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Study of environmental feasibility of paste and thickened tailings by life-cycle assessment

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Abstract

Paste and thickened tailings (P&TT) technology has important advantages not only from the safety point of view, but especially from the environmental point of view. The objective of this paper is to prove that this technology is a real sustainable alternative that can be evaluated using life-cycle analysis (LCA) methodology.

P&TT has emerged in recent years as an alternative for the treatment and disposal of mine waste. It involves thickening the tailings (a mix of process water and waste solids obtained after the process of separating the gangue of an ore) to a higher solid content, recovering the water, and recycling it back to the process. The volume of the final waste once it has been thickened is smaller and requires less storage capacity.

Conventional tailings disposal has some important disadvantages such as poor water recovery, high volume storage requirements, the need for containment structures like basins or dams (which can present stability and safety issues), and lower rehabilitation potential. Thickening technologies applied to tailings, in order to reach solid concentrations over 50%, are a real alternative to traditional disposal techniques. Scarcity of water and increasing demand for higher recycling rates can be partially solved, pollution and seepage problems are avoided, smaller containment facilities are required, and footprint is reduced due to smaller land needs, even allowing partial rehabilitation while the mine is still under operation.

Besides these important benefits, P&TT technologies require specific equipment and important energy consumption, with associated economic costs and environmental impacts. In order to evaluate them, a standardised tool should be used. This tool is the LCA, which allows calculating the potential environmental impact of an activity such as tailings thickening process during its whole lifecycle, quantifying the use of natural resources and the impacts on the evaluated system.

The International Organization for Standardization (ISO) defines LCA as a technique for assessing the potential environmental aspects and potential impacts associated with a product, process, or activity by compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with those inputs and outputs, and interpreting the results of the inventory and impact phases in relation to the objectives of the study.

The selection of LCA as an evaluation methodology for this study is due to the strong presence of this kind of tool in the environmental literature in the last several years. Its implementation has been fast, and several databases and software programs adequate for the inventory and impact assessment phases have been developed.

1 Introduction

Mining generates significant environmental impacts. The main environmental problems are the large scale of mining operations and the long-term effects of a significant amount of waste. In fact, we can assume that waste generation accounts for 29% of all activity (Kulczycka, 2008).

Moreover, the trend towards mining deposits of lower purity makes the volume of waste much higher, and environmental regulations are increasingly establishing stricter limitations on the methods of waste disposal (Kizil and Muller, 2011). Large areas are required for the storage of liquid and solid wastes that generate many environmental problems (Reid et al., 2008).

Brazil, the world's leading producer of iron ore, is pro-active in the effective management of mine tailings. On average, the iron ore mines in Minas Gerais generate about one ton of waste for each ton of ore, which is less than the world average. On the other hand, several of the iron ore mines are located in areas with torrential summer rain, which makes water management more difficult. Mining and processing activities have been linked with discharge of iron ore and sediment-laden runoff to downstream watercourses (Bates et al., 2008).

The main goal of waste strategy is to reduce harmful waste production and to promote recovery of waste in order to control several environmental impacts and problems linked to environmental legal requirements.

There is an increased interest in the treatment and processing of tailings to limit the volumes to be handled and to reduce the size of tailing dams. The economic and environmental feasibility of tailings thickening is determined by the long-term impact on the disposal area. Water availability and available land may be critical issues. In addition, it is possible to reduce the complexity of the dam if the tailings are thickened. Another concern is dam safety; some reported tailings dam failures and incidents may be related to large amounts of water in the disposal area.

However, thickening the tailings requires specific facilities and equipment and a strong energy input; that is why the sustainability of this alternative should study the balance between the dam needs and energy consumption (the main input needed on site).

In order to make an informed decision from the environmental point of view, it is necessary to consider all aspects involved. Keeping conventional management of tailings or adopting a P&TT alternative affects not only equipment and inputs consumed but also many aspects of the life of the mining facility. The P&TT alternative affects all stages of the life-cycle of the installation:

- During construction, it is necessary to consider the facilities and equipment for transport, thickening and disposal.
- In the use phase, which may last several decades, P&TT consumes electricity and requires equipment maintenance, but it reduces the occupation of the land and the volume of storage ponds or dams.
- At the end of the life of the installation, the P&TT alternative can facilitate the gradual recovery of the land occupied by waste, minimising the impact of land occupation.

In order to do this, it is necessary to use a methodology that takes into account the lifecycle concept, considering all the stages of the process. LCA methodology is an excellent alternative, as it is frequently used to evaluate the environmental impact generated by products and processes. This methodology follows the standards established by the Society of Environmental Toxicology and Chemistry (SETAC), which can be found in ISO 14040 and 14044 (ISO, 2006).

Among the tools available to evaluate environmental impacts, LCA provides a holistic approach to evaluating environmental performance by considering the potential impacts from all stages of manufacture, product use, and end of life stages. This is referred to as the cradle-to-grave approach (World Steel Association, 2011).

Section 2 includes a brief description of life-cycle assessment and describes its applications in the field of mining, as well as its limitations. This methodology is then applied to two scenarios: the first one corresponds to conventional tailings disposal — without thickening — while the second scenario is the P&TT alternative — a case of thickened tailings deposition with 60% solids.

2 LCA methodology

As environmental awareness increases, industries and businesses have started to assess how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. Many businesses have responded to this awareness by providing 'greener' products and using 'greener' processes.

