than 18 million visitors who have contributed to amortize the initial investment, in addition, during all this time it also has managed to inspired an economic renaissance in Cornwall, by contributing more than 1.7 billion pounds to the local economy.

5.2 *Cabárceno Park*

Cabárceno Natural Park, is a space located in Cabárceno village, in Pisueña Valley near the Spanish city Santander. It is located in a former open cut iron mine, and nowadays it is a rehabilitated area with a beautiful primitive karst landscape. The mine was exploited since the prehistoric centuries, the exact period of time it not know with accuracy, and finally around the beginning of this century the was the time for the mine closure, thus the Cantabria community decided to create a zoological park due to the mild climate that exists in the area, as well as a biological reserve for the conservation of species, among them brown bear of the Cantabrian mountain range that is still in danger of extinction

The park has two roles, one is the conservation of endangered species and the other is environmental education, developed in around 750 hectares being the home of different animal from the five continents, which are living in semi free conditions, since except for provided them food, animal's activities are developed in total freedom.

Fig 4. Opencast coal mine in Cabarceno

The initial investment that was necessary for the construction of the Cabárceno natural park is not known with accuracy, only 1500 million pesetas (*Delgado, El País, 1989*) in the first stage of the rehabilitation. However, according with *(La Región Internacional, Cantabria, Spain 2019)* it is known that the park counts with economical help from the European Union and the Cantabria community where is the park located, for all the reconstruction works. This year it received 4.767.561 euros, which 50% was from the European Union.

Fig 5. Cabarceno Natural Park

5.3 Songijang Hotel

The hotel which has this name, is a complex and ambitious engineering project which is located in a former open cut hardrock quarry in the bottom of Tainmashan mountain at 45 kilometres from Shanghái. The exploitations activities began in 1950 and after 50 years the cycle life of the mine came to its end and it was abandoned, but at that time there already was a 100 m deep hole, 240 m length and 160 m width, semi flooded and it entailed severe degradation to the nearby lands.

Fig 6. Songijang quarry

Due to that situation it was decided by the land owner company to carry out this ambitious project which will be formed by a 19 floors hotel, with 6 of them underwater, and a very big lake and waterfall, and stocked by geothermal energy.

Fig 7. Songijang Hotel

5.4 Wieliczka Salt mine

The well known "Poland underground mine salt" is located in the polish town of Wieliczka, in the metropolitan area of Krakow. It is formed in the one of the most actives salt mines of the world, which has 327 metres depth and more than 300 kilometres length and it has been continuously exploited since XIII century. Nowadays is still producing normal kitchen salt and it includes a touristic rout throughout 3,5 kilometres, which has salt sculpted historic and mythical characters. Besides that, there are also chambers and chapels and dug in salt.

Fig 8. Nowadays Wieliczka salt mine

The mien was declared world heritage by the UNESCO in 1978, and it receives approximately 800000 visits per year.

5.5 Soudan underground Laboratory

The laboratory is located in Soudan, Minnesota, 714 metres beneath the surface in an old iron mine. The location is deep enough that particles physics experiments see less than 100000 times the cosmic radiation than on the surface, and with this is possible allow sensitive searches for exotic particles like neutrinos and dark matter. The Soudan laboratory has been the leading deep underground where scientists from around the world have been working for 35 years trying to answer question about the Universe.

Fig 9. Soudan Laboratory, Minnesota

5.6 Braga football team stadium

The stadium is located in the Portuguese city of Braga, and it was built in 2004 in an aggregate quarry which was exploited continuously since the 40's, but in 1999 the quarry was almost without resources so it was not profitable continuing the exploitation. Finally in 2003 the stadium was constructed by the Portuguese architect Eduardo Souto de Moura and nowadays has 30154 people capacity. It presents a special form since it has only terraces in the laterals of the stadium, and the others parts are offering a beautiful panoramic view of the town of Braga.

Fig 10.Hardrock quarry before rehabilitation

Fig 11. Braga football team stadium

5.7 As Pontes Lake

This mining rehabilitation project is known as the biggest one carried out in Spain by the Spanish company Endesa, concretely in the city of Coruña in the north west of the country, in Galicia community. In its day it was the largest opencast lignite mine in the country and today it is a huge natural enclave with great ecological wealth, and almost 2400 rehabilitated hectares.

Fig 12.As Pontes mine before rehabilitation

The mine was in continuous operation from 1946 to 2007, being the greatest lignite mine in Spain which provided raw material to thermal central "As Pontes" which at that moment an energetic production around 1400 MW. Finally in 2007, due to a new European Union law, according to environmental responsibilities, it was decided to close the mine and use import lignite instead, since the mineral properties were not the best for being burnt, regarding the gases emissions into the atmosphere.

Transfer mining was the used method in the mine, to allow exploitation activities to be carried out at the same time as rehabilitation ones, thus the land rehabilitation began before the mine closure. The first step in the restoration project was creating an stable topsoil where the dump took place, and the progressive landscape recovery. The flood hole for create the lake began in 2008, just after finishing the exploitation works and it took until 2012 to be completely filled, leading to one of the largest lakes in Europe with 543 hm^3 of water, which improved the first expectations both in chemical quality and in integration in the natural environment.

Nowadays the lake in its surroundings are used as leisure areas, where is possible to practice aquatic sports such as triathlon, swimming areas and even one beach.

Fig 13.As Pontes lake after rehabilitation

According with *Cinco Días (Madrid, 2014)* the approximate investment for the rehabilitation project was 100 million euros, including the landscape recovery, the lake filling with all the infrastructures that it entails, such as 7 km bridge between Eume river to the lake to supply it with water, the creation of the dump and the topsoil, and the reforestation.

5.8 Stoney Cove

Stoney Cove was a large quarry of granite, which was used to repair roads, during the 19th century *("OUR HERITAGE", Stoney Cove, 2019).* During the entire life of the quarry, the spring water was constantly a problem, and pumps were used to prevent the quarry from flooding, but in 1958 the spring water was allowed to flood the quarry workings. Five years later, the flooded quarry becomes popular with local pioneers of diving and water skiing.

Fig 14. Stoney Cove as a granite quarry

Due to the different levels that were developed during the life cycle of the mine, the area presents nowadays three depths which are allow to do different scuba diving activities depending on the depth. The area also presents a diving school for those people who want to learn how to do it, and for those who already know the sport and they want to practise it by their own.

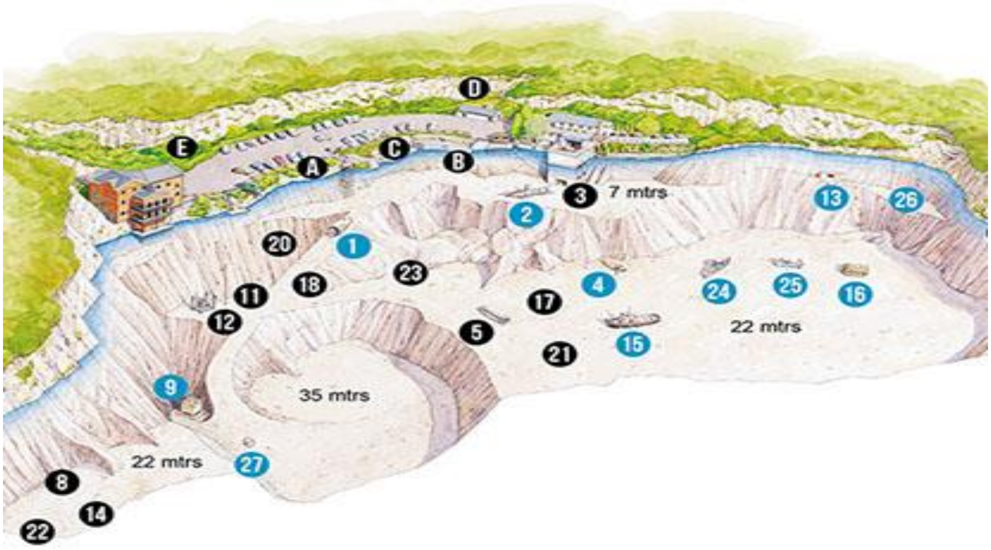

Fig 15. Depth levels in Stoney Cove

Fig 16. Stoney Cove nowadays

5.8 *Natural Rehabilitation*

It is known as natural rehabilitation those lands which are rehabilitated with very little human intervention, where revegetation occurs periodically following the natural courses of growth, without accelerating the rehabilitation process. Some of those examples are those ones which were carried out by the Energy and Natural Resources Ministry of Quebec (MERN), which has invested 134$ million since 2006 for reclamation, security, maintenance and monitoring of abandoned mining sites, and abandoned lands.

5.8.1 Barvue

Barvue is the name of an open-pit and underground Zinc and silver mine, which operated from 1952 to 1957 as the first period, and from 1985 to 1990 as the second period. They were extracted 5Mt during all the operation periods, and meanwhile in 1950 occurred the major breach of the tailings containment dike. Finally, the mine was abandoned in the nineties until 2012 year in which began the reclamations works until 2016.

Fig 17.Geomembrane application in Barvue

According with the MERN, 35.5$ M was the total cost of the rehabilitation project, since they used a rehabilitation concept that involves a multi-layer HDPE geomembrane to limit the water inflow and reduce oxidation of tailings, thereby limiting contamination of the receiving environment. Once the oxidation was controlled the revegetation was carried out over the entire site, with use of fertilizing residuals. Divided into four phases, the rehabilitation work began in 2012 and was completed in 2016.

Fig 18. Nowadays Barvue mine appearance

5.8.2 Siscoe

Siscoe was an open-pit gold mine, which was operated continuously form 1926 until 1949, on those 3.5 Mt ore were extracted. The mine was abandoned during 74 years, but in 2014 the rehabilitation project began levelling of tailings site and digging of ditches to improve surface drainage. At the last step of the work it took place the installation of a single-layer granular covering and the revegetation over the entire site. Finally the work was completed in 2015 with a final investment of 2.1$ M.

Fig 19. Siscoe mine in 1949

Fig 20. Siscoe mine after natural rehabilitation

6. Rehabilitation Prioritization and Methodologies

As it have said, depending on the country there is a different mining legislation, and each one has its different section regarding closure plans and mining rehabilitation. Although it also exists some countries that do not have any specific mining legislation in reference to rehabilitation. As an overall idea about mine closure and rehabilitation of the space affected by mining activities, could be said that without specifying any country, everyone has a lack of fund to carry out the rehabilitation project at the end of the life-cycle mine.

Moreover, this problem is the consequence of the fact that many mining companies operate in foreign countries where the law does not obligate them to take responsibility for the land once the resource has been extracted. In most cases, it is more rewarding to leave the abandoned farm than to restore the area, since they are very expensive projects and even if in some countries the companies have to give some money as a guarantee at the beginning of the mine life, lose the money at the closure stage is economically better for them. In addition, even if the companies are working in countries that have specific mining legislation for rehabilitation, they prefer to pay a fine once the mining activities are finished, than to invest more money in the land restoration.

