Application of Life Cycle Assessment in process design: Case study on SO_2 abatement technologies in the PGM sector

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This dissertation is presented to the University of Cape Town
In partial fulfilment of the requirements for the degree of Master of Philosophy in
Engineering in the department of Chemical Engineering

minerals to metals
DEPARTMENT OF CHEMICAL ENGINEERING

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EXECUTIVE SUMMARY

Platinum group elements (PGEs) are increasingly being used in a variety of environmentally-related technologies such as catalysts and catalytic convertors which have strong expected growth to meet environmental and technological challenges this century. The platinum industry is actively seeking to progress its commitment to sustainability principles by reducing the negative impacts of their mining and mineral processing operations. Technical innovation to improve future plant designs, as well as the development of management policies, guidelines and protocols for efficient operation of process plants has therefore become a strategic priority for the South African platinum industry. The industry has also made an effort to understand the environmental impacts of its products from mine to metal, using life cycle methods.

However, very limited research has been done to investigate what environmental value could be created if strategic and design decisions in minerals processing were life cycle based, particularly in the context of PGMs. Seminal work by Stewart (1999) investigating the environmental life cycle consideration for design-related decision making in the minerals industry has not led to significant adoption. Forbes et al. (2000) analysed metal processing using LCA and were able to identify opportunities for improved environmental performance. They however did not explore how it would be incorporated into the decision making cycle. Therefore, the main objective of this research is to determine whether life cycle assessment could help inform design decision making in the minerals industry.

In the years 2002-2008 several PGM-producing companies commissioned new SO_2 scrubbing technologies to meet the regulations that had been set to prevent the release of excessive amounts of sulphur dioxide from smelters in the Rustenburg area, a mining town located in the North West Province of South Africa. Using these clean-up process retrofits as case studies, this dissertation aims to determine whether the introduction of LCA as an environmental analysis tool would have provided additional value to the decision makers.

The case study approach that was chosen compared and assessed the performance of SO_2 abatement technologies and the effect of efficiencies chosen on environmental performance by using life cycle assessment modelling. By doing the life cycle assessment on the different options that the companies had, it was possible to evaluate the indirect environmental impacts that could have been overlooked during the design decision making process. In addition, experts who were involved in the design processes of the SO_2 abatement retrofits were interviewed to establish: i) how the design decisions were made and ii) whether the life cycle based insights into technology performance would have been of use in the design work.

The goal of the life cycle assessment was to identify whether there were design decisions that induced environmental burden shifting when platinum smelters in the Rustenburg area added SO_2 abatement technologies to their processes, which could have been avoided had the LCA perspective been taken into account. The assessments considered two key variables, namely extent of recovery and technology choice.

The study shows that the energy requirements increase exponentially with increasing recovery for both technology options. This is a result of the increased pumping energy requirements which are directly related to the increasing quantities of solvent that have to be pumped.

The environmental impacts that were analysed during the Life Cycle Impact Assessment (LCIA) phase were: abiotic resource depletion, fossil fuel depletion, acidification, global warming, human toxicity and water depletion. The background processes for soda ash and lime production dominated abiotic resource depletion, fossil fuel depletion, global warming potential and human toxicity impacts that were associated with the concentrated dual alkali process. The foreground system had significant effects on the acidification potential, water depletion as well as global warming potential.

For the scrubber with acid plant, the transportation of the acid that was produced and the sulphuric acid production used in the system expansion were observed to have a major impact on most of the impact categories, with the exception being the acidification potential and water depletion in which the foreground system was the principal contributor to the impact categories.

The magnitude of impacts increased with increasing recovery in the concentrated dual alkali case with the only exception being the acidification potential. For the scrubber with acid plant option, the magnitude of impacts decreased with increasing recovery with the exception being the amount of water used and the global warming potential. Overall, the LCA revealed that the scrubber with acid plant choice mostly has significantly lower environmental impacts.

The results of the LCA were then presented to design experts as way of gaining insights as to whether or not carrying out a life cycle assessment during the design phase would be capable of informing and influencing design decision making in mining companies. The interviews were also used as a platform to gain a better understanding of how design decision making works in the mining sector.

The expert interviews revealed that the decision making process is not an individual job but rather requires input from different project teams. Before a decision is made they would all need to agree unanimously on a specific technology option which they would all deem beneficial after carrying out a cost benefit analysis.

With regards to decisions on retrofitting, the major drivers were identified to be the case in which design specifications were not being met, surfacing of new regulations or availability of improved technology. With regards to choosing between technologies that satisfied the same purposes the interviewees felt that the main determinant would be the quality of gas to be treated. Once this had been established, the company would then decide on whether or not they wanted to opt for a high OPEX or high CAPEX process depending on their financial stability.

Most of the interviewees felt that companies did not do much to incorporate environmental concerns into their design apart from doing the prescribed Environmental Impact Assessment (EIA). Therefore once presented with the LCA results from the study they felt that such an assessment would be really useful especially if it were to be incorporated during the early stages of the design. By so doing the environmental aspects would gain more weighting in the decision making matrix that is used.

The major concern that was brought up was that in as much as the LCA quantified the impacts associated with the different options, and a comparison was made between the different key variables, it would be difficult to make decisions without also including a rational and consistent normalisation process. This would help decision makers see

the relevance of the impacts presented to them, by relating them to some form of reference system.

It is concluded that in the case analysed, LCA would have generated useful further insights to the design team on the technology and design variable choices. Additionally, there would be some interest from design decision-makers to include such insights into design projects if this could be done without introducing significant extra work or delays.

ACKNOWLEDGEMENTS

First and foremost I would like to thank the Almighty God for taking me this far and for his protection throughout this whole journey. Great is thy faithfulness!

I would also like to extend my sincere gratitude to my supervisors Prof Harro von Blottnitz and Dr Jenny Broadhurst. Harro, I thank you for all the guidance and constructive feedback which made this project possible. Thank you for all the good ideas and sound advice that you offered during the peer review process.

I would also like to extend my appreciation to all the expert design engineers who I interviewed who made this project a success. Your insights were very valuable.

Special mention goes to my parents Ignasio and Ellen, words alone cannot express how grateful I am for all the support you have given me throughout this whole journey. The sacrifices you have made and for believing in me. Thank you both for giving me strength to reach for the stars and chase my dreams. You didn't give up on me and I will forever be grateful. But most importantly to my sister Charmaine who has had to be part of my whole journey and for being the most understanding person, I owe you.

To Shungu, thanks for all the love and support throughout this journey and for being there to listen and motivate me. You are the best!

To my MPhil colleagues, Takunda, Lesly and Ayanda, you guys are amazing. Thank you for all the support throughout the course and for your input into my project.

To my friends Dorothy and Tafadzwa who kept me sane during the whole degree, motivating and encouraging me, I am grateful.

I would also like to acknowledge the financial support I received from the NRF through the Minerals to Metals Research Initiative.

"Tenda Mambo mweya wangu....'

This thesis is dedicated to my parents, Ignasio and Ellen Munyongani and to my sister Charmaine

For their endless love, support and encouragement

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GLOSSARY

Background data	the input and output information associated with the production of energy or materials used in the processes.
Cleaner Production:	Processes that emphasise the reduction of negative environmental impacts and the implementation of improved management strategies as a way of increasing the overall efficiency of a process
Decision Context:	A set of all criteria that describe the nature and consequences of a decision
Decision Making:	The process of elucidating, analysing and evaluating various alternative approaches or options to achieving a defined objective or goal.
Environmental Impact:	Potential impact on the natural environment, human health or the depletion of natural resources, caused by the interventions between the technosphere and the ecosphere as covered by LCA (e.g. emissions, resource extraction, land use).
Environmental Impact Assessment	is a process of evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse.
Foreground data	is the input and output information directly related to the SO_2 removal processes.
Functional unit:	is a quantified description of the performance of the product systems, for use as a reference unit.
Life Cycle Assessment:	An analytical methodological framework that is used to quantify the environmental impacts attributable to the life cycle of products, processes or services.
Life Cycle Impact Assessment:	aims at understanding and evaluating the magnitude and significance of the potential

	environmental impacts for a product system throughout the life cycle of the product.
Life Cycle Inventory:	considers emissions and other flows from or to the environment.
Operational Decision Context:	All decisions relating to operational management, marketing and communication happen.
Reference flow:	is a quantified amount of product(s), including product parts, necessary for a specific product system to deliver.
Strategic Decision Context:	Decisions that typically entail capital investments.
System Expansion:	Adding specific processes or products and the related life cycle inventories to the analysed system. Used to make several multifunctional systems with an only partly equivalent set of functions comparable within LCA.
Tactical Decision Context:	Mainly decisions that are executed during design and development of products and technologies.
Unit Process:	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified.

CHAPTER 1. INTRODUCTION

Mining has been a major driving force behind the history and development of Africa's most advanced and richest economy: South Africa is a prime example and is one of the world's leading mining and mineral processing countries. It is the largest producer of platinum, providing more than 80% of the world's supply (Glaister & Mudd, 2010). Mining activities are however associated with significant environmental impacts. These range from emissions into the environment to the impacts experienced as a result of resource consumption and any other pressures on nature that are associated with extraction of resources (Rebitzer et al., 2004). The primary production of metals (i.e. the processing and production stages) require large amounts of energy and chemicals and produce large amounts of (sometimes toxic) waste that is potentially harmful to the society (van Berkel, 2007a).