LCA is a cradle-to-grave approach for assessing products, services, and processes. Cradle-to-grave begins with the gathering of raw materials from the earth to create the product and ends at the point where all materials are returned to the earth.

LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product, process, or service life-cycle, often including impacts not considered in more traditional analyses (for example, raw material extraction, material transportation, ultimate product disposal, and so on).

Figure 1 Life-cycle (Source: Coldstream consulting)

Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process or service by doing the following:

- Compiling an inventory of relevant energy and material inputs and environmental releases.
- Evaluating the potential environmental impacts associated with identified inputs and releases.
- Interpreting the results to provide a valuable, internationally recognised decision tool.

This means that the LCA technique, through different phases, assesses all the inputs and outputs of a product, process, or service (life-cycle inventory); assesses the associated wastes, human health, and ecological burdens (impact assessment); and interprets and communicates the results of the assessment (life-cycle interpretation) throughout the life-cycle of the products or processes under review.

2.1 Definition

LCA methodology allows determination of the area of the significant environmental impacts (hot spots) and identification of possible improvement opportunities in the life-cycle (Kulczycka, 2008). It is defined by the ISO 14040 standard as

> *"a technique to assess the environmental aspects and potential impacts associated with a product, process, or service by: compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts associated with identified inputs and releases; interpreting the results to help you make a more informed decision" (ISO, 2006).*

The LCA is composed of a series of interrelated stages, as shown in Figure 2.

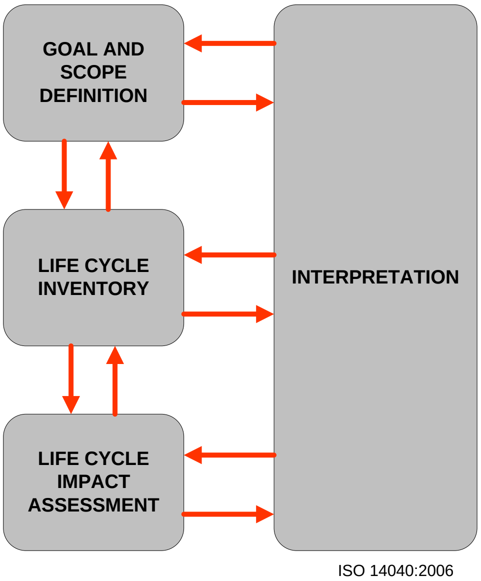

Figure 2 Stages in life-cycle assessment (ISO, 2006)

The following stages are included:

- Goal definition and scoping. This defines and describes the product, process, or activity.
- Life-cycle inventory. This identifies and quantifies energy, water, and materials usage and environmental releases.
- Life-cycle impact assessment (LCIA). This assesses the human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

- Interpretation. This evaluates the results of the inventory analysis and impact assessment to select the preferred product, process, or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

Eco-Indicator 99 (EI99; the indicator selected for an initial approach) is one of the most widely used impact assessment methods in LCA. This indicator establishes three different damage categories: damage to human health, measured in disability life years; damage on ecosystem quality, expressed as the percentage of extinct species in a specific area due to the environmental burden; and damage to resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuels (Goedkoop et al., 2009).

2.2 Overview of life-cycle assessment of mining wastes

Application of LCA in the mining and minerals processing industry started in the mid to late 1990s and was initially aimed at carrying out life-cycle inventories (LCI) for metal production processes to be used in support of LCA for consumer product selection and design. Since then, the use of LCA has been extended to project and process selection within companies. A number of international initiatives have been launched in recent years to evaluate the use of LCA in the context of minerals and metals production. Among them, the *Mining, Minerals and Sustainable Development* (MMSD) project concluded that "LCA is a useful tool to provide an assessment of environmental considerations during decision making within the industry," in spite of the limitations of the tool related to the methodology of LCIA phases (Reid et al., 2008; Stewart and Petrie, 1999).

In addition, in EU countries, the role of life-cycle thinking is essential to successfully move towards the sustainable use of natural resources and the management of related wastes (Kulczycka, 2008).

An interesting point was raised by Van Zyl (Reid et al., 2008), who said that the environmental impacts of mines have to be evaluated using specific data considering all life-cycle stages and not only the operation step. A holistic life-cycle assessment system for the extractive industries, which accounts for all stages of minerals production, from exploration and development of a mineral deposit to mining, processing, waste disposal, remediation, decommissioning, and aftercare is necessary; Durucan et al. (2006) note that it has not yet been developed.

Moreover, life-cycle assessment methodology has been applied to mineral processing cycles by considering as inputs the volume of materials used and the energy consumed in the process to compare the economic benefits and the waste production for different metals. But some writers (Durucan et al., 2006; Reid et al., 2008) suggest that it should be used to select one or more control methods for mine operation, waste management, and closure. Different management options should be assessed and compared with respect to their potential environmental impacts. Comparisons are most often based on cost, but need to also be based on social impacts as well as environmental effects (Reid et al., 2008).

2.3 Limitations

Throughout all LCA studies performed in the mining industry, very little emphasis has been placed on the extraction of mineral ore and on the consequent waste handling aspect of the industry in relation to the allocation of environmental burdens (Durucan et al., 2006). The mining system has been largely simplified in a single fact sheet. Moreover, in most LCA studies, solid wastes are directly considered as an emission to the environment without considering the process of waste management. In other words, the end-of-life step of the residues is not included in the most of these studies. However, EU Directive 2006/21/EC establishes as mandatory not only proper management of tailings dumps but also guarantees regarding the after-care phase of the facility (Kulczycka, 2008). Recent research proposes considering solid waste management as an additional unit process (end-of-life process) within the system generating emissions. For example, the Ecoinvent LCI datasets (Classen et al., 2009), one of the most comprehensive databases, describes the sulphidic tailings management process but considers only the occupation of land, neglecting to consider emissions from the tailings over time and the energy and material requirements for sulphidic tailings management (Lesage et al., 2008).

