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" The Chilean copper industry towards a more ecologically durable exploitation?"

"A historical analysis of the ecological durability of Chilean copper exploitation and the influence of different stakeholders on this evolution."

Mémoire de Fin d'Etudes présenté par
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Abstract

Le mémoire fait une analyse de la manière dans laquelle le Chili a affronté le paradoxe qui existe entre l'exploitation de cuivre et la préservation de l'environnement. Ce paradoxe pose que notre société ne peut pas être soutenu sans l'utilisation de cuivre, mais pas non plus dans un environnement en mauvaise santé. Le problème étant que l'exploitation du cuivre a un impact écologique très important. L'approche est une analyse historique de la période 1970-2009 où on fait attention aux évolutions et où on cherche une explication dans l'interaction entre les parties prenantes plus importantes du débat. L'impact écologique négatif augmente jusqu'à les premiers années de la décennie 90. À ce moment-là, une période de transition commence dans laquelle certains aspects de l'impact écologique diminuent. Des exemples pertinentes sont la pollution des eaux avec des métaux lourds et l'émission des gaz comme le SO_2, l'arsenic et le PM_{10}. L'état pourvoit l'incitation plus importante dans cette évolution, mais son comportement est influencé d'une manière importante par des autres acteurs. Un fait étonnant est que les corporations transnationales, qui cherchent la maximalisation du profit, veulent eux-mêmes diminuer leur impact. Pendant les dernières années de la décennie 80 ils sont même des pionniers dans la matière. La société civil réussi à fortement augmenter leur influence.

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List of Abbreviations

AMD	-	Acid Mine Drainage
CER	-	Corporate Environmental Responsibility
CIPMA	-	Centro de Investigación y Planificación del Medio Ambiente
CODEFF	-	Comité de Defensa de Flora y Fauna
CODELCO	-	Corporación Nacional del Cobre
CONAF	-	Corporación Nacional Forestal (National Forest Corporation)
CONAMA	-	Comisión Nacional del Medio Ambiente
COREMAS	-	Comisiones Regionales del Medio Ambiente
CS	-	Civil Society
CSR	-	Corporate Social Responsibility
DFI	-	Direct Foreign Investment
EIA	-	Environmental Impact Assesment
ENAMI	-	Empresa Nacional de Minería
FTA	-	Free Trade Agreement
GDP	-	Gross Domestic Product
IEP	-	Instituto de Ecología Politica
IFC	-	International Finance Corporation
IFI	-	International Financial Institution
NGO	-	Nongovernmental Organisation
PDC	-	Partido Demócrata Cristiano (Christian Democratic Party)
PN	-	Partido Nacional (National Party)
SING	-	Sistema Interconectada del Norte Grande (Norte Grande Interconnected System)
SNASPE	-	Sistema Nacional de Areas Protegidas del Estado (National System of State-protected Areas)
TNC	-	Transnational Corporation
UP	-	Unidad Popular (People's Unity)
WHO	-	World Health Organization

1. Introduction

1.1 Subject

Since its first use about 10 000 years ago, copper has always played an important role in sustaining and improving human society. The metal is used for a wide variety of applications, going from statues, pipelines and roofing to high-technological applications like semi-conductors and the copper chip. This fact makes the copper industry of vital importance to worldwide society. It is difficult to imagine human society without copper (International Copper Study Group 2009).

On the other hand, however, the exploitation of copper is accompanied with a large environmental impact. On the other hand, however, the extraction of copper involves large quantities of water, the application of heavy chemicals, the discharge of heavy metals, huge amounts of energy and vast amounts of waste. This means that copper exploitation leaves a large environmental impact.

It is widely accepted that a sustainable society cannot exist in an unhealthy environment. By consequence, the environment is arguably more important to our society than copper. This leaves us with a paradox. If we want to sustain and improve our society, we need to exploit more copper, but if we exploit copper with disregard to the environment, we won't be able to sustain our society. This makes for a very vivid and very intense debate about the ecological impacts of copper exploitation and, in a wider sense, mining in general. Even more so because this paradox will only become stronger in the future, when mineral reserves become more depleted and the worldwide demand for them will continue to increase (Hartman et al. 1992).

A lot of actors are involved in the debate about the ecological impact of copper. All of these actors find each other in Chile, where the export of copper is of huge importance for the national economy. Chile is by far the most important producer of mined copper in the world, providing 36% of the world's supply in copper ores and concentrates (International Copper Study Group 2009). In 2008 49% of Chile's total trade income was provided by the export of copper[1]. These figures show exactly how important copper is for Chile and by consequence how much stronger the paradox is for this country.

It is thus interesting to learn how the copper industry in the world's number one producing country has coped and still copes with the consequences of this paradox. Does the copper industry take its responsibility or does it follow a *"je m'en fous"* attitude? On the other hand it's also interesting to research how the stakeholders in the debate have influenced this attitude over the years. This information can than serve in comparisons with other countries and shed a light on what the future will bring.

1.2 Research question

As in every research, it is important to formulate the correct questions to investigate the presented subject. To be able to formulate these research questions it is necessary to know the goal of the dissertation. In other words, what do we want to reach with the dissertation? The goal is twofold. We are presented with a country, Chile, with a copper industry that since long has been an immensely important sector for the national economy. Therefore the country is confronted with a strong paradox: copper – environment. The dissertation has to produce an understanding of the way

[1] Percentage based on data from the World Bank (World Bank 2009).

in which Chile's copper industry copes with this paradox. Has it found a sustainable way of combining both factors of the paradox or did it favor one of the two? A second goal is to shed a light on the different stakeholders in the presented debate and their influence on the debate.

The first goal translates itself into a very simple research question: has there been an evolution of the ecological impact of Chile's copper mines? If we want to formulate an answer to this question, we need to map out the different ecological impacts over the years. This brings us to a first sub-question: What different ecological impacts did the copper mines have on their environment? This question implies that we learn about the copper extraction process and the faults within that process. We can then link different possible ecological impacts to these faults. With this information we can subsequently tackle the situation in Chile during the studied period.

The information, gathered with this first sub-question, will make it clear whether there has been an evolution or a stand-still. In the light of the research questions, we can however already assume that there has been an evolution. The next question will then be: in what direction did this evolution go? Did the impacts increase or did they decrease? By posing this question we can learn about the stated paradox. We will know if the balance has shifted in favor of the copper production or if there has been found an equilibrium between the copper production and environmental preservation in Chile.

To reach our second goal, we have to start by posing a first, fairly obvious question: which actors had an influence on the evolution of the ecological impact of Chile's copper mines? This allows us to map out the different actors or stakeholders that have played a notable role in the studied period. Once we've determined these actors we can start to pose some more interesting questions. Firstly, we can ask in what way the stakeholders can exert their influence. This will show us the different methods and channels that are available to different stakeholders. We can then investigate how these methods and channels have been used in Chile. Secondly, we can start to compare the different actors to each other and determine the relative importance of their influence. In other words: how important were the stakeholders compared to each other in influencing the direction of the evolution? Finally, we can investigate how the relative importance of the stakeholders evolved throughout the studied period. As a result, this body of questions will not only give us a clear understanding about the individual stakeholders and their influence, but also about the synergy that has been created between the different stakeholders over the years.

To be clear, the following are the research questions that will be treated in the dissertation:

- Has there been an evolution of the ecological impact of Chile's copper mines?
    - What different ecological impacts did the copper mines have on their environment?
    - How did these impacts evolve? Did the overall ecological impact increase or decrease?
- Which actors had an influence on the evolution of the ecological impact of Chile's copper mines?
    - In what way did they exert their influence?
    - What was the relative importance (compared to each other) of their influence?
    - How did this relative importance change?

1.3 Chosen boundaries

The research questions help us attain the goal of our research. These questions on their own, however, still leave too much room for interpretation. They are not specific enough to have a well defined field of research. Therefore we have to create some boundaries.

In this particular case it is important to define who is the polluter. By defining the polluter, we limit the body of environmental impacts that have to be taken into account. Furthermore, tradition states that an historical research – like the one this dissertation will present – has to be limited in time and place.

1.3.1 Polluter

The polluter is the acting object of this research. By polluter we mean the body of operations or companies that produce the ecological impact we want to investigate. It is important to define this body very clearly. This way, the causal link with the environmental impacts, which results in a well defined body of environmental impacts that can be investigated.

As you have noticed, the research questions do not mention Chile's copper industry. We do not intend to analyze Chile's copper industry in its entirety. This would make are field of research too broad. Instead, the questions refer to the copper mines, but even this differentiation isn't enough to give us a well defined body of impacts. We will focus even further on the so called open-pit mines, as opposed to underground mining operations.

The choice for open-pit mines has been made for two good reasons. First of all, it is the most widely used type of operation to exploit copper. This means that the research in this dissertation is much more comparable to situations in other regions, where open-pit mining is probably the most important type of exploitation. Secondly, open-pit mines create much larger volumes of waste. Out of a researcher's point of view, this makes them much more high profile. By consequence there will be more information available.

If we define the polluter, we also have to define what we regard as its production process. This again has to be done in light of our body of ecological impacts. To make this body as approachable for research as possible, we will focus on that part of the process that is done on-site. As a result we do not need to take into account parts of the process that aren't executed in the vicinity of the mine. By doing so we avoid that material flows from other regions enter the equation so that the link between the polluter and the impact remains clear.

More specifically, this choice implies that we will look at the mining itself, the mineral processing and the metallurgical extraction. Part of the metallurgical extraction, however, is often not done in situ and will not be treated by consequence. We refer to the process of pyrometallurgical extraction. In contrast, other types of metallurgical extraction are done in the vicinity of the mine. We will of course discuss these types.

1.3.2 Time

We focus our research on the recent history of Chile. More specifically the last 40 years. This gives us a large enough period of time to distinguish any possible evolution. Moreover, trends in the way in which different stakeholders reacted to the tension field between economical profits from the copper industry and preservation of the environment will become clear.

The starting date is set in 1970. This is no arbitrary choice. 1970 is the year that saw Salvador Allende rise to power. This marked the beginning of a series of intense regime changes in Chile. Allende nationalized the copper sector in Chile. Three years later Pinochet would seize power through a coup-d'état and install the values of the free market, promoting direct foreign investment. Finally, when Pinochet makes place for new democratic governments, the electorate once again becomes an important actor. Because the copper industry is so important for the country's economy, all of these political changes have had an intense effect on this sector. By consequence also the copper mines' ecological impact have been affected by these political changes.

Therefore, the political history of the last forty years in Chile form an interesting context in which we can place our research questions. Even more so because the state will appear to be one of the most important stakeholders in the debate about copper versus the environment. We don't want to rush ahead of things however.

1.3.3 Place

The spatial boundaries of our research are quite obvious. We want to investigate the way in which Chile has coped with the ecological impacts of its copper sector, so it's fairly reasonable that we take Chile's borders as the boundaries of our research.

This means that we look at mining operations that are located within Chile's borders. Some of the impacts of these operations have a more global effect. For instance, the emission of greenhouse gasses contributes to a worldwide problem. These impacts will be included, because they originate from within the researched locality.

Also, some actors that have an effect on the ecological impacts of Chile's copper mines aren't located within Chile's borders. Different international actors will become clear during the following research. These actors will be included in the research, because they have an impact on the operations within the researched locality.

As for the case study that will conclude this dissertation, the studied region will be Antofagasta. This region in the northern Atacama desert provides us with two very comparable mining operations. Choosing two cases from the same region is important for our research, because factors like precipitation, climate and seismic activity have a considerable effect on the ecological impacts of a mining operation.

1.4 Methodology

Regarding the methodology of the research in this dissertation, we have to put attention on three important aspects. First of all, the research applies a historical approach to its subject. A large part of its contribution is to be found in this approach. Secondly, the main body of this dissertation consists of a literature study. Primary sources are used, but mainly in the case study. Finally, the dissertation will be concluded by a case study. We will now discuss in more detail what the implications of these aspects are.

1.4.1 Historical analysis

We will approach our research from a historical point of view. The formulated research questions already made this clear. The questions also specified that our historical analysis will focus on trends and evolutions. By consequence it will not be a snap-shot of a certain point in time. We will analyze trends and evolutions over the period of time that we've already discussed: the last forty years of Chile's history. This will be done by comparing the situation of our research subject at several intervals within the chosen period. By doing so, small variations will be filtered out and the important trends will come to light.

The main body of our analysis will be based on a literature study. This choice has been made for a number of reasons. First of all, it is an immensely big task to deduct the ecological impacts of all the copper exploitations for the entire period out of reports. The timeframe of this study didn't allow for such an approach. In addition, such an undertaking would be redundant, because analysis of the sector's impact already exist. We might as well use this valuable work to gather our data for the entire period. Secondly, in an ideal world part of the research should have been executed in Chile itself. The interaction and synergy between different stakeholders, for instance, is a subject best to be studied within the local archives of the stakeholders or by means of interviews. This was not possible, so we are obliged to ground ourselves upon the study of literature.

This absolutely doesn't mean that the dissertation depicts a collection of already performed efforts. A historical approach of the subject in Chile has never before been attempted. This is where the added value of the dissertation can be found. It provides a time dimension to the debate. This time dimension doesn't only bring forward different trends, but also some very interesting new considerations regarding the role of several important stakeholders.

In this methodological framework, primary resources are used to fill in voids in the gathered information. The dissertation uses them in the form of reports of different institutions: academic research groups, constitutional bodies or private companies. Primary sources also form the foundation of the case study.

1.4.2 Comparison through a case study

The case study fasts forward from the early 90s to 2009. There it zooms in on two mining operations to investigate the current state of the research subject. This makes it the closing piece of the dissertation. With the case study our image of the way in which the ecological impact of the Chilean copper sector evolved during the past 40 years will be completed. In addition our image of the way in which the role, importance and interaction of different stakeholders evolved will equally be completed.

The case study uses sustainability reports of two mining operations, Codelco Norte and Minera Escondida, to form a detailed snapshot of their ecological impact. As already said, this will complete our view of the described evolution. However, a comparison between both cases also allows us to look into an extra dimension of the research subject. We will be able to compare the way in which a state-run operation (Codelco Norte) copes with its ecological impact and the pressure from stakeholders to the way in which a transnational corporation (Minera Escondida) does this. Both of them, the state and transnational corporations, are important stakeholders. By consequence, it will be enlightening to compare them.

1.4.3 Structure of the dissertation

The dissertation will start with a part that discusses the different possible impacts of a copper mine on its environment. The first chapter in this part provides us with a clear explanation of the mining process and the different steps to extract copper. The goal is to provide multidisciplinary researchers that lack the technical background with enough knowledge of the production process to understand its ecological impacts. The next chapter then proceeds towards linking different ecological impacts to faults in the process. In a third chapter different improvements to reduce the impact of an open-pit copper mine are presented.

In a second part we will get to know the principal actors that participate in the debate about the mining sector's ecological impact. A first chapter determines the principal stakeholders of corporate environmental responsibility. The second chapter of this part then investigates their relative influence and the way in which they exert their influence.

The dissertation then proceeds towards the final part of what forms the framework in which we investigate our research question. By now the reader has learned about the production process of an open-pit copper mine and its ecological impact. The different actors and their influence have equally been discussed. Only the historical context in which Chile's copper industry is set is still lacking. The part focuses on Chile's political history, because the changing regimes of the last forty years have had a large influence on Chile's copper industry and subsequently it's ecological impact.

In the next part we look more specifically to the ecological impacts related to Chile's copper exploitation. The evolution of these impacts from the 1970s till the early 1990s will become clear in a first chapter. In a second chapter we will then discuss the different stakeholders and their influence on the evolution of these impacts. It will become clear how the stakeholders have exerted their influence in different ways over the discussed period and how the importance of their influence changed.

The last part, the case study, then fasts forward from the early 1990s to the recent past (2009) and focuses on two specific cases, Codelco Norte and Minera Escondida. The cases will give us an understanding of the present situation, the impacts that still exist and the actors that still have an influence. The similarity of these open-pit copper operations allows us to learn in what way state-owned operations (Codelco Norte) and private operations (Minera Escondida) evolved compared to each other. It will also become clear how the importance of the influence of different actors evolved towards the present.

2. The ecological impact of a copper mine

2.1 Open-pit mining: the process

2.1.1 Mining

Man has invented a variety of ways to exploit the mineral riches of the world. The resulting long list of mining methods can be divided into two major classes according to their locale: surface mining and underground mining. Of these two classes, surface mining is the predominant exploitation method worldwide. For example, in the United States, surface mining contributes nearly 85% of all minerals, excluding petroleum and natural gas (Pfleider 1968). Regarding metallic ore, almost all of it (98%) is mined using surface methods in the USA (Hartman et al. 1992).

There are a lot of good reasons for mining companies to choose surface mining methods. Especially the mechanical extraction ones. While they require large capital investment, these methods generally result in high productivity and low operating costs. In fact, by their very nature, these are large-scale, mass-production techniques, handling enormous volumes of material per year. The Chuquicamata copper mine, that will be used in our case study later on, illustrates this perfectly. From the beginning of its operations in 1915 to the end of 2007, the mine has produced a staggering 29 million tons of copper. The production for the year 2007 alone was 896 308 fine metric tons of copper (CODELCO 2007).

The high output rate of ore makes surface mining economically attractive, but there are other factors upon which the choice of mining method depends. The type of mineral that is being mined, the shape, orientation, continuity and depth of the ore body, the ore-grade, the environmental impacts, the area of land available for waste disposal, safety concerns. All of these factors, and many more, result in a strongly variable mining context and therefore in a wide variety of methods used. For an overview of these different methods, I would like to refer the reader to other literature.

From this point on, we will just be focusing on open-pit mining. The SME Mining Engineering Handbook provides us with a general definition of the method: *'An open-pit mine is an excavation or cut made at the surface of the ground for the purpose of extracting ore and which is open to the surface for the duration of the mine's life.'* (Hartman et al. 1992, p.1274) Open-pit mines are commonly used for the extraction of metals. It's the predominant technique used in the projects of the *'gran minería del cobre'* of Chile.

There are different stages in the life of an open-pit mine. After prospecting and exploring the ore body, the proper mining – consisting of a development and exploitation stage – can begin. During the development stage, the terrain is prepared for the excavation of the pit. This means that the overburden, covering the ore body, has to be stripped. Removing the overburden can be done using the same cycle of operations as that employed in exploitation of the ore. This fact implies that stripping cannot begin before preliminary infrastructural work is done. The infrastructural facilities, essential to the exploitation cycle, consist of access roads and other transportation, power sources, ore processing facilities, dams and waste disposal areas. Once the overburden can be removed, it's transported to an adjacent waste embankment or to a previously mined-out pit (Hartman et al. 1992).

Reaching the actual ore body, the open-pit mine enters the exploitation stage. Given the ore deposit can reach various depths and the diameter of a mining pit is related to its depth, stripping and exploitation can happen simultaneously. Figure 2.1 illustrates how the deeper the ore body goes, the greater the final pit depth is, the larger its diameter has to be. This means that, during an open-pit mine's lifetime, stripping has to be continued according to a certain stripping ratio scheme. The options are a declining stripping ratio, an increasing stripping ratio and a constant stripping ratio. As figures 2.2 to 2.4 show, the choice made implies a greater waste rock production in the early years of the mine, an increasing waste rock production towards the end of the mine's lifecycle or a constant waste rock production.

Fig. 2.1: Pit depth versus pit diameter[2]

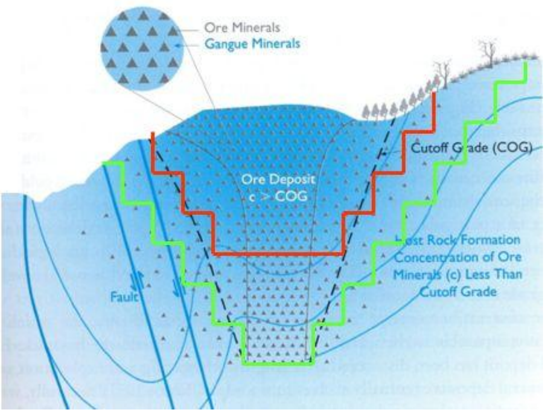


Fig. 2.2: Declining stripping ratio method[3]

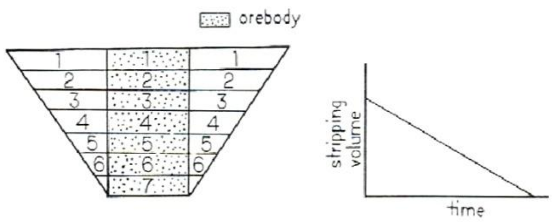


Fig. 2.3: Increasing stripping ratio method

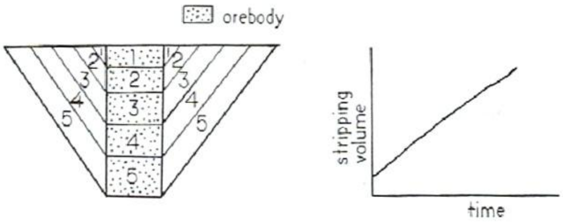
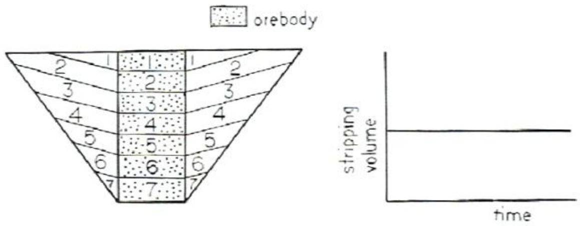


Fig. 2.4: Constant stripping ratio method



Excavation is done by blasting sections of the mine. At present, this method is still the most cost-efficient: no mechanical device can match the huge quantities of energy that can be so compactly stored in chemical form in an explosive charge. First a certain pattern of blast holes, depending on the rock type, is drilled into the bench face. These holes are then loaded with a booster, a detonating cord and an explosive. Two types of explosives are generally used: ANFO, which is a blend of ammonium nitrate and fuel oil, and commercial bulk emulsion-blend explosives. ANFO is the preferred explosive and usually blended in-situ. The emulsion-blend explosives are typically used in wet holes (Hartman et al. 1992).

The whole excavation sequence follows a system of benches. The bench height is dictated by specifications of the operating machines. It should be well within the maximum digging range so that the slope and the tendency toward caving of the face can be better controlled (Rumfelt 1968). The

[2] Figure from (Spitz & Trudinger 2009a) with adjustments by (Muller 2009c).
[3] Figures 2 to 4 from (Hartman et al. 1992)

width of the benches is determined by the clearances required to load transport and the stability of the pit wall. Benches are alternated with ramps on which a haul road is built. These haul roads can follow a spiral around the pit or zigzag up a pit wall (Hartman et al. 1992).