Platinum has in recent years seen an increased use in a variety of environmentally-related technologies such as catalysts and catalytic convertors amongst others which have a strong expected growth to meet the environmental and technological challenges of the future. The platinum industry is actively seeking to progress its commitment to sustainability principles by reducing the negative environmental impacts of mining and mineral processing (IPA, 2014). Technical innovation to improve future plant designs, as well as the development of management policies, guidelines and protocols for efficient operation of process plants has therefore become a strategic priority for the South African platinum industry (Guma, 2010).

1.1 Background

1.1.1 Sustainable Development in the minerals industry

Since at least 2002, sustainable development has been an increasingly important consideration in the minerals industry, be it from a perspective of securing an ongoing licence to operate or improving economic, environmental and social performance (Corder et al., 2010). A rich and diverse literature is emerging on what this may mean, as witnessed by the 87 articles in the 2014 special issue of the Journal of Cleaner Production. One of the main areas of interest in the issue is cleaner production and pollution prevention at a corporate level. Basu & van Zyl (2004 suggest that policies should emphasise waste minimisation, recycling, pollution control and waste disposal activities at a local level. Corder et al., (2010) stress that an essential element of sustainable development integration for the minerals industry is its ability to address the needs of a diverse range of users across the project and the production cycle.

The major concern that most people might have is that of the feasibility of having a sustainable minerals industry. Rajaram et al. (2005) acknowledge that indeed at first sight it might seem as though mining and sustainability are two incompatible terms but it is crucial for one to note that sustainable development does not only focus on ensuring that non-renewable resources are not depleted but rather it encompasses many more values other than the continuing availability of the resource being developed.

Instead of focusing on mining high grade materials, it has been suggested that a more sustainable mining approach will also consider mining lower grades which will enable the mine to extend its lifespan and stakeholder benefits, ideally without compromising its revenue stream (Laurence, 2011). However, Jones (2015) suggests that improving the revenue stream in the short term could lay a good financial foundation for investing in the other capitals. Therefore, technical innovation to improve future plant designs as well as the development of management policies, guidelines and protocols for efficient operation of process plants has become a strategic priority for the South African platinum industry in particular (Guma, 2010).

1.1.2 Decision making in the minerals industry

It is argued that the mining industry has a generalistic approach to decision making which can be used across all decision making contexts known as the Decision Analysis (DA) framework (Basson & Petrie, 2006). This framework allows for the integration of relevant information into an overall strategy for decision support. In cases where there have been multiple objectives, uncertainties and conflict between the cost and the benefits of the alternatives of the Multi Criteria Decision Analysis (MCDA) framework has been argued as a way of comparing the available alternatives without necessarily reducing the different costs and benefits to a common basis. Decision making in the mining industry is, however, not the sole responsibility of the mining company but requires an amount of stakeholder input at all its levels. The stakeholder input is either direct or indirect depending on the level at which the decisions are made.

At the strategic and early design stages, decision making is usually guided by policy framework and legislative regimes, and in cases where these are not provided, an active approach through either the use of questionnaires or active stakeholder workshops may be required (Basson & Petrie, 2006) . However, the mining company is responsible for deciding on what is regarded as adequate policy framework or legislative regime based on its ethical commitments at a policy level.

Whilst Environmental Impact Assessments (EIAs) are able to point out the environmental impacts that will be experienced throughout the stages of the mining cycle, they tend to focus on the local geographical level and tend to overlook the impact that the processes have on a regional or global level. This leaves a leeway for some indirect impacts that the processes have to be overlooked resulting in burden shifting to other geographies or types of impacts. It is therefore important to explore the use of methodologies such as LCA into the prefeasibility studies as they are capable of identifying both the direct and indirect environmental impacts of the mineral extraction and beneficiation process, This would be most beneficial if analysis is to be carried out on a cradle to grave basis (i.e. from raw material extraction right through to the disposal, reuse or recycling of all the reagents and ancillary materials used in the mineral extraction and beneficiation process).

1.1.3 Life Cycle assessment and the decision making process

To date, investigations have been done on how sustainable development can be incorporated into the mineral industry especially for use in decision making process and also the tools that would be required to achieve this. For example, Stewart (1999) investigated the environmental life cycle consideration for design-related decision making in the minerals industry.

Forbes et al. (2000) carried out studies in which life cycle thinking was applied in the metal processing industry. They carried out a process based Life Cycle assessment on the refining process which incorporated the impacts that were related to the production of reagents and utilities that formed part of their assessment. Through this they were able to identify opportunities for improved environmental performance. They however did not explore how it would be incorporated into the decision making cycle.

Stewart (2002) in her seminal work suggested that it is very important to incorporate an understanding of material and project life cycles in decision making, as it ensures that decisions that are taken support ambitions to contribute to sustainable development. In addition, she highlighted that it is the initial decisions that are made in the project life cycle that are of utmost importance as they determine the performance of any alternatives selected. Therefore to ensure that a project is developed within sustainability principles it is important to ensure that sufficient information is available at these early stages and by so doing the use of LCA in the early stages of decision making might be of great environmental value. When LCA is used to help decision making, the data it provides can be directly mapped onto the decision cycle. This ensures that most of the issues that the decision cycle addresses are taken into account with the advantage of providing extra detailed information of the environmental impacts of a process both on a local and global level.

Basson and Petrie (2006) then devised a roadmap for decision making in different decision making contexts. In 2010 Guma also worked in that tradition, and Corder et al. (2013) have been working on Sustainable Operations (SUSOP).

These are some of the studies that have been done as way of introducing sustainable development into mineral processing and also the tools that would be most beneficial especially to the decision making process.

1.2 Problem statement

As aforementioned, studies have been done by Guma (2010), Basson and Petrie (2001), Forbes et al. (2000) and Stewart (1998) which have looked at ways of incorporating sustainable development practices into the minerals processing design. The seminal work that was carried out by Stewart (1999) investigating the environmental life cycle consideration for design-related decision making has not led to any significant adoption. Forbes et al. (2002), carried out life cycle assessments on PGMs as way of determining the environmental impacts associated with their extraction and processing. They however were not able to explore ways in which this could be incorporated into the decision making cycle. Therefore, it can be seen that very limited research has so far been done to investigate what environmental value could be created if strategic and design decisions in minerals processing were life cycle based. In fact, none have been done in the context of PGMs. It is therefore of utmost importance to evaluate the importance of carrying out life cycle assessments as way of informing decision making in the minerals industry.

1.3 Objective and approach

The main objective of this study is therefore: *to determine whether life cycle assessment could help inform design decision making in the minerals industry.* To achieve this objective, a case study approach will be taken. It will evaluate the key environmental impacts for the processes under study which will then be used to gain insights from the design experts on the usefulness of carrying out such assessments during design decision making.

1.4 Structure of dissertation

Chapter 1 has outlined the context of the study, including the justification for carrying out the study. This is followed by a critical analysis of the pertinent literature as reviewed in Chapter 2. Chapter 3 draws on the key findings of the critical analysis done to develop the research questions and methodology for the study. Since the investigation of the usefulness of LCA in mineral process design makes use of an LCA, this chapter also provides the goal and scope definition of the life cycle assessment to be performed. Chapter 4 presents the case study that will be used determine whether the introduction of life cycle based indicators could be of importance to the platinum industry. The chapter also presents the results that are obtained from the analysis. Chapter 5 presents the results and a discussion of the findings obtained from the design expert interviews carried out. Chapter 6 then synthesises the results of the study and also provides a summary and conclusions to the thesis.