In other countries such as the cases in South America, although there is mining legislation in the most of them, such as Chile where mining is one of the principal activities in the country, there are not specific mining rehabilitation legislation. In Argentina is a new trend which it is not known at all.

However there are some countries, such as Australia, United States or Spain that have specific rehabilitation legislation for mining activities, which forces the companies to pay the rehabilitation project. Concretely in Spain, an environmental impact assessment is required along with a mining rehabilitation project, once the end of the mine life time has been reached. As a remarkable fact in terms of positive advances in mining rehabilitation subject, it has to take into account the Superfund project, and the Energy and Natural Resources Ministries initiatives of Australia and Canada, that force the companies to pay the rehabilitation projects, or the government takes the responsibility to carry out the rehabilitation. In cases of abandoned mines whose owner is not known, or those who have an owner but do not have sufficient funds or who do not want to take over the land.

Due to all the present obstacles to carry out a mining rehabilitation project, it is necessary to be clear about most appropriate rehabilitation methodologies, even if it only is for an economic issue. Below are the different methodologies that are known, based on previous projects and various known experiences. It will be compared among them, and also with the methodologies followed in the first mining rehabilitations, taking into account all the aspects that surround, economic, environmental and technical ones. Finally, regarding the previous information the pertinent conclusions will be obtained.

6.1 General considerations about rehabilitation

Depending on the mine location there are different issues associated with abandoned mines, such as physical, environmental, socio-economic and financial considerations. According with the *International Institute for Environment and Development (2008)*, in countries with a long mining history the most important issues of abandoned mines are the physical hazards. Regarding the safety of excavations and structures, the environmental contamination and the public opinion. That is the reason why, taking prior considerations before start the project, is required.

1. *Physical considerations*

The typical concerns which are included in the physical concerns are public health and safety, visual impacts, stability issues and dust problems (*Mining for the future", 2002*). Deteriorating structures, lethal concentrations of explosive and toxic gases like methane, carbon monoxide and hydrogen sulphide can be found accumulated in underground passages. It can be also possible to encounter pockets of oxygen-depleted air. Apart from that, in abandoned mines is normal to find unsafe structures include support timbers, ladders, cabins and other related features, which due to weathering they may easily crumble, sometimes unused or misfired explosives are triggered and many of abandoned mines become flooded and shallow water can conceal other hazards.

2. *Environmental considerations*

Generally, the environmental consequences associated with abandoned mine sites are altered landscape, unused sites, shafts, land no longer useable due to loss of soil or soil contamination, abandoned tailings disposal facilities, contaminated aquatic sediments, subsidence, and of course vegetation changes. Water is one of the most resources frequently polluted by abandoned mines. Besides that, it is also the main conduit by which impacts from abandoned mines extent beyond the immediate site. The most common and also most significant problem at abandoned mines, is the elevate concentrations of metals and increased levels of suspended sediment, acidity, hydrocarbons that can threaten surface and underground water quality and aquatic habitats.

2.1 Atmosphere emissions

The different processes that take place in the restoration phase usually produce the emission of dust particles into the atmosphere, against which it is necessary to fight. The emission of polluting substances, such as SO2, and other compounds of sulfur, oxides of nitrogen or carbon monoxide, is due to vehicles, internal combustion engines, generators, etc. and blasting

2.2 Noise

During the restoration phase, noise is generated, but generally intermittently, as it is produced by specific operations such as the daily start-up of the engines, loading of the material in the dump trucks, unloading of the material, etc. Although this is a difficult problem to control, due to the nature of the operations described, however, the vast majority of aggregate companies only emit noise during daytime hours. In addition, the farms are usually at great distances from the possible urban areas, so that the inconveniences caused to third parties by the activity are not, generally, excessive.

2.3 Vibrations

The vibrations that can have an influence on the environment are usually produced by blasting in the quarries. The correct design of the blasting together with its proper execution and the use of microretardant detonation systems, allow to keep this effect under control.

2.4 Wastes

During all phases of the restoration will generate waste such as used tires, filters, oils, packaging etc. that must be managed following the basic principles of recycling;

- Generation reduction
- Selective collection
- Separation
- Inventory
- Management

2.5 Soil contamination

The prevention of soil contamination during the restoration, by discharges of harmful substances (gas oil), and its aspect that should not be overlooked, for which reason the refueling of the mobile equipment should be foreseen in conditioned places and provided with collection of spills.

3. Socio-Economic considerations

Before carry out the land rehabilitation it has to be taken into account not only the points that are related with the environment or the land which has the exploitation in, since the closure of a mine has collateral damages which are difficult to avoid. Those problems are related with the economic and social situation in the area where the mine is located. In general, regardless the place, the most important concern caused by mining closure is the loss of employment and business activities in the community and the other socio-economic considerations are mostly arise from the other considerations discussed previously. It is necessary to keep in mind that all the considerations that are mentioned are connected, since for example, the physical impacts of abandoned mines like slope stability, contamination of soils by acid drainage, usually cause the loss of productive land, and due to that the population who has the agriculture as the principal income does not have any job.

As it was said all the considerations are connected for example, the ground contamination and the surface water impact on the aquatic systems, and makes the water unusable for any activity. Besides that, if the abandoned mine is used as a waste disposal site, can be a health hazard due to normally it contains certain minerals and heavy metals, that can damage the population around and windblown dust containing contaminants such as silica or chromium can be transfer to other places or populations.

Therefore before carrying out a mine rehabilitation project, the company or government who does it has to take into account all the considerations that has been mentioned, to be able to remedy the problems and prevent they occur again. In most of rehabilitation projects which are taken place in those countries that have a specific environmental law related with mines closure, to collect all the problems presented by the mine in the state of abandon, an environmental assessment, or an environmental impact study is required, just before the beginning of the mining activities, as in the case of Spain.

6.2 Project types of mine rehabilitation

Before decide which kind of rehabilitation project is going to be develop, is necessary to take into account the main points and goals of mining rehabilitation projects.

Some attempts have been done for a long time so as to minimize the mining activities impacts, and address mining goals at the same time, such as minimizing haul distances, optimizing earth movement, working within the lease boundary, and minimizing impact on the surrounding land holdings. As a traditional practice, once the use of the land is completed after mining operations, large "pyramids" shaped waste dumps are built just next to the working pit (*Eckels, 2010*). There some important principals that it is always required keeping in mind.

1. *Minimizing the "footprint" of the operations*

The footprint term makes reference to the area of the waste dump. All the areas affected by the mining activities are considered as a less agricultural productive land, even after being rehabilitated. Thus the goal is to keep the footprint the smaller as possible, putting the waste material in a small area. The shape of the waste dumps is a pyramid, since is the shape which is considered the most practical way to hold the material in a small area.

2. *Minimizing effects of running water*

In order to minimize this effect on the waste dump, mines implement common tools to remove the water from the dump as quickly as possible. Some of those tools are techniques that include the use of gradient terraces (contour banks), concrete channels, and drop structures (rock drains) which transfer water from one level to another while attempting to minimize erosion, the problem is that this structures need constant maintenance. Contour banks often fill with silt, causing occasional overflow. In the concrete channels need to be cleaned out, and during storms immediately attention is required since the water will undermine and flow around the rock drains.

Fig 21. Pyramid shape in a waste dump

It is known that land rehabilitation is one part of the final mine life-cycle, which depends on numerous factors, such as the location of the mine, the mining type exploitation and the kind of activities that had been developed in the area, the nearby population needs, the mine extension area, etc..... Then it will be explain the different kinds of mine rehabilitation which can be carry out depending on different factors (*Fernández Rubio, 2014)*.

Facilities and infrastructures rehabilitations

Different infrastructures with many kinds of natures are required for mining activities, such as accesses, electrification, water supplies, telephony facilities, and other buildings for administrations issues. It should be note that in the case of mining activities are developed in large areas located far from the civilization and sometimes is difficult to

1. *Natural and forestry rehabilitation*

To develop all the necessary information about this type of rehabilitation the "Guadiamar green corridor" event which took place in Spain will be explain.

This event took place the 25th of April in 1998 in Spain, it was a enormous mining accident which finally became one of the most spectacular territorial recovery in Europe. The accident consisted in the raft sterile rupture in Aznalcóllar area (Sevilla, Spain), which involved the spill of 4 million cubic meters of acidic water, and 2 million cubic meters of sterile pyritic mud. Therefor was necessary to eliminate the toxic sludge, remediation and soil conditioning, and removal of contaminated fauna and flora, but once the initial phases were done, it was decided not to interfere in the nature and impulse the natural ecosystems autoregulation.

Fig 22. Aznalcóllar disaster in 1998 (Spain)

At the end almost 1800 hectares were rehabilitated, since that area was contaminated by acid water retentions. Therefore, after the purification of the contaminated water and the revegetation of the area, the obstacles that diverted the system form its natural functioning were eliminated, such as pipes, walls or drainages, taking into consideration the image presented by natural marshes. Regarding the revegetation issue, those species that were native to the area were planted.

Fig 23. “Corredor del Guadiamar” nowadays

2. *Cultural and scientific rehabilitation*

It has to be stand out that, when the mine’s life is in the end companies always think about that just after the closure process the best way to rehabilitate the area is recovering the original vegetation, due to this option can be the best in some occasions, but sometimes the structures created by mining activities that can be accessible after the mine closure they have an indisputable patrimonial value. One way to make viable to recovery and enhancement of these elements, so that they can be known, used and enjoyed by the population in general, is protecting them in situ, inside mining parks created for that purpose. In addition, these enclosures provide information to the society of the indispensable role, often unknown, that mining has played and is still playing nowadays, as a supplier of raw materials that are necessary for our quality of life. In every place where those are located, they have much social acceptation, which is contradicting the negative valuation that mining work has for the today’s society.

At least in Europe exist 700 mining parks and museums, one example of that is the Wieliczka mine salt, which has been mentioned previous sections. In the case of Spain there are several examples of this type of rehabilitation, such as Gavá, Las Médulas).

Fig 24. Cultural rehabilitation in "Las Médulas", Spain

As a museum can be mentioned the mining museum located in Puertollano village, in Spain. In it is possible to visit the ancient mining underground galleries and the means of transport that were used at that moment, and of course the history of that coal mine.

Fig 25. Puertollano mining museum, Spain

3. *Touristic and leisure rehabilitations*

Apart from the other types of rehabilitations there is also another one which has leisure activities as the main goal. Inside this section a lot of examples can be mentioned, but in this case it will be taken into account a particular case of rehabilitation; rehabilitation of mine piers.