Because resource depletion cannot be avoided, it is necessary to focus on the next larger impacts which can be modified to improve their environmental impacts. Among the potential impacts of management methods for mining wastes, deterioration of the land is a major concern (Ripley et al., 1995; Jolliet et al., 2004). Land surface use for anthropogenic activities is recognised as a potential threat to species and ecosystems. In spite of its importance, the land-use category still does not benefit from an international consensus, and further development is still needed. This limitation has also been pointed out in different workshops in the mining and metal industry. As a result, LCAs conducted for the mineral industry often exclude the land-use category (Reid et al., 2008).

On the other hand, evaluation of the impact of land-use is delicate: depending on the evaluation method used, the weight of this category will be different, and variations in the final impact could be very important.

Another important category that must be observed is water depletion and contamination (Gunson et al., 2011), collecting several efforts that have been made to quantify and understand mine water use, with a focus on life-cycle analysis and key indicators. The goal was to determine the best way to save water in tailings management. However, there is no impact assessment method that quantifies the impact of water consumption or saving; it is only possible to assess pollution from emissions to water.

3 Goal and scope definition

This section describes the goal and general scope of the study, according to the recommendations of ISO-14040 and the ILCD handbook (ILCD, 2010). This phase includes the system description, the election of the functional unit, the definition of the boundaries of the study, the data collection procedure, and restrictions and the selection of methodologies for LCIA.

3.1 System description

This study aims to evaluate the impact of two different alternatives for the disposal of tailings from a mine, generated during a flotation process. This will assess two key factors from the point of view of environmental sustainability – land-use and energy consumption – with the objective of identifying the best tailings disposal option. The study analyses two scenarios:

- Scenario 1: The tailings slurry is conventionally discharged with a considerable quantity of process water into a settling pond (20% solids concentration).
- Scenario 2: The tailings slurry is thickened from 20% to 60% before being discharged into a pond.

Although one of the advantages of this technique is the possibility of filling the mine for its closure, in this case, this option is not observed, as it will be evaluated as an open pit mine.

This study concerns the full life-cycle – from cradle-to-grave – of a tailings storage. The life-cycle stages are shown in Figure 3.

Figure 3 From cradle-to-grave concept

Facilities have been accounted only as materials; the efforts required for their construction have been left outside the inventory, which is a common practice in many comparative LCA studies.

3.2 Functional unit

The functional unit is a central element of an LCA. Without it, a meaningful and valid comparison is not possible. The first step of defining the functional unit is to identify and quantify the relevant quantifiable properties and the technical/functional performance of the system (ILCD, 2010).

In this case, several possibilities for selecting a functional unit are considered. One ton of ore produced in the mine could be selected, but this functional unit would be difficult to quantify, as it is not directly related to the next process or to the characteristics of the facility, as this mainly depends on the mineral purity. That leads to the second possibility: using 1,000 m^3 of tailings generated during the flotation process.

To carry out the study, a process is modelled, starting with a flow of 255 m^3/h of tailings with 20% solids content and a facility life estimation of 20 years. The steps to be followed to perform the analysis in other cases would be the same as the ones described here.

3.3 Data

Data quality is composed of accuracy (i.e. representativeness and methodological appropriateness and consistency), precision/uncertainty, and completeness of the inventory (ILCD, 2010). To get an adequate quality data, a combination of reliable data from a model is combined with actualised background data of LCI databases, such as Ecoinvent and GaBi Professional.

Cut-off criteria refer to the omission of irrelevant life-cycle stages, activity types, specific processes and products, and elementary flows from the system model. Cut-offs are quantified in relation to the percentage of environmental impacts that is approximated to be excluded via the cut-off (ILCD, 2010).

The cut-off criteria of this study permit the exclusion of materials, energy, and emission data with the following criteria:

- Mass: if the process is less than the 3% of the total mass managed in the model, it can be excluded, assuming that the environmental impact is not relevant.
- Energy: if the process represents less than the 3% of the total primary energy of the inventory, it can be excluded, assuming that the environmental impact is not relevant.
- Environmental relevance: if a particular process that meets the above conditions, due to the special characteristics of the material or the energy production process, has an environmental impact in some of the categories greater than 5%, this process cannot be excluded.

4 Life-cycle inventory

Two scenarios are presented with a data set corresponding to an application example. In the model, all variables can be modified to provide the basis for future development of a decision system to evaluate the most suitable alternative.

4.1 Scenario 1

The tailings slurry is conventionally discharged with a considerable quantity of process water into a settling pond. In general, slopes are below 0.5% in the disposal area. The solids concentration is often well below 20% by mass with a potential of segregation after deposition, i.e. hydraulic sorting of particles in the settling pond (Wennberg, 2010).