A roadmap of the dissertation is provided in Figure 1-1

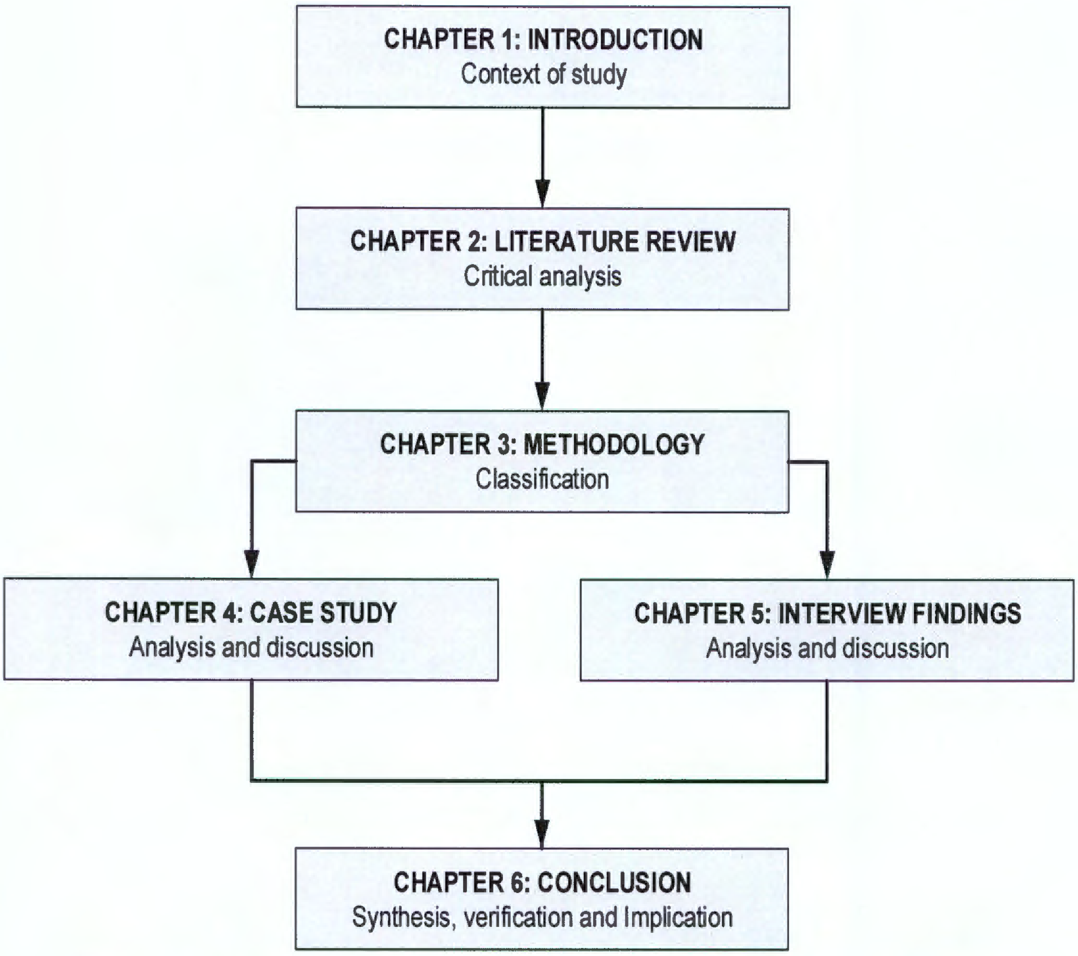

Figure 1-1: Overall dissertation structure and approach used in each chapter

1.5 A note on the context and nature of this dissertation

This research forms part of the 'Minerals to Metals Initiative' at the University of Cape Town (UCT), whose long term research aim is to improve both fundamental and systemic understanding of the selection, design and optimisation of mineral processing technology options towards achieving environmental sustainability objectives throughout the minerals to metals value chain. The dissertation also is one of the first to be completed in the M.Phil. programme, leading to a specialisation in Sustainable Mineral Resource Development, which was launched in 2014 under the auspices of the MtM Initiative. The aim of this degree programme is to study the critical factors of sustainable development in the context of mining and minerals processing in Africa. This dissertation therefore merges the more quantitative research tradition of the MtM initiative with a more qualitative research approach to be expected for an M.Phil. degree.

CHAPTER 2. LITERATURE REVIEW

This literature review aims to inspect how the incorporation of life cycle assessment as a sustainability performance tool has been of value in mineral processing. In particular, it focuses on the contributions it could make in informing design decisions made by mineral processing companies. The review is divided into four sub sections: section 2.1 starts off by considering how sustainable development has been incorporated into the minerals sector in recent years and points out some of the tools that have been used to achieve this. Section 2.2 reviews cleaner production as way of achieving the eco-efficient processing of metals. In section 2.3 the decision making process and contexts are explored and how life cycle assessment can be mapped onto the decision making cycle. Section 2.4 then looks into the applications of life cycle assessment into the minerals sector with the main focus being on design decision making. This will then enable the development of a motivation and methodology for the specific study to be carried out.

2.1 Sustainable development in the minerals sector

Since at least the Johannesburg World Summit on Sustainable Development (WSSD), the minerals industry has been actively seeking to progress its commitment to 'sustainable development of society', in part by reducing negative environmental impacts of its processes (McLellan et al., 2009). The environmental intensity of primary economic sectors has long been known (Jackson, 1996), and the mining sector is no exception, requiring extensive use of energy and capital (Basu & van Zyl, 2006).

The three major environmental impacts of mining were identified in the 2002 Mining Minerals and Sustainable Development (MMSD) report as mine-site closure and rehabilitation (including acid rock drainage prevention or treatment), management of large volume tailings and legacy sites; additionally energy intensity with associated GHG emissions, biodiversity impacts and metals in the environment were also identified. Mineral processing, the focus of this dissertation, typically causes the aforementioned impacts, which also are amenable to mitigation by the choice of cleaner technologies or a cleaner production approach to operations.

McLellan et al. (2009), argued that just focusing on reducing the negative environmental impacts (especially on a per tonne of product basis) is insufficient, as little attention is then directed to the total amount of emissions that will be produced. They stress that at times it is possible to have processes that reduce environmental impacts per tonne but what then happens is that the number of tonnes produced then increases which will now have a greater contribution to impacts, such as global warming. Indeed, this so-called 'rebound' effect or 'Jevons paradox' is well-documented in the sustainability literature (Bardi, 2013;Vivanco & Voet, 2014). It has been suggested that the challenge of the rebound effect can only be tackled through an integrated life cycle approach that addresses both consumption and production (UNEP, 2005).

A tool that has specifically been developed to address such concerns is the SUStainable OPerations (SUSOP) procedure, as described in Corder et al. (2010). It has been developed with the aim of creating useful and practical methods of incorporating sustainable development in all stages of the minerals production life cycle. Corder et al. (2010) suggest that most of the SUSOP principles might provide some guidance on the directions that should be taken especially in the case of mining companies towards sustainable development. In their 2010 paper they do not state the extent to which this can be done at a practical level; experiences with its use are being gained on an ongoing basis. Further studies have however been done to investigate the integration of SUSOP on a more practical level by McLellan and Corder (2013) and a current one is being conducted by Jones (2014). McLellan and Corder carried out a study in which they applied the SUSOP mechanism to explore the risks that could be identified and the solutions that could be developed to reduce risk at an appropriate stage in design, through the use of a case study. Jones (2014) on the other hand is exploring how the integration of Enterprise Optimisation and SUSOP could possibly enhance the financial viability of a project and enable demonstrable sustainability improvements as measured across each of the five capitals. Enterprise Optimisation is a methodology for increasing the economic value of mining and mineral processing operations through better long-term planning decisions (Jones, 2014).

Cleaner technology and eco-efficiency have also formed a major part of the debate on the integration of sustainable development into the minerals industry. The two concepts are reviewed in the following section.

2.2 Cleaner Technology and Eco-efficiency

Cleaner Production (CP), a term that was coined in 1989 by the United Nations Environmental Programme (UNEP), is used to define a management philosophy that emphasizes the reduction of negative environmental impacts from processes, products and services and the improved management of strategies, methods and tools (Basu & van Zyl, 2006). The preventative focus of the cleaner production approach represents an advance on the reactive approaches to environmental impact minimisation, typically by means of 'end-of-pipe' pollution control equipment.

Eco-efficiency is a somewhat newer term, defined with primary reference to manufacturing businesses as an environmental assessment philosophy. It aims to foster the development of products, processes and policies that achieve economic and ecological benefits to society while creating more value with less negative environmental impacts (Burnett & Hansen, 2008). It is sometimes simplified as the notion of "doing more with less" (van Berkel, 2007;Dahlstrom & Ekins, 2005). This makes it possible for companies monitoring to assess ways of reducing costs and increasing productivity while simultaneously improving the environmental performance of their processes (Burnett & Hansen, 2008).

Cleaner production focuses on efficient use of natural resources and reduction of waste and emissions. This is mainly achieved through the implementation of the five generic "prevention practices":

- product modification;
- input substitution;
- technology modification;
- good housekeeping ;and,
- on site reuse and recycling (van Berkel, 2007b).

Hilson (2003) notes that cleaner production should be viewed as an overarching environmental strategy that emphasises improvements, relevant also to mining operations and processes. In order to achieve it, mining management should continually assess the suitability of its input materials, the design of its operations and disposal techniques. He goes further to explain that eco-efficiency extends beyond the technological and design related characteristics of the industry and focuses equally on key managerial and policy making aspects such as environmental tools, and implementation of management systems. Cleaner production can thus be viewed as a notion that incorporates managerial changes, policy changes and physical changes.

Contrary to the above view of a manufacturing phase focus, an eco-efficiency assessment should consider the entire life cycle from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end-of-life treatment and final disposal (ISO14045, 2012). Through such a systematic overview and perspective, the shifting of a potential impact between life cycle stages or individual processes can be identified and assessed with a view to create overall eco-efficiency. Within eco-efficiency assessment, environmental impacts are evaluated using Life Cycle Assessment (LCA) as prescribed by other International Standards (ISO 14040, ISO 14044). Consequently, eco-efficiency assessment shares with LCA many important principles such as life cycle perspective, comprehensiveness, functional unit approach, iterative nature, transparency and priority of a scientific approach.

An often encountered view is that improving the environmental performance of processes is associated with increased costs. This consequently means that no improvement can be associated with an increase in economic efficiency, implying that there will always be a win-lose paradigm (Burnett & Hansen, 2008). However, several researchers (Guma 2010; Burnett & Hansen 2008; Berkel, 2007; van Berkel, 2007a) have shown, through their analysis of resource eco-efficiency, that it is possible to reduce the environmental impacts and increase the economic outputs. Based on such confirmatory evidence, it is possible for managers or directors to actually adopt this notion as a way of managing their companies which will allow them to disclose their company's performance to potential investors. Van Berkel (2007a) suggests that eco-efficiency provides the starting point for the opportunities for environmental innovations in the primary metals production.

A tool that has been used in support of the complementarity of the two concepts is life cycle assessment of either products or processes. When carried out correctly a life cycle assessment is capable of identifying the hot spots in which environmental value can be created and also areas in which environmental impacts need to be reduced.

The next section explores decision making and how life cycle assessment can be mapped onto the decision cycle.

2.3 Decision Making

Decision making is a problem solving activity that identifies and assists in choosing alternatives which are usually based on the values and preferences of the decision maker and it usually encompasses the first two stages in problem solving where alternatives are chosen (Anderson et al., 2012). Decision making in companies is mainly done by people who form part of the management team and the whole process is the main focal point of the company's management team.

The three main elements of decision making are:

1. ***Problem structuring***: this element focuses on stakeholder involvement and procedures for their involvement. It also looks at the choice of system boundaries, how the alternatives are defined or the extent to which designs for alternatives are developed, and the choice of performance measures or indicators (e.g. financial, environmental) (Basson & Petrie, 2001).