In those cases where the mine pier was rehabilitated is nowadays used as touristic place, or simply a place where is possible to practice aquatic sports. Those piers were complexes engineering structures that were used as a mean of transport, storage and shipment of the mineral from mines that were located in remote areas far from the coast.

One example of this particular rehabilitation, is located in Spain, specifically in Almería, and it is called “The English Cable” which was a pier in the 10’s for transporting the mineral from the *Alquife* coal mines. Today, this old mining structure is an ornament of the city of Almeria, and is integrated among the attractions of the city.

Fig 26. "The English Cable", rehabilitated old mine pier (Almería, Spain)

4. *Urban and residential rehabilitation*

In many cases where possible future activities have been foreseen, the infrastructure created during the exploitation phase of the mine can be exploited. There are two options as to how they can be used;

- Creation of urban centres in the immediate vicinity of the mine, a very common practice in the past when means of communication and transport were not so advanced as for the movement of all the workers *(Matesanz Parellada & Hernández Aja, 2016).* Nowadays, this type of practice is carried out when the mine is located in isolated and remote places.

- Another option is to take advantage of existing urban centres at reasonable distances, to improve their infrastructures and to develop the new activities planned for the area, favouring the local workforce, and to offer new services to urban areas outside the mining activity.

In the first case it is possible to dismantle the population nucleus once the mining activity is finished, restoring the environment to its primitive conditions, or it is possible to take advantage of the infrastructures created, giving rise to an urban and residential rehabilitation.

In the second case, the importance lies in the possibilities of boosting employment and quality of life, with activities that take advantage of improved services, introduced thanks to previous mining activities, as well as developing business activities that allow for a smooth, non-traumatic transition from the post-mine situation.

As an example of the first case there are mining neighbourhoods or worker housing estates, , which are born under the mining and industrial activity existing at the time. In Spain there are several cases, in the regions of Mieres, Langreo or Cuenca de Nalón (Asturias), which are currently home to many families.

Fig 27. Residential quarter of Langreo

Underground Mines Rehabilitation

1. Touristic and leisure rehabilitation

As it is known in spite of the fact that underground mines do not need that much measure to rehabilitate them, since the visual impact or the consequences due to the climate do not affect the mine. Even though, there are some different final uses for underground mines that can be useful for the population, and at the same they reduce the environmental impact. In this section the touristic and leisure rehabilitation are developed

As an example of it, the mercury mine of Almadén (Ciudad Real, Spain) should be mentioned. It stopped its activity in June 2001, and its definitely closure was in 2002, but at that moment the entire story of the mine was hidden under 700 meters of depth with its 27 floors. To not lose all that, it was decided to carry out a touristic and leisure rehabilitation, in which it different floors were made using the mine galleries, and with that finally a mining park was done, known as "The Almadén Mining Park".

Fig 28. Almaden Mining Park

Another aspect of interest that underground mines may have after exploitation, derives from the fact that in underground mining in soluble rock, there is the possibility of discovering natural krastic cavities through mining work.

Thus***,*** *Fernández Ortega and Valls Uriol (2004)* presents the discovery of the caverns found in the mines of the Eastern Massif of Picos de Europe (Cantabria, Spain). Of all the caves discovered, the ones that receive the greatest honour are the caves of El Soplao (Cantabria, Spain), an area that today is dedicated to tourism.

Fig 29. EL Soplao caves entrance

These caves are found in ancient lead and zinc deposits, in limestones and dolomites. The latter are formed by substitution of Ca++ ions and Mg++ ions in original carbonate sediment, substitution that leads to holes in the rock, increased porosity of the rock, which allowed the circulation of hydrothermal fluids that deposited their metal charge in the empty spaces, in the form of sulphides, giving rise to important deposits of blende and galena. Finally, in 2003, it was decided to prepare the abandoned mine for tourist purposes, carrying out works in the old mining galleries.

Fig 30. Inside space in El Soplao caves

Criteria to consider the rehabilitation type choice

It is advisable to carry out a precise study of the available information on all aspects that may condition the rehabilitation, including topography, geology, land use, communication networks, vegetation, protected areas...It is necessary that the project is carried out with the advice of different experts, which may be more expensive than the rehabilitation itself, but the guarantees of success will be greater.

Depending on the mining exploitation type it is necessary to choose one rehabilitation type or another. In the next table is explaining a simply classification of the possible exploitation types:

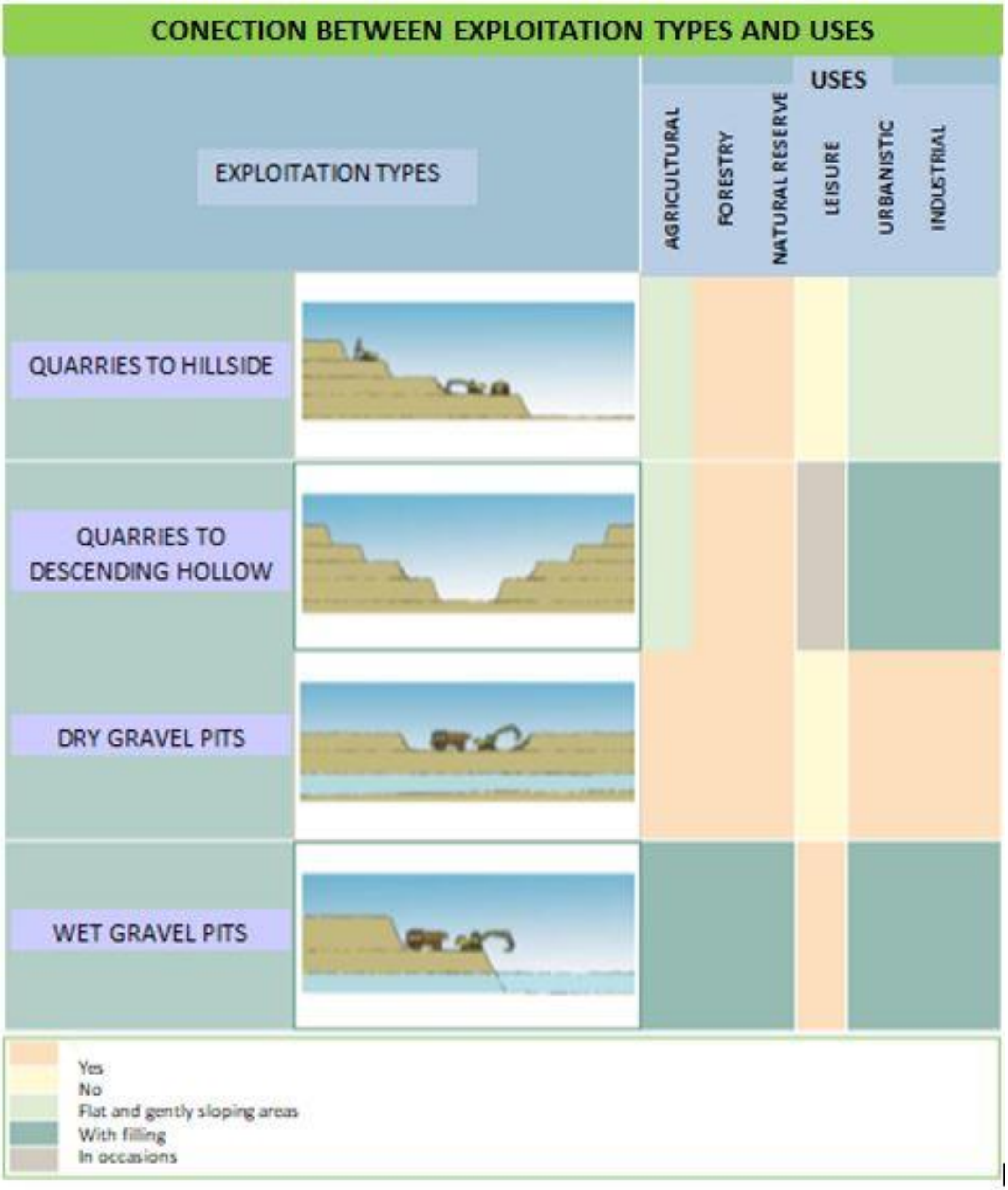

Fig 31. Criteria for the rehabilitation type choice (Elena Alonso notes from Environmental Engineering course, 2018

Environmental environment of the exploitation

The knowledge of the natural environment of the area where the exploitation is going to be developed is a key element that, very possibly, will condition the type of rehabilitation that will be designed. In this sense, they must be aware;

- The characteristics of the affection zone and the environment of the mining activity as well as other secondary elements (accesses, complementary facilities etc. ...)
- Each one of the variables and aspects that allow defining the configuration of the environment: identification, census, inventory, quantification and, where appropriate, cartography and key ecological interactions.
- Environmental assessment of the area and definition of the degree of interest for conservation. The proximity of protected spaces can condition the type of restoration.
- It is also necessary to take into account the type of habitats in the exploitation area.

1. *Cultural and socioeconomic environment*

The effect of the socioeconomic environment on the type of rehabilitation is greater than one might think. It is becoming increasingly important to involve local entities in the type of action that may be viable, so that potential rejections to the project are overcome from the beginning. In addition, it is necessary to know the impact of the project on the elements of historical-artistic and archaeological heritage that could be affected. In the case of recreational, industrial or urbanization uses and adequate socioeconomic study will help ensure the sustainability of the rehabilitation action over time.

2. *Costs*

The cost of the rehabilitation project is a very important factor, which necessarily has to form part of the viability study of an extractive project, hence a very careful study of the different possibilities is required. An erroneous or poorly prepared approach may lead to an alternative that, in long time, is not viable and eventually falls into the abandonment of the exploitation due to the lack funds. At the beginning, when the viability study is carried out is has to be taken into account that normally, the expected costs are lower than those required finally.

6.3. Prioritizations of mining rehabilitation

Land reclamation methods are required to prioritize abandoned mines, to ensure that they focus on those presenting the greatest hazards to the population health and the environment. However, as it was mentioned in previous sections, there are many factors that the rehabilitations projects depend on, so taking a decision about which kind of mines have to be rehabilitated first, is difficult. There is no guideline about it, but there are studies that present different theories to assist these challenges and develop a decision model that prioritize abandoned or inactive mines bases on hazards, and recommend the most appropriate reclamation alternatives (*Environment Earth Science, 2014*). Apart from the guides that can be used for prioritize between different cases of abandoned mines; there are some models that help to assess the physical and environmental hazards at abandoned mines, such as Delphi method and analytic hierarchy process (AHP). They are two well-known techniques that can be useful to calibrate decision models and score and rank alternatives. Those models were developed as a decision-making process by *Kubit, Pluhar, and De Graff (2015).*

In one hand, the Delphi method is a systematic decision-making technique relying on a panel of experts. The method captures the expertise embodies in individuals and distils it into an algorithm used in decision making. Experts first answer a questionnaire about the relative importance of decision model parameters. They receive an anonymous summary of the responses and are encouraged to revise their answers after reviewing the range of responses.