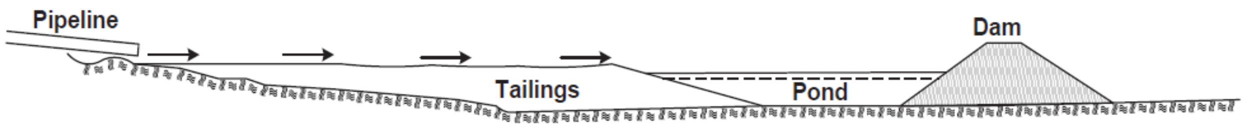

Figure 4 Conventional tailings disposal system

This corresponds to the reference scenario, which studies the impact generated by the traditional way of storing waste from extractive mining. The disposal of tailings, or final disposal on ponds, is the second major impact of mining activities, even for non-toxic waste such as that from iron ore extraction.

This stage comprises a phase in which the residual material from the flotation process for obtaining the ore is pumped to the discharge point. Even if there are examples of direct discharges into the river (subaqueous disposal), there are specific recommendations to change this practice and adopt less aggressive techniques. Therefore, in this case study, the environmental impacts associated with the discharge and storage in a settling pond will be evaluated.

4.1.1 Facilities

The tailings transport system requires a pumping station consisting of centrifugal pumps that generate the required transport energy. According to Moolman and Toit (Moolman and Vietti, 2012; Toit and Crozier, 2011), the pipeline will be made of high-density polyethylene (HDPE); 2,500 m of pipeline will be installed to transport tailings from the mine facility to the pond.

Apart from the transport system, the dam or pond is the main facility. It consists of waste rock from the mine, transported and compacted. The ponds for non-thickened tailings suffer higher pressure from the fluid, so that the walls of the dams have to be large. They also require land sealing to prevent infiltration of leachate and acid water underground, both for environmental reasons and to prevent damage to the foundation.

This dam is constructed during the plant operation and the subsequent deposition of tailings; therefore, its dimensions must withstand the final total deposition of tailings generated by the activity of the mine along its entire life. The construction of the dam is inventoried as transport of materials needed by lorry. One other necessary element is the geotextile, which is placed in the bottom, occupying the entire area.

The pond life-time will cover the operational phase of 20 years and closure of 100 years, according to Doka (2008). This means that the dam will occupy the land for 100 years. This fact, linked to the evidence that storage of non-thickened tailings requires extensive land-use, is expected to turn into the biggest impact of the study.

4.1.2 Use

The tailings are pumped to the storage pond, which is located 2,500 m from the facility. A pumping efficiency of 70% and a total drop of zero metres are considered. An adequate pumping velocity must be achieved to avoid depositions that could block the tailings transport.

4.1.3 End-of-life

The dismantling of the facilities is a fundamental part of the LCA. In this case, this only affects the transportation system, pumps, and pipeline, because this study does not consider the drainage of the tailings pond.

Every material of pumps and pipelines will be recycled; this action will improve the whole LCA. A 95% recuperation ratio for steel and iron components is assumed. The plastic elements are not easily classified and it is assumed that they are sent to an inert landfill with energy recuperation. The material that is not recycled is sent to a landfill for inert materials, using a model representative of the European OECD (Organization for Economic Cooperation and Development) waste management technology.

4.2 Scenario 2

This scenario evaluates a P&TT alternative disposal, supposing that the tailings are generated after the flotation tank (Peck, 2007). With a tailings system that includes a thickener producing a highly concentrated underflow, the thickener can be placed near the concentrator or near the disposal area. In flat terrain, the thickened tailings are discharged from an artificial ramp or a tower, forming a ridge or cone. It may be favourable to locate the thickener close to the disposal area when deposition takes place along a hillside or down a valley (Wennberg, 2010).

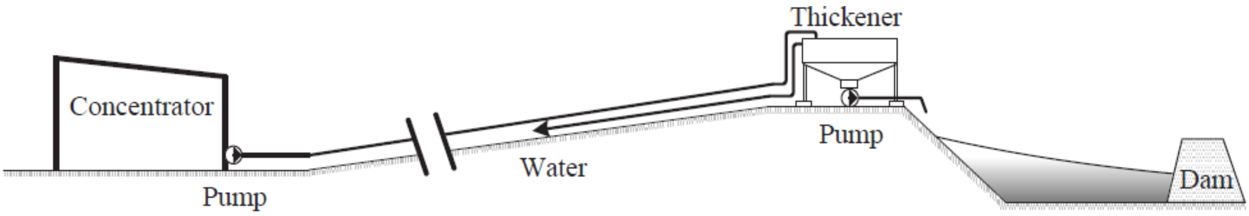

Figure 5 Thickened tailings system with thickener close to the disposal area

With an elevated location of the thickener close to the disposal area, only a short distance of pumping of thickened slurry is initially required. With a thickened tailings system, up to 90% of the water can be recycled directly from the overflow of the thickener. The solids concentrations by volume will be above 60% solids to achieve paste properties. This generates a conceptually even slope of deposited tailings of 2% with no segregation of particles and virtually no drainage of water (Wennberg, 2010).

4.2.1 Facilities

As in the previous scenario, the transport system is based on the same centrifugal pumps, but in this case duty and standby trains of six centrifugal pumps with 90 kW motors must be installed in a series. The first and the last pumps in the train are equipped with variable speed drives. HDPE pipes from the paste thickener connect to HDPE lines on the dam walls.

The return water pumping system pumps overflow water from the secondary thickener back to the plant. Rainwater from the residue storage dam pond is pumped by a floating pontoon pump to the secondary thickener and returned to the plant via the return water pumping system (Toit and Crozier, 2011).