   The elements of problem structuring include:

   - Problem definition in which stakeholders are identified, and consensus is obtained from all stakeholders as to the decision to be taken;
   - Identification of objectives to be met by the decision outcome, this includes eliciting the preferences of stakeholders for different decision outcomes;
   - Specification of performance measures used to measure the satisfaction of these objectives (Stewart, 2002).

Such an approach to decision making is based on the fact that all the participants of the decision making process are willing to achieve rational outcomes (Stewart, 2002). The outcome that is achieved from the problem structuring phase is an objectives hierarchy; when applied to process industry decision-making focused on 'sustainability', it may take the form shown in Figure 2-1.

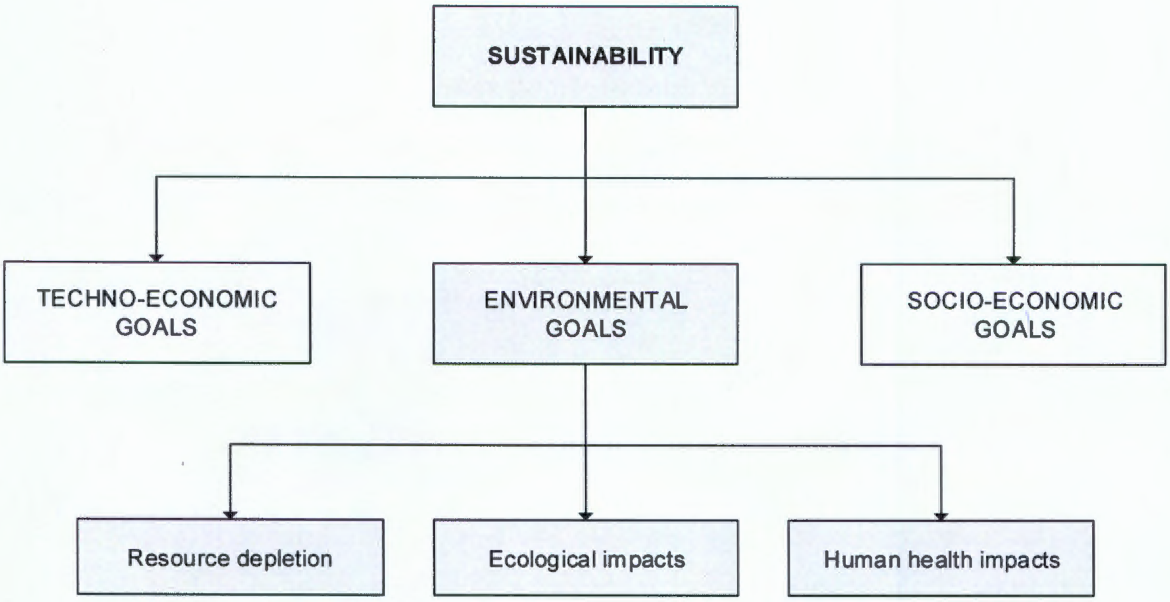

Figure 2-1: Objectives Hierarchy adopted from (Stewart 2002)

2. ***Problem analysis:*** this focuses on the manner in which the different alternatives are modelled and the evaluation strategies that are used together with the strategies for the management of uncertainty which ensures that in the end there is robustness in the conclusions that are drawn (Basson & Petrie, 2001).

   The elements of problem structuring include:

   - Analysis of the alternatives available which would have been determined in the problem structuring phase;
   - Comparison of the consequences;
   - Uncertainty, Sensitivity and Robustness Analysis;
   - Choosing of a preferred alternative (Stewart, 2002).

3. ***Implementation:*** once the problem analysis stage is complete and a preferred alternative has been established, the decision is then made which sees the implementation of the alternative and ways of monitoring the process are established.

2.3.1 Decision making contexts

When decisions are made they are usually delimited into three contexts as shown Figure 2-2.

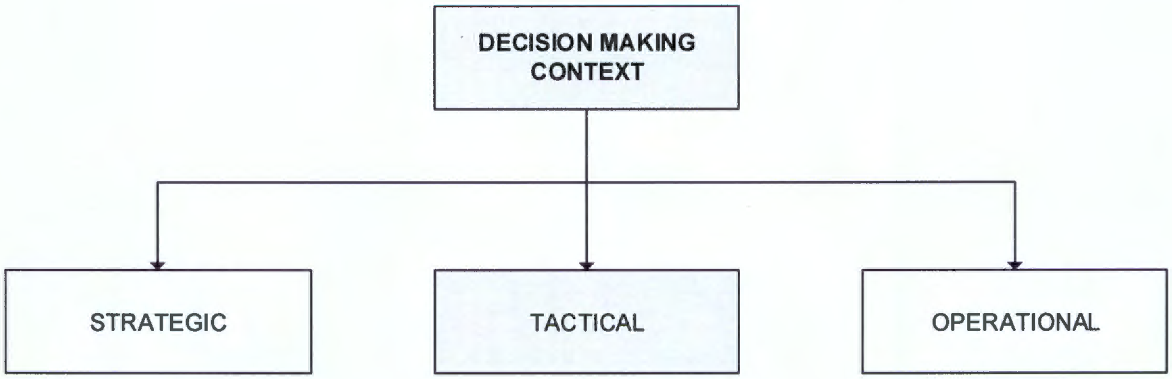

Figure 2-2: Delimitation of decision making contexts

The three main decision making contexts are: strategic, tactic and operational. Guma (2010) highlights that as one progresses from the strategic to the operational decision contexts across a project life cycle there tends to be an increase in the amount of information detail and a reduction in the uncertainty levels (Basson & Petrie, 2001; Notten, 2001). The three contexts are discussed in detail below:

Strategic Decisions

Strategic decisions are usually typified by large temporal and spatial boundaries and are often made under significant uncertainty in which a significant number of alternatives will be under consideration and the stakeholder preferences diverse (Stewart, 2002). Examples of such are: policy making and future or planning decisions. Most strategic decisions are made by top level managers in companies whose responsibility it is to ensure that the decision they make are always cohesive with the company's objectives and mission statements. They tend to focus more on the long term picture of where a company is headed allowing the company to make intelligent decisions for their future plans. The people involved in making strategic decisions also focus on the emerging trends with the company's industry and subsequently predict any issues that might affect the their operation.

Tactical Decisions

Tactical decisions on the other hand are made by the mid-level managers and they are usually made to meet the strategic objectives of the companies. They usually contain decisions executed during the design and development of products, technologies and processes and are directed towards the development of divisional plans and structuring of work flows (Basson & Petrie, 2001). They mainly deal with the issues at hand such as the competitors within the industry and also helps a company optimise it productivity. This is done through the analysis of the current processing methods and if better alternatives are available the people responsible for tactical decision making then take those into account.

Operational Decisions

This type of decision making has fewer alternatives compared to strategic decision making. This is because the temporal and spatial boundaries are limited and there exists direct stakeholder involvement (Stewart, 2002). They are usually made by the frontline managers and often at times they are administrative in nature and bear minimal risk. They have short term horizons and usually occur repetitively.

2.3.2 Environmental considerations affecting process design

Process design, involving decisions at a tactical level, is usually focused on the reduction of energy consumption and the minimisation of wastes and pollution. Advanced environmental regulations and corporate sustainability strategies require new approaches to process design. Increasingly, designers of metal-based products (e.g. in the automotive sector) aim to make design decisions which will result in the reduction of environmental impacts occurring at all stages of the products life cycle.

The main assessment done by most companies, when a new production site is planned, or an existing one modified, is the basic Environmental Impact Assessment (EIA). The assessment ensures the identification, forecasting, interpretation and measurement of the environmental consequences of the projects to be carried out (Morero et al., 2015). According to the International Association of Impact Assessment (2016) the main purpose of conducting an EIA is to ensure that the decision making process concerning activities that may have a significant influence on the environment takes into account the environmental aspects related to the decision. The EIA also helps to establish the terms and conditions for project implementation. This then ensures that diversity of species is maintained and there is no harm done to the quality of life .The assessment if often regarded as a synonym for local, point source oriented evaluation of the environmental impacts which takes into account time-related aspects and the existing background pressure on the environment (Tukker, 2000).

The key element of an EIA is that it provides a comparison of the proposed activity to the most environmentally friendly option and 'business as usual case'. This therefore means that an EIA is not just a tool but is also intended to provide a framework for organising the decision making process (Tukker, 2000). The main downfall with carrying out an EIA is that there often is no uniformity in the results it generates as it is carried out for different reasons hence making it impossible for one to generate a detailed method of impact assessment and system choice that will apply for every EIA.

Both LCA and EIA have the same basic purpose of supporting decision making on the environmental aspects of a project (Manuilova et al., 2009).Tukker (2000) points out that the major difference between LCA and an EIA is that LCA provides a time and location independent assessment of the potential impacts in relation to an entire production system. He however suggests that if the two assessments were to be merged the differences between the two can be used to complete one another providing a much stronger assessment tool. Studies have also shown that when the two are merged LCA can indeed compliment and add value to the EIA process (Manuilova et al., 2009; Tukker, 2000). This would mean that while the EIA will be carried which will be specific to a particular project, the LCA will then comprehensively compare available alternatives and take into account all the important aspects that are usually not present when only studying one project (Morero et al., 2015).

Various environmental assessments can be applied during the conceptual and embodiment design phases preceding the condition of an LCA when there is limited time or limited data to ensure the conduction of a full LCA. Increasing the extent of the impact of industrial activity on the environment has led to both the study of the feasibility of industrial processes using LCA at both local and international levels as part of the environmental impact assessment (Morero et al., 2015).