This technique is defined as a method of structuring of a group process communication that is effective in enabling a group, as a whole, deal with a complex problem. Making a Delphi consists on the election of a group of experts who are asked for his views on issues relating to the future developments. The expert estimates are made in successive rounds, anonymously, to the possible extent to seek consensus, but with maximum autonomy on the part of participants. That means that, Delphi method proceeds by means of the interrogation to experts with the help of successive questionnaires in order to show convergences of opinion and to deduce possible consequences.

On the other hand the AHP is a common technique that uses pair-wise comparisons between parameters to assign parameter weighting factors in a decision model. The user determines parameter weighting factors based on their relative importance: the “intensity of importance” during each pairwise comparison. Both of the methods mentioned are simple, easy to use and widely accepted, but even though several assessments that have been done until the moment conclude that no existing model succeeded in satisfying all of the elements identified, as important to guiding mine reclamation workers.

It is known that methodological tools for the prioritization of reclamation programs are needed. Some of those tools are based on GIS software, which introduced environmental and socio-economic factors, and also some hazard maps compilation *(Mavrommtis and Menegaki, 2017*). Nonetheless, according with some authors there are different lines to follow to prioritize the rehabilitation project in a mine, but depending on the area where the mine is located, they diverge from each other. Even though, the existing models are mostly based in environmental, human health and public safety hazards that is possible to find in an abandoned mine, however they present lack of transparency and model calibration *(Kubit, Pluhar and De Graff 2015)***.**

According with *Mavrommtis and Menegaki, 2017*, in which Visibility Ranking Index methodology is developed, explaining how the visibility of surface mining operations are estimated with regard to the interest places the nearby areas. For the estimation of VRI, the quantification of four selected sub-indices is needed, namely: the Observation Intensity, the Excavation Exposure, the Relative Visibility and the Relative Surface. Every index has to be quantified, according with the specific legislation framework of the focus region, the population at the interested places, and the size of population, since it can be used as weighting factor of the visual impact on the areas. In the case of Milos which is described in the aforementioned article, is an island in which the tourism is the main income source, and due to that situation and regarding the region, the visual impact is one of the most important points to be taken into account in prioritising rehabilitation activities.

However as it is known, the prioritization methodology has to be accomplished through the specific region features, since each mine has different qualities and needs. For instance, there are some cases located in Spain where there were hurdles to carry out the rehabilitation projects, due to the mine were located in a region named “Santiago’s path”, which was named as World Heritage Site in 1980, and the ICOMOS who is the UN advisor for select the world heritage sites *(Vilas López, 2018).* The organization blamed the mining community for allowing a waste dump on the stretch of road, and has warned about the loss of the heritage title due to this fault. Regarding this example, every mine with a heritage place or a protected area has to prioritize this issue before others in the rehabilitation project.

Another way to prioritised rehabilitation activities, is developing hazard maps which can assist the challenge. According with *Mhlongo, Amponsah-Dacosta and Mphephu, 2013*, some hazards were identified, scored and rated using hazard maps that were modified by the Historic Mine Site Scoring System for the Nyala Mine, located in the region of Limpopo province of South Africa. The developed of the maps showed that give priority to extremely and moderately hazardous pits; surface infrastructure and spoil dumps, and then to tailings dumps characterized with less physical hazards but extremely high environmental hazards, was the best approach of reducing the physical and environmental hazards at Nyala Magnesite Mine. The hazard scoring aided to found pits and spoil materials less problematic, and provided more robust scientific methodologies to prioritized the rehabilitation actions.

While the prioritisation methods are in developed, many mine rehabilitation projects are carrying out, but not as much as the environment would appreciate.

6.4 Classical methodologies for natural rehabilitation

The soil removal and location is an important aspect to successfully achieve the final rehabilitation of the area. That is the reason why, good planning of the different phases of the project is needed. As it is known, even the mine closure is at the end of the mine's life, a lot of studies are required, so is recommended to make a study about the fauna and flora that live in the area and maybe make the future mine aspect after the land rehabilitation, including all the transportation networks and the nearby populations.

It can be distinguished three important parts in a mine rehabilitation project (*Elena Alonso notes from Environmental Engineering course, 2018);*

1. *Designed.*

Before the beginning of the project it has to be known the final geometry of the area, waste dumps and the structure of the filler, taking into account the constituent materials and their specifications (sterile filler, waterproofing cores, drains…), and drainage systems and filtration control devices, that are so important due to the creep of the sludge accumulated in slag heaps. At the same time in this phase has to be taken into account the areas where substrate treatment or waterproofing is required. So as to organize the entire project, appropriate work shifts must be established.

2. *Enforcement*

Before start this phase, the verification of compliance with technical specifications is needed, besides that monitoring the characteristics of the materials used, so as to be sure of their function, and compliance with the technical specifications of dumping operations is required. Once all the operations and the materials are organized and revised, the next operations are carrying out.

- ✓ Soil removal
- ✓ Soil collection
- ✓ Conditioning of openings
- ✓ Water management
- ✓ Landscape integration of fronts
- ✓ Conditioning of waste dumps and rafts
- ✓ Demolition of structures and foundations
- ✓ Soil reconstitution
- ✓ Creation of gaps
- ✓ Replacement of vegetation and, where appropriate, the fauna.

As it was mentioned in one of the previous sections there are different final uses for which a rehabilitation project can be done, depending in the needs of the area where the mine is located. Due to that fact, some of the operations that have been mentioned before are not required, since there is no rehabilitation that is the same as another, there are many constraints that make the process followed different in each case.

3. *Project closure*

Once all the operation required are completed, the only important thing that has be done regularly is the maintenance and control of the area, controlling that natural parameters are within established limits, and that the area os safe both for nearby populations and for flora and fauna.

Soil removal at the beginning of mining activities

The topsoil layer and the altered mineral layer must be removed properly. This temporary reserve of fertile soils should be used in the final restoration. In the event that this reserve does not ensure the creation of a layer at least 25 cm thick in the final restoration, an external contribution of fertile soils must be provided.

Fig 32. Soil removal

The correct manipulation of the soil requires applying, as far as possible, preventive measures to preserve its initial characteristics:

- The bearing capacity of the soil and the suction force must be calculated to prevent excessive compaction due to the weight of the transport equipment.
- Work on wet soils should be avoided as dry soils have more suitable load-bearing characteristics for the transit of mobile equipment, and compaction is prevented.

- Collection of plants (shrubs, meadows, etc...) from the soil, together with the layer of topsoil, for this to be enriched with its organic matter.
- Adoption of advanced working methods for the pickling of topsoil so that equipment does not circulate on top of it.

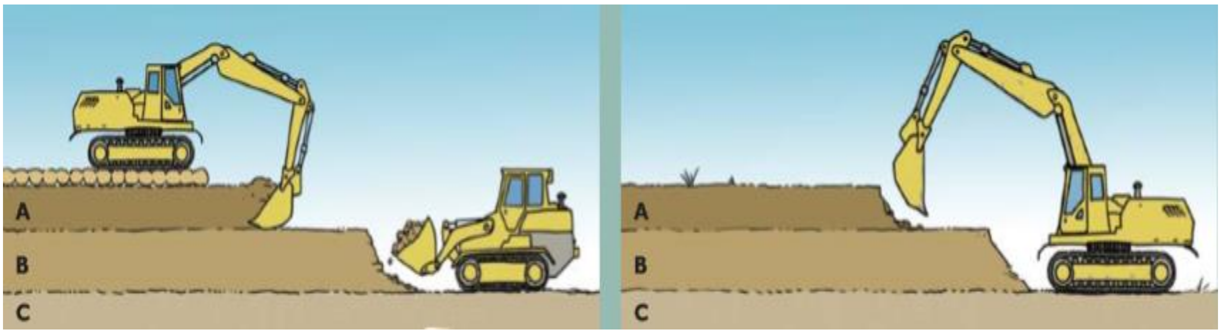

Fig 33. Works in advance (Elena Alonso notes from Environmental Engineering course, 2018)

Soil collection

Each soil type must be grouped separately to preserve its original characteristics. This operation is especially important since its success will depend on the availability of adequate materials for future rehabilitation. The ideal is that the waiting time between the removal of the soil and its reconstitution is the minimum, although in many occasions it is not possible.

For this reason, it is necessary to plan the collection in the exploitation project presented before the beginning of the mining activities, considering the time that the soils will have to be conserved before their use.

- Placement of the stockpile in a place away from the transit of mobile equipment and prohibition to circulate on them, as well as in relatively flat areas to ensure stability.

- Deposition of materials without compaction to preserve biological activity and gaseous exchanges. The work procedures and equipment used will insist on this aspect, both to avoid compaction in the soil deposition operation and to prevent that the wheels or chains of the equipment affect the lower parts.

- Choosing a site with vegetation cover as it reduces compaction and improves soil organic composition.

- For the formation of the deposit:
    - The slope must be, at least, of 4% that allows the evacuation of the excess water in case of rains, reason why it will not be carried out in hollows, if not in zones of small slopes or flat and in its case a system of drainage will be foreseen.
    - The height of the deposit must not exceed the rooting depth, between 2 – 2.5 metres.

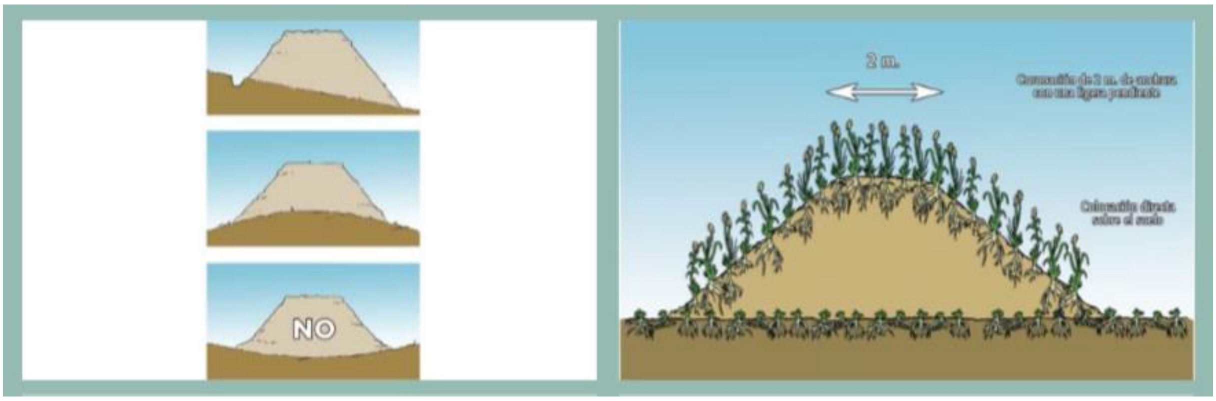

Fig 34. Vegetal soil location (Elena Alonso notes from Environmental Engineering course, 2018)

If the storage allows it (more than 6 months) is very important to sow and fertilize the collection with species that maintain the biological characteristics and aeration of the soil over time. If it is collected for more than one year, the process must be repeated annually.