Following the established assumptions and simplifications, the thickener would be inventoried as a group of materials (concrete, steel, and electrical systems), excluding the processes needed for the manufacturing of the thickener. The paste thickener has a device to optimise flocculant consumption installed (Toit and Crozier, 2011).

In this case, the pond facility has been designed as compacted earth embankments into which the tailings stream is deposited, but the dam is built in the same way as in the previous scenario. Volume paste discharged is three times lower, so a smaller dam is required; this is inventoried as transported material by lorry. The surface pond land-use is three times smaller than in Scenario 1 and geotextile is not necessary.

Supernatant and rainwater on the dam is removed by means of a penstock to the return water dam; the harvested water is recycled to the primary thickener along with the paste thickener overflow and is used in the primary plant operations. Clean water runoff arising from the external catchment will be prevented from flowing onto the paste disposal facilities and consequently becoming contaminated. In order to divert the flows from each portion of the catchment, cut-off trenches and diversion bund walls are included in the design (Toit and Crozier, 2011).

The pond life-time will cover the operational phase, 20 years, but this scenario favours sealing the dam as it is filled in. This means that in five years, the terrain on which the tailings were disposed could be reclaimed. By doing this, not only is the occupied land surface lower, but the occupying period is also shorter.

4.2.2 Use

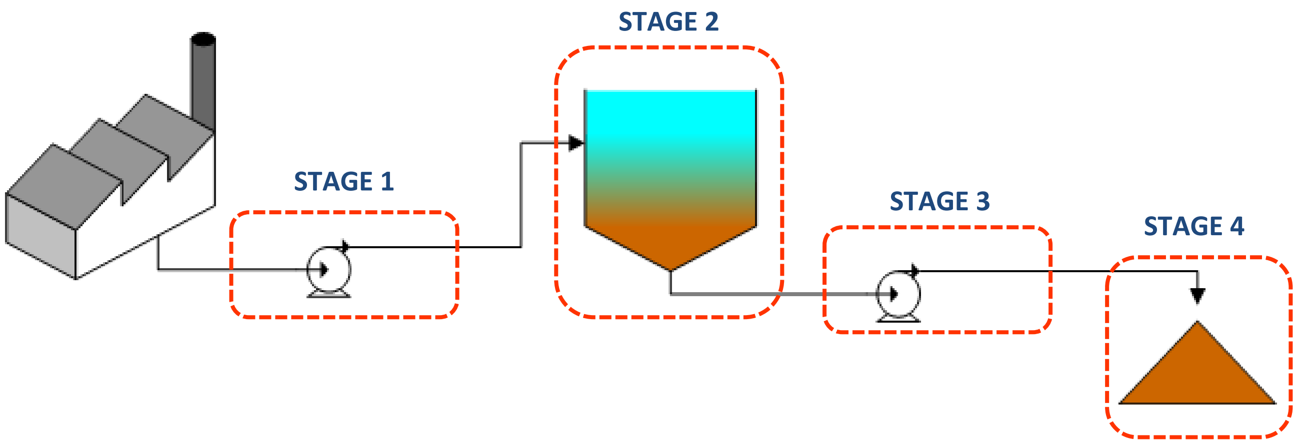

Figure 6 The four stages describing the whole process

This process takes place in four stages. The first stage is the transportation of un-thickened tailings to a tailings thickener, where the second stage begins. This pumping is performed over 2,500 m, saving a height of 20 m. This assumes a speed of 2.4 m/s, a pipe diameter of 0.225 m, and a transport efficiency of 70% (Wes Tech Engineering, 2011).

Once in the thickener, addition of a flocculant promotes aggregation of the solid particles forming agglomerates, which are naturally decanted, settling on the tank bottom. The choice of flocculant depends mainly on the initial percentage of solids, solids characteristics, final concentration desired, pH, and residence time. The percentage of solids considered in the input is 20%, reaching levels of 60% in the output (paste). After the residence time, the thickened tailings are discharged through the bottom, and clean water is extracted from the top (Wes Tech Engineering, 2011).

The third stage involves pumping the thickened tailings up to the pond over a distance of 186 m and without a height difference. This assumes a transportation speed of 2.5 m/s, a pipe diameter of 0.225 m, and 50% efficiency (Weir Minerals North America-Hazleton, 2007).

The paste discharged is determined by the type of dam selected. Choosing the most appropriate characteristics depend on the terrain, total amount to be deposited, weather conditions (rainfall, evapotranspiration, and wind regimes), and geology and seismicity of the location. In this case, valley disposal has been selected.

4.2.3 End-of-life

At the end-of-life, facilities will be dismantled and every material of the transport system and thickener will be recycled, improving the global LCA in the same way as in Scenario 1.

In this scenario, the closure will be different, because, when the mine ceases trading, all the water will have been drained and the pond will be able to hold ground cover, or even to be reforested (Böhm et al., 2005).

5 Environmental impacts assessment

EI99 is the selected methodology for the LCIA. The method evaluates the impacts in the categories shown in Figure 7.