Once the rock material has been loosened by the blast, large shovels can be used to load transport. Thanks to computer models of the deposit, mining engineers can already make a first separation between ore and waste rock at this stage. Based upon the model, they define if a certain section contains ore or waste. If the section is within a projected ore zone, samples are taken out of each blast hole. If not, samples are only taken every fourth hole. With these samples the grade of the surrounding material can be defined. Each section is then identified by survey stakes and marked with flagging. In this way the area supervisor and shovel operator are able to distinguish between ore and waste (Hartman et al. 1992).

The haulage of waste rock and ore can be done by truck, railway or belt conveyor. Today, the most profitable way to transport the material from the blasting site is by truck. Transport by railway is a more dated method. Trucks, loaded with waste rock, bring their load to overburden embankments. These are usually side-hill fills, but valley fills and heaps can also be employed. Trucks with ore bring their load to the crusher for mineral processing. Since the installation of the first mobile crusher in 1956, crushers have been increasingly installed inside the pit. The great advantage of installing the crusher inside the pit is a huge decrease in transport costs. Material no longer has to be transported on high maintenance roads to the processing plant. Trucks just have to bring the material to the crusher at the bottom of the pit, from where it can be transported by means of a belt conveyor after crushing (Hartman et al. 1992).

2.1.2 Mineral processing

At the crusher, a new step in the evolution of the copper ore towards metal begins: the mineral processing. The step aims to physically separate and concentrate ore mineral from ore rock (Muller 2009d). This is often done on the mine site, as opposed to the next step, metallurgical extraction, which is done of site. Mineral processing consists of two major operations. The first is comminution, in which the size of the rocks is reduced by crushing and grinding. Comminution is followed by concentration, an operation that actually separates the ore mineral from waste rock. Alongside these major operations, some small operations of equal importance exist. They include thickening, filtering and drying (Hartman et al. 1992).

The first stage in the comminution unit operation, crushing, reduces rocks of the order of 1 to 1,5 m in diameter to about 1 cm. This may happen in several stages. Usually, a primary crushing will reduce the maximum rock size to about 10 cm in diameter (Muller 2009d). High throughput open pit mines use gyratory crushers as primary crusher, because their capacity is higher than jaw crushers. Jaw crushers are used for throughputs below 450 t/h, because of their lower cost (Hartman et al. 1992). Secondary crushing reduces rock size further to about 1 cm. Crushing is highly energy intensive and is often the most expensive phase of mineral processing. The crushing is always done in the absence of water. This means that the by-product is waste rock. Crushing doesn’t produce tailings (Muller 2009d).

Grinding, on the contrary, is done in the presence of water and therefore generates tailings. Grinding – or milling – further reduces the crushed products to a size suitable for a subsequent concentration process. This is achieved by tumbling the crushed ore together with a grinding media, like steel balls, rods or rock pebbles, in a rotating cylinder or a stirred vertical cylinder. Grinding is a low-efficiency, power-intensive process. It may account for up to 40% of the total direct operating cost of the concentrator plant (Hartman et al. 1992). Grinding reduces the particle size according to different categories (Muller 2009d):

- Coarse grinding: 1 cm to 1 mm
- Fine grinding: 1 mm to 0,1 mm
- Very fine grinding: 0,1 mm to 0,01 mm
- Superfine grinding: 0,01 mm to 1 µm

The concentration of copper sulfides is done by flotation. This process requires a particle size between 205 µm and 37 µm (Currie 1973). Therefore, copper mines use mills for fine to very fine grinding. The final product of the mills is a slurry with a consistency between 25 and 45% solids by weight (Hartman et al. 1992). The slurry can easily be transported by means of a pipeline towards concentration and metallurgical extraction.

There is a clear difference between the first and second stage of the comminution unit operation. Both are also done in a different place. Where the crushing can be done by a mobile crusher at the bottom of the pit, the grinding mills are placed within the concentrator plant. This plant is usually located at the border of the mine. The crushed rock has to be transported by a belt conveyer towards the concentrator plant. The problem with all the transport-sections within the mining cycle is its discontinuous character as compared to a relatively continuous mining or processing operation (Hartman et al. 1992). Consequently, there is a need for storage facilities to keep the different operations running. These storage piles equally serve as buffers to prevent a shutdown of the entire cycle because of a malfunction in one of the separate operations. A system of piles exposed to the weather predominates, unless there are environmental reasons or the mineral can be damaged by the elements (Hartman et al. 1992).

Before we continue to the second phase – concentration – the reader has to understand the difference between copper oxides and copper sulfides. Copper oxides and sulfides are two groups in which we can subdivide almost all of the 165 copper containing compounds. Copper oxides can be found close to the earth's surface and were the first to be exploited by mankind. Copper sulfides can be found underneath this first layer of oxides. Today the great majority of copper mines exploit this type of ore body. The difference in chemical properties between oxides and sulfides makes for a different concentration operation. Copper oxides can be extracted, using sulfuric acid as a leach solution. This process will be further explained under *'Metallurgical extraction'*. Copper sulfides can't dissolve in sulfuric acid and have to be extracted with the more complex flotation method (Moussa 1999).

In short, froth flotation is a physiochemical process for the separation of finely divided solids from one another. This is effected by the selective attachment of the particle surface to a gas bubble. To attain the attachment, the surface of the particle generally has to be modified by surfactant chemicals. The gas bubble subsequently brings the particle to the surface (Muller 2009d).

Flotation exploits the differences in surface properties of minerals, when they are very small in size (i.e. between 205 µm and 37 µm). All mineral surfaces are hydrophilic, but, relying on the differences in surface properties, a reagent specifically chosen to affect the mineral to be recovered is added.

This reagent, called collector, gives the mineral particle a water repellent surface. The reagent thereby facilitates the attachment of the particle to the gas bubbles. Another reagent is added that assists in establishing a stable froth at the surface. The slurry passes through a series of containers to provide time to the mineral particles to rise to the surface where it can be absorbed by the froth. The mineral-bearing froth is eventually skimmed off (Hartman et al. 1992). The remaining tailing is disposed of.

We can without any doubt say that the froth flotation process has saved the copper industry (and the exploitation of a lot of other metals). Virtually the entire world supply of copper is first collected from low-grade ores as a flotation froth. With the classical gravity concentration process, it has never been profitable to utilize both low-grade and complex ores. Flotation has made possible the exploitation of these ores that otherwise hadn't been economic. Today open pit mines are operating profitably with cutoff grades as low as 0,25% Cu (Hartman et al. 1992).

The last steps to be taken before the mineral can continue to the metallurgical extraction are thickening and drying. The concentrate, produced by the flotation process, is transferred to big cylindrical tanks. In these tanks, the solids are allowed to settle at the bottom, where they are scraped away by rotating rakes. This process is called thickening. During a final step, complete dewatering is achieved in disk, drum or vacuum filters. The final product is a dry mineral concentrate (Muller 2009d).

2.1.3 Metallurgical extraction

Metallurgical extraction aims to break down the concentrated ore minerals, produced by the mineral processing, in order to recover the desired metal (Muller 2009d). We've already stated that this part of the process often takes place at localities separate or remote from mine sites. This renders it less interesting for the dissertation. By consequence, it will not be treated in depth here. There are, though, certain types of metallurgical extraction, which are done in the vicinity of the mine.

The metallurgical extraction processes, done in-situ, can be grouped under a common denominator: leaching. It includes three different extraction processes – vat leaching, heap leaching and dump leaching – all of which are based on the use of a selective dissolution. In the case of copper oxides, this is sulfuric acid. The process is especially suited for oxides. Copper sulfides first need to be treated with oxidizing bacteria, called *'bio-leach'*, to facilitate the leaching process (Muller 2009d). Vat leaching and heap leaching are processes, used on mined and crushed minerals. Dump leaching is a secondary operation, used to recuperate left minerals in waste-rock dumps (Hartman et al. 1992).

While heap and dump leaching are very much alike, vat leaching is the odd one out. It's a process that has been used a lot in gold exploitation during the late 80's. Since then it was superseded by other methods (Cope 1999). In the copper industry it has also become a fairly rare extraction process, due to the depleted copper oxide reserves. Ores are finely ground to maximize their surface area. They are then held in suspension in closed tanks, filled with a concentrated leaching solution, using agitators. The process produces large quantities of fine tailings (Muller 2009d).

The process used for dump leaching and heap leaching is the same in its essence. Both of them are actually operations for low-grade ores, where the more capital-intensive process of milling and flotation wouldn't be economical. Dump leaching is a process that mining-operations use to recover the amount of copper that was left in untreated waste rock. Hence the word *'dump'*, which refers to old waste rock dumps (Muller 2009d). It is actually a cheap way for a mining company to increase its profits, because they just have to let a leach solution filter through the dumps. As the dumps were already there, no lining is present underneath. The process is very popular in the copper industry (Hartman et al. 1992).

Heap leaching actually shortcuts the milling and flotation operations by moving directly from crushing to the extraction of the metal (Muller 2009d). Ore is first crushed to a gravel size and then placed on lined pads. A liquid reagent – being sulfuric acid or a bio-leach – is then sprinkled over these heaps. The leach solution filters through the heap and exits as a *'pregnant solution'*. This solution is then further processed to extract what is known as *'copper cathodes'*. The barren solution is again enriched with sulfuric acid to be subsequently reused. Leaching can take several weeks. Once leaching is complete, the heap is rinsed with water. Dump leaching and heap leaching don't produce tailings, but they do produce barren leach-heaps and process-waters (Muller 2009d).

One final step has to be undertaken in order to produce the copper cathodes. This product, that consists of 99% to 99,999% pure copper, is obtained by electrowinning (Hartman et al. 1992). Electrowinning is an electrolytic process [4]. This means that an electric current is passed through the pregnant solution in order to separate it from the metal ions. The solution enters electrolytic cells, which are tanks that contain a certain number of negative and positive electrodes. Due to the electric current, the metal ions in the solution can be deposited on the negative electrode. At the same time, oxygen is evolved from the solution at the positive electrode. The negative electrodes in electrolytic cells are called cathodes, while the positive electrodes are called anodes. Hence the name *'copper cathodes'* for electrowon copper (Woods 2010).

2.2 Shortcomings of the process: waste production

The abovementioned production cycle of an open-pit mine is far from perfect. In its essence, it's a very intensive operation that produces a huge amount of waste. This chapter will map the most important wastes and the faults in the process that cause them. It will also explain how these wastes have an impact on the environment. In the following chapter different ways of controlling the ecological impacts will be presented.

2.2.1 Classification

What we call waste, is actually an array of externalities, produced by a production process, which are no longer useable. This means that they cannot be put to good use with the technologies that are currently available. An open-pit mine produces wastes in all three states of matter and throughout the entire process. A classification of the great diversity of externalities produced is quite essential to keeping a mental survey. Bernd Lottermoser suggests a classification according to the different stages of the production process (Lottermoser 2007). Following this method, he classifies solid mining, processing and metallurgical wastes and mine waters (Table 2.1).

[4] Do not confuse electrowinning with electrorefining. Electrowinning is the final step in the leaching process. Electrorefining is an operation in the pyrometallurgical extraction of copper. It is used to purify the copper (Hartman et al. 1992). Given the fact that it forms a part of the pyrometallurgical extraction process, it doesn't form part of the processes on the mine-site. By consequence it doesn't produce on-site externalities and isn't treated in this dissertation.

Table 2.1: Waste classification according to the production process[5].

Acitivity generating the mine waste	Mine wastes
Open pit mining, underground mining	Mining wastes (e.g. waste rocks, overburden, spoils, mining water, atmospheric emissions)
Mineral processing, coal washing, mineral fuel processing	Processing wastes (e.g. tailings, sludges, mill water, atmospheric emissions)
Pyrometallurgy, hydrometallurgy, electrometallurgy	Metallurgical wastes (e.g. slags, roasted ores, flue dusts, ashes, leached ores, process water, atmospheric emissions)

Solid mining wastes either don't contain metals or don't have an economically profitable concentration of it. Solid mining wastes are in fact waste rock and overburden that has to be removed to access the ore body. Naturally, surface mining operations, especially open pits, are the most important sources of this type of waste. Waste rock is usually dumped in large piles close to the mining pit. Processing wastes are produced during mineral processing. Herein, they are defined as that part of the crushed, milled, ground or treated resource deemed too poor for further treatment. This definition includes tailings, sludges and waste water. Processing wastes are usually disposed of in a tailings dam next to the mine. Metallurgical wastes proceed from pyro- and hydrometallurgical processes. They are again the residues of these processes deemed too poor for further treatment (Lottermoser 2007). We will only focus on the wastes produced by leaching operations.

Mine waters deserve to be seen as a group on its own. Water is omnipresent at a mining operation. Water is needed at a mine site for dust suppression, mineral processing and hydrometallurgical extraction. Mine waters can be seen as ground or meteoric water, which undergo modifications due to reactions with the minerals at mine sites. Examples of mine waters are *'mill water'*, which is used to grind ore, and *'process water'*, which is used during hydrometallurgical extraction (Lottermoser 2007). *'Acid mine drainage'* (AMD), a waste which will get more attention further on, can also be seen as mine water. Mine waters have to be treated before being discharged into the environment. Finally, a group which Lottermoser doesn't classify is gaseous wastes. Nevertheless, atmospheric emissions are produced in every part of the mining cycle. They take the form of greenhouse gasses, dust, acid mists and other emissions.

2.2.2 Amount of waste

Copper is immensely important for the world economy. In 1999 12,6 Mt of copper was produced (USGS (United States Geological Survey) Mineral Resources Program 2001). In 2008, this number had gone up to 18 Mt (International Copper Study Group 2009). It is used in almost every aspect of our society. From electrical appliances, to communication, to construction, to high-technological machinery and equipment. The same goes for a lot of the products the modern mining industry provides. As a consequence the global mining industry is huge. It produces vast amounts of material, but even larger amounts of waste.

If we zoom in on the copper industry and open-pit mines, the relative amount of waste rises even further. This is due to two characteristics. First of all, copper mining – unlike for example gravel or

[5] Each step of the mining operation produces solid, liquid and gaseous wastes. Table from (Lottermoser 2007).

sand mining – aims to extract only a few percent concentrations of copper. The majority of the total mined material is gangue, which is rejected as waste (Lottermoser 2007). Secondly, with open pits this waste production only rises, given the fact that a huge amount of overburden has to be removed. Table 2.2 shows us the waste production of surface operations and that of underground operations in the USA. The waste production of surface operations is 73% of the total amount of rock extracted against only 7% for underground operations. This number would be even higher if the table only showed metalliferous mining operations.

Table 2.2: Waste production of surface operations vs. waste production of underground operations[6].

	Surface			Underground			All Mining		
Commodity	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total
				(million tons)					
Metals	1290	1,863	3,153	64	3	67	1,354	1,866	3,220
Nonmetals	2778	449	3,227	123	0	123	2,901	449	3,350
Coal	669	10,303*	10,972	421	45*	466	1,090	10,348	11,438
Total	4737	12,615	17,352	608	48	656	5,345	12,663	18,008

Sources: Moore (1997) and Energy Information Administration (2000).
*These values based on ore/waste ratios reported by Energy Information Administration (1983).

The huge amount of waste produced by the mining industry can be further illustrated by the following comparison. Total solid mine waste production is estimated at 15 000 to 20 000 Mt each year (Lottermoser 2007). This is approximately the same order of magnitude as the quantity of earth's materials moved by fundamental global geological processes (Fyfe 1981; Förstner 1999). This means that mining operations globally move as much material as volcano activity, erosion, oceanic crust formation and other processes do. In addition the amount of waste will only increase, because increasingly lower ore grades are being exploited. According to Förstner the amount of mine wastes may even double within 20 to 30 years (Förstner 1999).

Of course not all of this waste is a source of contamination or pollution for the environment. A large amount is inert rock. Even so, the sheer amount produced in a mining operation poses a threat for the local environment. The large quantities of waste need large surfaces for storage. Waste rock is dumped in large heaps, tailings need enormous tailing dams for storage, the pit itself can have a diameter of several kilometers. All of this results in alterations of terrain, the cutting of forests, the disappearance of precious ecosystems like the paramos in Peru and Ecuador, and so on. As a result the earth is getting increasingly shaped by mine wastes (Lottermoser 2007).

2.2.3 Water usage

A copper mining operation needs vast quantities of water. Generally the volume of mine water used and disposed of at mine sites is even larger than the volume of solid waste generated (Lottermoser 2007). Most of this water is used during mineral processing or hydrometallurgical operations. From the grinding onwards, water is needed in every single part of the production process. In addition, a pit that is lower than the water table will need constant pumping to remain dry. This lowers the water table and the pumped water can be contaminated with acid mine drainage, which means it

[6] Table from (Hartman & Mutmansky 2002)

has to be disposed of in a tailings dam. In fact, the tailings dam is where most of the spent process waters are released (Lottermoser 2007).

As a consequence, the mining industry as a whole can nearly put a monopoly on water consumption in certain regions. For instance, in Antofagasta and Atacama – two arid regions in Chile – the mining industry consumes respectively 70% and 60% of the present water resources (OCDE & CEPAL 2005b)[7]. This consumption rate puts an enormous pressure on the already scarce water supply and its regeneration rate. In addition, the mining industry keeps expanding so the pressure on water sources keeps increasing.

Another consequence is the ever increasing price of water in such arid regions. Water rights can cost up to 200 thousand dollars per liter per second in Chile (Guajardo 2009). This inevitably leads to social conflicts with local farmers, who can no longer find the necessary water to irrigate their lands. Because of the high cost, mining operations try to recycle as much of their process waters as possible. At the moment the most important operations are able to recycle up to 60%, but this percentage will have to increase even more (OCDE & CEPAL 2005b).

2.2.4 Acid Mine Drainage

By now it is clear that water forms a very important aspect of any mining operation. It comes into contact and reacts with the extracted minerals at every stage of the process. One of the most important wastewaters these reactions produce is *'acid mine drainage'* (AMD). AMD is a waste product resulting from the chemical reaction between sulfidic mine wastes, air and water. Given that the great majority of the world's copper production comes from sulfide minerals, AMD forms an important part of the total waste production of a copper mine (Moussa 1999).

The chemical reaction that forms AMD is actually an oxidation of sulfidic minerals after contact with air and water. These sulfides are stable under reducing conditions, but become very unstable in an oxidizing environment. As a result sulfuric acid is formed. This acid mine drainage will in its turn dissolve heavy metals (Fe, Cu, Pb, etc.) , metalloids (As, Sb) and other elements (Mn, Ca, K, Na, Mg, Si, etc.) (Lottermoser 2007; PSG 2007). There are different sources of AMD. Any operation where water comes into contact with exposed sulfides, can lead to AMD. Ore stockpiles, tailings storage facilities, waste rock piles and heap leach piles are all sources. Acid generation can even occur on the walls and the floor of the mining pit (Lottermoser 2007).

Today, acid mine drainage actually forms the most important environmental problem facing the mining industry. Next to the fact that there are so many possible sources for AMD in an open-pit copper mine, sulfide oxidation is also an autocatalytic reaction. The reaction produces heat and acid, which in turn speed up the process. This means that the reaction will continue at an ever increasing rate until either the sulfide or oxygen source is exhausted. By consequence, once a mining operation faces the problem of AMD, it will be very hard to eradicate it (Muller 2009a). AMD generation can occur within months or even weeks and is most severe in the first few decades after sulfide oxidation begins (Demchak et al. 2004). In extreme cases, though, AMD may continue for thousands of years. The Rio Tinto mining district in Spain illustrates this very well. Mining operations in the district date

[7] Water consumption is very regional. Atacama and Antofagasta are two regions with a very extensive mining industry. In addition water in such dry regions is already a very rare commodity. The water consumption of the mining industry on a national level in Chile is only 5% (Guajardo 2009).

back to the Copper Age around 5000 years ago and the effects of AMD are visible to this day (Lottermoser 2007).

Acid mine drainage has high concentrations of acidity, heavy metals, metalloids, total dissolved solids (TDS) and salts. If AMD is discharged into the environment without control, these factors can cause significant impacts on surface waters, ground waters, aquatic life, soils and sediments. Annex 2 gives an overview of the different environmental impacts per property of AMD. In what follows, the impacts will be presented per section of the environment.

If AMD enters surface waters, it can impact the use of waterways downstream. Low pH-levels, high salinity and high metal concentrations can render these waters useless for irrigation and stock watering. In addition, fish stocks can be affected, which in its turn has an impact on fishing activities (Lottermoser 2007). An even more direct impact for human populations is the contamination of potable water supplies. These supplies have to be under constant surveillance and national drinking water quality guidelines have to be met (Cidu & Fanfani 2002). At the mine site itself, poor water quality limits its reuse as process water. Too low pH-levels can cause corrosion, while to high salinity levels can cause encrustation of the processing circuit. This, in its turn can lead to system failures and added ecological impacts (Lottermoser 2007).

Aquatic life can be severely disrupted by the effects of AMD. Photosynthetic aquatic organisms suffer under the high acidity and turbidity of AMD. A pH below 4,3 will destroy the natural bicarbonate buffer system of surface waters (Brown et al. 2002). This system keeps the acidity of natural waters within a distinct pH range and provides photosynthetic organisms with their inorganic carbon source. As a consequence they will not be able to survive. In addition, the high turbidity of AMD disperses and adsorbs sunlight, which is vital to the photosynthetic process. Turbidity is caused by suspended particles floating in the water column, the so-called TDS. These particles aren't toxic on their own, but they are important in transporting heavy metals, metalloids and other elements (Schemel et al. 2000). For metals to become toxic (ie. hazardous for living organisms) they have to be bioavailable and present in high concentrations. In AMD, the great majority of the metal load is available to organisms because they are present in ionic forms. AMD waters contain high concentrations of metal and high acidity turns elements into more toxic forms. This makes AMD waters lethal to aquatic life and of concern to human and animal health (Lottermoser 2007). The biodiversity can be severely reduced.

As mentioned, acid mine drainage contains significant amounts of dissolved ions. As a result AMD waters become highly saline. Ions can remain in the solution in ionic form and be adsorbed by suspended particles. Few will remain in solution indefinitely. Others will reach saturation levels and precipitate as secondary minerals at a certain point. This can happen in the sulfidic wastes, but also in ground or surface waters. If this is the case, soils, floodplain sediments and stream sediments may be contaminated with metals, metalloids and salts (Lottermoser 2007). Especially salinization and the formation of salt crusts can be a serious problem for plant and animal life. The Cori Chaka mine near Oruro in Bolivia illustrates what the consequences of salinization can be. The region has become a salt desert and many animals suffer from blindness by salt poisoning (CATAPA 2009b).