Fillers and mineral layer collection

This elements that are part of the soil, do not have that biological value, it is necessary to take less safeguards than with the topsoil, and the maintenance is not necessarily required, since this element has not enough minerals. Even though, it is necessary to collect them separate and avoid the vehicles to pass over the collection.

Conditioning and mine shaft filling

Once the ore has been extracted from the relevant mine, the hole is conditioned so that the materials can be placed in a way that is safe for the environment and for people, ensuring their stability over time.

Fig 35. Hole conditioning (Elena Alonso notes from Environmental Engineering course, 2018)

Landscape integration of the mining shaft

Nowadays, the landscape is part of the cultural heritage and is considered as one more natural resource that must be valued. For this reason it is more and more important to correctly integrate the landscape of the exploited areas.

- Reusing mining tailings, soil or suitable external inert materials from another source and adapting them to the construction and demolition terrain profiles and terrain profiles.
- Reproducing the characteristic forms of the terrain avoiding, as far as possible, introducing elements that denote artificiality (of disproportionate size, with very marked angles and lines).
- In most of the occasions, despite trying to hide the pronounced shape of the exploitations or the waste dumps, during the rehabilitation, it is not possible to achieve it at all. Therefore, is possible to create an artificial visual screen with the excavation materials or by planting sets or trees and shrubs with appropriate height and length that prevent the visibility of the mine shape.

Fig 36. Trees and shrubs in the mine slopes (Elena Alonso notes from Environmental Engineering course, 2018)

Gap filling

The following materials may be used in rehabilitation work where it is necessary to fill the gaps produced by the operation, up to the specified level:

- The materials from the exploitation; tailings, washing sludge and rejects from treatment processes.
- Materials that do not belong to the exploitation; suitable inert materials from earthwork, construction products, manufacturing facilities or construction and demolition waste treatment facilities.

Fig 37. Treatments for the gap filling (Elena Alonso notes from Environmental Engineering course, 2018)

Water management

In order to be able to revegetate the area, it is necessary to make an efficient use of the water, which consists of increasing the capacity of water retention in the soil for a better development of vegetation.

In areas where water scarcity is predominant, there are measures to take advantage of runoff water; ascending slopes of berms, or the collection and storage of water in ponds, dikes, ponds, etc...

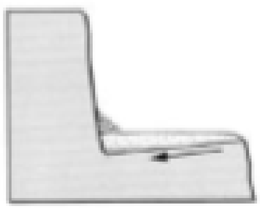

Fig 38. Slope orientation for collecting the water

Fig 39. Example of a sludge pond

Measurements to prevent torrential rains

The periods of drought bring as a consequence the hardening of the upper layer of the soil that later, in case of precipitations, has initially scarce permeability what produces two negative effects; the water does not infiltrate in depth and, not being retained, it produces important erosive effects since the torrents of rains follow the lines of maximum slope causing losses of the soil. To this end, it is appropriate to establish elements that can divert the streams from the areas most sensitive to erosion, such as ditches.

In addition to producing soil erosion, water can induce conditions of instability in a slope, when its content increases, since there is a variation in the forces exerted on the ground and the cohesion of the materials is weakened by increasing the shear force. Measures may need to be taken to prevent water from reaching the slope by applying the following:

- Guard gutters or perimeter trenches at the head of the slope to collect runoff water.
- Another solution is the revegetation of the berms, or the provision of retaining walls.
- Vertical wells in the slope to be able to extract the water of the interior of the one and thus to reduce the pressure
- Drainage buttresses used to prevent slides and to collect surface or infiltrated water.
- Drainage mattresses that are layers of drainage material, which are located under embankments and release water into a pipe that allows the evacuation.

In some cases where the final use of the hole is as a rubbish dump, so that toxic products can be deposited, the soil must be isolated to avoid infiltrations and dispersion by runoff, waterproofing with appropriate materials.

Landscape integration of fronts and berms

A rehabilitation of the area should be carried out by restoring the topography that eliminates the too pronounced or geometric shapes, giving rise to slopes with a moderate slope and modelling them to recover the aspect in agreement with the environment. When high slopes are expected, the slopes should be softened by creating several terraces or berms to facilitate plant restoration and thus prevent erosion.

For remodelling the fronts two techniques can be used. In the case that they are constituted by soft materials they can be remodelled using suitable equipment. However, in the case of quarries, partial remodelling blasting can be carried out, which consists in drilling spaced boulders which, once fired, cause the rock to break off, depositing it at the bottom of the slope and giving rise to piles of smaller size.

On the other hand there is total remodelling blasting, which consists of drilling several rows of holes at different depths and with a certain angle, creating berms where the material is accumulated in favour of revegetation.

I the case of berms remodelling, it has other goals, such as allow the orchards to be carrying out and break the remarkable inclinations, applying the following procedures;

- Thread the berm, creating an ascending slope to retain the water in areas of low rainfall and, if necessary, to allow the passage of hydro seeding equipment.
- Modelling of slopes creating ascending gradients.
- Rounding of the edges by smoothing them
- To avoid totally parallel berms or equidistant, so that they are not seen artificially.

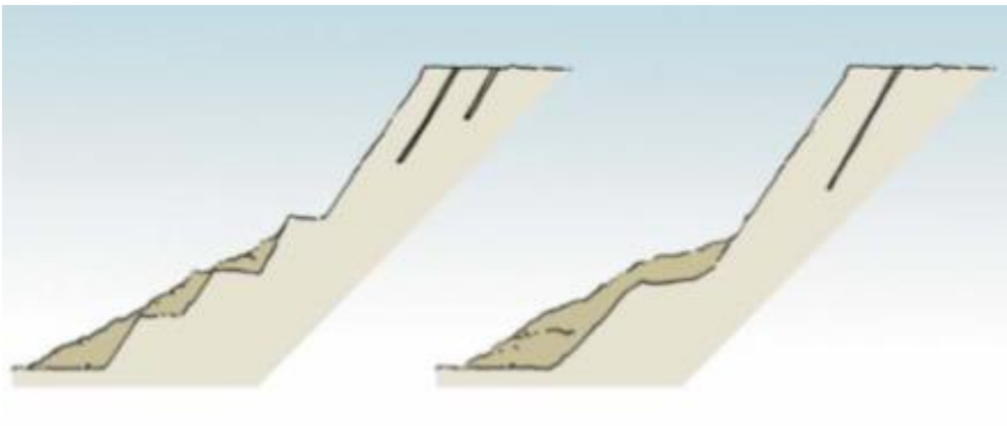

Fig 40. Berms remodelling

Face's stability

In order to prevent the instability of the fronts, the following measures can be carried out:

Preliminary cleaning of the front to avoid the risk of landslide, avoiding too smooth surfaces susceptible to erosion.

Slope water drainage measures.

Retaining walls that help reduce the inclination of the slope, although they are not effective on very high slopes.

Another method to face's stability is the cutting installation, which consists in in digging furrows where branches are inserted, and rooted to implant certain tree species, such as willows or poplars. Is often used in those slopes that have high inclination.

Fig 41. Rehabilitated slope

To avoid landslides, consolidation structures are usually used, normally on slopes with a slope greater than 45°. To reduce the visual impact of the metal mesh, plant cover berms are made.

Fig 42. Metal mesh in a slope

In some occasions is the slopes can be rehabilitated, thus for reduce the visual impact an artificial aging is applied. For this purpose, mixtures of oxides, wet acids or sprayed fixatives are used.

Conditioning of waste dumps

The waste dump of an exploitation is a very important element during and after mining activities. It has to be taking into account in the environmental assessment and in the rehabilitated project that should be done before the beginning of the activities, since is a problem when its landscape integration is not prevented.

An attempt should be made to reproduce the natural form of the geomorphology of the environment in order to achieve the maximum integration of the heap into the landscape. At the same time, the location must have been chosen in a way to avoid the problems caused by the collapse of the structure. For the landscape integration different techniques can be applied;

Hiding, in depressions of the land, so that it cannot be seen from nearby populated areas. It is normally applied in the design of new heaps, otherwise the existing ones will have to be moved. Another option is to create a vegetation barrier on the outer perimeter to act as a barrier.

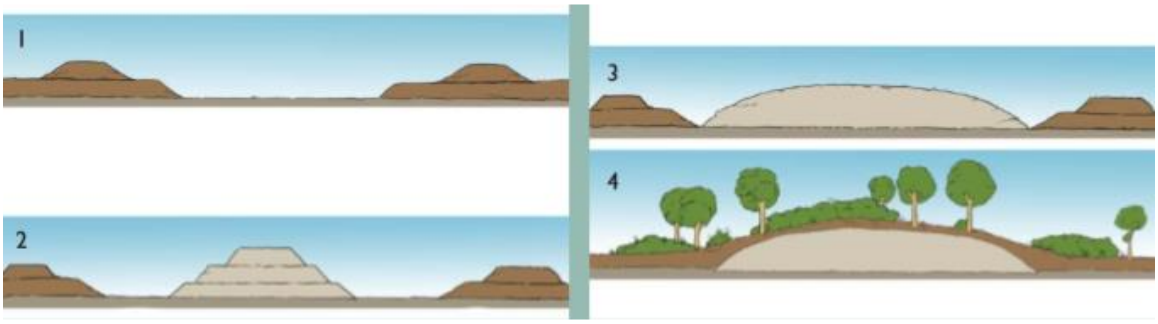

Fig 43. Dump waste colocation steps (Elena Alonso notes from Environmental Engineering course, 2018)

<u>Remodelling, applying the following visual rules:</u>

- An elongated, low mass produces less visual impact than a narrow, high mass, since the human eye perceives vertical dimensions more than horizontal ones.
- The material distributed on a sloping slope means that the farthest part is seen as having less apparent mass.
- The height of the heap must not exceed the skyline.
- The visual effect of rounded surfaces is less than that of straight lines and cuts that only accentuate shapes and volumes.
- If it is possible to place the heap on a slope, the visual effect is reduced because the slopes, shapes and natural lines of the terrain are reproduced as much as possible.

Besides the remodelling and visual issues, the water is one of the elements that has to be taken into account, since is the water is one of the main destabilizing agents of a waste dump, for that drainage systems are needed.

Structures and basements demolition

The rehabilitation plan should consider whether the buildings and facilities constructed during the useful life of the plant may have any service in the restored area. When constructions are used, they must be prepared for the function assigned to them, but if not they must be demolished and dismantled. In the case that they are demolished, all the wastes produced during the mine life, can be used as a gap filling.