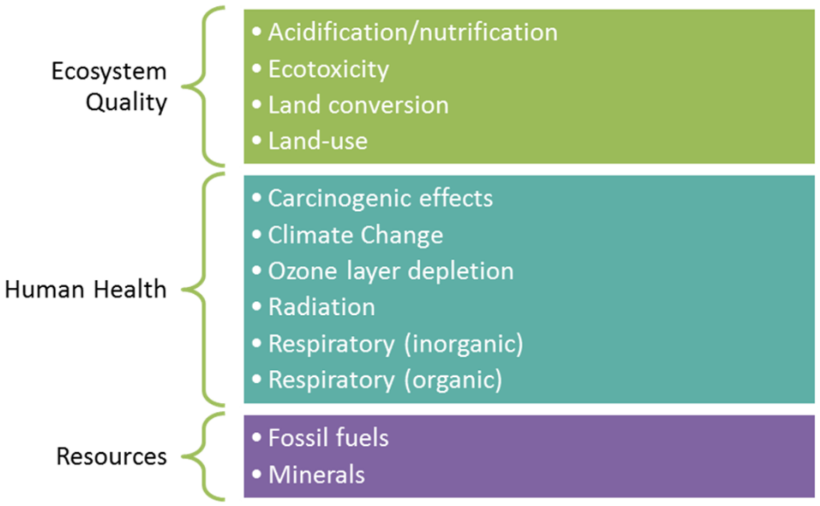

Figure 7 Grouping of endpoint damage categories and sub-categories

There are three main categories: ecosystem quality, human health, and resources. Each one has different sub-categories. Damage in the human health category is measured in extent of disability life years; damage in the ecosystem quality sub-categories is measured as a percentage of extinct species in a particular area because of the environmental load; finally, damage in the resource usage categories is expressed as the increase in energy needed to offset the increased difficulty in obtaining the same resources.

The results are normalised and weighted in order to be added and compared with each other, offering a vision of the total environmental impact, which allows comparison of the two scenarios. These weighted indicators are called endpoints and they are expressed in dimensionless units called points, arbitrarily defined as one hundredth of the average impact of a European citizen ('Pt' in the following figures).

5.1 EI99 HA endpoint results – Scenario 1

In the final analysis, the categories of damage in this scenario clearly show the strong impact of land-use in the final category of ecosystem quality. The transformation and land-use due to the pond that lasts for 100 years is heavily penalised in EI99.

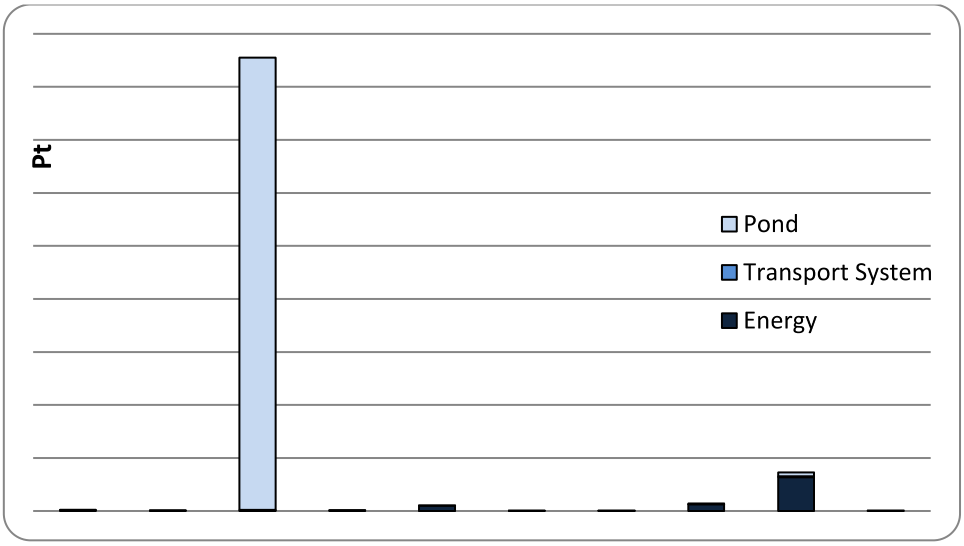

Figure 8 Environmental impact assessment EI99 HA by inputs – Scenario 1

Taking into account the fact that the highest score is for the land conversion and land-use sub-category, the highest impact goes to the ecosystem quality category. The score points in the resources category correspond to the fossil fuels spent to generate the required transport energy.

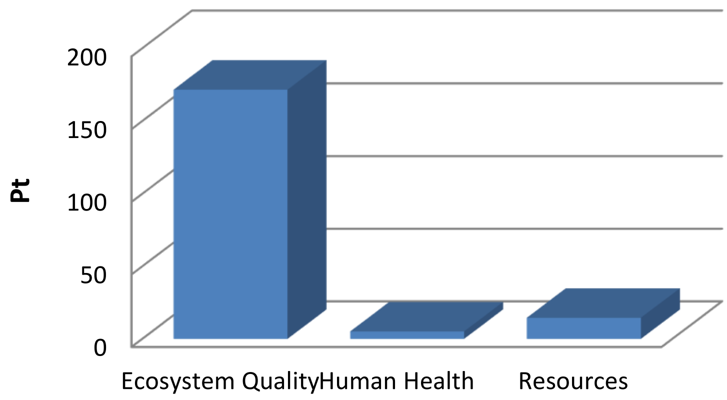

Figure 9 Global score: environmental impact assessment EI99 HA – Scenario 1

5.2 EI99 HA endpoint results – Scenario 2

The inventory shows that Scenario 2 has a strong energy demand, which is supplied by electrical consumption, affecting not only the fossil fuels sub-category but also the respiratory (organic, inorganic) and climate change sub-categories, because of emissions during energy generation. Another characteristic of Scenario 2 reflected in the graph is the lower land-use required by the tailings thickening alternative.