Acid mine drainage affects ground waters more frequently than surface waters. Contaminated water may move into aquifers if a waste repository is unlined and permeable at its base or if the lining has been breached. A plume of contaminated water will migrate over time down gradient and resurface at seepage points to contaminate surface waters (Lachmar et al. 2006). Contaminant levels depend on the interaction between the water and the soil, sediment or rock through which it flows. Various minerals can buffer the AMD (Lottermoser 2007).

Sulfidic waste rock heaps also can equally be seen as an ecological system that suffers from its own sulfidic oxidation. Flora on these heaps can be impoverished or absent. This is due to the high acid and salt levels within the heap, the metal content within the heap and salt crusts on the heap (Bullock & Bell 1997). Sparse vegetation is also caused by a lack of nutrients and organic matter (Lottermoser 2007). The lack of vegetation accelerates another problem: erosion. This increases the moonscape appearance of the waste dumps, but more importantly increases the areas affected by waste particles that are transported by water and wind (Cidu & Fanfani 2002). As such, the area affected by the waste heaps can no longer be limited to the limits of the mine site.

2.2.5 Tailings

Tailings are defined as the processing waste from a mill or flotation plant. In metal mining, it can constitute up to 99% of the total mined material (Lottermoser 2007). Therefore they represent the most voluminous waste at metal mine sites. Tailings consist of liquids and solids at a concentration of about 20 – 40 weight percent solids (Muller 2009a). The solids in tailings are very fine grained due to crushing and milling[8].

Tailings have to be stored in storage facilities, called tailings dams. Process waters and used AMD can equally be stored in tailing dams. Once in the repository, these waters are called *"tailing liquids"*. Tailing liquids contain high concentrations of hazardous process chemicals, like flotation reagents, flocculants, oxidants and others. If the copper mine uses a leaching process, acid waters will start the AMD generation process within the tailings dam. Finally tailing liquids can become extremely saline. Tailing solids provide the sulfides for AMD generation. This process can be much more rapid than in waste rock heaps, because tailings are so fine grained (Lottermoser 2007). They also still contain heavy metals, metalloids and other elements.

Tailings repositories contain an enormous variety of hazardous substances. A part will be destroyed in time by natural bacterial, chemical or photolytic degradation processes or engineered degradation processes. Others, though, will remain within the dam indefinitely (Lottermoser 2007). This brings us to an inherent property of tailings treatment at mining operations. They're always based upon storage operations and not actual treatment of the waste. The waste stored in a tailings dams remains hazardous and by consequence the tailings dams remain an infinite threat to their environment. In 2010, Europe became very familiar with the disastrous consequences of a dam failure when an aluminum tailings dam in Hungary breached after heavy rainfall (De Standaard Online 2010a). Nine people died, a big area including seven villages was covered in red, toxic slurry and major waterways like the Danube were affected (De Standaard Online 2010b).

Being that tailings remain hazardous, their repositories must be built to withstand time. Sadly, this is often not the case. It has been – and still is – a very common practice to prefer cheaper containment methods to more sustainable methods. Tailings dams are constructed as cross valley, sidehill or paddock impoundments. They have to be built so that seepage into the environment is negligible. Seepage from tailings dams is a common environmental concern. It is controlled by the permeability

[8] As already mentioned, the solids are grinded to a size between 205 µm and 37 µm.

of the tailings and of the liner or ground beneath. Tailings dams are not built to completion, but raised as the impoundment fills. This is done using an upstream method towards the tailings, a downstream method away from the tailings or a centerline method (Vick 1983).

Fig. 2.5: Construction of dams for sequentially raised tailings impoundments[9].

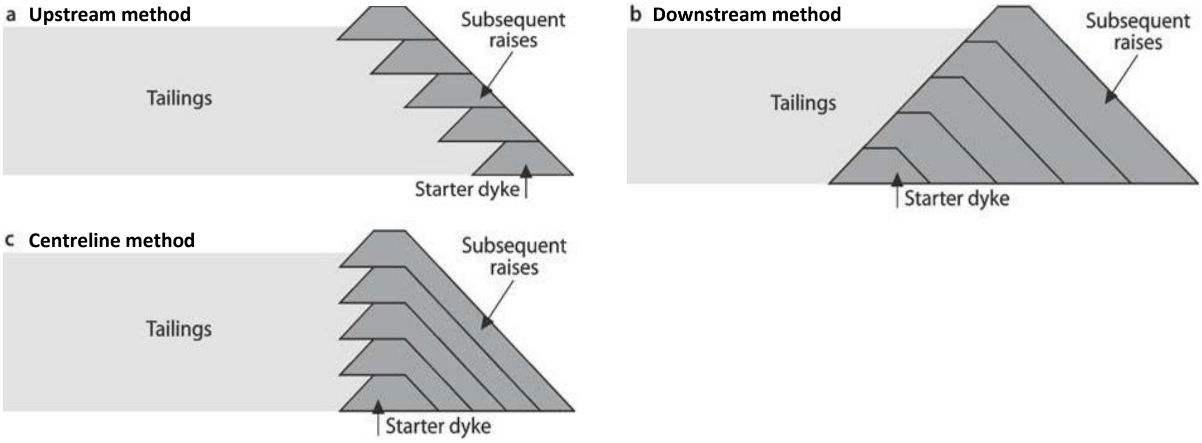


Figure 2.5 clearly shows how the upstream method requires a lot less material. It is also built on top of the tailings, which form a very unstable foundation because of their small grain size. This makes for a method that is very susceptible to erosion and failure. Nonetheless more than 50% of tailings dams worldwide are built according to the upstream method (Lottermoser 2007).

Every 20th upstream tailings dam that is built fails. This means that the method has a failure rate of 5% (Muller 2009b). Tailings dams should be built to withstand extreme geological and climatic events. Upstream dams don't have the capacity to do so. A survey of the most important dam failures between the 1930s and 1990s (Annex 3) shows how a lot of failures are caused by such extreme events. Heavy rainfall is the cause of failure in 13 cases, liquefaction due to earthquakes is the cause in 7 cases. In Indonesia and Papua New Guinea earthquakes and heavy rainfall are so common that the copper mining companies don't even bother to build a tailings dam. Instead, they discharge the tailings directly into streams (Lottermoser 2007). Other causes can be foundation failure, rapid increase in height or excessive seepage.

The consequences of dam failure can impact a large region. The wastes can spill into waterways and travel considerable distances downstream, as was the case with the Hungarian dam breach. In the case of a copper exploitation, these waterways will be polluted with AMD and heavy metals. Their acid and salt levels will also rise. Large areas can become covered in thick mud, rich in metals and process chemicals. As a consequence the region's sediment and water quality can be reduced and contaminants can enter the biosphere (Hudson-Edwards et al. 2003; Mark G. Macklin et al. 2003). This can lead to a loss in biodiversity, damaging of ecosystems and in some cases the loss of human life. The economic and environmental costs always prove to be enormous (Mining Journal Research Services 1996).

In semi-arid and arid regions there have been very few tailings dam failures (Lottermoser 2007). This is important to know for the cases treated further on in this dissertation. It is also an indicator of how dangerous heavy rainfall can be for a tailings dam. However, tailings dams face other problems in

[9] Figure from (Vick 1983)

these regions. Firstly, seepage problems are very common. Secondly, the supernatant ponds contain higher levels of process chemicals, because evaporation of water concentrates them more. Thirdly, the tailings surface is extremely saline, which causes surface crusting. This prevents drying out of the tailings. This means that AMD generation and tailings deposition continues for many years and rehabilitation cannot be undertaken. Rehabilitation includes the covering of the tailings impoundment. Without this cover, tailings are very susceptible to water and wind erosion because of their fine grain size. Wind-blown particles from tailings can greatly increase the area affected by the tailings impoundment. These particles can pollute the air, streams and soils of a large region (Lottermoser 2007).

2.2.6 Atmospheric Emissions

A copper mining operation produces various types of atmospheric emissions. Crushing, milling and electrowinning are highly energy-intensive processes. The required energy for these processes still comes from fossil fuels. Transportation of ore and waste rock within the mine is also still based on fossil fuels. By consequence, mining operations are important contributors to the production of greenhouse gasses.

Copper mines are also very important producers of sulfur dioxide (SO_2). In Chile, they are responsible for 76% of the total sulfur dioxide emissions (OCDE & CEPAL 2005b). Particularly the pyrometallurgical process of smelting produces a lot of SO_2. An important consequence of abundant sulfur dioxide in the atmosphere is acid rain. Acid rain changes the pH values of water bodies and soils, accelerates the AMD-process and is harmful for flora (US EPA 2010a, US EPA 2010b). As a greenhouse gas, SO_2 also contributes to global warming (G. Lagos 1989).

A last important atmospheric emission is particulate matter (PM_{10}) (OCDE & CEPAL 2005a). Particulate matter is fine dust of different chemical compositions which can carry toxic compounds like sulfur oxides. PM_{10} is a designation for particulate matter with an average diameter that is lower than 10 µm. We've already seen how grinding can reduce particle size to 1 µm. The erosion of tailings is therefore without doubt a source of PM_{10}, but it also originates from smelting and the combustion of fossil fuels. Particulate matter originating from copper smelters in Chile are an important source of arsenic contamination (G. Lagos 1990).

2.3 Improvements to reduce ecological impacts

It is impossible present the reader with an overview of all the technologies that help reduce the ecological impact of copper mines. Such an overview would be enough on its own to fill a book. Instead, I will explain some simple concepts that can greatly reduce the impacts of a mining operation.

The reason why I will describe relatively simple technologies, is to draw attention to the fact that technologic improvements can't go without changes of mentality. Though several technologies can easily be implemented, this doesn't mean mining companies will do so. Several cases are known where mining companies have left a devastated wasteland after their operations. The reason why mining companies don't always use readily available technologies to reduce their impact becomes clear if we look at the goal of a mine plan:

> *"The simple aim in selecting and implementing a particular mine plan is always to mine a mineral deposit so that profit is maximised given the unique characteristics of the*

deposit and its location, current market prices for the mined mineral, and the limits imposed by safety, economy, environment (Spitz & Trudinger 2009a)*."*

Profit always has to be maximized. The limits of the environment to this hunt for profit are very arbitrary. Different actors fight to move these limits either to a sustainable place or to the economically most profitable place. The influence of different actors on this mentality change will be the subject of the next part.

For now, we will focus on some possible improvements to diminish a mine's ecological impact. A first – and majorly important – concept in waste management is *'total resource utilization'*. To understand this, we have to consider waste as products of a process that have no economic value. They can't be sold or put to good use. If we can change the wastes of a mining process into valuable commodities, we attain a total resource utilization. This means that waste disposal problems would be eliminated. This is a very challenging concept to every engineer, but examples already exist. For instance, we've already seen how old waste rock dumps can be reprocessed today to extract copper. This practice, called dump leaching, is a good example of a waste product that has become a commodity due to technological improvements. The leaching solution that is used for dump and heap leaching is another example. The sulfuric acid, needed to extract the copper, is readily available in AMD. AMD can therefore be collected and treated to be used as a leaching solution (Shum & Lavkulich 1999). A much newer example is the use of hyperaccumulators for phytomining. This technique uses plants that collect heavy metals in their tissue to extract copper from low grade ores and wastes (Anderson et al. 1998; Lottermoser 2007). The advantage over leaching processes is that hyperaccumulators actually clean the waste rock and don't leave contaminating AMD behind.

Other measures seek to diminish the ecological impact of a certain externality by reducing it. One way to obtain this is the use of larger and more efficient equipment. Another way is the development of new technologies. Again, extraction by leaching is a good example. This process uses a lot less energy than the classical extraction process through flotation (Moussa 1999). In addition it diminishes the quantity of process chemicals and the quantity of water used[10]. Heap leaching becomes even more interesting in arid and semi-arid regions if the quantity of needed fresh water is reduced. In this respect, two projects in Chile – Lince and Manto Verde – use sea water for their leaching process (Chappuis 1995). In addition to reducing externalities, they can also be prevented. There are many simple ways to do so, among which the application of covers. Covers are a way to isolate sulfidic wastes from one or more causing factors of AMD (Lottermoser 2007). Waste rock can be submerged in water, called a liquid cover, to isolate it from oxygen. In arid regions, though, dry covers are used, because liquid covers would evaporate. Dry covers are made to reduce oxygen and water flow into the sulfidic waste (Harries & Ritchie 1987).

The prevention of AMD is always a lot cheaper and easier than the treatment of the problem once it has developed (Lottermoser 2007). Different and often complex measures have to be taken to eradicate AMD. In surface waters, chemicals can be added to neutralize the acid water, anoxic limestone drains can be used to buffer the AMD and wetlands can be used as filters. Ground water has to be treated by pumping it to the surface or placing permeable reactive barriers (Lottermoser 2007). These are all very complex techniques, which can be prevented by the use of covers and liners

[10] The production of copper cathodes uses about one fourth of the water used by the classical flotation process (Folchi 2003).

underneath waste dumps. The measures to treat AMD also form part of a last category of improvements, which have rehabilitation as a common goal. Another example of measures in this category is the use of dry covers for tailings. During operation tailings dams are mostly covered with water, which prevents wind erosion and AMD generation. Upon closure this liquid cover will evaporate. Therefore, a dry capping has to be put into place to take over the job of the liquid cover. Dry covers consist of materials that have a low hydraulic conductivity. They are also constructed in a way to maximize rainfall run-off. Finally, they can be topped with a loose soil to promote the establishment of vegetation that can buffer water-erosion (Lottermoser 2007).

3. Stakeholders of corporate environmental responsibility

This part of the dissertation will shed a light on the principal actors involved in the debate about the ecological impact of enterprises. The main drivers for a reduced ecological impact will be identified. Subsequently, we will look upon their relative influence and the way in which they exert their influence. Before we can enter upon those questions, though, we first have to understand the concept of *'corporate environmental responsibility'* (CER). It is this concept that today forms the principal paradigm in which policies for minimizing environmental impacts exist (Vogel 2005).

3.1 Corporate environmental responsibility (CER)

CER is a constituent part of '*corporate social responsibility'* (CSR). The term corporate social responsibility suggests that corporations have to behave in a responsible manner within society. This means they have to minimize their negative impacts and maximize their benefits (Rondinelli & Berry 2000). CER, then, forms that part of corporate social responsibility that ranges:

> *'from natural resource management and use to waste generation and disposal, recycling, the marketing of environmentally friendly products, and pollution prevention and control.'* (Vogel 2005, p.110)

In other words, it forms the environmental component of corporate social responsibility.

The history of the concept takes us to the 1960s and 1970s. It was during these two decades that the big public started to concern itself with the environment. Governments responded to this concern with a set of new rules. Companies had to comply or face sentence. This phase is known as the *'command and control'* regime (Dummet 2008). In the late 70s and early 80s, corporate culture went beyond compliance to a sense of responsibility. Companies started to recognize their responsibility and acted to it (Robbins 2001; Clark 2000). The number of enterprises that adopted this new corporate culture remained limited. From the 80s onwards, awareness of corporate environmental responsibility was further accelerated by the UN (Dummet 2008). In 1983 it started the '*World Commission on Environment and Development'* (WCED), which produced the Brundlandt Report in 1987. This report marked environmental protection as one of the three pillars of sustainable development (Brundtland & United Nations WCED 1987).

So, historically speaking, we see an evolution of corporations complying with government regulation towards them taking actions on their own initiative. Today we have a situation in which there is a foundation of rules and a number of companies that wish to go beyond mere compliance with these rules. As such, CER is currently the dominant framework within which policies and strategies for minimizing social and environmental impacts exist (Dummet 2008).

However, corporate environmental responsibility, in its condition of dominant framework, poses some important problems. All of these difficulties can be connected with the voluntary character the definition obtained throughout the years. Dummet found three major remarks in academic literature (Dummet 2008).

A first one is a concern that is especially present among NGOs like Greenpeace and Friends of the Earth. These organizations suspect that CER and CSR are abused by corporations for *'greenwashing'*. This term refers to companies hiding their real environmental impacts behind a screen of green sounding words. In this manner they can greenwash their activities and reputation. In addition they can convince the public that no more green regulations or other forms of government intervention are needed (Bruno & Karliner 2002). The very fact that CER relies on the corporation to form its own green morale, rather than adopt a standardized one by the government, allows the company to put up a green smokescreen.

A second remark has to do with the way in which CER is seen as the dominant framework. The fact that CER goes *'beyond compliance'* results in the understanding that it cannot be a generic framework. It is rather a niche, because not every company will accept its environmental responsibility. Like Vogel says:

> *'while there is a place in the market economy for responsible firms there is also a place for less responsible competing firms.'* (Vogel 2005)

As long as acting environmentally responsible can pose a competitive disadvantage, there will be companies that prioritize the economical goal of maximizing profit.

Finally, CER especially doesn't work in developing countries, where environmental problems are more serious. Vogel explains that a lot more company codes govern labor standards than environmental policies (Vogel 2005). So, while environmental problems are more serious in developing countries, there are a lot less corporate initiatives to deal with these problems. This is explained by the lack of regulation or the prospect of it in these countries.

We can conclude that the voluntary way in which corporate environmental responsibility is seen today has some serious weaknesses. It would appear that government regulation plays an important role in this story. More regulation and more unequivocal regulation would level the market playing field and abolish competitive disadvantages. Later on, we will see that corporations even ask for better regulation just for this reason. Instead of companies plotting their environmental policy, governments should give an ecological framework in which companies can maximize their profits. Ideally this should be done at an international level with local specifications.

3.2 The principal stakeholders

Determining which actors play a part in encouraging or forcing corporate environmental responsibility is a difficult exercise. There are a lot of different factors that either separately or in concert with one another help cause corporate change. This makes the matter fairly complex to tackle. A quick search immediately provides us with a diagram presenting 22 different stakeholders[11].

This dissertation doesn't allow us to tackle all stakeholders, so we need to determine the principal ones. Thankfully, this can be achieved fairly easily thanks to a research paper that already exists. Kel Dummet, in his article *'Drivers for corporate environmental responsibility'*, provides us with a set of drivers for corporate change (Dummet 2006). Based upon these drivers, we can extrapolate some key actors.

Dummet interviewed business leaders from different international companies as well as key academics, corporate analysts and environmentalists. Analysis of these interviews resulted in ten key drivers for corporate environmental responsibility (Dummet 2006, p.377):

[11] This diagram can be found in Annex 3.

- Government legislation or threat of legislation
- Cost savings
- Market advantage
- Protection or enhancement of reputation and brands
- Avoiding risk or responding to accident or environmental threat
- A *'champion'* within the organization
- Pressure from shareholders
- Pressure from consumers
- Pressure from non-government organization
- Societal expectation

Dummet emphasizes that one, some or all of these drivers can matter for a company. Because this dissertation doesn't focus on drivers, but specifically on actors, we will transform this list into four actors. These key actors embody all of the drivers found by Dummet. Later on we will also mention other, secondary actors that have a major influence in a more indirect way.

The first driver is government legislation or the threat of legislation. This is indeed a very powerful tool for governments. The government also possesses other tools that are equally powerful and which we will discuss later. Because the government can wield such powerful tools, it comes as no surprise that it has a lot of influence. In fact, most studies about the subject concur that government legislation is the number one driver for CSR (Husted 2003; Emtairah et al. 2002; Dummet 2006). However, we will see that governments don't necessarily use their influence. This is due to a whole array of other factors that drive governments.

Different drivers in the list can be classified as economical. Cost savings, market advantage and pressure from stakeholders all refer to the goal of maximizing profit. Protection or enhancement of reputation and brands, avoiding risk or responding to accident or environmental threat, and a champion within the organization all refer in a way to keeping a company's good name. As such it also refers to its popularity on the market. The actor that encompasses these drivers within itself is the corporation. Because the private sector in Chile's gran minería is run by transnational corporations (TNC), we will refer to them as TNCs.

There still remain three drivers. All of these refer to the civil society (CS). Civil society is a very vague term, which we will have to define. With this definition we will be able to distinguish between 2 actors hidden within civil society. Academic literature provides us with a wide variety of definitions. The following are two very representative ones that state that CS:

> *'… means […] the ensemble of organized social activities, formal and informal, that are not directly grounded in family and kinship, economic production and exchange, or the state but are politically relevant.'* (Rueschmeyer 1998, p.18)

> *'… setst sich aus jenen mehr oder weniger spontan entstandenen Vereinigungen, Organisationen und Bewegungen zusammen, welche die Resonan, die die gesellschaftlichen Problemlagen in den privaten Lebensbereichen finden, aufnehmen, kondensieren und lautverstärkend an die politische Öffentlichkeit weiterleiten.'* (Habermas 1992, p.443)

These definitions characterize civil society as a form of organization based on associative connections. This sets it apart from family, economic production and exchange or the state. Connections in these fields are involuntary (family) or based on money or a power structure (Dekker 2002). Civil society reflects and amplifies everyday problems and issues and makes them politically relevant. Understanding civil society as an array of associations that to a certain degree embody associative relations results in a relatively broad field. We can divide this field into a core and a grey zone (Warren 2001).

Nongovernmental organizations (NGO) form the core of civil society. They have strong associative connections and act to inform and empower. Different kinds of non-profit organizations can as well be classified in this category. Publics, then, is the grey area of civil society. Associative connections in this area are less strong. Publics, in general, is not very well organized. In this group we focus especially on consumers and the national electorate.

3.3 Stakeholders and their influence

Now that we have our set of key actors – government, TNCs, NGOs and the public – it is time to see what their influence is. With what tools do they exert influence and in which manner? We will also see how they connect to each other and to other, more indirect influences.

Our first actor to examine is the state or more precisely the state government. Today, a lot of academics, working from a system-analytic approach, state that a focus on governments or states is dated. A good example is Leslie Sklair (Sklair 2002). Defending a theory, called *'capitalist globalization'*, he argues that states today have been surpassed by TNCs that have risen to a truly global level. This instead of the international level on which governments find themselves. He argues that TNCs often possess more economic resources and can avoid state regulations by moving their operations to a more hospitable environment (i.e. a state with laxer legislation). The economical part is definitely true. Sklair assembled a list with the world's largest economical entities (Sklair 2002, p.37). Of the top ten, almost half are TNCs and 35 out of the 50 largest are TNCs. However, we will now see that governments still have a lot of influence. Even over the larger TNCs. This is definitely true for the copper mining industry, where the corporations' location is geographically bound to the copper ore bodies.