Soil reconstitution

The reconstitution of the soil is an essential part of the entire rehabilitation, since the fertility and development of the vegetation to be implanted will depend to a large extent on this operation.

Soil reconstitution objectives

Once you have a well compacted fill and an adequate drainage system, you can begin to reconstitute the soil. The objective is to obtain a soil with similar or even better characteristics than the original one, adapted to the type of use foreseen in the restoration. There are two stages in the process;

- Extension of the altered mineral layer, formed by materials coming from that same layer, altered, well-structured, permeable, poor in humus that allow rooting.
- Extended topsoil or topsoil, from natural soil, with a maximum depth of 40 cm, rich in humus, very altered and with great biological activity.

In some cases the immediate soil rehabilitation is possible; when the exploitation method allows the direct transfer of the soil between the advance zones and the rehabilitation zones, the reconstitution is carried out in the most favourable framework.

- The effect on the biological characteristics and structure of the soil is minimum.
- The need for intermediate storage is eliminated, which simplifies and makes the operation cheaper.
- Reduces the area affected and the time spent on the operation.
- Some intermediate stages are avoided

The reconstitution of the altered mineral layer or subsoil also requires extensive care. On the one hand, unlike the filler in this case, the materials must be laid without compaction. On the other hand it is recommended that it contains 10% of small stones to facilitate the passage of water.

After some time has passed since the mineral layer is reconstituted, the subsoil should be sown with native species of plants, resistant, fast-growing species with deep roots. The decomposition of the roots leaves water circulation pathways, increases the biological richness of the soil, improves the bearing capacity of the mineral layer and protects it against erosion. In the case that the subsoil is stony, a contribution of compost can be interesting.

Topsoil reconstitution

The layer of topsoil must be distributed in the subsoil, if possible with the same thickness as the original. In this case the material is deposited without compacting, and in the case that it was necessary to circulate on the altered mineral layer it would be used machinery that exerts little pressure on the ground. If necessary, tracks could be fitted out before being covered with topsoil and decompaction would be necessary, since it will be necessary to fragment the surface layer of the soil in such a way as to reduce its density, facilitating both rooting and the growth of new species and the water infiltration.

- Depending on the compacting level of the soil, different techniques are used:
- Move soil layers.
- Ripping the soil for decompact at depth.
- Scarify, sponging the ground on the surface.

On the other hand, in order to favour water infiltration, it is necessary to provide the soil with a good inclination and thus favour drainage. In addition, to reducing runoff and consequent erosion, it is recommended that scarifying be carried out according to the contour lines perpendicular to the gradient.

Except when the surface is very compact, in which case it is necessary to reach 50-60 cm, the scarifying depth is usually about 20 cm. In more extreme cases, such as roads for heavy mobile equipment or buildings, to rip 1 m of depth is required.

Fig 44. Ripping operation

In the one hand, there are some cases where the chemical and physic properties of the ground are not good enough for the new species development, so in order to improve the ground conditions it is necessary to take some measures, although there are not any guideline to follow since every ground properties are different depending on the place where is located. Some of the criteria which it has to be taken into account to improve the ground properties are; Check the nutrients availability in the waste dump, the cost of operation, the effect of fertilizers on the soil, and the species to be planted.

On the other hand, it is normally to make some corrections regarding the ground acidity, since those acid grounds have lower capacity for water retention, less nutrients and not that much organic content for the vegetal soil establishment. The most often used technique for adjust the acid pH, is add quicklime and calcium carbonate (dolomite), or remains of ashes or trash. These elements have to be added at 15 cm of depth before spreading the vegetal soil, fertilizers etc.…

In the case of landfills made up of basic rocks, such as limestone, it is advisable to cover the material with organic substance, such as manure to neutralize the alkalinity of the soil. In the case of landfills made up of basic rocks, such as limestone, it is advisable to cover the material with organic matter, such as manure to neutralize the alkalinity of the soil. In other cases, composting and chemical fertilization may be necessary, when certain areas cannot be covered with vegetation cover or when these areas have deficient levels of nutrients. The contribution of organic matter supposes, the improvement of the capacity of retention of water, increase of the drainage of the land, change of slightly sandy or rocky soils, increases the superficial stability, and favours the germination.

Creation of lagoons

The wetlands are the wealthiest ecosystems in the world biodiversity, nevertheless is one of the most threatened on the planet. Not only do they make a significant contribution to biological diversity, but also to cultural, landscape and wildlife heritage. When the rehabilitation project of the mine considers that making a lagoon is the best option, it is possible trying to introduce new animals and plants that are in danger extinction so as to allow them to reproduce.

For the rehabilitation of the wetland, it is previously required to remodel the hole, for which the following criteria will be taken into account;

Depth of water: as there are areas with shallow waters that can be easily colonized by vegetation. If the shores are maintained with little vegetation, the appearance of species such as surface ducks is favoured. These shallow areas can be created by filling the void with sterile. In areas more than 1.5 m deep has no emerging plants, but if the development of vegetation is adequate will favour the emergence of populations of invertebrates, fish and amphibians.

In the case of deeper waters, they host more or less aquatic plant species depending on the degree of turbidity and eutrophication of the water. If the water is rich in sediments and molluscs, the appearance of diving fish and ducks will be favoured.

As it was said before, every little detail of the mine rehabilitation design plays an important role in the final result. The design of the lagoon banks, for example, also increases the diversity of habitats. For this design to be suitable in very shallow water areas (10-30 cm), the slope of the shore must be very gentle. It is convenient to provide the land with continuous and smooth slopes, with hollows generating greater depths than the rest and elevations that exceed water. If it is possible to locate the lagoon close to a slope, it will be favourable for the creation of new habitats, since vertical slopes close to the water are ideal places for nesting.

Lagoon's shape

If is pretended to give to the lagoon a natural appearance, its shape is a very important requirement. For a given water surface, the length of the shore should be as long as possible, giving the hole an elongated and irregular shape, creating salient and entrants. It is convenient to give it an irregular shape, during the exploitation phase, extracting material in a selective way or pouring sterile at different points forming peninsulas and projections. In the case of a single lagoon, it can be divided into smaller areas by dikes and fillings created during the operation, leaving areas of unexploded material.

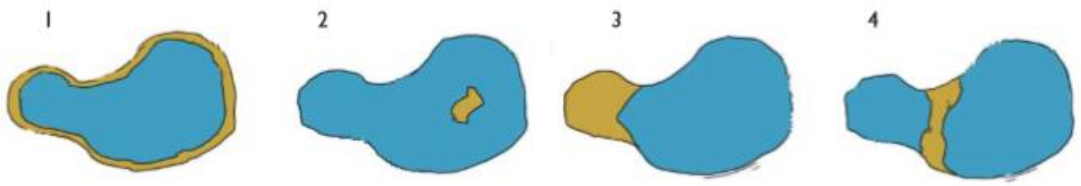

Fig 45. Different Lagoon shapes (Elena Alonso notes from Environmental Engineering course, 2018)

Regarding the Figure 37, it can be distinguish 4 different ways and shapes of forming a lagoon. The first one show the deal of the shore around the entire lagoon, however the second one shows an island in the middle. On the other hand the third and the fourth one show a shallow water lagoon and the division of it respectively.

In the case of the construction of an island, they have to be constructed in different shapes and sizes, the slopes around them may have a soft inclination to allow the birds and animals come back. It must not be built high islands that do not permit the panoramic view of the lagoon. In those areas where the islands are exposed to strong gusts of wind they have to constructed with a high altitude, since they will be act as protection screens. They may be as far as possible from the shore just to be protected from predators.

Fig 46. Wetland view with fauna and flora life

Vegetation and fauna restocking

Once the soil has been reconstituted, it should not remain outdoors for a long time, so it is recommended to sow or plant as soon as possible, with the following benefits;

- Roots contribute to soil stabilization.
- Improved bearing capacity.
- Promotes biological activity and nutrient enrichment.
- Protected against slipping.
- The original ecological balance is restored by facilitating the natural colonization of natural species.
- The land is protected against erosion and desertification.

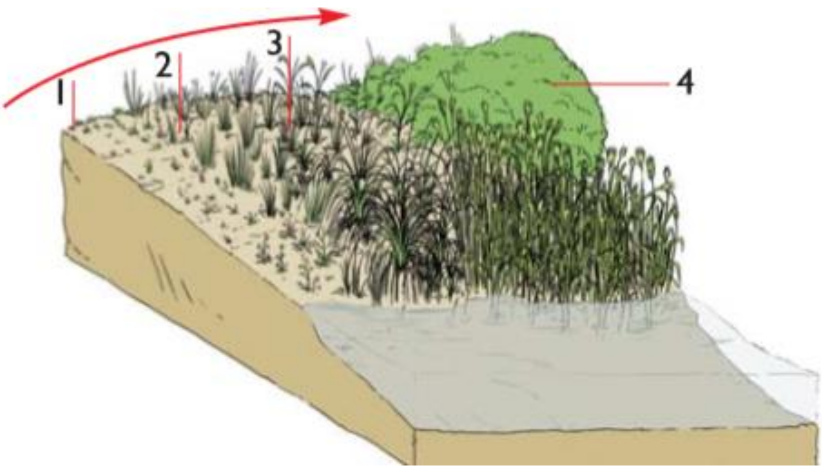

Fig 47. Progression of plant dynamics

Species selection

The key to a good mining rehabilitation depends, to a large extent, on the proper selection of plant species, the choice of the most appropriate methods, and the nature of the area. Therefore the species of seeds or trees should be selected based on the intended end use, the need for water and nutrients, the desired growth rate, and the ecological factors of the area (type of climate, soil condition). Besides that, is also necessary to take into account the soil class and characteristics (humidity, thickness, texture, organic matter content, acidity, etc.), erosive factors, or the presence of predators and the difficulty of placement.

It is obvious that the purpose of rehabilitation is that the vegetation that is implanted, can survive after abandonment and closure. For this reason, care must be taken in the case of introducing unusual or unadapt exotic species that could unbalance the ecosystem. Another key factor in the success of revegetation is the careful selection of the time of planting to ensure the survival of the species. In Mediterranean climates, the best season is late summer and early autumn, just before or after the first autumn rains. In cool areas or oceanic climates, the period may extend into late winter and early spring.

Fig 48. Vegetation planting

The sowing of herbaceous plants is necessary in all those surfaces that are considered convenient in order to stop the erosive processes, to avoid the proliferation of dust and to increase the stability of the soils. The density and distribution of the vegetation cover established must be adapted to the characteristics of the environment.

It is best to start sowing in spring and autumn, using a mixture of grasses and legumes as they offer good results in the short term and enrich the soil with nitrogen.