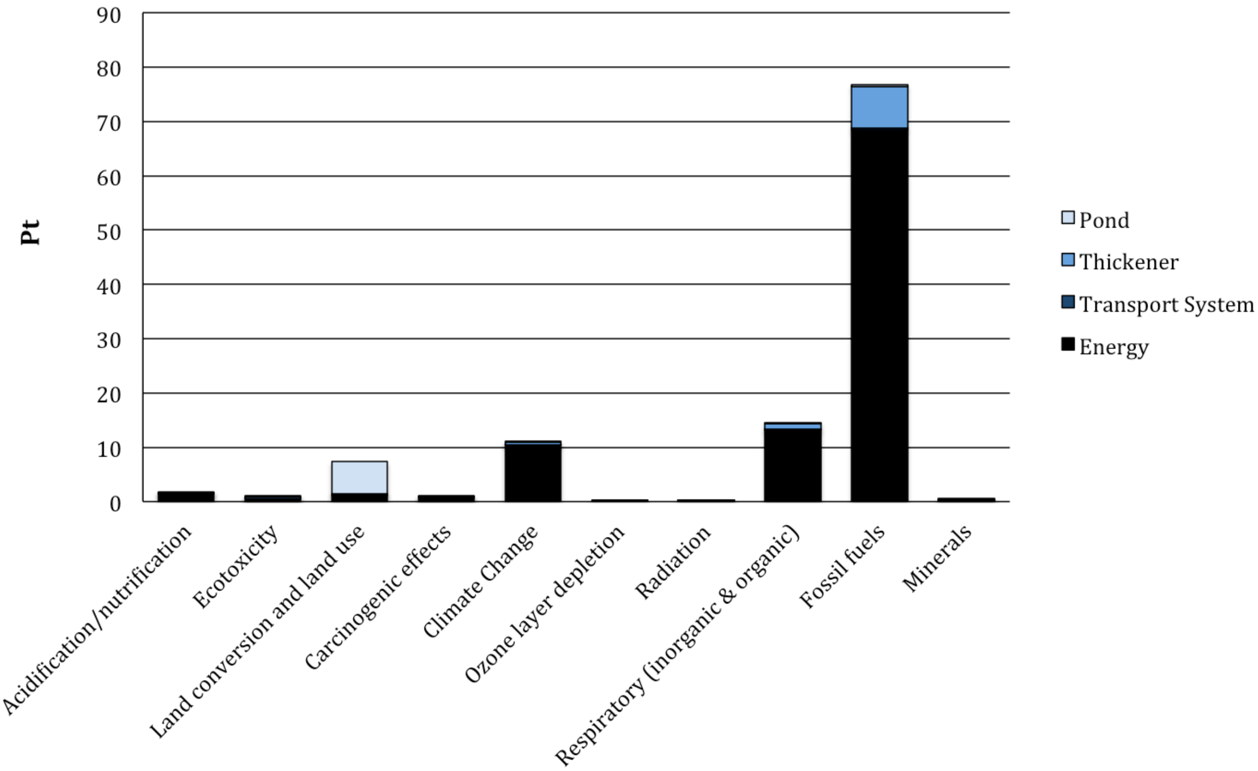

Figure 10 Environmental impact assessment EI99 HA by inputs – Scenario 2

If all these impacts are grouped to see how the global impact of Scenario 2 is distributed, it is possible to appreciate the main difference from Scenario 1: thickening the tailings has resulted in a score that is distributed among the three main impact categories (with the resources score the highest one). This score would not be so high if the origin of the energy used for transportation included renewable energies instead of diesel. This would improve the paste alternative scenario, reducing its environmental impact.

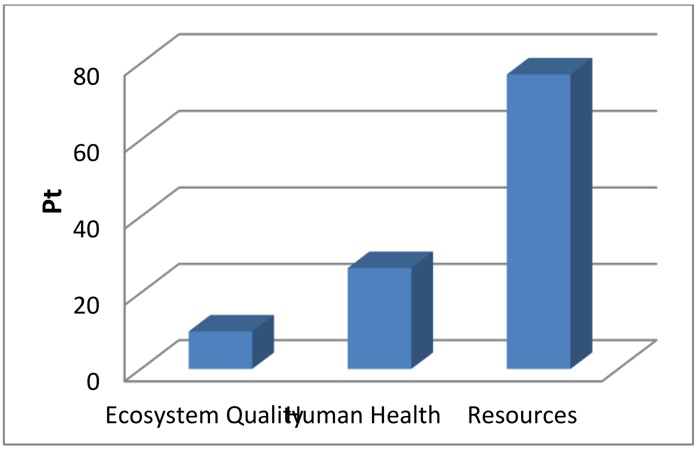

Figure 11 Global score: environmental impact assessment EI99 HA – Scenario 2

5.3 Scenario comparison

Figure 12 shows the thickened tailings scenario as the best alternative for the environment, as its global impact is significantly smaller. This is because Scenario 1 needs a bigger disposal area than Scenario 2. Indeed, the pond is the most important input in Scenario 1 but the third most important impact in Scenario 2. Instead, energy consumption is the greatest input in the paste scenario, while it is not important in the conventional disposal scenario.