2.3.3 Mapping LCA onto the decision cycle

Stewart (2002) suggests that LCA is more applicable to the strategic and tactical decision making context since the decisions made at these stages are not entirely based on the environmental outcomes but the entire information set which will include the techno-economic and social aspects.

When LCA is used to help decision making, the data it provides is very detailed and well defined and can be directly mapped onto the decision cycle as shown in Figure 2-3.

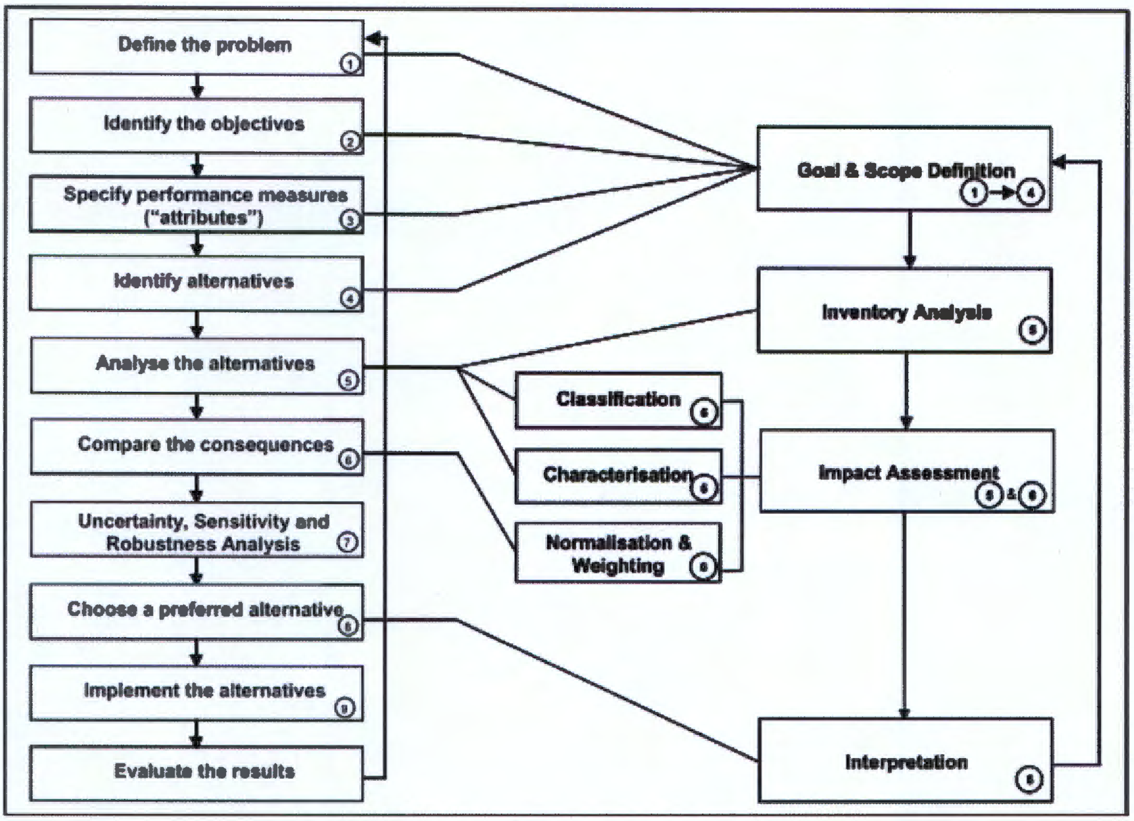

Figure 2-3: Mapping of LCA onto Decision Cycle adopted from Bason and Stewart (2001)

As can be seen above, LCA addresses most of the issues that decision cycle addresses with the exception of uncertainty analysis, sensitivity and robustness analysis as well as the implementation of an alternative. This therefore makes it a useful tool in industrial decision making as it is capable of providing extra detailed information of the environmental impacts of a process both on a local and global level.

Stewart (2002) suggests that it is very important to incorporate an understanding of material and project life cycles in decision making as it ensures that decisions that are taken support sustainable development. In addition she highlights that it is the initial decisions that are made in the project life cycle that are of utmost importance as they determine the performance of any alternatives selected. Therefore to ensure that a project is developed within sustainability principles it is important to ensure that sufficient information is available at these early stages and by so doing the use of LCA in the early stages of decision making might actually be of great environmental value.

In view of the fact that LCA can actually be mapped onto the decision making cycle, and has been seen to help decision makers understand either product or process life cycles, it is important for one to look into the actual application of life cycle assessments in the mineral sector. The next section therefore looks into cases in which life cycle assessments have been carried out in the minerals industry and what the major motivations have been for carrying out the assessments. It also identifies cases in which the use of the life cycle assessment tool would be of great value in terms of identifying the impacts that process options might have.

2.3.4 Limitations of Life Cycle Assessment

LCA, like any other effective assessment tool, has limitations that the user must be cognisant of, in order to avoid the generation of inaccurate results. The assessment is guided by the ISO life cycle assessment standards, however, these just give a basic framework and guidelines as to how one can conduct a life cycle assessment and leave much to the interpretation by the person carrying out the study (Curran, 2014). Conducting an LCA is inherently an attempt to map all aspects of an extensive system, of which one does not have complete knowledge.

A key limitation of LCA thus the difficulty of including all relevant parts of the system. Misleading results can be obtained if important processes are omitted whilst setting the system boundaries. This could be as result of unjustified cut off criteria or lack of proper screening of the important processes (ILCD, 2010). In addition, the need for relevant and detailed data has been pointed out as one of the hurdles when conducting an LCA. Even though data is now widely available from different databases, there are still issues like confidentiality and withholding of data by government authorities in cases of some country specific data that deter the data collection process. This causes many LCAs to be conducted using secondary data sources, which introduces inaccuracies into the study. In cases were data is available, it takes a lot effort and time to collect it.

Pizzol et al (2011) point out the absence of consistency between impact assessment methods as another area of concern. The lack of consistency results in differences in

LCA results based on the chosen method. Selecting impact categories that fully account for the potential impacts being analysed, and choosing impact assessment models that accurately describe these, is not trivial. In addition, when different impact assessment methods are used, it is difficult to make direct comparisons as the units of measurement are often different.

2.4 Application of LCA in the minerals sector

The application of LCA in the minerals processing industry has been happening since the mid-late 1990s with the majority of the initial work having been focused on the development of Life Cycle Inventories for metal production processes (Durucan et al., 2006). This then developed into actually carrying out LCAs for consumer product selection and design and also process selection (Dubreuil, 2005).

The LCA perspective brings powerful insights into addressing sustainable mineral resource development by evaluating the environmental impacts that all stages of the life cycle of the process have and aims to minimise them while increasing the economic output (UNEP, 2009). However critics of the concept have perceived it as an anti–development oriented approach as it is mainly damage-focused, and does not reflect any of the positive aspects of development, both social and economic. It also fails to address developing countries' most significant concerns e.g. employment rates and poverty eradication. There is, therefore, a need for mining companies to work with sustainability frameworks that equally address environmental, economic and social benefits and damages (Lodhia & Hess, 2014). Social Life Cycle Assessments (S-LCA) and Life Cycle Sustainability Analysis (LCSA) may make a contribution to these concerns in time, with UNEP's guide on LCSA (UNEP 2009) already including the DRC Coltan case.

LCA studies have been done in copper production, the iron and steel industry and other basic metals, but in the particular studies conducted, very little or no emphasis has actually been placed on the extraction of the mineral ore and the consequent waste handling aspects of the industry in relation to the allocation of the environmental burden (Durucan et al., 2006). In the most relevant recent study by the IPA (2014), a life cycle assessment was carried out on the platinum industry, with the majority of the operations assessed being based in South Africa. The results obtained from the study were then used to inform clients (who in this case would be companies that make either hydrogen fuel cells or catalytic convertors) on how the actual extraction process is performing. It is not known whether the results were also used to directly inform decision making processes within the industry itself.

Of interest to this study is the incorporation of LCA to help inform design decision making. A relevant example, chosen as subject of a case analysis in this dissertation, is that of deciding on how waste gases containing high concentrations of toxic gases such as SO_2 can be treated in platinum mining companies. A brief overview of the possible treatment options that are available to decision makers is provided in the next section.

2.4.1 Treatment of gases containing high SO_2 concentrations

It is well known that sulphur dioxide poses a number of environmental and human-health hazards. In humans the major effect has been that of its toxicological nature of which high concentrations can result in wheezing, chest tightness, and shortness of breath (Antonio et al., 2007). The major environmental impact of sulphur release is that of acid rain as gaseous sulphur combines with liquid to form sulphurous acid which in air easily oxidises to sulphuric acid. The growing awareness of environmental protection has led to the increasing stringent regulations, primarily aimed at reducing the SO_2 emissions in defined off-gas streams (Daum, 2009). It is such restrictive regulations that have in turn forced the development and deployment of technologies aimed at cleaning off-gases from processes thereby reducing the amount of SO_2 emitted.

Various technologies exist that have been designed to help reduce the SO_2 content in flue gas that is generated by plants. The technologies can either be classified as once through or regenerable as shown in Figure 2-4. This classification is mainly based on how the extraction solvent is treated after the absorption of SO_2 has taken place. For regenerable processes, the SO_2 is released from the sorbent and can be used to make a co-product like sulphuric acid and the solvent is recycled back to the absorber or scrubber. Once through processes on the other hand usually produce by-products such as gypsum and in such cases SO_2 is permanently bound by the absorbent and the products are usually disposed of as wastes. Both the regenerable and once-through process can be further classified as either dry or wet. Dry technologies produce dry waste and a flue gas that is not saturated with moisture whereas in wet technologies wet slurry is produced and the flue gas leaving the system is usually saturated with moisture.