But first things first. What are the tools upon which governments can rely to incite corporate environmental responsibility? A first one is government legislation. Different studies indicate legislation as the number one driver for CER. According to a Swedish study 70% of the studied companies said government legislation was what drove them towards greater environmental responsibility (Emtairah et al. 2002). In a UK study, this was even 79% (Faruk 2003). Legislation seems such a powerful instrument that even the threat of legislation is raised as a driver by several business leaders. TNCs will comply with new legislation, but if they suspect that new rules are in the making, they will try to anticipate them with their actions (Dummet 2006). Governments can also use incentive policies. Economic incentives can be used to even out the competition, to create a level playing field. It also shows corporations the direction that government would like to see society moving (Dummet 2006). A final, but extreme measure society has witnessed governments undertake is nationalization. With this, often costly, measure even the poorest or smallest countries can put an end to an enterprise's operations in that country (Sklair 2002). The government can subsequently govern the operations to its own ideals.

These are powerful tools that all draw their power out of the Achilles heel of corporate culture: the economical goal of maximizing profit. Faced with legislation, companies have to comply or risk facing heavy fines. Trying to anticipate new rules gives companies a competitive advantage over companies that failed to do so and are forced to adjust their operations in a later stage. Economic incentives have the same effect. As for nationalization, even the mere threat of governments taking over is horrible for a corporation.

A state government is an important driver. Yet, this doesn't mean it will always use its influence to incite CER. State governments are in turn also subject to different influences that don't necessarily make them want to be a driver for CER. Countries, but especially developing countries, need corporate investment to keep their economy healthy. Developing countries are in general capital-poor countries with high levels of unemployment. This means that they are in desperate need of *'direct foreign investment'* (DFI). A direct foreign investment is one in which an enterprise is established of which the parent company exercises decisive management control (Sklair 2002). In other words: TNCs will start enterprises which they will keep under direct control. Now, TNCs, in their neo-liberalistic discourse, want to get rid of as many obstacles to free trade as possible. In this, they are supported by international financial institutions (IFI) like the IMF. Being that developing countries occupy a market niche, they all have to compete with one another for DFI. This gives them a very disadvantageous bargaining position, so they have no choice but to constantly lower taxation and regulation (Babb 2005). Environmental regulation is always a victim of this *'race-to-the-bottom'*. The need for DFI can be a strong counterforce against corporate environmental responsibility. This may also explain why international conventions in regard of CSR like those made within the UN, need so much time to be ratified (Blanco & Bustos 2002).

On the other hand, other drivers are able to push the government towards action for CER. We will see how the great public has its influence over the government. Once a problem receives attention in publics, it becomes a politically relevant issue (G. Lagos 1990). Whether or not a government chooses to comply with the public's demands, determines if it will be reelected or not. The electorate is at stake[12]. The importance of informing this grey zone of civil society immediately becomes obvious. It's only when the great public is aware of a problem, that it can lift it to political relevancy. An important source of information is the media. Sklair, however, suggests that ownership and control of television, satellite and cable systems, newspapers, magazines and films are concentrated in relatively few large TNCs (Sklair 2002). This may raise questions on the ability of media to provide unbiased information. NGOs are another informer. Thanks to the internet and other new means of communication, it is possible for them to go around the conventional media to inform the public. And they do this with success. Academics and environmentalists interviewed by Dummet emphasize that NGOs have caused a lot of high profile media attention to environmental incidents. The fact that they also in many occasions control corporations' environmental performance has been an important driver for change (Dummet 2006).

The fact that NGOs and other environmentalist organizations are constantly monitoring TNCs and informing the public about their performance, puts a serious amount of pressure on the TNC to do well. We will see that this has largely to do with how much a corporation values its market reputation. To put the finger where it hurts is probably the most important task of an NGO, but it can

[12] This is of course only possible in a democracy, where the people have the power to determine who governs the state.

also drive towards CER by empowerment. Again, academics in Dummet's interviews, state that environmental campaigns have often forced companies to change (Dummet 2006). If NGOs can get the loosely organized (international) public to focus their energy on one goal, this can be a major driver for CER. An example in the social domain is the exposure Nike got for using sweatshops. As already mentioned, publics can have an indirect influence through pressure on their government. However, as consumers they can put pressure directly on the company as well. All business is ultimately customer driven. Unfortunately, till this day, the influence of consumers hasn't been fully used because they lack organization as a group (Dummet 2006).

Until now we've presented the TNC as an actor which undergoes influences from other actors to change its environmental policies. There can, however, also be a strong drive for CER coming from within the TNC as an entity. CER can be unprofitable because environmental costs have to be internalized, where before they could be translated to society (Matta 2004). Yet, on the other hand business leaders understand how important the reputation of their brand is. They also understand how easily this reputation can be dragged through the mud (Dummet 2006). Take BP for example. This company has spent years trying to create a green image, but has lost all credibility following the Deepwater Horizon oil spill (Fonda 2006; Walsh 2010). A green reputation gives companies a way to differentiate and by consequence create a market advantage. A damaged reputation, on the other hand, can cause shareholders to stop their investments or consumers to stop buying.

It appears that companies are willing to take their responsibility, just as long as this doesn't give them a competitive disadvantage. That is why they try to anticipate new rules, but will never go too far ahead of regulation. This could again turn into be a disadvantage if the government chooses a different direction. We can once more find proof for this theory in Dummet's research. His most remarkable finding was that companies themselves actually supported more government intervention. Their CEOs argued that a guiding regulatory framework creates certainty and a level playing field (Dummet 2006). The competitive disadvantage of CER would disappear and companies would be more certain as to where society is moving. A regulatory framework would provide the clarity and competitive equity that is needed for a more complete corporate environmental responsibility.

4. Copper exploitation in Chile

4.1 Chile's political history (1970-2000)

During the 1960s and 1970s the Chilean electorate was fragmented in a big variety of social groups. All these different groups had very different interests. The consequence was a proliferation of political parties, which were all struggling to convince as large a proportion as possible[13]. One of these groups was the middle class. The group included a section of the work-force, known as white-collar workers (or 'empleados'), which in 1970 made up 24% of the work-force in manufacturing, 49% in the service sector and 29% in the commercial sector (Bethell 1993). The group also included teachers, shopkeepers, managers, etc. The sheer size of the group and its consequent political power made it a key subject of political struggle in Chile.

The fragmentation of the electorate, combined with their increasing power to make organized demands on the economic system, made economic issues highly politicized in Chile. It also gave rise to a general feeling that the economy was in serious difficulty. What the situation was like at the time is clearly illustrated by president Frei in his outgoing speech:

> *'The country is destined to tackle inflation either by consensus which is the democratic approach or by coercion: but an inflationary process like that which Chile has been experiencing over recent decades will lead inevitably to a Grave social and economic crisis. The problem is more than merely technical. From the technical point of view the procedures for containing inflation are well known. But what happens here is that the patient calls the doctor and then he doesn't want to take the medicine. The problem is mainly political. […] Everyone wants the sacrifices to be made by others than themselves. Every year I presented laws which would have enabled us to control inflation and every year they were rejected. Then the very people who had rejected these laws and fomented conflicts were the very ones who said that the government was to blame for inflation. It is a game with sinister overtones.'* (Thorp & Whitehead 1979, p.68)

The fluctuating rate of inflation in Chile between 1958 and 1988 clearly indicates the instability of the Chilean economy[14]. But the poor economic performance shouldn't be exaggerated. The overall annual growth rate per capita between 1960 and 1970 was 2,6% and also thereafter there were high rates of growth despite a decline in the overall rate (Bethell 1993). The political incapacity to counter the country's inflation enlarged the feeling that the economy was in difficulty.

[13] The Unidad Popular on its own already consisted of six parties. The socialist party (PSCh), the communist party (PCCh), the radical party (PR), the social democrats (PSD), the MAPU and the API.

[14] The rate in Alessandri's first year was 33,1%, which was reduced to 5,4 and 9,4 in the following two years, before accelerating again to 45,9% in 1963. The Frei government slowed the rate down again to 17,9% in 1966, but it accelerated again in 1970 to 34,9%. Allende again found a way to diminish the rate to 22,7% in 1971, but in 1973 it stood at an all-time high with 605,9%. During the two decades of Pinochet's regime, inflation kept dropping to a low point of 9,5% in 1981, after which it rose again to 20,7% in 1982 and eventually 12,7% in 1988 (Bethell 1993). During 1990s inflation diminished again to 5,1% in 1998 (World Bank 2009).

The fact that economic issues became so highly politicized in Chile gave way to a strong presence of the state in almost every aspect of economic activity. During the administrations, leading towards the election of Salvador Allende, the state came to control a growing share of the GDP, rising from 38% under Alessandri to 43% under Frei and 53% under Allende himself. The state's share of investment was even higher (Bethell 1993). Even during Pinochet's regime a very important part of economic activity continued to be controlled by the state[15]. The high level of state involvement in the economy is known as statism or etatism. In Chile we find this type of political economy under a more direct form of state-controlled enterprises (as opposed to the communist command economies).

As a consequence of this central characteristic of Chilean economy, we have to examine the political history of Chile to be able to understand the economical context in which the copper-industry in Chile has evolved during the last four decades.

Before the election of Salvador Allende, the political scene in Chile changed. The large quantity of national parties merged into three political groups. In 1957 the Falange Nacional and the Social Christian Conservative Party formed the Partido Demócrata Cristiano (PDC – Christian Democratic Party) to support Eduardo Frei Montalva's presidential candidacy. The PDC represented the center of the political landscape. On the Right ideological disagreements between the different parties were overcome under the threat of their electoral collapse. In 1965 the Liberal Party, the conservatives of the Acción Nacional and an important number of political independents joined forces to form the Partido Nacional (PN – National Party). In a response to the new competition posed by the PDC, the Socialist and Communist Parties decided to broaden and strengthen their fragile alliance. Together with four other parties, they formed the Unidad Popular (UP – People's Unity) as a new left-wing alliance.

The three political groups all brought forth one candidate that enjoyed the support of all the parties in their union. Radomiro Tomic, the candidate of the PDC, based his campaign on the acceleration of reforms already implemented by the outgoing PDC administration under Frei. The UP chose Salvador Allende as candidate. It was his fourth time running for president. He focused his campaign on profound economic, political and social change. There were actually many similarities between the PDC- and UP-campaign. Both wanted social and economical reforms, but a major difference was to which extent. This gave the candidate of the PN, Jorge Alessandri, an advantage over the others. He based himself on a platform emphasizing very different subjects like authority, law and order. So, while the others had to basically divide the same electorate between themselves, Alessandri could rely on his own electorate without competition.

Nevertheless Allende was elected, albeit by a very narrow margin over Alessandri. Allende beat Alessandri by 1,32%[16]. The support he had was small and fragile and in it lay the roots for the coup d'état of 1973. The tasks Allende faced were much more formidable than those of his predecessors. His campaign had been based on a program of nationalization of all major industries and commercial enterprises, a redistribution of incomes by wage and taxation policy, and a couple of fundamental

[15] In 1980 the top eight firms in Chile were still in state hands, even though they were expected to operate as private firms. In addition much of the financial system was taken over by the government during the recession of 1982-1983 (Bethell 1993).

[16] 36,3% of the electorate voted for Salvador Allende. 34,98% voted for Alessandri and 27,84% voted for Tomic (Hickman 1998).

constitutional changes (Hickman 1998). Allende was determined to follow this revolutionary program no matter what, but was faced with a large opposition and a weak support. On its own, this situation was nothing more than an extreme version of previous administrations. What made the situation unique, though, were the high levels of intensity the political and ideological polarization and conflict reached during his three years of power. According to Bethell no constitutional political system could have survived it (Bethell 1993).

The ambitions of the UP during its early days in power were made very clear by Carlos Altamirano, leader of a more extremist faction within the UP: *'The bourgeois state in Chile will not serve as a basis for socialism, and it is necessary to destroy it'* (Hickman 1998, pp.94-95). Although it was the more extreme faction of the UP which declared this class war, President Allende took up the theme with enthusiasm. A first step was to finish the 'enemy' off now that he was on the ground. The economical power of the bourgeois and middle classes had to be broken before they could recover from their electoral defeat. This was to be done by the more rigorous application of the *'Ley de Reforma Agraria'* (Agrarian Reform Law) of the Frei administration. And – more importantly for this work – the nationalization of the major industries. The nationalization was also a more extreme continuation of what had already started under the Frei administration. The PDC – during its government years – had started with the 'chileanisation' of the economy. At the end of the Frei government, 40% of the economy was already state-owned, 30% depended on state funding and only 30% was entirely in private hands. The UP took it to the next level by announcing that it would nationalize another 120 of the key enterprises in the national economy. The mining sector became an obvious target, having few defenders within Chile itself. In a period of twelve months the government had taken over the *'gran minería'*, the financial sector and the most important manufacturing concerns, thus nationalizing not 120, but 190 large companies (Hickman 1998).

The first year of the UP government, the drastic measures seemed to have a positive effect on Chile's economy. It was even one of the best years of economic performance in Chile's history. The GDP per capita increased by 7,7%, unemployment dropped 3,1% and inflation decreased to 22,7% (Bethell 1993; Hickman 1998). Allende took further measures to increase economic performance by awarding an average wage increase of 35% to all workers and freezing prices. This led to a huge wave of consumption as millions of impoverished people suddenly had financial resources. This one golden year evidently came at a huge prize.

A lot has been speculated about the involvement of the United States in the economical collapse of Chile in 1971-1972. Allende, himself, repeatedly blamed the 'invisible blockade' of Chilean economy by the US. Hickman rejects the idea of a US boycott, but Bethell nuances this view and believes that there actually was a virtual economical boycott[17] (Bethell 1993; Hickman 1998). However, they do agree that – with or without an 'invisible blockade' – the decline in export earnings, the flight of private capital and a rising fiscal deficit were all prime causes. Inflation rocketed to 260% in 1972 and 600% in 1973 (Hickman 1998). This was an increase Chile had never experienced before. The government started to lose control of the economy. Production dropped every month. There were

[17] Bethell shows that US loans were cut off, the US influence in the World Bank and Inter-American Development Bank were used to Block loans, US copper companies took legal actions to block export of Chilean copper, and so on. He also puts the attention on the fact that the Chilean economy was so tied to the US economic system, that these actions definitely have had a negative effect.

huge shortages of almost all consumer goods, especially food. As a consequence, the government also lost control of the people. The opposition regained power, there was a nationwide protest and Allende had to call in the help of the armed forces. Eventually the situation led to a spiral of violence, resulting in the putsch of 11 September 1973.

From the putsch on, Augusto Pinochet reigned a military regime in Chile for almost 2 decades. He was the nominal leader of the military coup and after the coup he was chosen as leader of the temporary military junta. A year later he was appointed President of Chile. Understanding his background, this came as a bit of a surprise. He was born a son of a customs officer in Valparaiso and joined the military academy in 1932 at the age of 16. Notwithstanding his subsequently quick rise in military ranks, he never openly confessed political color. He stayed loyal to the Chilean military tradition of unquestioningly serving any constitutionally elected president. He became the last commander-in-chief under the UP government and enjoyed complete confidence of President Allende. Allende is even said to have declared that he was just an old soldier *‘not even capable of deceiving his wife’* (Hickman 1998, p.120). It was only until less than three weeks before the date of the coup, that he placed himself at the head of the conspiracy. And even during the coup he carefully sat on the fence. Also in the process of deciding the course of actions to be followed after the coup he wasn’t a dominant voice, but he quickly proved to be a fast and determined learner (Hickman 1998).

The military coup brought with itself a fundamental change in Chilean economic politics. After a hesitating start, during which hope for a stabile economy was still placed with state intervention, Chile broke with its tradition of statism. Instead, during the Pinochet regime, Chilean economic policy would follow the monetarist guidelines set out by a group of economists, known as the *‘Chicago Boys’*. The Chicago boys were basically a large group of Chilean economic students (especially from the Universidad Católica) who absorbed the monetarist theory of economics from its most renowned protagonists, Milton Friedman and Arnold Harberger, at the University of Chicago. They were able to study in the United States under the new Point IV exchange program. Back in Chile they passed the theory on to others under the guidance of Sergio de Castro, Dean of the Catholic University’s Economics Faculty. Their bible was a huge document, presenting a plan for a Chilean economy based on the free market model, which they quite accurately called *‘el ladrillo’* (the brick). In short they saw the application of free market forces combined with tight control of money supply as the keys to a good economic policy and even to many aspects of social affairs (Hickman 1998).

The Chicago Boys didn’t really gain influence until 1976. The military leaders still shared the opinion that economic assets were a matter of national security. Therefore economic policy ought to be controlled by a national authority. Although economic policy already followed their ideas of shock treatment to turn the economy around, it was only at the end of 1976 that Sergio de Castro was appointed as Minister of Finance[18]. He was supported by other Chicago Boys in key positions: Pablo Baraona was Minister of Economy, Alvaro Bardón President of the Central Bank and Miguel Kast became Roberto Kelly’s chief collaborator in ODEPLAN (Hickman 1998). From then on they would guide the economical recovery of Chile with the unconditional support of President Pinochet.

The monetarist economic theory focuses on macro-economic indicators to determine a country’s economical success. According to these indicators, Chile did very well between the second half of the

[18] He was to stay in this post until April 1982 (Bethell 1993).

1970s and the 1980s. In 1973, as already mentioned, inflation was over 600% and rising. Production was declining rapidly in nearly all sectors, the overall GDP was 4,3% lower than the previous year and government deficit was a quarter of the GDP. In addition, nationalized industries were losing $500 million per year , so the government deficit was likely to rise even further. All the currency reserves had disappeared and Chile wasn't able to pay its international debt (Hickman 1998). As from 1975, thanks to the adoption of free market principles, the opportunities created by privatization and a better legal status for foreign private investors, foreign lenders and investors were again happy to invest money into Chile[19]. As a result, the macro-economic indicators were very positive at the end of a decade of Chilean monetarism. GDP had been rising by more than 5% per year for three years and inflation was down to 31% and falling[20]. The fiscal deficit had entirely disappeared and the balance of payments was positive. The international debt was manageable at $10 billion. In addition the reserves amounted to $4 billion thanks to the large inflow of foreign investment and loans (Hickman 1998). Another improvement worth mentioning is that the promotion of export-driven growth gave an incredible boost to the production and export of Fishing products, timber, wood pulp and paper, and fruit. As a consequence, Chile's dangerous over-reliance on exports of copper and other metals was reduced (Hickman 1998).

However successful the macro-economic indicators presented the Chilean economy, only a limited share of the people reaped it's fruits. The Chicago Boys upheld a classic neo-liberalistic idea: if the sea rises, all ships must eventually rise with it. According to them the fruits of Chile's economic success would eventually trickle down to the poorest people. In 1975, the bad condition of the economy was hitting everyone in the working classes. Even those with jobs were desperately poor. At the end of the decade many well-placed Chileans were getting richer, but the trickle-down effect didn't seem to kick in for the poorest half of the population. ODEPLAN estimated that in 1975 21% was living in extreme poverty. In 1982 that level had fallen to 14,2%, but other studies showed that even in 1985 45% was still poor (Hickman 1998; Torche 1987). The government didn't sit at the sideline and watched, though. Efforts were made, especially from 1979 onwards, to improve the social situation, but despite these new improvements poverty kept being persistent (Hickman 1998).

During the years 1982 and 1983 Chile received its worst economical crisis since the 1929-1930 depression. It began with the *'second oil shock'* of 1979. The world slid into recession and demand for exports diminished rapidly. For Chile this was a disaster. Its peso was seriously overvalued and the private sector had incredible foreign debts. This was directly and indirectly the fault of Sergio de Castro and the Chicago Boys. They were out of favor, but the Chicago model survived and made a come-back in 1985 – albeit under a slightly adjusted form[21] – with the appointment of Hernán Büchi

[19] For a detailed analysis of the economic measures taken by the Chicago Boys under Pinochet, I'd like to redirect you to Bethell 1993, pp 181-186; Hickman 1998, pp 140-155. Bethell and Hickman both suggest other works concerning the economy under the military regime (Bethell 1993, p 230; Hickman 1998, pp 242-243). Arturo Fontaine gives an insider account of the role of the Chicago Boys', which should be very interesting and is mentioned by both authors (Fontaine 1987).

[20] By 1981 it was down to 9,5% (Bethell 1993).

[21] Büchi followed the neo-liberal principles, but was prepared to intervene in the markets if necessary. An example is his use of tariff and price support measures to protect traditional farmers from unfair foreign competition and the wilder fluctuations of the market. He accepted the free market model, but was above all a pragmatist and a problem solver (Hickman 1998).

as Minister of Finance. However, before this come-back, during the crisis, the state was again forced to take over 80% of the privatized financial system and an important number of industries. The Chilean economy was once again in serious troubles with a GDP that had fallen by 14,1%, a peso that had fallen by 40% and industrial production that had fallen by 21% at the end of 1982. Unemployment rose to nearly 20% and the resulting social unrest gave the opposition to the military regime a chance to grow again (Hickman 1998).

During the rest of the 1980s the economy recovered – especially thanks to Finance Minister Büchi – but the critics to the regime had found permanent ground and Pinochet became increasingly cornered. Not only from within the country, by the Alianza Democrática (Democratic Alliance), but also from the international community. A heavy blow in this respect was the official stance Ronald Reagan took against Pinochet in 1984, saying that *'The lack of progress towards democracy in Chile and Paraguay is an affront to human consciousness* (Hickman 1998, p.186)*.'* Pinochet tried to postpone the progress to democracy as long as possible, but by the end of the decennium he had to give in. In 1988 a plebiscite was held, in which 55% voted for a return to democracy (Hickman 1998).

Obeying the plebiscite, Pinochet announced presidential and congressional elections to be held in December 1989. The elections of 1989 were fought out between three presidential candidates. The Christian Democrats, leading the Concertación de Partidos por la Democrácia (Coalition of Parties for Democracy) delegated Patricio Aylwin Azocar, the de facto leader of the Coalition[22]. The right send Hernán Büchi as their candidate. His good reputation as architect of the economical recovery was damaged, though, by the lack of unity on the right. The emergence of another candidate, the populist millionaire Franscisco Javier Errázuriz, diminished the chances of the right even more. Patricio Aylwin won the elections with a decisive 55,2%[23] (Hickman 1998).