In the case of lagoons and wetlands are sought, they should be revegetated with emerging and floating plants, or aquatic plants in marginal areas up to two metres deep.

Fig 49. Wetlands revegetation

Revegetation methodology

In this section the different methodologies will be described.

Sowing

It consists of the contribution of seeds to a land that has been previously prepared, spreading them aerially, by broadcast or in a row. According with, *Elena Alonso notes from Environmental Engineering course, 2018,* in general, 5 to 15 grams of seeds per square metre are dosed for shrub and woody species, and from 30 to 40 grams per square metre for herbaceous species. Its main objective is to establish a low and dense vegetation cover capable of protecting the soil from erosion, landslides, external temperatures, etc....

In the case of sowing in rows, it is done in soils of soft relief where a tractor can work, by a single pass in which the seeds are deposited in furrows previously opened with a disc plough. Finally manual sowing is simpler and cheaper, it is simply necessary to deposit the seeds on the ground.

Hydro seeding

Hydro seeding with herbaceous species allows the creation, in a shorter period of time, of a protective vegetation cover in order to avoid the appearance of erosive phenomena, especially on slopes. It is a technique which consists of spraying a mixture of water and seeds with other optional additives such as fixatives or fertilizers at high pressure on the surface of the soil.

Fig 50. Hydro seeding technique

Other revegetation alternatives

Another technique that can also be used is the placement of biodegradable rolls, consisting of rolls of fabric of pre-seeded natural fibers that protect the soil from erosion and restore the vegetation cover. The subsequent decomposition of the fabric also allows the fertilization of the soil.

Fig 51. Biodegradable rolls

Artificial lawns, sheets of land covered with grass, can be another option, that are cut to move them to another place, with resistant species that require little amount of water and little maintenance are a quick way of recovering slopes of little slope, although they have a very high cost.

Fig 52. Installation of artificial lawns in a mining rehabilitation

Finally, the most traditional option is direct planting when the conditions in the treatment area are not adequate for the seeds to germinate. It consists of mechanically placing plants in holes prepared for it, and can sometimes be combined with the hydro seeding of herbaceous species that allow the appearance of a plant cover that prevents erosive phenomena on the slopes.

Reintroduction of native fauna

The original modifications to the terrain lead to the appearance of habitats where animal species find refuge. It may be common to find numerous species that have remained since the beginning of the exploitation or that have colonised it and that have habitually coexisted with the workers.

Species selection

In the event that the reintroduction of any animal species is not necessary, all impacts that prevent its spontaneous and natural development must be eliminated. On the other hand, if species are introduced, they must be autochthonous, as other types can cause damage to the vegetation and the ecosystem.

Once the species are introduced, the application of practices for the protection of biotopes is required. In order for the measures adopted to be adequate for the area, a study of the food chain should be carried out, seeking to avoid imbalances, study of the rest areas and roosts of the animals, establishment of dividing elements between the restored areas and those that are not affected, and carrying out population censuses.

Environmental factors affecting vegetation restoration

Climatic factors

According with the characteristics of the climate that act directly on plants are solar radiation, rainfall, temperature and wind. Solar radiation is the essential climatic factor as it allows photosynthesis. In the case of water, it is essential for plant life and atmospheric precipitation is its main source of supply. As far as temperature is concerned, it is the factor on which the assimilation of chlorophyll and transpiration and the functioning of the cellular metabolism depend. Wind is also a climatic factor that can influence vegetation when strong and frequent winds are involved.

Edaphic factors

The soil acts in a complex way on the vegetation, being the source of nutrients and water and in it is the oxygen content necessary for the respiration of the roots and microorganisms of the soil. Edaphic factors that summarize the influence of soil on vegetation;

- Texture and structure.
- Plant nutrient content and availability.
- Soil Reaction (pH).
- Depth.

The pH is a complex factor that reflects the chemical activity of the soil. It depends on the nature of the parent rock and determines the presence or absence of certain plants. On the other hand the soil also plays an important role as a modifier of the general climatic conditions.

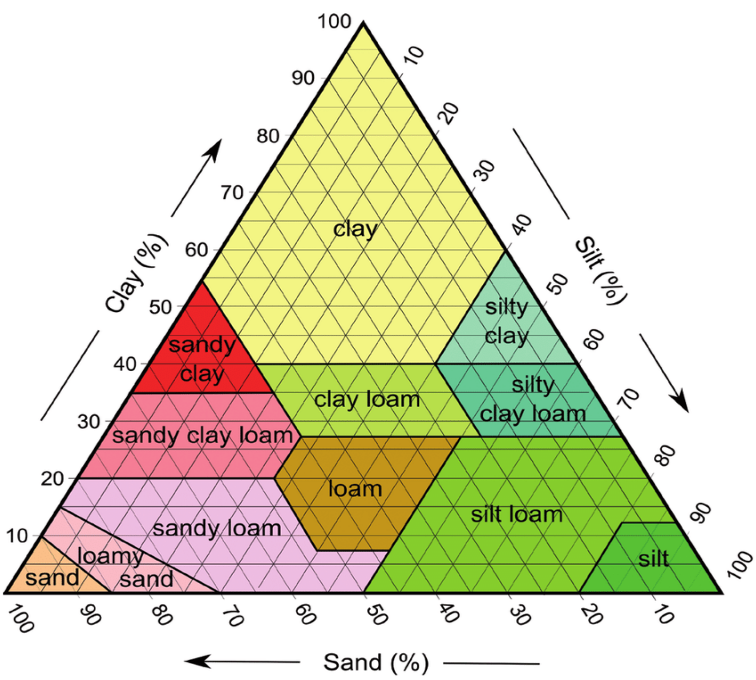

Fig 53. Texture's diagram

Topographical factors

Those elements of the topography that exert the greatest influence on the vegetation are;

- Conditions of the relief, which can modify the wind regimes, precipitations, humidity and temperatures, mountainous barriers, valleys and depressions.
- Exposure, since it implies an increase in the damping of climatic factors according to which zone is exposed.
- Orientation, which refers to the position of the area with respect to the geographical north. It directly modifies the radiation and from it the rest of the climatic characteristics.
- Altitude, which acts especially on temperature and precipitation. The altitude causes a decrease in the average wax temperature of 1 degree for every 180 meters.
- Slope, which is what modifies the thermal and lighting conditions of the locality

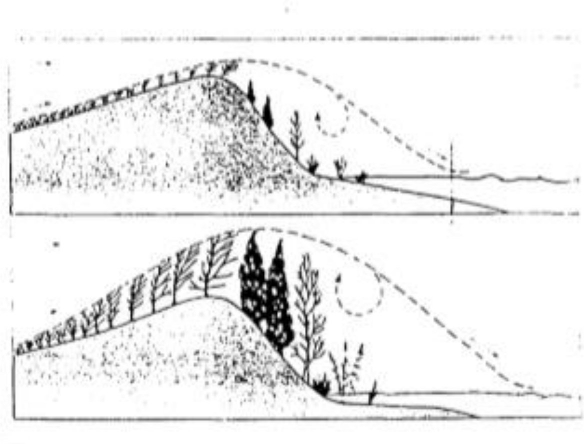

Fig 54. Wind modification depending on the relief (Elena Alonso notes from Environmental Engineering course, 2018)

7. Economic factors depending on methodology used

There are some specific activities that influence the economic part of the rehabilitation project, since this operation is one of the most expensive parts of the mine life cycle. As it is known, many times happened that the rehabilitation does not carry out due to the lack of funds. That is the reason why the budget can be change by every specific modification.

Regarding the previous activities of the extraction, small contaminations of the ground can be done, such as fuel refuelling or lubricants. In this case, if afterwards in the mine rehabilitation, the land treatment is carrying out "in situ", means that is not necessary to take off the soil and the costs are reduced, even though it takes more time.

As it was mentioned in previous sections, regarding the dump waste location, it has to be located in the closest possible area, since the more time it takes to transport the material, the more prices are found. Besides that, some kind of revegetation activities are more expensive than others. For example, using artificial lawns can be more expensive that biodegradable rolls, but in some occasions those materials are more suitable. In the case of sowing, the row planting is cheaper that the hydro seeding technique, but the cheapest one is the broadcast sowing, even though the time that takes to finish it may make the process more expensive.

In general, there are no specific activities that may make the rehabilitation cheaper or more expensive, since some of them can be lower priced at the beginning. However they can be not suitable for the location which can make the process more expensive, or if it takes too long to carry out any stage of the rehabilitation, the project will end up being unprofitable, as it would slow down the rest of the phases.Nevertheless, as it was mentioned during the project, the lack of funds to carry out mining rehabilitation projects is the biggest obstacle, thus making an economic analysis in every rehabilitation project is needed. Hereinafter, a qualitative economic analysis of some of the mentioned rehabilitation methodologies, developed with the available data, having regard to the visual impact, the rehabilitation costs for each methodology and the mining costs, will be presented.

For this purpose, a range of measurement from Low level to High level has been established, considering high as the greatest visual impact and Low as an almost negligible impact. On the other hand, those practices evaluated with high level are considered to have an abrupt impact on the project's budget. While with a low level, those practices that are considered to have the least impact on the project's budget are evaluated. The following table presents the evaluations that have been considered appropriate.

Table 1. Qualitative Economic Evaluation

PRACTICE	ENVIRONMENTAL PERFORMANCE	REHABILITATION COST	MINING COST
Dump waste location	Medium	Low	High
Hollow flooding	Medium	Medium/High	Low
Hydro seeding	Low	High	Medium
Waterproofing and sludge ponds	Low	High	Medium/Low
Biodegradable rolls and artificial lawns	Low	High	Low

On the one hand, the dump waste location in the rehabilitation is one of greatest points, since depending on the place where it is located it will have more or less impact in the area. The most favourable place to locate the dump, is always marked by the areas surrounding the mine but each mining project is different. Sometimes the visual impact is one of the most important points of the project, for instance due to the mine is in a protected or public interest area for which it is essential to control the visual impact exhaustively. On the other hand, in some cases locate it in a valley, slope or even to use the discharges that produce the dump to fill holes produced during the stages of exploitation, it is recommended, due to the morphology of the surrounding areas. In general it is not recommended to locate the dump waste close to the mine so as to avoid the difference of dimensions with respect to the mining hollow. Besides that, its extension must be controlled as well, so that is does not alter adjacent habitats or protected areas and drainage must also be guaranteed to avoid leach contamination. Regarding to mining costs, it should be taken into account that the further away the landfill is, the higher the costs of transporting the material to the waste area will be.

In respect of the dump location issue, the aspects that should always be taken into account are; trying to minimise transport and dumping costs, integrating and restoring the waste facility into the environment, ensuring drainage, minimising the affected area and avoiding the alteration of protected habitats and species.