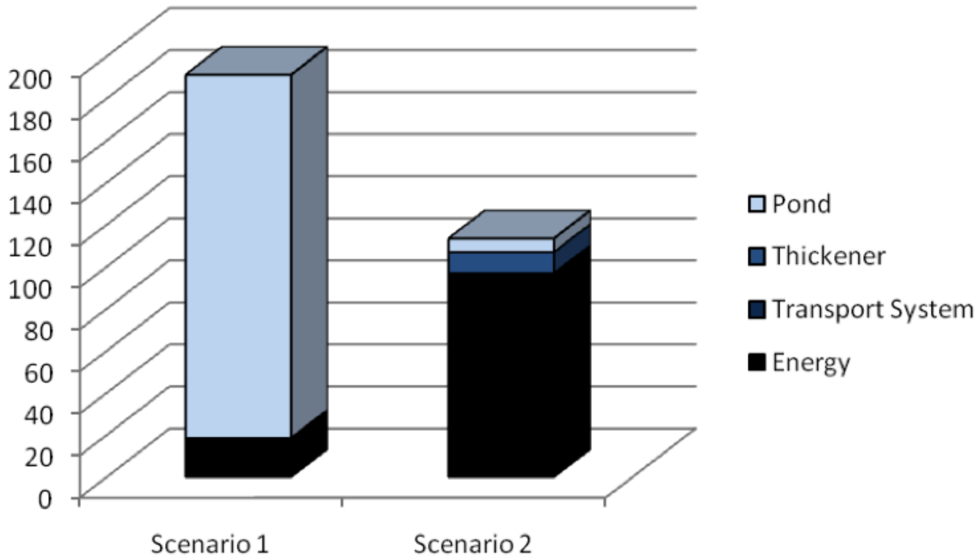

Figure 12 Environmental impact assessment EI99 HA by inputs

Therefore, in non-thickened tailings disposal, the most important impact is land-use, while in thickened tailings, it is energy consumption. Taking into account that EI99 strongly penalises the land-use impact category, Scenario 2 is the best option for the environment.

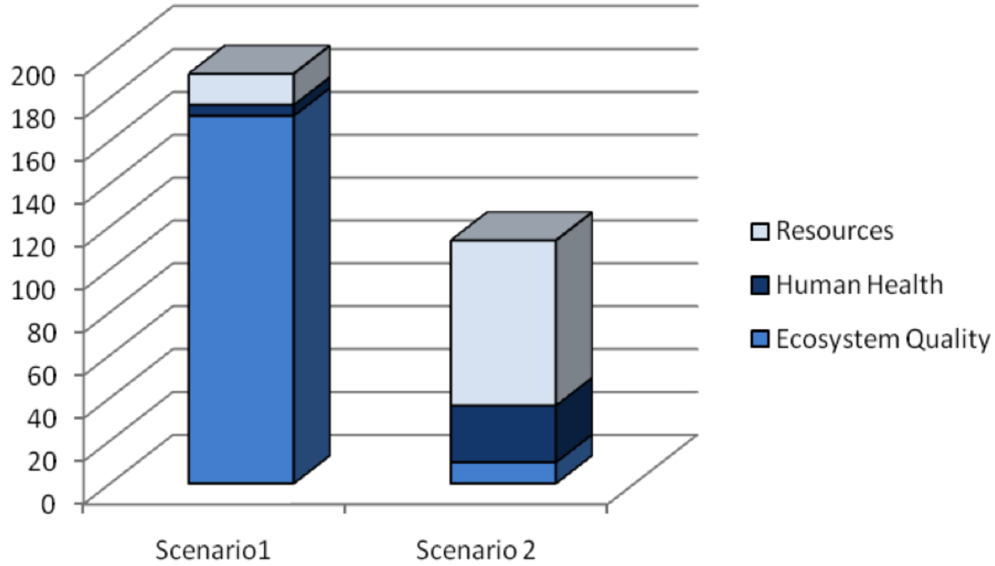

Figure 13 Environmental impact assessment EI99 HA by impact categories

However, what would happen if it was highly degraded environment where the land had no value and where there was no scarcity of water? This is a key question, because EI99 does not evaluate water savings; in fact, water savings are penalising in the tailings thickening option because of water pumping needs. One of the biggest benefits of P&TT, water savings, is not being recognised with this indicator. Regarding land value, it would be necessary to change the weighting of the category of land-use, which would dramatically reduce the impact of the ecosystem quality category. Given this hypothesis, Scenario 2 would clearly be worse for the environment, since the benefits granted by the smaller size of the reservoir (and its subsequent revegetation and recirculation of water into the production process) does not offset the energy expenditure that aggravates the categories of human health and quality of natural resources (Gunson et al., 2011).

6 Conclusions

This analysis of the environmental impact assessment of two tailings disposal alternatives concludes that the P&TT technique can transform mining into a more sustainable activity, even when it requires a higher demand for energy and materials than conventional (non-thickened) tailings disposal.

However, defining the tailings thickening process in detail is not easy: transportation of paste and thickened tailings is complex, and other elements, such as thickener designs, require further definition. On the other hand, there is a strong dependence on the mine location; this underlines the need to specify the conditions for each individual case study.

Indeed, it is only in locations where the use of land or water scarcity are not problems that paste and thickened tailings would be penalised. However, even in these cases, the traditional tailings storage would remain non-favourable: a failure of a dam, for example, would have a huge impact. Many cases of these environmental disasters are known, such as the case of pyrite tailings in Aznalcóllar (Spain) or more recently, aluminium in Kolontár (Hungary). Despite the above, the LCA is a powerful methodology to assess which option is the best in each case: it offers the ability to test 'what-if' situations easily, and is a worldwide recognised decision support tool.

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