All the following democratic presidents – Eduardo Frei Ruiz-Tagle, Ricardo Lagos and Michelle Bachelet – were candidates of the centre-left Concertación de Partidos por la Democrácia. Current President Sebastian Piñera is the first to break with this tradition. He comes from the right-wing Coalition for Change.

The Concertación could take advantage of a strong economic growth behind it. Fundamental changes with the economic policy of the Pinochet-years weren't made. The Chilean political field – with the exception of the communists – by now were convinced that private initiative could deliver the economic development more efficiently than state-run enterprises. As a consequence the main lines of economic policy were kept: export orientation, low and non-discriminatory tariffs, and strong guarantees for private investment. Alejandro Foxley, the new Finance Minister, kept himself to fine-tuning interest rates and the money supply to correct macro-economic faults. The two most obvious changes were that there were only a small number of further privatizations after 1989 and that government expenditure was raised to level the social debt, built up through the previous two decades (Hickman 1998).

This was done through a new social development fund, financed largely with the additional revenue from higher taxation. The Aylwin administration increased spending on public services like health and

[22] It was the Concertación de Partidos por la Democrácia that formed the main opposition to Pinochet in the 1980s. It was a coalition of parties with the PDC as most important and dominant member.
[23] Büchi received 29,4% and Errázuriz 15,4%.

education by about one-third between 1989 and 1993 under the device *'no one actually lives in the macro-economy'*. The new policy was described as one of promoting *'growth with equity'* (Hickman 1998).

The macro-economic indicators for this most recent period in Chilean history remain stable. In 1990 inflation had gone up again to 26,3%, but by 1998 it stabilized at 5,1%. Last year Chilean inflation was even lower at 1,5%, though we have to take into account the effects of the global economical crisis[24]. The growth rate of the GDP dropped from 10% to 2,1% in 1990. In 2007 and 2008 it remained between 3% and 5%[25]. The account balance remains manageable: in 1990 -0,8 billion dollars and in 2009 -7,2 billion dollars. External debt went from 18,6 billion in 1990 to 60,9 billion dollars in 2009. Also, DFI knew an impressive growth from 587 million dollars in 1990 to 116,5 billion dollars in 2009 (CIA 2010; World Bank 1992).

The part about the social reforms made by Chicago Boys under Pinochet can come in the part about the history of copper mining in Chile (applied to the sector) or in this part.

4.2 Nationalization and privatization: searching the balance

The majority of Chile's copper reserves are located in its northernmost regions, called El Norte Grande. Chile obtained this territory and its mineral riches during the War of the Pacific at the end of the 19th century (Hickman 1998). Though this war was a dispute about the important saltpeter sources in the region, it are the copper reserves that have become so important for Chilean economy. Only a small part of the Chilean labor-force works and has worked in the mining industry, but the sector is of vital importance for the money-flow of the nation[26]. Until the end of the Pinochet regime between a quarter and a third of total tax revenue came from the copper sector and from imports (Bethell 1993). Chile's economy has always been highly dependent on foreign trade. And although Chile now can rely on other export products like fruit, wine, seafood and wood, its most important export product has since long been copper (Hickman 1998). Even in the 21st century, the export of raw and refined copper constitutes 56,5% of Chile's total export[27].

As a result, Chilean government has always tried to make the sector as profitable as possible. We've already seen that opinions on how to achieve this profitability have differed greatly. These opinions always revolved around the amount of DFI. We can describe the general evolution as a pendulum swinging from a privatized industry, towards nationalization, towards a mixture of both.

The Frei-administration took the first step towards limiting foreign investment in the Chilean copper-industry. At the time almost all the major copper mines (the gran minería) were controlled by North American copper companies. The Christian Democrats started negotiations with the principal US interests, Anaconda and Kennecott, for a 'c*hileanisation*' of the industry. The goal was to acquire

[24] In 2008, inflation was at a rate of 8,7%.
[25] 4,7% for 2007and 3,2% for 2008. The growth rate for 2009 is -1,7%, but again we have to take into account the global crisis.
[26] In 1950 5,1% of the work-force worked in mining. In 1980 this had become only 3% (R. Lagos & Tokman 1984).
[27] This is the percentage of the year 2006. The years 2005 and 2004 also give a percentage in the 50%. The years 2003 and 2002 give a lower percentage: 36,1% and 39,7%. But this can be a consequence of the poor state of Chilean economy during these years (Ministerio de Minería 2011a).

majority interests in each of the companies, thus having a better grip on the sector[28]. This was a variation on the original plan of the Christian Democrats to nationalize the industry. Negotiations did not lead to a final agreement till 1969.

The Allende-administration took things to the next level. In their urge to undermine the bourgeois and middle class, they sought to nationalize the key sectors of the Chilean economy. The foreign investments in the copper industry became a prime target. The chileanisation law, approved by the congress under Frei, already stipulated that the state had to have a 51% share in all the foreign owned ore deposits. By the end of Frei's term, this target was achieved in the most important deposits. In 1971, with Allende in power, congress unanimously approved a new law nationalizing the entire '*gran minería del cobre'* (CODELCO 2008b). A new state-owned corporation, CODELCO, was created. This corporation had to manage the entirety of the gran minería.

The nationalization of the Chilean copper-industry formed part of a larger wave of nationalizations around the world. Along with CODELCO, other state-owned mining corporations were created like ZCCM in Zambia and Gécamines in what was then known as Zaïre. As we can see on table 1, these corporations kicked the large private corporation of their throne and became the largest producers of copper. The large private corporations, like Kennecott and Anaconda, obviously didn't want to go down without a fight. They started putting pressure on their own government in the US to retaliate. The relations between Chile and the Nixon-administration were already pretty cool, so proposals for economic sanctions and legal actions were taken under consideration. Nixon threatened '*to make the Chilean economy scream*', but Washington's eventual response was fairly restrained (Hickman 1998, p.96). This was due to pressure of other US companies that feared for their investments in Chile.

The big private companies weren't able to recover from the crisis they had entered. As a result these companies started to change owners, merge and even disappear. Kennecott and Anaconda, till then the biggest copper producers, didn't escape this fate. After losing its enormous Chuquicamata-mine, Anaconda was obtained by ARCO in 1977. A sudden drop in copper prices caused ARCO to stop the company's activities. Kennecott was eventually bought by the UK-based Rio Tinto Zinc (now known as Rio Tinto) in 1989. Rio Tinto Zinc was the last in a series of companies that purchased majority interests in Kennecott. Rio Tinto is today the second largest shareholder in the Escondida-project that operates the Escondida and Escondida Norte mines in Chile[29].

Under Pinochet efforts were again made to attract transnational copper-mining corporations. CODELCO kept on existing, but now became state-owned company among private companies. Nationalization had become a thing of the past. Different laws were voted to try and attract DFI once again. The *'Ley Orgánica Constitucional de Concesiones Mineras'* guaranteed TNCs that they would be able to keep their acquired property by transferring the competence of expropriation to the judicial power (Ministerio de Minería 2011b). Such efforts at first encountered a lot of skepticism,

[28] Hickman notes that US capital was so dominant in the Chilean copper industry in the 1960s that it could be manipulated in such a way to control the Chilean copper prices well below the prevailing international prices (Hickman 1998).

[29] The merging and changing ownership of these enterprises forms a complicated history. This paragraph gives a very concise view of the changes they went through. I base my synthesis on the websites of the various companies (Kennecott 2010) and (Rio Tinto 2010) and on a CEPAL-report about the evolution of copper mining in the twentieth century (Moussa 1999).

but eventually led to a massive surge in DFI. This copper boom started in the late 1980s with investments by Escondida (G. Lagos 2004).

Between 1990 and 2002 the copper boom was good for an investment of 18 000 million US dollars. This was the most important part of total foreign investment in Chile. Chile's copper production tripled in this period, reaching an annual production of 4,6 million tons of copper. By consequence, Chile's share in the world's total copper production in 2002 amounted to 30% (Ministerio de Minería 2011b). This massive production increase also led to a massive increase in waste production and water- and energy-consumption. By consequence the ecological impacts of Chile's copper mines increased dramatically.

The copper boom left Chile with a copper industry in which private companies and state-owned companies operated next to each other. A balance was found after a first period in which the sector had been completely in the hands of TNCs and a second period in which the sector had been state-owned in its entirety.

Table 4.1: The principal copper-producing companies of the western world (expressed in marketshare*)[30].

1925		**1935**		**1948**	
Kennecott	22,8	Anaconda	17,1	Kennecott	21,6
Anaconda	18,6	Kennecott	13,6	Anaconda	15,2
Calumet & Hecla	7,6	Niquel International	7,8	Phelps Dodge	10,4
Phelps Dodge	7,2	Union Minière	7,8	Union Minière	7,2
Union Minière	6,8	Amax Roan	6,6	Amax Roan	5,7
First Five	63,0	First Five	52,9	First Five	60,1
1960		**1969**		**1980**	
Kennecott	14,4	Kennecott	13,3	CODELCO	13,0
Anaconda	13,0	Anaconda	11,3	Gécamines	8,9
Anglo American	10,2	Anglo American	8,0	Zimco (ZCCM)	5,9
Union Minière	8,4	Union Minière	7,5	Kennecott	5,6
Amax Roan	6,1	Amax Roan	7,0	Phelps Dodge	4,5
First Five	52,1	First Five	47,1	First Five	37,9
1993		**1995**		**1998**	
CODELCO	15,1	CODELCO	14,5	CODELCO	14,6
RTZ	7,6	BHP/Magma	9,6	BHP/Magma	8,1
Phelps Dodge	7,3	Phelps Dodge	8,0	Phelps Dodge	7,8
ZCCM	5,4	RTZ	7,7	RTZ	7,5
ASARCO	4,1	Freeport	5,5	Freeport	6,4
First Five	39,5	First Five	45,3	First Five	44,5

* For the year 1980, the numbers refer to production capacity. For the other years, the numbers refer to actual production.

[30] Based upon (CEPAL 1994) and different annual reports of CODELCO, through (Moussa 1999).

5. Chilean copper and the environment

Throughout the thesis, we came to understand the potential ecological impact of a copper mine, the ways in which these impacts can be reduced and the driving actors for such reducing initiatives. We also obtained insight in the way Chile's political history influenced the Chilean copper industry. Now it's time to use this knowledge to understand the evolving impact of Chile's copper industry on the environment, as well as the way in which this evolution was pushed by different actors.

5.1 The ecological impact of Chile's copper industry (1970-2000)

There's no question about it: Chile's copper industry has had an enormous impact on the environment throughout the years. The impact was already considerable in the early 70s due to a complete lack of environmental consciousness and sense of environmental responsibility (Camus & Hajek 1998). In the following decades, it has done nothing but grow. This growth can largely be ascribed to two evolutions. First, the production rate of Chilean copper increased significantly. Especially during the copper boom of the late 80s-90s. Secondly, the ore-grades of Chilean copper kept dropping. Both evolutions resulted in an increased waste production (G. Lagos 1989). These recent decades of unrestrained exploitation of Chile's copper reserves have led to an enormous ecological debt, which can't be covered by today's initiatives for ecological responsibility (Camus & Hajek 1998).

The emission of the gas sulfur dioxide (SO_2) is a fine illustration of the enormous impact of Chile's copper industry on the environment. In 1989, the industry produced 60% of the total SO_2 production in the country (G. Lagos 1989). This large share becomes even more staggering if we consider the difference of SO_2 emission between Chile and the United States. Chile produced about 2 million metric tons of SO_2 in 1980. The United States produced 24,1 metric tons in the same year. This means that an economy with a GDP 150 times bigger than Chile's produced only 12 times more SO_2 (G. Lagos 1989). This difference illustrates clearly the high relative levels of contamination for Chile and the little attention for the problem at the time.

In what follows I will discuss the key issues of the ecological impact of the copper industry in Chile. I will not try to give a complete overview of all environmental problems. If the reader is interested in such information, he can consult the works of Hajek, Gross and Espinoza (Espinoza et al. 1994; Hajek et al. 1990). These present an extensive panorama of the environmental problems Chile faced at the beginning of the 90s.

5.1.1 Atmosphere

For Chile, the impacts we've considered extensively earlier on mainly affect the atmosphere, water bodies and soils. When it comes to the atmosphere, the main contaminants are SO_2, arsenic (As_2O_3) and heavy metals. The most important causes of SO_2 are the pyrometallurgical facilities of the copper industry and thermal power stations[31]. In actual numbers, the emission of SO_2 in 1989 had risen to about 2 million metric tons per year. This number started to drop from 1990 onwards thanks to improvements which we will discuss later. In 1993 the industry emitted 1,6 million tons (G. Lagos 1990). This was still a large amount. The effects of SO_2 mainly concern loss of biodiversity in plant

[31] Thermal power stations in Chile used to operate on carbon. Today they are again switching over to carbon after an intermezzo of petrol-based energy. Carbon can contain large amounts of sulfur. In Chile, however, sulfur-rates in carbon are low. As a result the share of thermal power stations in the total production of SO_2 in Chile isn't that big (G. Lagos 1989).

life. The gas destroys plants' chlorophyll and thus their ability to photosynthesize (Gonzalez & Bergovist 1986). If SO_2 mixes with water in the atmosphere, it precipitates as acid rain. The well-known effects of acid rain are lethal for a large part of Chilean plant life. On a more global scale, SO_2 also contributes to the greenhouse effect.

The fact that SO_2 is so harmful for the flora of a region makes it a great danger for another important economic sector of Chile: agriculture. Especially plants like alfalfa, wheat, barley, peas, spinach, lettuce, tomatoes and beans are vulnerable. A well-known example of how the copper industry has inhibited agriculture in certain regions of Chile is Ventanas. The emission of SO_2 and other contaminants (like heavy metals) by the copper smelter of Ventanas has made any agricultural or cattle breeding activity impossible within a large region around the smelter (G. Lagos 1989).

Arsenic and heavy metals are also produced by pyrometallurgical facilities, but can equally come from dried out tailing dams. These contaminants travel via particulate matter. Heavy metals precipitate in a relatively small area around smelters. Heavy metals affect plant's growth and reproduction. They can be deadly for animals in high concentrations and block their reproductive capacities in lower concentrations. In some cases animal life disappeared completely in areas close to smelters (G. Lagos 1989). Arsenic can be found in high concentrations in the country's minerals. As a result, arsenic can be seen next to sulfur dioxide as the two most important problems Chilean atmosphere faced in the 70s and 80s. In addition, the impact of arsenic on public health is much bigger than that of sulfur dioxide (G. Lagos 1990). Before 1989, however, this was still not a concern for most of the Chilean smelters. For instance, in 1987, the smelter of the Chuquicamata mine emitted between 30 and 35 metric tons per day (Zauschquevich 1987). This was such a high amount that it alarmed the inhabitants of the nearby town of Calama and led to the evacuation of the population of Chuquicamata (G. Lagos 1989). Other important emitters of arsenic in the atmosphere were the smelters of Ventanas, Refimet (now known as Altonorte) and El Indio. The last one being a gold smelter.

5.1.2 Hydrosphere

The impact of the copper industry on the atmosphere in Chile was already well studied by the early 90s. It was also a relatively easy field of research: there was one major cause, the copper smelters, and the link between the contamination and the effects was quickly determined. This was not the case for the impact on waters and soils. The sources of contamination were much more diverse and not only linked to the copper industry. In addition, the effects were much more complicated (G. Lagos 1989). Finally, until 1990, there just wasn't much known about the contamination of waters and soils in Chile. Most of the research about the problem started after this date and once more knowledge was gathered, the problem proved to be much bigger than previously expected (G. Lagos 1990).

There is one study, that dates from before the 90s (1998), which can be seen as the first effort to map out the hydrological contamination in Chile (CADE-IDEPE 2004). It's a study of the contamination in the drainage basin of the río Maipo and the estuary Carén. The study was very relevant for this research, because the basin received the effluents of La Disputada de Las Condes and El Teniente, two copper mines. The study focused on the presence of heavy metals and process chemicals in the basin. According to the study the two mines had an overwhelming share in the provision of heavy metals. 99,9% of the molybdenum was traced back to El Teniente. Of the total amount of lead and arsenic, respectively 52% and 78,7% was traced back to El Teniente. Regarding copper, 76,4% came from La Disputada de Las Condes and 10,3% came from El Teniente. If we take in account that El Teniente is an underground mining operation and La Disputada de Las Condes an open-pit operation, this difference isn't that odd. As we have learned, an open pit creates much more waste, with much more possibility of heavy metals leaching and entering water bodies.

These overwhelming shares in the presence of heavy metals don't say anything, though, about contamination. To learn more about the contamination, we have to look at the number of times the norms were exceeded. At the time, these had been established for drinking water and irrigation water. In both cases the two mines were major causes of values in excess of the norm. In the case of irrigation water, the number of times they made heavy metal values in the basin rise above the norm was almost as large as that of the entire capital city. In the case of drinking water, they were the only two anthropogenic sources of contamination. It's important to remark that natural leaching was also an important source of contamination with certain heavy metals. These large values are reflected in the surrounding soils, which have accumulated heavy metals. The researchers already realized that this was a major problem for the agriculture in the area. Especially because it was irreversible, for they didn't know a way to purify the soil.

It is remarkable that the study didn't mention the problem of acid mine drainage. This has proven to be the biggest environmental problem a mining operation can face, but the researchers didn't seem to be aware of it. If we look closely at the study, however, we see that AMD was a problem. First of all, we have learned that it is acid mine drainage that leaches waste rock and tailing dams and carries away heavy metals. Therefore, AMD can very well have been the reason why heavy metal values were so high in waters and soils of the Maipo basin. This is confirmed by the fact that 78,2% of the encountered sulfates originated from El Teniente.

A similar study of the same basin in 2004 shows us that the situation hasn't changed a lot (CADE-IDEPE 2004). The study still points out that mining in the region is the most important reason why values of heavy metals and process chemicals exceed the norm. Disputada de Las Condes is even named as the single most important source of large quantities of heavy metals. It is again important to know that for metals like copper, molybdenum and manganese, natural leaching is still an important source. In this respect it comes second to the mining activities in the region. With respect to acid mine drainage, the researchers now indicate that AMD-generation – along with breaches in tailing dams, discharge of mine waters and leaching of waste rock – is an important cause.

A completely different way in which the mining industry has had an hydrological impact on Chile is through its water consumption. We've already seen how much water a mine can consume. Keep in mind that mining today consumes 70% of the present water resources in Antofagasta and 60% in Atacama. This poses a big threat for the traditional communities, especially Aymaras, in the region. Because of the scarcity of water, caused by mining operations, these communities can no longer depend on agriculture for their survival (Camus & Hajek 1998). The threat of losing their means of survival is one of the most important reasons why local people resist the arrival of new mining operations all over the world. This leads to social conflicts that often take a violent turn. One of the most recent of these bloody conflicts was that of Bagua in northern Peru where at least 30 people lost their lives (CATAPA 2009a).

5.1.3 Lithosphere

Other than the atmosphere and the hydrosphere, the Chilean copper industry has also had a big impact on the lithosphere. Soils probably have suffered the biggest impact, because they accumulate all the contaminants that mankind emits into the atmosphere, the hydrosphere and the lithosphere. This means that every time a norm for a contaminant in a certain sphere is exceeded, this has an accumulated effect on the soils. However, soils also have an active, filtering effect. An example is the case of the river Elqui. A study in 1990 showed that this river was severely polluted with heavy metals by the goldmine of El Indio. However, about 50 km downstream from the mine these values were once again normal. The reason was that the soils through which the river flowed had a pH greater than 8, which made them alkaline. As such they made the water lose its acidity, which canceled the dissolving effect of AMD on the heavy metals. So the alkaline soils actually served as a buffer, purifying the river by making the dissolved heavy metals precipitate (G. Lagos 1990).

Although this buffer has kept downstream regions save from the effects of heavy metals, it has by no means eliminated the threat. The precipitation of heavy metals leave behind a heavily contaminated sediment. If an event would increase the acidity of the river the heavy metals that have accumulated in the sediment for decades would re-dissolve all at once (G. Lagos 1990). This would be catastrophic for aquatic life, animals and people that drink from the water and irrigated fields downstream.

The sea has the same accumulating characteristic as the lithosphere. All contaminants reach the sea sooner or later. Specifically for the coastal waters of Chile it are again the heavy metals – this time together with hydrocarbons from tankers – that form the most important problem (Chiang 1988). Contamination is mainly located around estuaries. Just like the lithosphere, the sea also has a filtering effect. Contaminants can be degraded, consumed, transformed or recycled. However, around estuaries of rivers that are heavily contaminated, the levels of heavy metals are too big to be filtered out. Famous examples in Chile are those of Coquimbo and Mejillones in the 80s. Shellfish, fish and algae were killed by the high levels of heavy metals (Diaz et al. 1986; G. Lagos 1989). As a result, local fishermen lost their means of survival. In both cases, the mining industry was responsible.

5.1.4 Public health

Defenders of the copper industry in Chili sometimes try to minimize its ecological impact by stating that its effect on public health is very small. To legitimize this statement, they pose that almost all the copper mines are located in the northern Atacama desert. This is not true. In fact, Antonio Daher points out that almost 50% of the extractive mining industry is located in what he calls "la Macrorregión Metropolitana" (Daher 1990, p.55). This region is formed by the fifth, sixth and metropolitan region, thus including the large majority of Chile's population. The important presence of the industry close to the country's main population centers, means that its ecological impact is in fact translated to the public health.

We have already discussed the way in which sulfur dioxide, arsenic and heavy metals in the atmosphere have an indirect effect on a population through agriculture. In addition, arsenic and sulfur dioxide also have a direct impact on humans. SO_2, for instance, affects the human respiratory system (G. Lagos 1989). Lagos tells us that in 1988 five of the nine pyrometallurgical facilities in Chile were located in the central regions of the country[32]. These facilities have definitely had an impact on the population of the metropolitan regions.

The ecological impacts of the mines El Teniente and Disputada de Las Condes on the drainage basin of the Río Maipo are also very relevant. It is this drainage basin that provides the metropolitan region with water. Therefore, the inhabitants of the region are exposed to all the contaminants that enter the basin as leachings, AMD, discharged process waters and through leaks in tailing dams (G. Lagos 1989). These tailing dams form another potential threat. We have seen that there is little guarantee that tailing dams won't breach. Especially in areas with a lot of seismic activity. A lot of dams have been constructed in the neighborhood of Santiago. Both El Salvador and Disputada y Andina constructed dams in the valley north of Santiago in 1989 (G. Lagos 2004). In 1987, the dams of Pérez Caldera actually threatened to break down and wash over the El Arrayán part of Santiago[33]. Annex 3 shows us that tailing dams of the Cerro Negro mining project in the fifth region have breached at two occasions. Once in 2004 and once in 1985, due to an earthquake. Building these dams in the neighborhood of large populations without guarantees about their durability is irresponsible. This is well illustrated by the disaster of 1965, when 250 people were killed after a dam breach caused by an earthquake[34].