Regarding the possibility of create lagoons or lakes in the proper hole made by the mining activities, the visual impact is something subjective, since after taking the ore a new artificial element appear in the area, and that can be an improvement in the region or it can affect the nearby ecosystems. On the other hand, the rehabilitation costs will be affected by the water availability, which means that if there is a natural river close the mining area it can be used as a water supply for the artificial lake or lagoon. For that reason can be evaluated with low level, counting the costs of canalization and water treatment. Even though, it can also be evaluated with medium level, if the engineers consider the possibility of create a lagoon or a lake, although there is any river close. In that case the economic impact in the project budget will be so significant, and the water treatment, canalization and water quality studies at least every month, will be still needed. Nevertheless this last option it is not the best, since other rehabilitation projects can be developed if any river is there.

Relating to the hydro seeding the visual impact was evaluated with low level, since it is just a way of revegetation which is always suitable to do in a rehabilitation project. With respect of rehabilitation costs, there were evaluated with high level due to the high price of this practice (average of price 0,55 €/m^2)*(Ubeda de Mingo, 1985).* However if the sowing is made in a row or broadcast is cheaper, because of that all the decisions will be taken according with the project budget or the more suitable activity if there are funds enough. Finally it is also necessary to take into account the belonging costs of mining activity, that in this case were evaluated with medium level, due to if hydro seeding is decided, the land must be prepared beforehand, which would increase costs. But, the most common thing is that no matter how good the results, it is a practice that is not usually applied due to its high cost and that the land must comply with very specific conditions.

Regarding the visual impact belong to waterproofing ponds or sludge, it is considered in a medium level due to it is a foreign element to the environment that must be integrated very well in the space so that the visual impact is not very high. Besides they can disturb the landscape and the ecosystem, due to the existing probabilities of breakage which entails a high risk of contamination. So as to avoid that situation, the ponds have to be elaborated with suitable materials and that can be introduced in the ecosystem which makes the process of rehabilitation more expensive, reason why it has been evaluated with high level. In reference to the mining costs are not those high since the ponds used to be close to the pit and there are not large distance for the land and sludge transportation. Although normally there are specific pipes to convey the sludge from the production point to the ponds. In respect of the mining costs, the used or not of ponds is not that significant due to it is a decision that has to be taken after the mining activities, and it is included in the rehabilitation project, due to that the economic impact in the mining stage is not important.

Biodegradable rolls and artificial lawns are another alternative of sowing that is cheaper than hydro seeding and specific soil conditions are not required. Due to that fact, the rehabilitation costs are not that high and in the case of biodegradable rolls the fabric is decomposed rapidly bringing organic fertilizer to the soil. For that reason, every single parameter was evaluated with low level, since the visual impact is totally invaluable as the sowing elements are perfectly introduced into the environment.

Apart from the project budget, the footprint of every technique has to be analysed. For that analysis some aspects such as the noise or the dust contamination, carbon dioxide production, or soil contamination must be considered. In the case of the dump waste location, the dust contamination can be a problem during the mining activities while the land is transported to the place where the dump waste is located. But once the dump waste is done the dust does not move due to it will be hidden during the rehabilitation. Regarding the carbon dioxide production and the soil contamination, both hazards can be produced by the means of transport used to carry the land from the mine to the dump waste, due to the carbon dioxide is produced by the movement of the machinery and the soil contamination owing to the petrol spills. In the case of lagoon creations, the noise can be considered an important factor in the footprint, in account of the one produced during the land movement activities, so as to fill the hole. Due to the same reason, soil contamination and carbon dioxide are produced. In respect of the two sow techniques mentioned, hydro seeding and biodegradable rolls or artificial lawns, they do not present that high impact in the footprint with regards to noise and carbon dioxide production. However, soil contamination can be and environmental impact, since in the sowing some fertilizers and pesticides are used to prevent pest or accelerate the growth. Finally, the waterproofing and sludge ponds don't present that much impact in the footprint, since they are usually used to prevent soil contamination, some impact can be produced by the machinery used to achieve the ponds.

As a conclusion of this section, there is no general guideline to know how expensive a rehabilitation project can be. All methodologies can make the process more expensive or cheaper, as none of them is better or worse and all depend on the type of terrain, the slope, the moisture content, the location of the mine, the climate of the area of the extension of the mining concession ... Therefore, the methodology chosen depends on various factors of each case in particular and sometimes a practice that a priori seems more expensive may make the rehabilitation project, cheaper because that is the most appropriate practice for the area. In this case an attempt has been made to make a qualitative economic assessment of some common practices. With respect to visual impact and rehabilitation and mining costs, taking into account their most common associated factors affecting the project budget, but one big question is still in the air; it is possible to afford the costs of the rehabilitation project depending on the practices used?. It is known that sure enough, the chosen methodology has a big impact in the rehabilitation project budget; even though in every case it has to be taken into account that every practice has good and weak points. Regarding the contents which had been proposed in Table 1, thus in every rehabilitation project a commitment economic-environmental impacts has to be taken.

8. Conclusions

After the deep researching realised during the development of this thesis there are some points needed to discuss. Starting from the beginning is important to talk about the knowledge acquired about rehabilitation legislation all over the world and comment which parts of the laws work and which ones does not. As a common point in almost every country, there is the same problem related with the lack of funds to carry out the rehabilitation projects, and due to that fact there are many abandoned mines around the world that are exposed to weak laws in each country. It is known that this situation has so many derivate problems owing to the contamination produced by the abandoned mines after the mining activities, such as water leaching and aquifer contamination.

According with the information gathered, one of the most noteworthy problems is that there is not much information on the exact number of abandoned mines in each country, nor on the dangers they pose to the environment. Therefore, it could be said that governments and mining companies have a challenge, to compile the number of abandoned mines in each country and get an inventory of the environmental, technical and economic problems that abandoned mines entail. On the other hand, it should be noted that mining rehabilitation is one of the most costly phases of the life cycle of a mine, and for the mining company is an activity from which it cannot extract any benefit, which is why many times these are declared with lack of funds to not carry out the project and finally abandon the mine. Even though there are some countries, specially developed ones, that have specific laws for mining rehabilitation, sometimes they are not enough to pressure companies to carry out rehabilitation because of the above-mentioned fact.

Regarding all the mining rehabilitation laws found, some improvements have been done in this issue in certain countries. Such as United States with the Superfund project, or Canada with NOAMI project, which provided the important tools to carry out rehabilitation projects, not only related with abandoned mines, but also in natural places that have been contaminated by other kind of activities apart from mining. However in the case of Superfund project, the lack of funds is the greatest problem, which precludes carry out the clean up of the contaminated lands, nowadays not many clean ups have been done. It occurs practically the same to NOAMI case; it only provides to the mining company the guidelines to follow in order to achieve the clean up, but it does not supply the required funds. Nevertheless, a rehabilitation project is required prior to the beginning of mining activities, so as to ensure the commitment of the mining company to comply with it, thus reducing the number of abandoned mines that exist in both countries. It is needed to take into account that, in reference to legislation there are still many improvements to be done, since most of the countries that have a strong mining legislation , are developed countries. There are still too many poor countries which have plenty resources that are being exploited without any humanitarian or environmental control, and under these conditions will result in one more abandoned mine on the large list.

Due to that, there are many different methodologies that can be applied, but there are also many factors that have to be taken into account, and it is necessary to prioritize the techniques that will be applied. There is no specific guideline to prioritize the rehabilitation activities. Nevertheless, regarding the information gathered, there are some statistic techniques such as Delphi method, which is a decision maker helped by some made questionnaires by the affected population. On the other hand, according with some authors, other techniques can be applied such as GIS software, nonetheless almost in every case the prioritization guidelines are the human and environmental health.

In order to decide which is the best methodology to apply in each case, a cost- benefit analysis must be made, taking into account the adequacy of the materials and techniques used in every part of the rehabilitation project. This means that, in several cases some materials or practices are more expensive than others, but the cost is bearable or must be to achieve good results. Thus avoid possible future disasters as was the case of Aznalcollar in Spain, where it came to contaminate a protected natural area by the rupture of a raft of sludge, due to the cheap materials that had been used. The following table presents the advantages and disadvantages of using some techniques during the rehabilitation process, which have been explained in previous sections, since these are the points that have to be considered in order to decide the best methodology for each case.

Table 2. Advantages and disadvantages as a conclusion of some rehabilitation techniques

TECHNIQUE OR MATERIAL	ADVANTAGES	DISADVANTAGES
WASTE DUMP MOVEMENT	It allows softening more the shape of the dump because there is more space to make it. The greater the distance from the mine, the leachate problems are avoided.	The further away you are from the mine, the fuel costs will be higher for transporting the material, and the mining cycle time will increase due to the distance you have to travel.
HOLLOW FLOODING	It achieves an element totally integrated into the environment, which allows a very simple integration of new fauna and flora. It can also be used for leisure and sports activities, or even to supply water to nearby urban areas.	Exhaustive water quality controls are required, pipes must be made from the nearest natural water source. It is an alternative that is conditioned by the existence of natural water in the vicinity of the mine.
SOWING	It is an economical, fast and simple system, and can be applied in large areas with very little labour.	Large quantities of seeds are needed, commercial mixtures should be avoided, and mixtures specifically created for the area should be used. In addition, careful preparation of the soil is necessary, and there are difficulties for the development of the species in the absence of

		rainfall.
HYDRO SEEDING	No specific slopes are required. Takes a very short period of time to see the results. Fertilization can also be performed in the same operation.	Very expensive technique for which very specialized machinery is needed
PLANTING (biodegradable rolls)	Very immediate visual effect, an exact location can be made in the terrain, and the species have a high probability of survival.	Need for labour force, intensive care in transport, planting and later stages.

As a conclusion of the main part of this thesis, many factors are involved in the rehabilitation project, such as the nearby population needs, the weather, the temperature, the land type, the extension of the mine, the soil quality, the autochthone fauna and flora and of course all the economic aspects that make possible the rehabilitation. There is no precise methodology, since as it is known, any mine is the same as the others, the exploited resource is different. Therefore the exploitation method used is not the same, a very influential factor in deciding the final use of the area after it has been rehabilitated.

As it was mentioned during the thesis, one of the weak and important points in every rehabilitation project is the lack of funds. That issue to carry out them in most of the countries, gives more importance to the economic analysis, which has to be done before decide the proper rehabilitation plan for each mine and region. According with the qualitative economic analysis, which has been developed in the previous section, there are a lot of factors that can change the economy of the project. In some cases using one specific methodology can increase the rehabilitation project budge. However if that methodology is the most suitable one for the specific region long-term costs could be amortised, as other types of corrective measures would be avoided due to the use of appropriate materials and methodologies. Anyway in every case, making an economic, environmental impact, and quality factors balance is recommended.

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