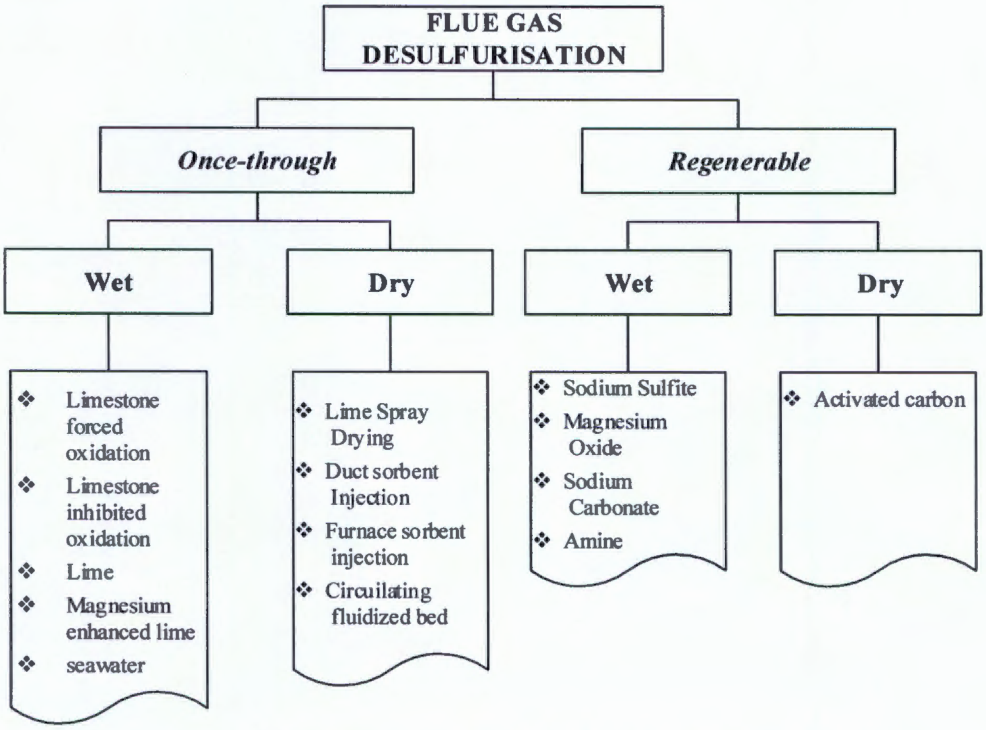

Figure 2-4: FGD Technology tree adopted from (Srivastava 2000)

The most relevant technologies that have been adopted have mainly been influenced by the concentration of the off SO_2 present in the off-gas stream to be treated (Antonio et al., 2007). Of these technologies wet scrubbing provides the greatest removal efficiencies and can be categorized based on the reagent that is employed. Table 2-1 below gives a summary of details of applicability of various reactive processes in terms of the reagents used and the expected efficiencies.

As can be seen from Table 2-1, it is only the sodium based scrubbing processes that can achieve efficiencies of greater than 99% as the neutralisation capacity for SO_2 by NaOH is extremely high.

Table 2-1: Applicability of SO_2 scrubbing processes in alkaline reagents (Bandyopadhyay & Biswas 2007)

Process	**Reagents**	**SO_2 conc. (ppm)**	**By-products**	**Efficiency**
Lime slurry	CaO	<100-6500	Calcium based solids	90-95
Limestone slurry	CaCO3	1000-4500	Calcium based solids	~ 95
Spray drying- lime	CaO, $Ca(OH)_2$	<100-3000	Calcium based solids	90-95
Dual Alkali: lime sodium	NaOH or Na_2CO_3 & CaO or $CA(OH)_2$	1200-150,000	Calcium based solids	99+
Dual Alkali : Dowa	$CaCO_3$ and $Al_2(SO_4)_3$	1000-25,000	Calcium based solids	85-98
Once through seawater	$NaHCO_3$ (CaO)	Up~2000	Calcium based solids	~98
Once through sodium	NaOH or Na_2CO_3	<100-10,000	Na_2SO_3, Na_2SO_4	99+

The efficiency of the scrubbing process influences mainly the amount of energy used in the process and the amount of solvent required. Smith, Laird & Mercer (2010) and Smith, Crevecoeur & Booth (n.d.) suggest that one way of determining the optimal removal efficiency of SO_2 scrubbing processes is by evaluating the Number of Transfer Units (NTU) which convey the amount of mass transfer 'work' that will be required for a scrubber to achieve a desired level of SO_2 emission.

NTU can be calculated from percentage removal based on the following formula:

$$NTU = -\ln(1 - \frac{SO_2\%}{100})$$

A plot showing how the NTUs vary with increasing removal efficiency is given in Figure 2-5.

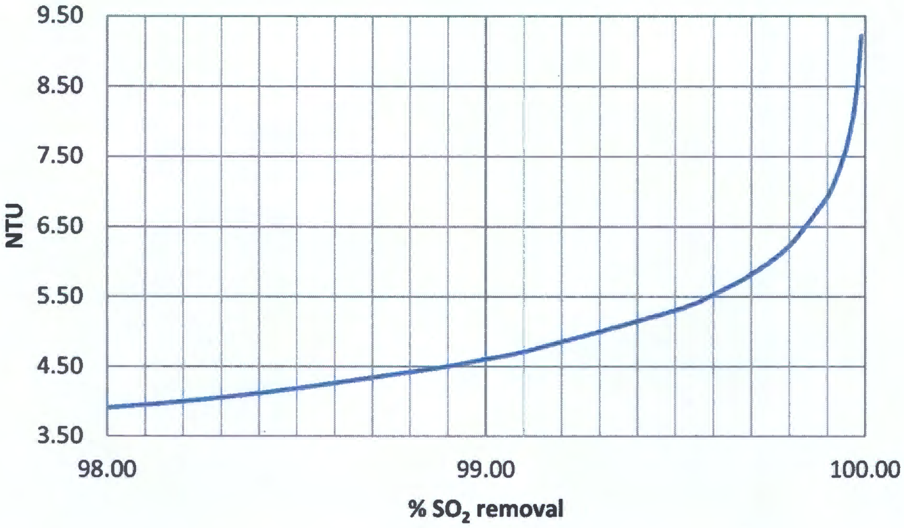

Figure 2-5: Relationship of % SO_2 removal to NTU

Figure 2-5 shows that there is an exponential growth of NTU as ones pushes for efficiencies closer to 100. This means that an increase in efficiency from 99.6% to 99.9% requires double the effort of increasing the efficiency from 98% to 99%.

Following from the aforementioned information, it is evident that there are a number of decisions that need to be made when specifying a process option, be it the choice of reagent used or the extent of SO_2 removal from the waste gas.

When smelting operations are carried out in PGM processing, sulphur is given off in both the furnace and convertor off-gas. The amount of sulphur that a process produces is mainly driven by the type of ore that is mined and the amount of pyrite present (Bezuidenhout et al., 2012). This therefore affects the process technology that a company can use to recover the sulphur produced and limit the amount that is released into the atmosphere.

With the advent of the Air Quality Act of 2004, the South African PGM industry was faced with the situation of having to choose process options as way of responding to regulatory measures on maximum permissible SO_2 that could be released into the air. Three major platinum smelters were noted to have been responsible for 96.2% of the total sulphur dioxide emissions in the North West Province (Holohan, 2000)[1]. The companies had to choose the process route of reducing their emissions. The next

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[1] Anglo Platinum EIA

section therefore details how the different mining company's reacted to the regulatory changes.

2.4.2 The SO_2 case in South Africa

In 2004, the Air Quality Act of South Africa set a new limit for the maximum allowable SO_2 emission from operations. What this meant was that all mining companies in the Rustenburg area had to develop and deploy technologies that would allow for the SO_2 abatement to below the set legal limits. The companies adopted either one of the two best wet scrubbing technologies (concentrated dual alkali route or the scrubbing plant with acid production) which both result in very high SO_2 removal efficiencies.

Westcott et al. (2007) pointed out that it was as a result of the increasing pressure from the authorities and the pending promulgation of the new quality act that made it necessary for their company to address their air quality issues. This therefore led their smelter emission control strategy to be based on three aspects:

1. To meet the ambient air quality standards as specified in the Air Quality Act;
2. To improve the visual aspect of the plant so that good public relations are fostered;
3. To minimise occupational exposure of employees to dust and sulphur dioxide gas so that occupational hygiene is improved.

This meant that the selected option in the case of that particular company would have to meet the above objectives.

In the work that has been published detailing some of the companies' operations it has been highlighted that the reason some companies opted for the concentrated dual alkali process was mainly guided by the typical off-gas that had to be treated, the composition of which varied between 0.5% and 6% SO_2 (Bezuidenhout et al., 2012; Eksteen et al., 2011; Jones, 2005). The high end of the concentration range was seen to be too high to be handled by a pure lime based process whereas the lower end was deemed unfit for an acid plant operation (Eksteen et al., 2011). Therefore the concentrated dual alkali scrubber was the technology of choice for some of the companies due to the perceived benefit of handling both high SO_2 concentrations and the swings in the off-gas SO_2 concentrations. Bezuidenhout et al. (2012) pointed out that one of the major advantages of adopting the dual alkali technology was that it overcame the disadvantages that were inherent to lime and limestone scrubbing such as scaling and low reactivity and that the technology had very low energy requirements. However, at the moment the CaSOx product that is produced is not of saleable quality and hence it is disposed of as waste. In addition there isn't a large market for gypsum therefore if it were to be produced as a by-product it would not be of much value to the companies.