5.2 Improvements and their drivers

5.2.1 1970-1974

The most important change during this period was the nationalization of the mining sector. By nationalizing the sector, the Chilean government demonstrated its power by removing all private investors. This was a very costly operation for the Allende-administration, but it definitely had enough impact on the private companies to reckon with this threat from then on. Authors like Sklair and Moran give the impression that this isn't the case, that TNCs aren't hindered by a nationalization of their enterprises. Sklair states that if TNCs are patient and persistent they usually at least recover the value of their seized assets (Sklair 2002). Moran states that in the case of Chile TNCs had a sufficient stranglehold over processing and marketing to recover their investment (Moran 1974). Nevertheless, we have already seen how the victimized companies didn't really recover and entered a period of changing owners, merging and disappearing. We can therefore conclude that the Chilean nationalization of the mining industry has in fact had a considerable impact on the private mining companies of that period.

Although DFI was again allowed in the following decades, the Chilean state retained considerable influence in the industry through companies like CODELCO and ENAMI. According to Lagos, this newly gained influence was positive for three reasons. For one, the state could dictate a constant rhythm of growth, thus keeping price fluctuations balanced. Secondly, the state could reduce the ecological impacts of the industry. Finally, profits from the exploitation of the nation's natural

[32] The other four facilities were all located in the north. In the north, there were the smelters of Chuquicamata, Potrerillos, Paipote and El Indio. In the centre, there were the smelters of Ventanas, Caletones, Chagres, Refimet and Molymet (G. Lagos 1989).

[33] This was a typical case of the upstream method. Three dams had been consequently built one above the other (G. Lagos 2004).

[34] You can find the dam failure in annex 3. On the internet there exists a small video fragment depicting the aftermath of the disaster (F.G. 1965).

resources could be invested in the development of the country instead of being flushed out of the country (G. Lagos 1989).

By using this last reason as a positive factor, Lagos is actually subscribing to the more general theory of interchangeable capitals. This theory was popular in Chilean literature in the late 80s and states that one capital – for instance natural resources – can be replaced by another capital – mankind – to maintain sustainable development[35]. In other words, in the late 80s there was a conviction that profits could be invested in technological improvements that would reduce the ecological or social cost of an economy. By now this theory has proven to be insufficient, but examples can be found in the history of Chile's copper industry. These examples prove that the Chilean government in 1970 didn't make such a bad decision nationalizing the mining industry. Thanks to this event Chile has had more means of fighting ecological deterioration than similar countries. For example, in the late 80s, state owned smelters like those of Chuquicamata and Refimet were able to reduce their emission of arsenic using national technology (G. Lagos 1989).

This was, however, an evolution of the late 80s when environmental consciousness had grown. Reducing the ecological impact of the industry was unfortunately not a big concern during the Allende-regime. The sector had been nationalized to form the driving engine (Viga Maestra) of Chile's economy. Therefore productivity was prioritized over ecological durability. In fact, environmental consciousness was practically non-existent at the time. This was because sustainable development and the environment only became internationally relevant issues after Stockholm and the Brundlandt report of 1972 (Camus & Hajek 1998).

Yet, we can already descry a few small efforts around the issue. In the academic world several Chilean universities started research groups on the issue of ecology and the environment between 1970 and 1974. NGOs only just started to show themselves. One of the first national NGOs on the issue of durable exploitation of natural resources was the Comité de Defensa de Flora y Fauna (CODEFF – Committee for the Protection of Flora and Fauna). It was formed in 1968 and remains until this day one of the most important actors against ecological problems related to the exploitation of natural resources in Chile (Camus & Hajek 1998). These driving actors were still in their embryonic phase and didn't yet have much influence on the big public or the state, nor on TNCs because these were temporarily out of the picture.

By nationalizing the mining sector, the Chilean state was now present as two different actors. On one hand, as CODELCO, it was a member of the economical actors – among which the TNCs – that were exploiting the copper ore-bodies. On the other hand, as the state, it was supposed to create a legislative and institutional framework within which those economical actors could function. On a legislative level, the state didn't do much. Some international conventions were signed, but without much effect. There were, however, some institutional initiatives from the state. Departments of environmental hygiene were formed, which were later transformed to departments of environmental health. Also the Comisión contra la Contaminación Ambiental (Commission on Environmental Contamination) was created in 1970. Unfortunately, this commission ceased to function in 1974 with the change of regime (Camus & Hajek 1998).

[35] In the first issue of the very prominent Chilean journal Ambiente y Desarrollo, in 1984, this theory is already discussed by Sutulov (Sutulov 1984).

5.2.2 1974-1989

With the change of power in 1974, the idea of a state-controlled economy disappeared and direct foreign investment became once again a possibility. TNCs started to reappear in the copper sector. Surprisingly enough these TNCs took up a leading role in the reduction of the industry's environmental impact. The most important goal of a TNC is after all profit maximization and we have seen that CER can be unprofitable. So why do TNCs in Chile take up this leading role? For one the presence and influence of NGOs was growing. Two new, national and influential NGOs appeared: the Instituto de Ecología (Institute of Ecology) in 1974 and the Instituto de Ecología Política (IEP – Institute of Political Ecology) in 1988. Both of them had a major influence on the public through campaigns, media attention and research (Camus & Hajek 1998). This severely increased the pressure on TNCs to become more environmentally responsible and share their efforts with the public (Matta 2004). The academic world gave them a chance to do so. In 1983 the Centro de Investigación y Planificación del Medio Ambiente (CIPMA – Centre of Environmental Investigation and Planning) started with scientific conferences to assess environmental problems in Chile. These conferences brought actors from the business world, the academic world, the political world and civil society together every 3 years. They gave the TNCs not only the chance to learn about new findings, but also to share their point of view and what they already had accomplished (Matta 2004; Camus & Hajek 1998).

Influences from the academic world and the civil society were surely drivers for CER in TNCs at such an early stage. There was, however, one driver without which the academic world and civil society could never have accomplished this: a TNC's ultimate goal of profit maximization itself. It seems rather unlikely that economical actors would adopt environmental responsibility out of idealism. Actually, they were operating out of economical motives. The losses they would make by internalizing their ecological impact was nothing compared with the losses they would make by not internalizing this impact. A lot of this has to do with the legal reality in their home countries. These were developed countries that already had an extensive environmental legislation. Although Chile didn't require them to, TNCs already adopted their home country's environmental policies in Chile out of fear of legal prosecution at home (G. Lagos 1990). In addition, following their home country's legal policies gave TNCs the guarantee that they could sell their products there. A third reason why they were keen on adopting these policies in Chile was that they could anticipate the imminent changes in Chile's environmental policy. They had the technology to reduce their ecological impact at home, so they rather immediately installed it in their new facilities in Chile than having to adapt after a couple of years (G. Lagos 1990; Quiroga 1994).

While TNCs were starting to take up their environmental responsibility, the state found itself in a new, neo-liberalistic vision on how its economy should be organized. Instigated by international financial institutions, the U.S. and the national Chicago boys, the logic was to eliminate as much of the trade barriers as possible (Camus & Hajek 1998). In doing so, Chile hoped to once again attract direct foreign investment for its copper industry. Like with the nationalization, they now sought to expand and fortify the presence of the sector on the international market by attracting DFI. Therefore, consciousness about the ecological impact of the industry was again not very present. Chile was in fact entering the *'race to the bottom'* we've discussed before. In this race, environmental regulation had to give way to an economy free of trade barriers (CEPAL 1991).

This attitude, however, changed over time. Within the international community ecology and the environment had started to become an issue. This made it possible for actors to create a national debate in the early 80s. Before, the big public wasn't aware of the environmental problems related to the exploitation of copper. In the 80s this awareness was growing thanks to campaigns of NGOs like Instituto de Ecología, IEP and CODEFF and conventions like that of CIPMA. As a result the debate started to intensify and spread to the big public. The regime started to realize that ecology and the environment had become an issue and reacted. This shows that even when the public didn't yet have electoral power, they did have an influence on the state.

The reaction on an institutional level was the creation of the Comisión Nacional de Ecología in 1984 (Camus & Hajek 1998). This commission was created in an effort to centralize environment-related policies. Unfortunately, the opposite happened. Environmental policy spread out over an incomprehensible maze of institutions. Lagos addressed this problem in 1990, stating that companies searching the government's responsible for the environment were faced with at least 10 institutions. These institutions shared environmental responsibility and authority without central coordination (G. Lagos 1990).

On a legislative level, the state started to create national laws and sign international conventions to protect the environment. Despite its arrears on the international community, it even included the protection of the environment in the constitution. From 1980 on the Chilean constitution guaranteed every person the right to live in an environment free of contamination(Camus & Hajek 1998). This meant that an environment free of contamination had become a fundamental right for every person, which had to be safeguarded by the state. The initiative actually helped NGOs win cases against mining companies. For instance CODELCO was forced to stop its discharge of tailings on the shore of Chañaral based on this article (Hajek 1993). The state also determined norms of contamination, like for example the código de minería in 1983 and the index of air quality in 88-89 (Camus & Hajek 1998). These were nevertheless a lot less strict than those applied in developed countries. As a result, it isn't surprising that TNCs had a head start on the state-owned companies like CODELCO. TNCs could easily meet the norms, because they were much stricter in their home countries. They just had to place the right technology in their new facilities. CODELCO, on the other hand had to adapt. This was a slow process for many reasons. Firstly, they had to break with a tradition of keeping secrets for the public. TNCs already had found ways to communicate their ecological responsibility to the public, while CODELCO still hid itself under a veil of mystery. Secondly, CODELCO's mining facilities were huge and terribly dated. Again, CODELCO had to adapt while TNCs could start with a lead. Thirdly, the investment that was necessary to modernize these facilities was huge (Matta 2004).

5.2.3 1989-2000

In the year 1989 a lot changed in Chile. For the first time in 19 years democratic elections were held. By now the media and public had become increasingly worried about the state of Chile's environment. The national debate had reached such intensity that the presidential candidates were obliged to incorporate the issue in their election campaigns. The economic model under Allende and Pinochet had never been preoccupied with environmental issues. As a result, even though there had been limited reactions from the private sector and the state, the presidential candidates were facing an incredible ecological debt (Asenjo 1990). In addition, the 80s had left behind an institutional and legislative mess with regard to environmental issues. There was no institutional integration, too many institutions and laws and a complete absence of the right tools or preoccupation within the ministerial structures. This made it impossible to form a coherent and integrated environmental policy (Camus & Hajek 1998).

After Patricio Aylwin won the elections, he devised an action plan to change this mess into a working system. Therefore, he relied upon three new principles: stability, graduality and realism. In 1990, the president signed a decree creating a new national commission: the Comisión Nacional del Medio Ambiente (CONAMA – National Commission for the Environment). Where its predecessor in the 80s (Comisión Nacional de Ecología) was meant to merely advise and assist Pinochet in cases regarding the environment, the job description of this new commission went much further. It had to create a completely new legislative framework and institutional structure. The commission worked with a lot of enthusiasm, but was plagued with set-backs on its trajectory. This was because older state organisms didn't cooperate fully in the fear that they would lose part of their competences (Camus & Hajek 1998; Alvarado 1995). The time it took to ratify and implement the legislative framework illustrates this perfectly. It took CONAMA from 1990 to 1994 to have the *'Ley sobre Bases Generales sobre el Medio Ambiente'* to be published, but it wasn't until 1997 that the law was approved in its entirety (G. Lagos 2004).

CONAMA had made an inventory of all environmental regulation before 1990 to form the Ley sobre Bases Generales sobre el Medio Ambiente. Thanks to the new law this regulation could now be put into a coordinated framework. The law cleared the road for the establishment and monitoring of environmental norms and emission norms. It designated CONAMA to coordinate all monitoring. In fact, CONAMA received the role of central coordinating organism of the state's entire environmental policy. This made it the single point of contact for environment-related issues. The law also stated that CONAMA had to be assisted by regional divisions, called Comisiones Regionales del Medio Ambiente (COREMAS – Regional Environmental Commissions) (CONAMA 2007; SINIA 2011). A large part of the law defined the terms for environmental impact assessments (EIA) and civil participation. It was this part of the law that took so long to be approved (CONAMA 2007; Camus & Hajek 1998). In the years before 1997, EIAs for projects were on a voluntary basis (Matta 2004). Finally, there was also a part included that stipulated the basis for a research and education program. All of this had to be funded by a fund specifically for environmental protection (CONAMA 2007).

With the Ley sobre Bases Generales sobre el Medio Ambiente, CONAMA had succeeded in creating an institutional and legislative framework in which an environmental policy could be elaborated. Meanwhile, it was also trying to integrate the environmental dimension in the policies of the different ministries. Thus also in the policies of the ministry of mining. From 1990 onwards this ministry started to analyze the ecological impact of the sector and in 1992 it established the first specific norms for the sector. In this year, the ministry issued a decree which set the norms for the emission of sulfuric gasses, arsenic and particulate matter. These norms were based on those of the CICA, the commission for air quality. It also issued a decree which rooted a technical secretariat of this commission in the ministry of mining (Camus & Hajek 1998). These first actions show that efforts were made to centralize and coordinate Chile's environmental policy. The environmental norms had to be complied with by private and state companies. Existing facilities had to reduce their emission through a series of maximums until they would reach the norm. New facilities had to meet the norms immediately (Camus & Hajek 1998).

The 1970s and 80s had been marked by CODELCO running behind the facts, while the TNCs were taking the lead on environmental issues. Especially TNCs in the mining sector were taking on a leading role, bringing the whole sector in the lead. This phenomenon went so far that it were actually the TNCs of the mining sector that demanded clear norms and a centralized environmental policy (G. Lagos 2004). From the 90s on, however, CODELCO started facing its environmental problems. It mainly focused on the problem of atmospheric emissions. In 1991 projects were started to clean the five state-owned smelters, among which CODELCO's Chuquicamata and Ventanas smelters. In addition, CODELCO constructed a fourth treatment plant of sulfuric acid at its Chuquicamata smelter (Camus & Hajek 1998; G. Lagos 2004). These treatment plants helped lower the SO_2 emissions of the smelters by filtering out the sulfur and turning it into sulfuric acid. Both sulfur and sulfuric acid can be sold as a commodity, so these plants can be seen as an example of *'total resource utilization'*. It was thanks to the construction of the treatment plants that SO_2 emissions were reduced to 1,6 million tons in 1993. This was about 60% of the total emission. The rest was treated (G. Lagos 1990). It wasn't a coincidence that CODELCO reacted by facing the problem of atmospheric emissions first. In the early 90s the black smoke from smelters was the most televised environmental problem in Chile (G. Lagos 2004). This illustrates how the state primarily reacted to high profile problems in the public debate.

Although CODELCO was turning around its environmental policy and was catching up, TNCs from the copper industry were still playing a leading role in CER. This became especially clear with the application of environmental impact assessments. As already said, the use of EIAs for new projects didn't become compulsory before 1997. Before 1997 – even though their use was voluntary – all new mining projects were submitted to an EIA. According to Lagos, more than 70% of the EIAs made during this voluntary period came from the mining sector and according to Matta, none of these new projects has presented environmental problems or crises (G. Lagos 2004; Matta 2004). Keep in mind, though, that – as we have seen – TNCs did this more out of economical than ideological motifs. Lagos also reminds us of this fact by stating that companies spent as little as possible on these studies (G. Lagos 1989).

These were, in short, the reactions of the state and TNCs to the environmental problems that Chile faced in the early 1990s. We have described how these changes are in part thanks to attention for the problems of the big public, the media and NGOs. Stating, however, that the new elections and the pressure of the electorate were the only drivers behind the changes of the early 90s would be inaccurate. The international market also played a huge role. Chile's copper sector had experienced an enormous boom, starting with the investments of Escondida in the late 80s and resulting in a massive ingression of DFI in the late 90s (G. Lagos 2004). Following the logic that literature on the subject has taught us, this massive ingression should have been accompanied by an abolishment of as much as the environmental regulation as possible. However, the opposite was the case. The international market perceived the lack of environmental regulation in Chile as an obstacle to free trade, it being a form of government subsidy for the copper sector. As a result, the international market increased the pressure for environmental regulation on the Chilean government throughout the late 80s and 90s.

The first incident happened in 1984, when 11 companies of the United States lobbied to put quotas on the import of Chilean copper. The reason they gave was that in Chile there was no control on the emission of SO_2. Therefore Chilean copper could be made much cheaper because no expensive technologies were needed to treat the SO_2 emission. This was an unfair competitive advantage. Eventually, the petition was rejected by Reagan, but Chile didn't seem to draw lessons out of the incident (Mardones & Marshall 1987). International pressure on Chile's copper industry increased with the Basel Convention[36]. When Chile signed this convention in 1990, it provoked an intense debate about the environmental impact of the industry. In its essence, the convention was devised to prevent developed countries dumping their waste in third world countries. However, the convention also marked copper contents in waste as toxic. This would mean that a part of Chile's copper industry – the part that specialized in the treatment of old copper – didn't have a future anymore. The Basel Convention was in this way a prime example of the conflict that can rise between economical and ecological motifs. Till this day Chile's ministry of health can still refuse the import of used copper for treatment, which means great insecurity for companies specializing in this treatment (G. Lagos 2004). In 1993, the WHO increased international pressure on the copper sector even further by listing copper as a danger to public health if present in drink water. Chile's government perceived this as a great threat for the international copper market and started to invest important sums in research on the subject and ways of treating the problem (G. Lagos 2004). Finally, there were the free trade agreements (FTA) with Canada and the United States. Both of these included agreements on the environment which stated that the compliance of Chile with its environmental regulation had to be examined and that the countries' environmental policies should be compared. The goal was to speed up Chile's learning process and its implementation of environmental regulation. Certain sectors, like the academic world, observed these agreements with skepticism, believing that the process should be gradual. According to them, Chile might have had an environmental legislation which was more conservative than that of other countries (Brazil and Argentina), but it did implement this legislation in a better way (G. E. Lagos 1993).

As we have already stated: a lot changed in Chile in the early 90s, also in the field of environmental protection. TNCs were advancing on the road they had chosen in the 80s, pushed by the economical reality they were facing and pressures from the civil society and the academic world. Meanwhile, CODELCO was trying to undertake a passing maneuver, driven by a new framework of the state and massive attention for certain problems by the media and the public. The state in the early 90s had to once again learn to take in account the electorate. Thus public opinion, driven by the media and civil society, pushed the state into finally creating a legal and institutional framework for an environmental policy. In addition, the international community kept increasing the pressure on Chile to face its environmental problems, be it out of economical motifs like unfair competition or concerns for public health. Although Chile really made progress, this doesn't mean that environmental problems were a thing of the past. A survey of Tironi in 1999 shows some painful defaults to Chile's environmental policy. Tironi is very concerned with the way in which Chile focuses its environmental policy on requiring EIAs while giving too little attention to actually avoiding pollution of the environment. In addition he discerns some problems in the evaluation system, it being too slow and to complicated. Another major problem, according to Tironi, is the way in which private companies have always been involved in environmental policy of the state. This while it should be the state giving the companies a framework in which to work and not the companies co-defining this framework (Tironi 1999).

[36] Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal

6. Codelco Norte vs. Minera Escondida: a case study

6.1 Important characteristics of the two mines

6.1.1 Codelco Norte

Codelco Norte is a division of the state-owned mining company CODELCO. As we by now know, CODELCO originates from the nationalizing days of Salvador Allende. To this date, the company is still completely owned by the Chilean state (CODELCO 2008b). The Codelco Norte division was created in 2002 by fusing the former Chuquicamata and Radomiro Tomic divisions (CODELCO 2011b).

The Codelco Norte operation is located about 1 650 km to the north of Santiago, in the Antofagasta region (map 6.1). It is located in one of the most arid and hot regions of the world: the Atacama desert. Certain places in the Atacama desert can go without rain for several years. For instance, the annual rainfall in Iquique is only 0,6 mm. This aridity also goes for the Antofagasta region with an annual precipitation in Antofagasta and Calama of 1,7 mm and 5,7 mm. Therefore, the Codelco Norte operations find themselves in a very harsh environment (Dirección Meteorológica de Chile 2011).

However, this is not a sterile environment. Very interesting ecosystems are present and the operations have had a considerable environmental impact in the past. Bear in mind how we already mentioned that two decades ago the town of Chuquicamata had to be evacuated because of the Codelco Norte mining operations.

Img. 6.1: Overlooking the Chuquicamata copper mine with its 4,3 km in length, 3 km in width and 850 m in depth[37].

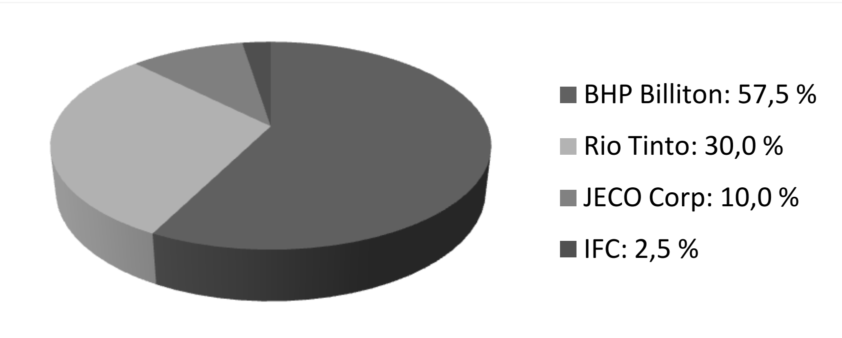
[37] (Anon 2011)

The operation consists of three open pit mines: Chuquicamata, Mina Sur and Radomiro Tomic. Out of these three pits Chuquicamata is the oldest and biggest one. It has been known since pre-hispanic times that copper could be found here, but the modern mine started operations in 1910 (CODELCO 2011a). Today it's still the mine with the largest total amount of copper exploited: 29 million tons. In annual production it has long been the largest mine in the world, but since a couple of years it has been surpassed by the Escondida mine. Radomiro Tomic is located 20 km to the north of Chuquicamata. It was discovered in the 50s, but operations only began in 1995. The mine produces copper oxides (CODELCO 2011b). Codelco Norte obtains its copper from both sulfides and oxides. The metal is extracted by flotation or electrowinning. In addition, Codelco Norte has started heap leaching its waste rock dumps.

6.1.2 Minera Escondida

The Minera Escondida mining operation is a project of several transnational corporations. Figure 6.1 shows us that BHP Billiton is the largest shareholder, followed by Rio Tinto. BHP Billiton is a TNC with its head office in Australia. It's the largest natural resources company in the world, consisting out of nine divisions. Minera Escondida forms part of its 'base metals'-division (BHP Billiton 2006). The second largest shareholder, Rio Tinto, is a TNC with British origins. It's also one of the largest natural resources companies in the world. JECO Corp is a small Japanese consortium. The International Finance Corporation (IFC) belongs to the World Bank and was created to promote sustainable development in the private sector in developing countries (Minera Escondida 2011a).

Fig. 6.1: Minera Escondida ownership (%)[38].



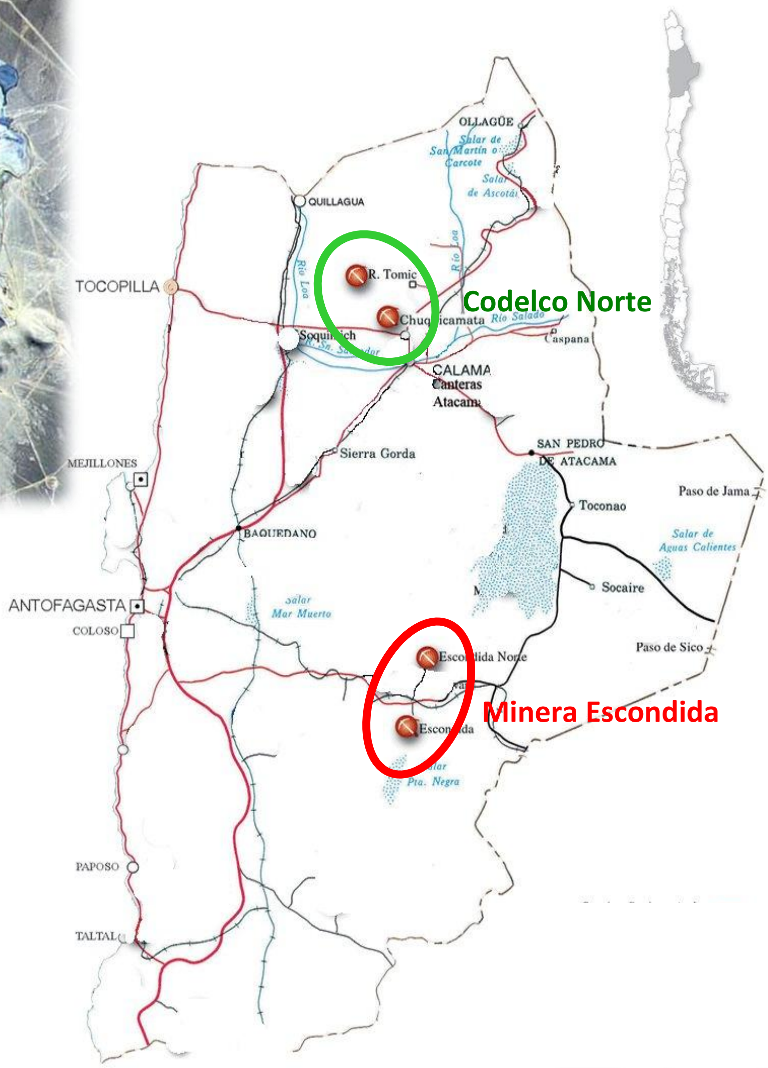
The operation is located in the Antofagasta region as well (map 6.1). Just like Codelco Norte, it finds itself in the hot, arid Atacama desert. The operation consists of two open pit mines: Escondida and Escondida Norte. Both pits are quite recent. Escondida started operations in 1990 and Escondida Norte started operations in 2005. Despite this young age, they have become the operation with the highest annual production of copper in the world. In 2008, 1 255 019 tons of fine copper were produced. This represented 23,5% of Chile's total production for that year (Minera Escondida 2011b).

Just like at Codelco Norte, copper is present as sulfides and oxides at Minera Escondida. Copper is extracted through flotation at the concentrator plant in Coloso or through electrowinnig. Minera Escondida is also in the process of leaching its waste rock dumps.

[38] Based upon (Minera Escondida 2011a).

Img. 6.2: Satelite view of the Minera Escondida operations[39].

Map 6.1: the Antofagasta region, depicting Codelco Norte and Minera Escondida[40].



[39] (NASA 2000)
[40] Own adjustment of a map provided by the Ministerio de Minería (Ministerio de Minería 2011c).

6.1.3The difference

Codelco Norte and Minera Escondida are similar in many ways. Both of them operate open pit mines. They are located in the same region and the same conditions. The Chuquicamata mine of Codelco Norte has been the biggest annual producer of copper in the world for many years and has recently been overtaken by the Minera Escondida operations. Both of them produce copper cathodes and concentrate from copper oxides and sulfides. This means that they use the same processing methods.

What makes them even more interesting for a case study, though, is one of the few differences between the two operations. One operation, Codelco Norte, is run by a state-owned company. The other, Minera Escondida, is run by a private owned TNC. This means that a study of both operations allows us to learn more about the different speeds with which the state and TNCs have evolved since the early 90s. It will be interesting to see if the gap between the two is still as big as it was before the 90s.

6.2 A comparison of their ecological impact for 2009

6.2.1 Biodiversity

Both the Escondida operations and Codelco Norte are situated in the Atacama desert. This region is not known for its immense biodiversity. Nevertheless there are some interesting, more bio-diverse regions located within or just outside both operations. Close to Codelco Norte we can find *'La Reserva Nacional Alto El* Loa' and Escondida's operations border on the *'Parque Nacional* Llullaillaco'. These are two national reserves, protected by the *'Sistema Nacional de Areas Protegidas del Estado'* (SNASPE – National System of State-Protected Areas). Minera Escondida works closely together with the *'Corporación Nacional Forestal'* (Conaf – Nacional Forestry Corporation) to monitor the operation's impact on *Llullaillaco*. These semestrial studies show no impact on the national park. Codelco also works together with Conaf in a monitoring project of the *Alto El Loa* reserve. This project was initiated in 2009 (CODELCO 2009a; Minera Escondida 2009).

In addition to their efforts in preserving these national reserves, both operations also participate in the preservation of other, unprotected, but bio-diverse areas. Codelco Norte considers the Calama Oasis as an important region to be protected. It organizes cleaning projects in the region and has a riverbank restoration project running (CODELCO 2009a). Minera Escondida, on the other hand, qualifies 55 hectares of its operations area as zones rich in biodiversity. The company works together with local authorities to monitor these zones for negative impacts (Minera Escondida 2009).

Note that a lot of the areas that are rich in biodiversity have to compete with the mines for use of the same water. This is also reflected in the protection plans of both operations. Minera Escondida focuses a considerable part of its efforts on the *'Salar de Punta Negra'* (Minera Escondida 2009). This place is much richer in fauna and flora, because there is a source of subterraneous water on site. The reason why Minera Escondida has to monitor the site is because they are using a large part of its subterraneous water supply for their operations. They have to monitor the effects of their consumption on the fauna and flora. The same goes for Codelco Norte. They are using water from an area known as *'Ojos de San Pedro'*. This area is protected by the '*Dirección General de Aguas'* (DGA –

National Water Management), so Codelco is obliged to monitor the impact of their consumption over biodiversity and restore the region's ecological capacity (CODELCO 2009a).

6.2.2 Energy

If we talk about energy in the light of durability, we're essentially telling a story about efficiency. In the future, renewable energy will become more important in the story. Codelco Norte, for example, is already studying the possibilities of solar thermal energy and a wind farm. For now, however, efficiency is the keyword.

Table 6.1: Energy efficiency of the Codelco Norte and Minera Escondida mining operations[41].

	Unit	Codelco Norte	Minera Escondida
Total Cu production	t	755 258[42]	1 102 976
Direct energy consumption	GJ	13 930 000	8 943 988
Indirect energy consumption	GJ	11 620 000	11 500 118
Total energy consumption	GJ	25 550 000[43]	20 444 106
Energy saved in 2009	GJ	647 279	193 848

As seen in table 6.1 Codelco Norte scores considerably lower on energy efficiency than Minera Escondida. Though the operations of Codelco Norte produced about 347 718 metric tons less copper, they consumed 5 105 894 GJ more energy in 2009. This is a considerable difference. The reason for this difference can partly be found in the ore grades of the different mines. The average ore grade in the two Escondida mines was 1,59% in 2006 (Minera Escondida 2011c). At Codelco Norte, the ore grade is a lot lower. The average ore grade of minerals extracted by Codelco was only 0,78% in 2008 (CODELCO 2008a). This means that more rock has to be treated to extract the same amount of copper. By consequence more energy is needed to extract the same amount of copper.

We have, however, already seen that this isn't the only problem Codelco has to face. In the early 90s, the state-company was still struggling to update its out of date infrastructure and machinery. Now, the adjustments, Codelco made to its production process in the Norte division, saved a considerably bigger amount of energy compared to Escondida. A lot of the energy (579 192 GJ) was saved by updating their fleet of mining trucks (CODELCO 2009a). The fact that Codelco is saving considerably more energy per year than Escondida and the fact that in 2009 Codelco saved most of its energy by updating its fleet of trucks suggests that they are still catching up.

[41] Based upon (CODELCO 2009a; Minera Escondida 2009).
[42] Figure from (CODELCO 2009b).
[43] Own calculation, based upon Codelco Norte's direct and indirect energy consumption (CODELCO 2009a, pp.93, 98).

Table 6.2: Total amount of greenhouse gasses emitted by the Codelco Norte and Minera Escondida operations in 2009[44].

	Unit	Codelco Norte	Minera Escondida
Direct	t CO_2eq	971 653	675 311
Indirect	t CO_2eq	2 953 205	2 845 783
Total	**t CO_2eq**	**3 924 858**	**3 521 094**

Another key subject linked to energy and durability is the emission of greenhouse gasses. The difference in efficiency between the two mining operations translates itself to the production of greenhouse gasses. Emission of greenhouse gasses is measured in CO_2 equivalent (CO_2eq). Table 6.2 shows us how the total amount of greenhouse gasses emitted by the two operations in 2009 is divided between direct and indirect consumption of energy.

Direct energy consumption comes from primary sources (petrol, diesel and gas), while indirect energy consumption comes from secondary sources (electricity). This is an important difference to make, because the mining operations can control the sources on which their direct consumption is based, but can’t control the sources of their indirect consumption. They have to buy this energy from their local supplier: SING (Sistema Interconectado del Norte Grande), that decides for its own what sources to use.

Table 6.1 shows us that Codelco Norte and Minera Escondida consume about the same amount of indirect energy. As we can see in table 6.2, the real difference in emission of greenhouse gasses is made at the supply of direct energy. Codelco Norte consumes about 500 000 GJ more direct energy than the Escondida operations. This translates itself to the amount of greenhouse gasses emitted. In total, Codelco Norte emits 403 764 t CO_2eq more than Minera Escondida. 296 342 t CO_2eq of the total comes from direct energy production. These figures clearly show that the difference between the two companies is made at their direct energy consumption. Again we can point to the lower ore grades and technological hind set at Codelco Norte as causes for this difference.

What is also very interesting to notice is the incredible contribution of indirect energy to the emission of greenhouse gasses of the two companies. In comparing the share of indirect energy and the share of direct energy needed to keep the operations running, it immediately becomes clear that there isn’t a big difference. Codelco Norte relies for 54,52% on direct energy and 45,48% on indirect energy. Minera Escondida relies for 43,74% on direct and 56,25% on indirect energy. However, if we compare the greenhouse gasses coming from the direct and indirect energy supply, there is a huge difference. At Codelco Norte, 75,24% of the total emissions come from indirect energy. For Minera Escondida the share is even more: 80,82%. This staggering dominance has to do with the sources that SING uses for its energy production.

Juan Carlos Guajardo, the executive director CESCO[45], stated that before 2009 SING used to largely depend upon Argentinean gas, but that this had become impossible. By consequence they had to use

[44] Based upon (CODELCO 2009a; Minera Escondida 2009).

an alternative source. Guajardo stated that SING changed to diesel as an alternative source and would eventually make the transition to coal (Guajardo 2009). He stated this in 2009, but probably didn't expect his prediction to become true so quickly. In the same year, SING switched to coal as its most important source of energy. SING based 56,7% of its energy production on coal in that year (Minera Escondida 2009). Being that coal is the most important producer of CO_2, the large share of SING's energy production to the emission of greenhouse gasses at the mining operations of Codelco Norte and Minera Escondida isn't that surprising.

6.2.3 Atmosphere

The atmosphere is the only place in which a comparison between the impact of the operations at Codelco Norte and those at Minera Escondida isn't really possible. The reason lies within the fact that Codelco Norte, contrary to Minera Escondida, operates a smelter. Therefore the activities that produce an impact on the atmosphere are too different to be compared.

We can, however, draw some conclusions out of a closer study of the two cases. A first one is that the large impact of smelters on the atmosphere, which was still considerable at the beginnings of the 90s, has now become manageable. Codelco Norte can present us with emission totals for SO_2, PM_{10} and As that stay well below the norm (CODELCO 2009a). However, the large output of SO_2, associated with a smelters in the late 80s and early 90s, remains to this date important. SO_2 is still by far the most important type of emission originating from the operations at Codelco Norte. In 2009 a total of 90 600 tons of SO_2 was emitted, compared to 470 tons of PM_{10} and As each (CODELCO 2009a).

Another conclusion we can make has to do with the importance of PM_{10} emissions at the operations of Codelco Norte and Minera Escondida. Especially the second company puts a lot of effort in the monitoring of PM_{10} levels around their operations. In total they have four stations that carefully monitor the levels of PM_{10} and report these levels to the authorities per semester. One of the stations is located at their operations at the port of Coloso, the other three are located in the three mining encampments (Minera Escondida 2009). We've already discussed that dust generation is an important problem in arid regions like Antofagasta. Especially the fine tailings in the tailings dams can be swept up into the atmosphere and spread heavy metals, As, etc. This is why the PM_{10} levels have to be closely monitored.

It's also in this area that today most efforts are made to try and reduce the impact. The problem is that most of these measures involve keeping operations, stock piles and roads humid. This involves an increased water consumption in a region that is already scarce in water. In 2009, though, Minera Escondida successfully applied a technology using bischofite for its roads (Minera Escondida 2009). This magnesium salt can be used to stabilize roads, reducing dust creation and retaining humidity.

6.2.4 Hydrosphere

As well in the Codelco Norte case as in the Minera Escondida case pollution of surface waters, aquifers or the sea is fairly restricted. This has largely to do with the fact that they discharge almost none of the used process waters. Codelco Norte doesn't discharge any of its process waters to marine or continental waters (CODELCO 2009a). Minera Escondida discharges a small fraction of its process waters to the sea. This fraction consists of what is known as brine, a water with very high

[45] Centro de Estudios del Cobre y la Minería, a study centre on copper and mining based in Santiago.

concentrations of salt. The brine is a byproduct of their desalting plant, used for part of the operations' water supply. In 2009 a total of 6 290 811 m³ of brine was discharged (Minera Escondida 2009).

The great majority of the process waters is recycled. As we have discussed before, water is an enormously scarce and expensive commodity in the Antofagasta region. Therefore it is in the companies' best interest to recycle as much of the used water as possible. In 2009, Minera Escondida recycled 23 679 304 m³ of water. This was 35,9% of the total water consumption (Minera Escondida 2009). For Codelco Norte the percentage given is 84% (CODELCO 2009a)[46]. If the water finally can't be used anymore, it is discharged in both cases in the tailings dams. But even then water can be recycled from the pond of clear water that is formed within the dam. Minera Escondida recycled 22 618 159 m³ in this manner (Minera Escondida 2009).

It is again important to remember that tailings dams aren't a full proof technique to store tailings and process waters. This is even more true in a regions like Chile with large seismic activity. Studies that we've already presented discuss several dam failures in Chile. Minera Escondida discharges its tailings and process waters in the Laguna Seca tailings dam. This dam has been built following the downstream method and using different techniques (tailings beach, drainage system, etc.) to prevent dam breaching or leakage (CDA 2002). Still, it's difficult to prepare a structure for a future of several thousands of years. The same goes for the Talabra dam of Codelco Norte. Plans exist to increase this dam's capacity even more. The question is whether or not this will influence the structural integrity of the dam (Juan 2009).

Another consideration we can make with regard to the pollution of the hydrosphere by Codelco Norte and Minera Escondida is the fact that contact waters aren't regarded as process waters. Contact waters include all the natural water flows that come into contact with the mining operations. The Chilean state says about contact waters (CODELCO 2009a):

> *'no resulta procedente que la SISS [Superintendencia de Servicios Sanitarios] califique tales aguas de contacto como residuos líquidos industriales y aplique a los respectivos flujos la norma de emisión para la regulación de contaminantes asociados a las descargas de residuos líquidos a aguas marinas y continentales superficiales del D.S.N°90 DEL 2000 de la Secretaría General de la Presidencia*[47]*.'*

This means that such contact waters aren't submitted to the norms qualified by the state. In an arid region like Antofagasta this fact isn't such a problem, because precipitation is very low. However, in regions with a higher precipitation, those contact waters will start to generate AMD which will pollute surface waters and aquifers. The more recent study of the río Maipo basin in the more humid sixth region, which we've already discussed, clearly marks AMD generation as a major cause of pollution (CADE-IDEPE 2004).

[46] The percentage, presented here, have to be treated with caution. Minera Escondida calculated its percentage of recycled water in respect with the total volume of fresh water consumed. Codelco calculated its percentage in respect with the total volume of water used (including the recycled water). This means that if we are to compare the two companies, Codelco's percentage would be even higher. Codelco Norte indeed recycles an incredible amount: 328 584 000 m³.

[47] Own interpretation: *'it isn't appropriate for the SISS to qualify contact waters as industrial process waters and submit those flows to the emission norms that regulate the contamination associated with discharges of process waters to marine and continental waters.'*

Still, in the arid Antofagasta region AMD generation is less of a problem and both companies have closed process water circles. So, to repeat myself, water pollution isn't the real problem in both cases. The biggest impact of the Codelco Norte and Minera Escondida operations with regard to the hydrosphere has to do with their water consumption.

In total, Codelco Norte consumed 61 547 000 m³ of fresh water in 2009 (CODELCO 2009a). Minera Escondida's fresh water consumption amounts to 61 878 955 m³. They are able to keep their consumption on that level because 6,2% (4 057 327 m³) of their water consumption is provided by their own desalting plant (Minera Escondida 2009). With this plant they are setting an example which other mining companies in the region will probably follow as water becomes even scarcer and the need for it higher. As we have seen, both companies try to compensate the enormous pressure that their water consumption brings with it by collaborating in the preservation of the source areas.

The total amount of consumed water can also be translated to m³ per ton of processed water to illustrate the operations' efficiency. At the Codelco Norte operations, an average of 0,37 m³/ton of processed material is used[48]. At Minera Escondida an average of 0,33 m³/ton of processed material is used (Minera Escondida 2009). These figures don't seem too bad, but still represent enormous quantities of water if compared to the amount of fine copper that is produced. At Minera Escondida, for example, this adds up to 59,8 m³/ton of fine copper[49].

6.3 The different stakeholders and their influence

In the previous chapters we came to some key conclusions about shareholders and their influence over the way in which Chilean mining companies approach their environmental impact. This approach has changed considerably over the past 40 years, but it seems that the same actors still play a critical role today.

A prominent phenomenon was the incredible influence that literature has attributed to the Chilean state. This actor had several tools that could be used to drive mining companies towards a more sustainable form of operation. The Codelco Norte and Minera Escondida cases show that the state in all its forms – as a legislative power through decrees, regulating organs, local authorities, etc. – remains to this date the most influential actor.

As such, the state is mentioned a great majority of times in both sustainability reports. In the 2009 sustainability report of Minera Escondida, the state was mentioned as an influence 16 out of 24 times. The company mentioned itself as taking initiative on its own on 4 occasions and the other 4 citations were divided between NGOs, the public and the international community (Minera Escondida 2009). Codelco mentioned the state (in other forms than Codelco itself) 15 out of 22 times in its 2009 sustainability report. The international community and Codelco itself got 3 citations each. The seventh citation was for NGOs (CODELCO 2009b, CODELCO 2009a).

In Chile, the state has also become an economical actor in the form of Codelco. But instead of being an example of environmental durability, Codelco always lagged behind in the past. Today, this arrears still exists on some levels. Compared to Minera Escondida, Codelco Norte is still less energy

[48] Codelco Norte doesn't give an average amount of consumed water per ton of processed material. They do give averages for oxides and sulfides at their different operations (CODELCO 2009a, p.180). The figure presented here is the result of calculations based on these averages.

[49] Codelco Norte doesn't provide us with a calculation based on the amount of fine copper that is produced.

efficient and still in the process of catching up. On other levels, however, Codelco Norte scored better than Minera Escondida for 2009. Codelco Norte is for example more efficient in its water consumption. They are able to do this by recycling more water in their production process[50]. So overall, the difference between private companies and Codelco has become a lot smaller compared to the early 90s. With this evolution the state, as an economical actor, has been able to proof itself an active participant in the struggle to reduce the environmental impact of the mining industry.

We also learned that the state doesn't necessarily use its large influence to incite change in favor of environmental durability. The state itself was subject to different drivers, like the need for DFI or the need for voters. Literature presented the influence of several actors in this light. The media and NGOs were able to influence public opinion and thus the way in which the state acted. The sustainability report for 2009 of Minera Escondida shows however that these stakeholders also have direct influence. The report lists up all interest groups that they deem important (Minera Escondida 2009). Local communities, local non-profit organizations and NGOs are mentioned in relation with the operations' environmental impact. All of these groups possess active participation channels. Local communities, for example, can go directly to the company with their complaints via contact centers like the *'Oficina de Asuntos Indígenas en San Pedro de Atacama de la Fundación Minera Escondida'* (Office of Indigenous Questions in San Pedro de Atacama of the Minera Escondida Foundation).

Another example of the way in which the local communities have a direct influence, is the social conflict that resulted from a spillage of concentrate on the 26th of august 2009. Local fishermen claimed this spillage affected their economic activities and demanded compensation. Minera Escondida refused to give in and manifestations started. Under this pressure the company agreed to start a dialogue. The result of this dialogue was the creation of a development fund of 100 million pesos per year for a period of five years. It was also agreed to improve the environmental situation of the area (Minera Escondida 2009).