Other companies decided to go with the acid production route (Davenport et al., 2006; Hundermark et al., 2011; Sichone, 2009). For one of the companies the major motivation for adopting this choice was based on "*CAPEX, OPEX, operability and ease of expansion*" (Kruger, 2004). This therefore means that other than just treating the off-gas the company is able to make a saleable product. Daum (2009) suggests that the production of sulphuric acid is the most viable option of sulphur recovery from smelter off-gas and the abatement of SO_2 into the atmosphere.

2.5 Summary of the literature review

This chapter has attempted to review the literature that is relevant to usage of life cycle assessments in design decision making contexts in the minerals industry. It has been noted that in trying to make decisions in the minerals industry on how to incorporate sustainable development, and in choosing the tools that can be used for assessment, mining companies may be swayed by poorly informed beliefs, such as there always being a trade-off between environmental protection and cost. There also exists the challenge of overcoming limited knowledge of the decision makers in understanding the full effects of their choices. When looking into environmental impacts of a process, conventional EIA tends to be narrow and focus only on a local spatial scale. This does not really provide a guide on the broad range of impacts that are associated with process technologies especially of a global level. More recently developed tools such as SUSOP do allow for simultaneous consideration of a range of environmental, social and economic criteria, but do not explicitly account for the possibility of shifting burdens off-site.

It is through the incorporation of life cycle thinking and in particular life cycle assessments that decision makers start to realise the importance of potential environmental impacts at off-site stages of the product or process life cycle, which might lead them to make more informed decisions. The broader look at life cycle considerations often illuminates unsuspected effects such as energy consumption, emissions and resource consumption associated with a specific process.

The South African platinum industry investment of the late 2000s into SO_2 abatement technologies presents a case of potential burden-shifting – the impacts of making an acid by-product are not trivially assessed, and the energy usage risks of overly high SO_2 recovery merit a look at whether LCA would have informed design decision making differently. It has therefore been chosen as the case study that will guide the study. The next chapter puts forward the research approach and methodology used to structure the study.

CHAPTER 3. RESEARCH QUESTIONS AND METHODOLOGY

Following from the statement of the purpose of the research in Chapter 1, and the findings of the literature review in Chapter 2, the key questions used to guide the research informing this dissertation are developed in this chapter. The chapter also provides a description and justification of the choice of research approach that was adopted for the investigation.

3.1 Overview

As mentioned in Chapter 1 the objective of this dissertation is to determine whether life cycle assessment can help inform design decision making in the minerals industry. A case study approach has been chosen which compares and assesses the performance of SO_2 abatement technologies and the effect of efficiencies chosen on environmental performance, by using life cycle assessment modelling. Experts who were involved in the design processes of the SO_2 abatement retrofits were interviewed to establish: i) how the design decisions were made and ii) whether the life cycle based insights into technology performance would have been of use in the design work.

3.2 Key questions

Based on the literature that has been reviewed in Chapter 2, it can be noted that the tactical (or design) decisions of relevance in this case relate to technologies that have been developed to respond to stringent regulatory measures. This therefore means that no trade-off can be considered per se between local and global environmental impacts, as already the regulations are designed with focus on local impacts of processes. However it is the trade-offs that one considers when going beyond compliance with the legal limits that are of interest.

The key questions that will be addressed in this study are:

1. **Can LCA help identify environmental burden shifting that could be induced as a result of key variable selection during process design?**

   This is achieved by exploring:

- How environmental impacts change with change in recovery and,
- How environmental impacts change across two process routes that satisfy the same function?

2. **How are design decisions made in the minerals processing industry?**

   As way of understanding how decisions are made in the minerals industry it is necessary to understand the following:

- What drives plant retrofitting, using new technologies?
- How is the choice made between two technologies that are meant to satisfy the same function?
- How does a company decide on which environmental assessment to incorporate?
- How are trade-offs dealt with in cases where design is driven by regulatory standards?

3. **How can LCA inform design decision making in the minerals industry?**

- Would the life cycle view, requiring specialist environmental input, be useful in informing design decision making?
- Would mining companies be willing to adopt LCA as part of the EIA process during their pre-feasibility studies to help with process selection?

3.3 Methodology

The methodology adopted to answer the research questions consists of two distinct components, both executed within the overall framework of the case study approach to research. The LCA method used is presented in section 3.3.1, and the methods for the expert interviews is presented in section 3.3.2.

3.3.1 Life Cycle Assessment of SO_2 abatement options

Goal definition

The goal of the LCA presented in this dissertation is to: *Identify whether there were design decisions that induced environmental burden shifting when platinum smelters in the Rustenburg area added SO_2 abatement technologies to their processes, which could have been avoided had the LCA perspective been taken into account.*

The intended audience for this particular study are metallurgical design engineers and engineering consultants; the study may also be relevant to EIA practitioners concerned with the balance between local and off-site impacts of developments, particularly in industrial settings.

Scope

This LCA is a comparative study of the two major technologies that were adopted by platinum mining companies as way of reducing SO_2 emissions; sulphur fixation using a dual alkali scrubber or the combination of a scrubber with an acid generation plant. The two main variables for the analysis are the technology choice between the two (concentrated dual alkali plant and the scrubber with an acid plant) and the specified sulphur removal efficiencies. The three efficiencies analysed are 92%, 96% and 99%, all of which have been determined to lie within the regulatory limits of the operation

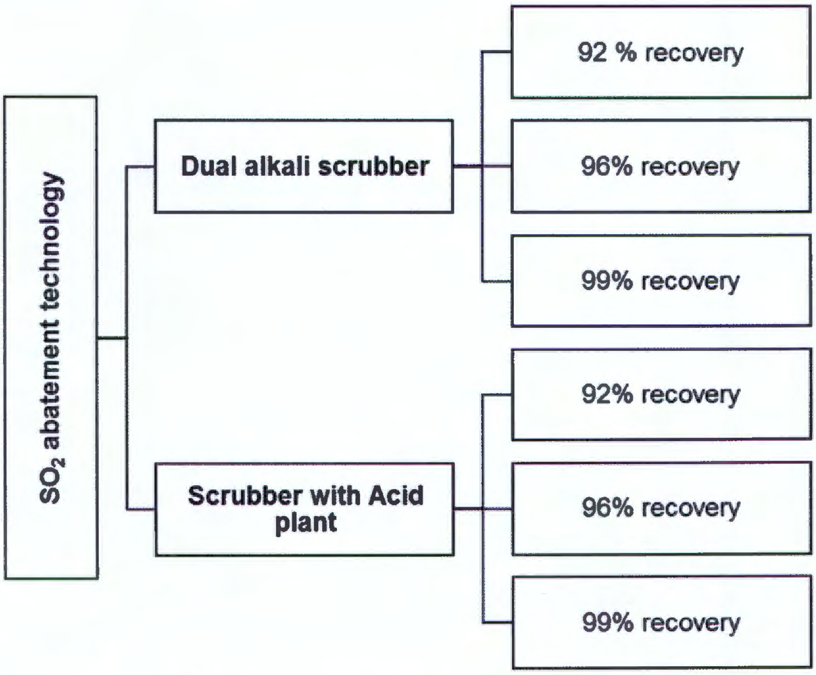

Figure 3-1: Schematic of the SO_2 abatement technologies and sulphur removal efficiencies analysed

When the different recoveries for the scrubber with acid plant option were investigated, a systems expansion was chosen to account for the useful by-product. This was carried out by adding the conventional production of some sulphuric acid, specifically the difference in acid produced by the 92% or 96% options to that of the 99% recovery. By so doing all the 3 process then produce the same amount of acid. The dual alkali options were initially analysed as is, with systems expansion only being incorporated at the level in which comparison between the two technologies was being done.

Functional Unit

Since the LCA aims to compare the environmental burdens of different sulphur removal technologies and configurations that could have been chosen to enable continued operation of platinum smelters, the functional unit specified for this study is the legally compliant treatment of off-gas produced by a smelter in one year. The basis for comparison was set as the smelting of 1.08 million tonnes of PGM concentrate[2].

Reference flow

The reference flow for the system analysis is the annual quantity of SO_2 present in the smelter off-gas, presented as an SO_2 concentration relative to an off-gas flow rate, and determined to be 90 000 tonnes. No more than 23 tonnes/day of this is allowed to be emitted.

Definition of the object of analysis and its life cycle

The object of analysis in most LCAs is a product, here it is a process option. Its life cycle is described based on the two cases to be analysed. Both cases are conceptual with the first one exploring the SO_2 abatement technology which uses the concentrated mode dual alkali scrubber. The second option sees the SO_2 being removed by incorporation of a gas cleaning and acid plant. The two abatement technologies are discussed in more detail below:

Option 1: Concentrated mode dual alkali scrubber

The first option is the abatement technology that has been adopted by one company ("company A"), a concentrated dual alkali scrubber. This process was chosen by the particular company because it has seen more than 50 global installations. It is also well known for achieving good scrubbing efficiencies. The flow diagram of the concentrated dual mode alkali is given in Figure 3-2.