On the other hand, the role of NGOs is no longer just pointing out bad environmental practices. These organizations now have direct channels of communication. For instance, they are represented in boards of directors of institutions of which Minera Escondida is a member (Consejo Minero Sonami, Asociación de industrials de Antofagasta, Corporación de Desarollo Productivo de la Región de Antofagasta). Minera Escondida also attends their seminars and workshops (Minera Escondida 2009). So different groups of interest have found tools to change their position of indirect influence towards one of direct influence. However, NGOs' role as a warning mechanism is still just as important. That they have earned their stripes in this role is also proven by the very fact that mining companies like Codelco and Minera Escondida publish sustainability reports. In doing so, they don't only give NGOs and other groups of interest a view of their companies' practices, but can also react to accusations.

Another important phenomenon, literature encountered, was the fact that TNCs aren't just passive actors in the evolution towards lesser environmental impact. It was in fact them that during the 80s and early 90s actively asked for more regulation on the subject and were well in advance of Codelco in implementing more environmentally durable practices and technologies in their operations. The

[50] Codelco recycled a total of 328 584 000 m³ in 2009. Minera Escondida only 23 679 304 m³ (CODELCO 2009b; Minera Escondida 2009).

Minera Escondida case proves that, although private companies might not have the advance of before anymore, they are still an active stakeholder.

Different actors within the company also stimulate this dynamic. In relation to the environmental impact of Minera Escondida, their report especially focuses on the proprietors. This group of interest is of course primarily interested in the profits of the operations, but they are also concerned with the impact of the operations on health, security, local communities and the environment. We have seen different driving reasons as to why this is a concern to them: the importance of their image, a green champion, avoiding risks. A synergy between these drivers incites their concern for ecological durability.

Minera Escondida's policy on energy efficiency illustrates the way in which the most important proprietor, BHP Billiton, exerts its influence. BHP Billiton has a issued a framework for what the policy on sustainable development should be like within their company. This framework offers the guidelines that Minera Escondida has to follow to form its strategy on energy efficiency. In the particular case of energy, the strategy is categorized in the overall BHP Billiton policy on climate change (BHP Billiton 2010).

A last interesting conclusion of this case study is the fact that both companies wrote their report following the ISO 14001 norm. This shows the influence of the international community, even if something is not poured in an enforceable shape. The norm is used widely in different sectors of industry, but it is not something that is enforced by the law. The ISO 14001 norm is a tool that the industry can use to implement an environmental policy in a standardized way. Writing sustainability reports is one of the criteria of ISO 14001 (International Organization for Standardization 2011).

7. Conclusion

We started our research with the description of a paradox: to sustain and improve society we need copper, but by extracting copper we damage the environment that needs to be healthy to sustain our society. This led to two bodies of research questions that were designed to bring to light how Chile, the leading copper producing country in the world, has coped with this dilemma since 1970 and how different actors had an influence on that evolution.

The research in this dissertation has been able to provide an answer for all the research questions that had been postulated. At the beginning of this study there was already a strong suspicion that the answer to the question: *'Has there been an evolution of the ecological impact of Chile's copper mines?*' would be positive. The dissertation has affirmed this suspicion. This was, however, the easy part of the first question. The more tricky bit was whether this evolution led to an increase or decrease of the ecological impact. The answer to this question was twofold.

A division can be made between the period from 1970 to the early 1990s. In this period the ecological impact of Chile's copper industry increased at a very strong rate. The impact manifested itself in all of the four ecospheres and left an enormous ecological debt. The early 1990s, then, were a transition period. From then on the ecological impact started to stabilize itself or even decrease on certain levels. On other levels, however, the ecological impact kept and still keeps on growing. This is one of the conclusions we could draw from the case study. Waste production, energy consumption and water consumption keep on growing every year and the resulting impacts do so too.

The fact that the evolution of ecological impacts has decreased on certain levels shows us that efforts have been made to make Chile's copper mines more ecologically durable. The problem has appeared to be that mining companies indeed were able to decrease their impact in relative figures, but not in absolute figures. In other words, the companies made efforts to reduce their impact, but these were nullified by the ever decreasing ore-grade and the ever increasing production rate. Especially during the copper boom of the 1990s.

After determining the evolution the ecological impact had followed, the thesis proceeded towards searching an explanation in the influence of different stakeholders. Based on the 10 key drivers presented by Dummet, we were able to determine the most important stakeholders. There were four: the state, TNCs, NGOs or non-profit organizations (civil society) and the public (civil society). The way in which these stakeholders exerted their influence, their relative importance and the way in which they interacted with each other changed over time.

One very distinct line marks these changes. On the one hand, stakeholders that were defending the environment in the debate gained influence over the years. These stakeholders came from civil society: NGOs, non-profit organizations and in the particular case of Chile the public. On the other hand, influential stakeholders that traditionally defended the economical part in the debate (TNCs) started to see (economical) benefits in an ecologically more durable copper exploitation. This new view at least in part has to be ascribed to a changing national and international reality.

The dissertation proved that throughout the investigated period the state has been the actor with the most powerful tools of influence. It could use legislation or even the mere threat of legislation, incentives and in extreme cases nationalization to achieve its goals. We also learned, however, how when it came to the ecological impact of copper mines (and the ecological impact of industry in general) the state was influenced by different drivers and has not always chosen the side of environment in the depicted dilemma.

Under Allende, the state had an enormous influence by nationalizing Chile's copper industry. In doing so it temporarily eliminated another important actor: the TNCs, and created a new one: CODELCO. CODELCO was a state-owned economical actor that would move within the legislative framework of the state just like the TNCs. Thus it could turn into a powerful tool to reduce the industry's ecological impact. Nevertheless CODELCO has been running behind from then till the early 90s, when it started to tackle its environmental problems. The case study proved that in doing so, it has been able to catch up with the private sector.

Although the state had a strong influence in these early days, its main concern was with economical gain and the environment was almost a non-issue. This was also true in the Pinochet-era, when the state set itself aside to allow direct foreign investment to flow in once again. It did so under influence of the neo-liberalistic ideas of the Chicago Boys and the TNCs supported by the international financial institutions. By the end of the regime pressure to take action against the environmental impacts rose from the 'civil society'-camp, but also from the TNCs. Changes were initiated, but the problem was really tackled by the democratic Aylwin-administration. Under his administration CONAMA and the *'Ley sobre Bases Generales sobre e Medio Ambiente'*, which formed the basis for an environmental legislative framework, were created. The case study shows that this framework is very present in the sustainability reports of the studied cases, Codelco Norte and Minera Escondida, citing numerous regulations, regulating organs and norms.

The second actor we investigated, the TNCs, proved to be the most surprising of the four. Departing from the assumption that the most important goal of a TNC is profit maximization and that internalizing the environmental cost of operations is less profitable, we expected the TNCs to be consistently against a reduction of the environmental impacts of their operations. This was not true. As a matter of fact, from the moment that they reappeared on the Chilean market they took a leading role in minimizing their environmental impacts. They also started asking for a legislative framework in which standards would be set for environmental impacts. This was partly thanks to a growing influence of NGOs and non-profit organizations. After a closer examination, though, it became clear that this surprising strategy was completely in line with the goal of profit maximization.

The TNCs responded to the legislative reality in their home and client countries. These countries had already formulated strict environmental regulations by the late 1980s. In order to not risk prosecution and to be able to sell their copper, the TNCs applied the regulations on their new operations in Chile. Thus they also anticipated (threat of legislation) the evolution in Chile, reasoning that it was cheaper to have a head start than to adjust afterwards. Because this practice of anticipating was an unsure and risky business, the TNCs demanded for a legislative framework. This way the norms would be the same for every mining company in Chile and the competitive playfield would be evened out.

Civil society has known the most important evolution in its influential importance. In the early 70s NGOs were still in their embryonic phase and the public wasn't informed about environmental issues. Both of them needed the following two decades to achieve indirect influence in the debate about mines' ecological impact. This influence was primarily guided through the state. NGOs and non-profit organizations started to function as independent control and information organisms. They putted the finger where it hurt and tried to focus the public's attention through campaigns. The public won an exponential amount of influence in 1989 with the elections of a new democratic regime. It was now once again an electorate and the state had to take them into account. Thus, civil society achieved its first victories in a struggle to minimize the ecological impacts. The importance of the media next to NGOs and non-profit organizations in this respect cannot be forgotten. In the early 90s, it were the high-profile problems that were being tackled. Hence the relatively early establishment of norms for atmospheric emissions, because the black smoke from smelters was such a televised problem.

The case study demonstrates that the influence of civil society has continued to grow. Both NGOs and the public (in the form of local communities) now have direct influence over the mining companies' practices. NGOs empower local communities, are represented in various institutions that determine the sector's path of development and organize various seminars in which the mining company is involved. Local communities, on the other hand, are able to enforce the company to compensate for damage through manifestations and can direct their complaints to centers of contact.

To conclude the conclusion, here follow some suggestions of how this dissertation can serve as a springboard to future research on the subject. The dissertation can be used as a context or even framework for more detailed, case-specific historic analyses. These studies could focus on one or a limited number of cases and give a detailed evolution of its or their ecological impacts. These could then be linked to the interactions and synergy of influences from stakeholders that are typical to that particular case. Such a research would require one to do his or her research on site. Another type of study, with a wider approach, could be a comparison between countries. This study could then form one part of the comparison. Peru or Bolivia, for instance, have a very different mining culture from Chile and very different scene of stakeholders. It would be interesting to see how this scene has led to a different evolution and what are the differences that have led to this differing evolution.

Annex 1: Main characteristics of AMD waters and their environmental impact[51].

Property	Chemical species	Concentration range in solution	Environmental impact
Acidity	H^+	pH < 4.5	Loss of bicarbonate to photosynthetic organisms; degradation and death to animals and plants; reduction in drinking water quality; mobilization of metal ions; corrosion of man-made structures
Iron precipitates	Fe^{3+}, Fe^{2+}, $Fe(OH)_{3(s)}$	100 to $1–9 \times 10^3$ mg l^{-1}	Discoloration and turbidity in receiving water as pH increases and ferric salts precipitate; smothering of benthic organisms and clogging up of fish gills; reduction in light penetrating the water column; encrustation of man-made structures
Dissolved heavy metals and metalloids	Cu, Pb, Zn, Cd, Co, Ni, Hg, As, Sb	0.01 to $1–9 \times 10^3$ mg l^{-1}	Degradation and death to animals and plants; bioaccumulation; reduction in drinking water quality; soil and sediment contamination
TDS	Ca, Mg, K, Na, Fe, Al, Si, Mn, sulfate	100 to more than $1–9 \times 10^4$ mg l^{-1}	Reduction in drinking water quality; reduction in stockwater quality; encrustation of man-made structures as TDS precipitate as salts; soil and sediment contamination

[51] Table after (Ritchie 1994), through (Lottermoser 2007).

Annex 2: Tailings dam failures between the 1920s and 1990s[52].

Date	Location	Incident	Release	Environmental impact and fatalities
30.04.2006	Miliang, China	Tailings dam failure during raise	?	17 people missing; cyanide release to local river
30.11.2004	Pinchi Lake, Canada	Tailings dam collapse	6 000–8 000 m^3 of rock and waste water	Spill into lake
20.03.2004	Malvesi, France	Tailings dam failure after heavy rain	30 000 m^3 of liquid and slurry	Nitrate contamination of lokal creek
03.10.2004	Cerro Negro, Chile	Tailings dam failure	50 000 t of tailings	Contamination of local system
27.08.2002	San Marcelino, Phillippines	Overflow spillway failure after heavy rain	?	Villages flooded with waste; contamination of lake and stream system
22.06.2001	Sebastiao das Aguas Claras, Brazil	Tailings dam failure	?	At least 2 mine workers killed
18.10.2000	Nandan, China	Tailings dam failure	?	At least 15 people killed, 100 missing; more than 100 houses destroyed
11.10.2000	Inez, USA	Tailings dam failure	950 000 m^3 of coal waste slurry released into local streams	Contamination of 120 km of rivers and streams; fish kills
09.09.2000	Aitik, Sweden	Tailings dam failure	1 million m^3 of water from the settling pond	?
04.05.2000	Grasberg, Irian Jaya	Waste rock dump failure after heavy rain	Unknown quantity of heavy metal bearing wastes	4 people perished; contamination of streams
10.03.2000	Borsa, Romania	Tailings dam failure after heavy rain	22 000 t of heavy metal bearing tailings	Contamination of streams
30.01.2000	Baia Mare, Romania	Tailings dam crest failure after heavy rain and snow melt	100 000 m^3 of cyanide-bearing contaminated liquid and tailings	Contamination of streams; massive fish kills and contamination of water supplies of >2 million people

[52] Table from (Morin & Hutt 1994; Wagener et al. 1998; WISE Uranium Project 2006; Genevois & Tecca 1993) through (Lottermoser 2007).

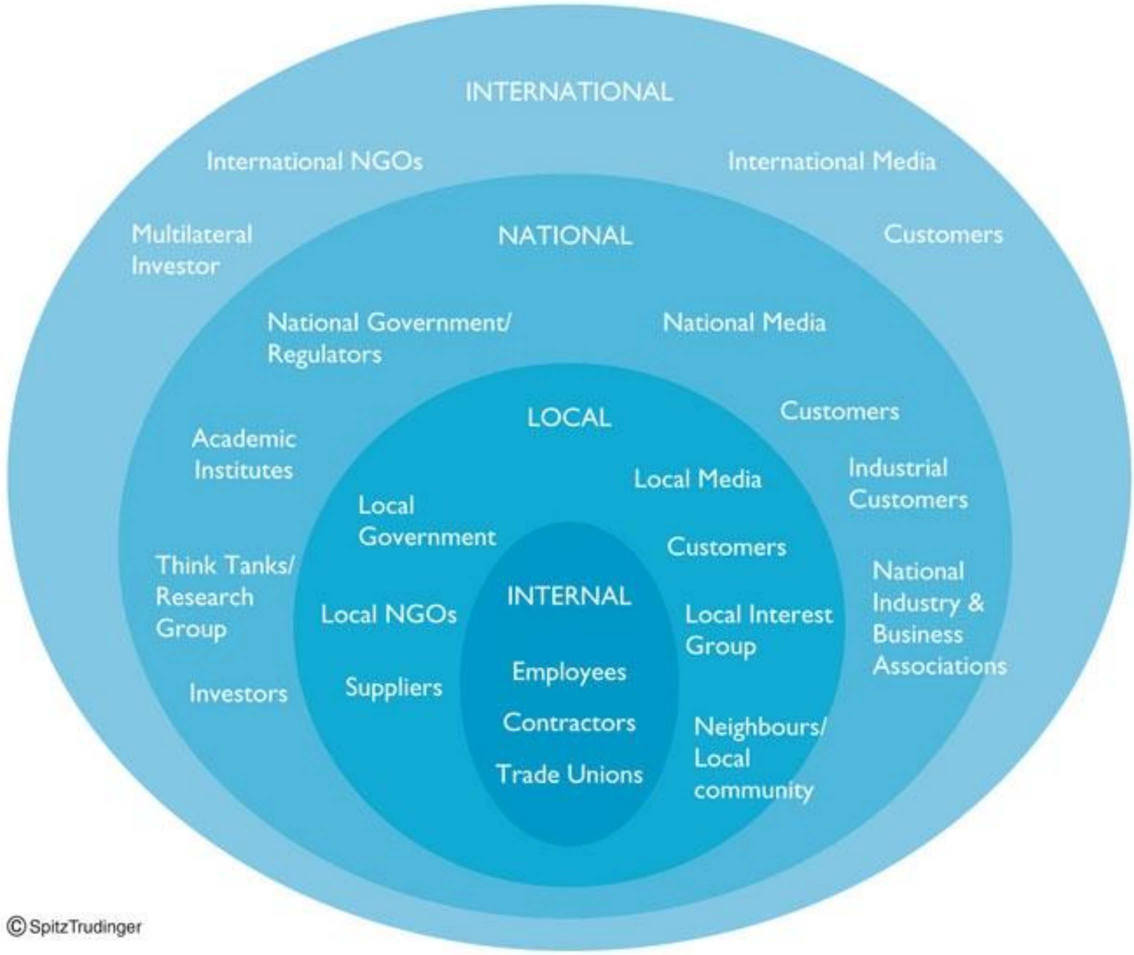
Date	Location	Incident	Release	Environmental impact and fatalities
26.04.1999	Surigao del Norte, Philippines	Tailings spillage from pipe	0.7 Mt of cyanide-bearing tailings	17 homes buried; 51 ha covered with tailings
31.12.1998	Huelva, Spain	Dam failure during storm	50 000 m^3 of phospho-gypsum tailings with pH 1.5	Spillage into local river
25.04.1998	Los Frailes, Aznacollar, Spain	Collapse of dam due to foundation failure	4.5 million m^3 of acid, pyrite-rich tailings	2 616 ha of farmland and river basins flooded with tailings; 40 km of stream contaminated with acid, metals and metalloids
22.10.1997	Pinto Valley, USA	Tailings dam slope failure	230 000 m^3 of tailings and waste rock	16 ha covered with tailings
29.08.1996	El Porco, Bolivia	Dam failure	0.4 Mt	300 km of stream contaminated
March 1996	Marinduque Island, Philippines	Loss of tailings through drainage tunnel	1.5 million t	Siltation of water courses
December 1995	Golden Cross, New Zealand	Dam movement	Nil	Nil
02.12.1995	Suriago del Norte, Philippines	Dam foundation failure after earthquake	50 000 m^3	12 people killed; coastal pollution
19.08.1995	Omai, Guyana	Tailings dam failure	4.2 million m^3 of cyanide-bearing tailings	80 km of local river declared environ-mental disaster zone
22.02.1994	Merriespruit, South Africa	Dam wall breach after heavy rain	600 000 m^3	17 people killed; extensive damage to town
14.02.1994	Olympic Dam, South Australia	Leakage of uranium tailings dam into aquifer	5 million m^3	?
1993	Marsa, Peru	Tailings dam failure from overtopping	?	6 people killed

Date	Location	Incident	Release	Environmental impact and fatalities
January 1992	Luzon, Philippines	Collapse of dam due to foundation failure	80 Mt	?
1989	Ok Tedi, Papua New Guinea	Collapse of waste rock dump and tailings dam	170 Mt waste rock and 4 Mt tailings	Flow into local river
30.04.1988	Jinduicheng, China	Breach of dam wall	700 000 m^3	20 people killed
19.01.1988	Grays Creek, USA	Dam failure due to internal erosion	250 000 m^3	?
May 1986	Itabirito, Brazil	Dam wall burst	100 000 m^3	Tailings flow 12 km downstream
1986	Huangmeishan, China	Dam failure from seepage/ instability	?	19 people killed
19.07.1985	Stava, Italy	Failure of fluorite tailings dam due to inadequate decant construction	200 000 m^3	269 people killed; two villages buried/wiped out
03.03.1985	Veta de Agua, Chile	Dam wall failure due to liquefaction during earthquake	280 000 m^3	Tailings flow 5 km downstream
03.03.1985	Cerro Negro, Chile	Dam wall failure due to liquefaction during earthquake	500 000 m^3	Tailings flow 8 km downstream
08.11.1982	Sipalay, Philippines	Collapse of dam due to foundation failure	28 Mt	Widespread inundation of agricultural land
18.12.1981	Ages, USA	Dam failure after heavy rain	96 000 m^3 of coal refuse slurry	Slurry flow downstream; 1 person killed; fish kill; homes destroyed
13.10.1980	Tyrone, USA	Dam wall breach due to rapid increase in dam wall height	2 million m^3	Tailings flow 8 km downstream
16.07.1979	Church Rock, USA	Dam wall breach	360 000 m^3 of radioactive tailings water; 1 000 t of tailings	Contamination of river sediments up to 110 km downstream

Date	Location	Incident	Release	Environmental impact and fatalities
1978	Lincoln, Montana	Dam wall breached by flood water following a small landslide	153 000 m^3 of tailings	Tailings flow into local river
31.01.1978	Arcturus, Zimbabwe	Slurry overflow after heavy rain	30 000 t	1 person killed; extensive siltation
14.01.1978	Mochikoshi, Japan	Wall failure of gold-silver tailings dam due to liquefaction during earthquake	80 000 m^3	1 person killed; tailings flow 7–8 km downstream
01.02.1977	Milan, USA	Dam failure	30 000 m^3	Nil
01.03.1976	Zlevoto, Yugoslavia	Dam failure due to excessive water levels and seepage	300 000 m^3	Tailings flow into river
1975	Mike Horse, USA	Dam failure after heavy rain	150 000 m^3	?
11.11.1974	Bafokeng, Impala, South Africa	Embankment failure of platinum tailings dam due to excessive seepage	3 million m^3	15 people killed; tailings flow 45 km downstream
01.06.1974	Deneen Mica, USA	Dam failure after heavy rain	38 000 m^3	Tailings flow into river
26.02.1972	Buffalo Creek, USA	Failure of coal refuse dam after heavy rain	500 000 m^3	150 people killed; 1 500 homes destroyed
1971	Florida, USA	Tailings dam failure caused by excessive seepage	0.8 Mt	Peace River polluted over a distance of 120 km
1970	Mufulira, Zambia	Tailings move into underground workings	1 Mt	89 miners killed
1967 and 1968	Blackpool and Cholwich, Great Britain	Failure of kaolinite tailings dams	?	?
1966	East Texas	Flow of liquefied tailings from impoundment caused by excessive seepage	80 000–130 000 m^3 of gypsum	?

Date	Location	Incident	Release	Environmental impact and fatalities
21.10.1966	Aberfan, Great Britain	Liquefaction of coal refuse dam after heavy rain	?	144 people killed
1965	El Cobre, Chile	Liquefaction of eleven tailings dams during earthquake	2 Mt	250 people killed
25.02.1963	Louisville, USA	Failure of calcium carbide tailings dam due to freezing of down stream slope	?	?
1944	Aberfan, Great Britain	Failure of coal refuse dam	?	?
December 1939	Abercyan, Great Britain	Liquefaction of coal refuse dam	?	?
1939	Cilfyndd Common, Great Britain	Failure of coal refuse dam	0.18 Mt	Flow into local river
15.12.1928	Barahona, Chile	Liquefaction of copper tailings dam during earthquake	4 Mt	54 people killed

Annex 3: Type of stakeholders for corporate social responsibility (CSR)[53].



[53] (Spitz & Trudinger 2009b)

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