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[2] http://www.angloamericanplatinum.com/~/media/Files/A/Anglo-American-Platinum/documents/operations-review-2014-040315.pdf

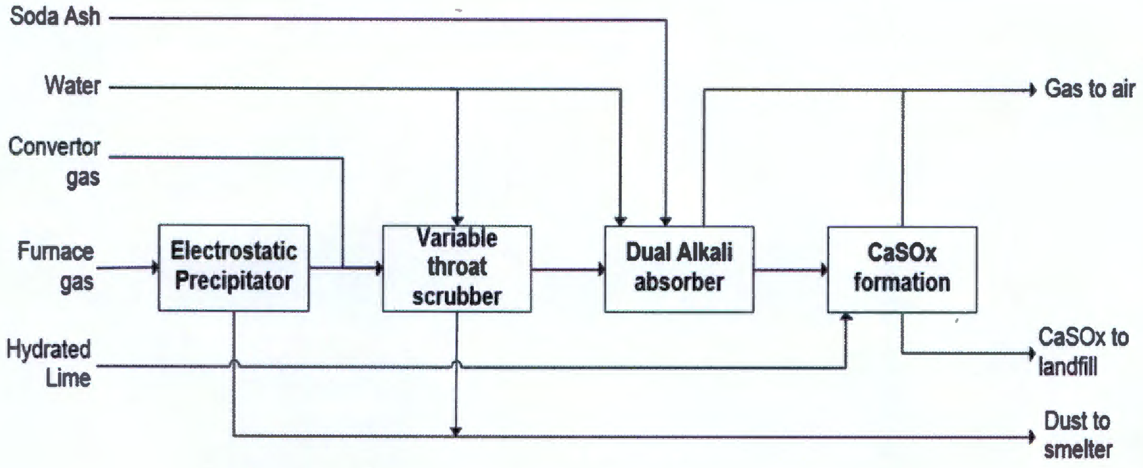

Figure 3-2: Concentrated dual-alkali scrubber plant

Electrostatic Precipitator (ESP)

The off-gases from the smelter furnaces are passed through a two-field electrostatic precipitator (ESP). In the electrostatic precipitator, particulate matter is removed with the majority of the particulate matter being in the form of dust. The particulate removal efficiency is approximately 99%. The product gas is then sent to the variable throat scrubber.

Variable throat scrubber

The gas from the ESP is mixed with the convertor gases prior to entering the variable throat scrubber. The convertor gas is not passed through the ESP because of the very small amount of particulate matter it contains.

The main purpose of the variable throat scrubber is to quench the gas with water; it also acts as the final particulate matter removal stage. Water is used as the scrubbing solvent hence a weak acid is produced in addition to the particulate matter removal.

The weak acid that is produced is then neutralised with a hydrated lime solution in the neutralisation tank and sent through to a thickener where the valuable particulate matter is removed as the underflow.

Absorber

The quenched gas from the variable throat scrubber passes through an absorber which is designed based on a counter current basis of gas and solvent flow.

A fresh solution of alkali (soda ash) solution is pumped into the absorber. The reaction that takes place is given by Equation 3-1 as follows:

$$Na_2CO_3 + SO_2 \rightarrow Na_2SO_3 + CO_2 \qquad \text{Equation 3-1}$$

The product of the 2 reactors contains NaOH which also reacts with SO_2 according to the following reaction in the absorber:

$$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O \qquad \text{Equation 3-2}$$

The pregnant solution from the absorber is sent through to the precipitation section which comprises of two reactors: a first stage reactor where lime is added and a second stage reactor which has a longer residence time that allows for the growth of crystals.

The pregnant solution is reacted with lime ($Ca(OH)_2$) as a way of regenerating the solvent outside the scrubbing circuit. This approach permits the gas to be contacted with a clear solution of highly soluble salts, thereby minimizing scaling, plugging and erosion problems in the absorbent circuit.

The following reaction takes place when powdered lime is added to the absorber pregnant solution in the first reactor:

$$2NaHSO_3 + Ca(OH)_2 \rightarrow Na_2SO_3 + CaSO_3.\frac{1}{2}\,H_2O + \frac{3}{2}\,H_2O \qquad \text{Equation 3-3}$$

The reaction occurs instantaneously and almost all the $NaHSO_3$ is reacted in this reaction. It forms massive precipitation in a very short time. Further precipitation then occurs in the second stage reactor where small crystals start forming as a result of the long residence time. The reaction taking place in the second reactor is as follows:

$$Na_2SO_3 + Ca(OH)_2 + H_2O \rightleftharpoons 2\,NaOH + CaSO_3.\frac{1}{2}H_2O + \frac{1}{2}H_2O \qquad \text{Equation 3-4}$$

This is an equilibrium reaction which tends to have a lower driving force compared to the one occurring in the first reactor.

The Na_2SO_3 produced in Equations 3-1, 3-2 and 3-3 is readily oxidised to form Na_2SO_4 as follows in the reactor:

$$2Na_2SO_3 + O_2 + H_2O \rightarrow 2\,Na_2SO_4$$ Equation 3-5

The sodium sulphate produced as a result of this oxidation will also precipitate based on the following equation:

$$Na_2SO_4 + Ca(OH)_2 + 2H_2O \rightarrow 2\,NaOH + CaSO_4.2H_2O$$ Equation 3-6

This therefore results in two major products of the process: $CaSO_4.2H_2O$ and $CaSO_3.1/2H_2O$

Mist Eliminator and Wet stack

After the absorber, the gas passes through a mist eliminator and then a wet stack.

<u>Option 2: Scrubber and acid plant</u>

The second option analysed is a SO_2 scrubber feeding an acid plant, as installed by Company B and Company C in their smelting Process. A flow diagram of the process is given below:

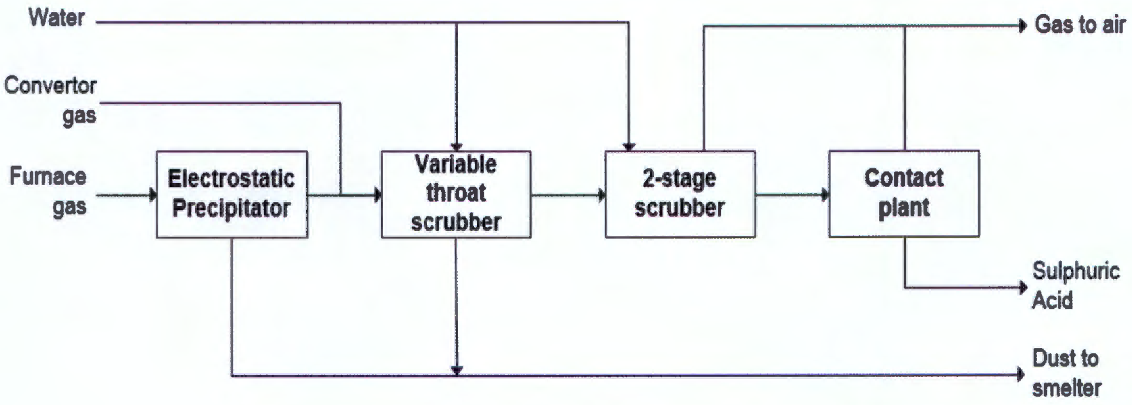

Figure 3-3: SO_2 scrubbing with acid generation plant

The smelting process of company B is based on the Ausmelt smelting technology which produces high strength SO_2 which is captured and sent to the gas cleaning plant to avoid direct venting to the atmosphere as this is a pollutant, hence guidelines of maximum allowable amounts that can be emitted apply.

The first two steps, being the ESP and the variable throat scrubber are the same as option 1.

Alkali scrubber

The final scrubbing stage is a two stage scrubber[3] which then scrubs out the majority of the remaining SO_2 using process water. The SO_2 rich convertor gases are then sent to the contact section of the acid plant which possesses a double contact double absorption SO_2 convertor for acid generation.

When the gas from the variable throat scrubber enters the first stage of the scrubber, the majority of the SO_2 is removed. Water is used to scrub the gas. After the first stage the gas then enters into a second stage. The two stages are separated by a trap-out tray. The second stage acts as a polishing step to achieve the low outlet SO_2 concentration limit via the stack.

The pregnant solution from the alkali scrubber then passes through a stripper which ensures that the process water is regenerated and sent back to the scrubber. The product from the stripper is then sent to the acid plant.

Acid Plant

The clean gas from the stripper is then passed through a pre-drying tower where the gas is contacted with 65% H_2SO_4 to remove approximately 70% of the moisture. The partially dried gas is then contacted with 96 % H_2SO_4 before entering a blower in which the discharge then enters into the double contact double absorption (DCDA) section of the plant.

The gas leaving the blower enters into a convertor which consists of 4 passes and is responsible for the conversion of SO_2 to SO_3. The convertor uses a combination of cesium-promoted and conventional vanadium pentoxide catalysts. The reaction taking place is as follows:

$$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3 \qquad \textbf{Equation 3-7}$$

After the third pass the conversion is 97%, at this point the high content of SO_3 inhibits the further oxidation of SO_2 hence the gas is sent through to the Inter pass absorption tower (IPAT) where all the SO_3 is absorbed into 98.5% H_2SO_4. The product containing the remaining SO_2 is then sent to the fourth pass where up to 97% of the remaining

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[3] (Bartocci n.d.)

SO_2 is converted. The maximum overall conversion achieved is 99.91%. The gas is then sent to the final absorption tower where all the SO_3 is converted into H_2SO_4. The unreacted gases are then vented into the air. The reaction taking place in the absorber is as follows:

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad \text{Equation 3-8}$$

Defining the system boundaries

The system boundary for the LCA was defined as presented below with all inputs and outputs being "elementary" flows. In order to make a good comparative analysis, a system expansion was made on the first option so that it would include the sulphuric acid production process as a positive material flow. This therefore ensures that both cases have sulphuric acid as the main product.

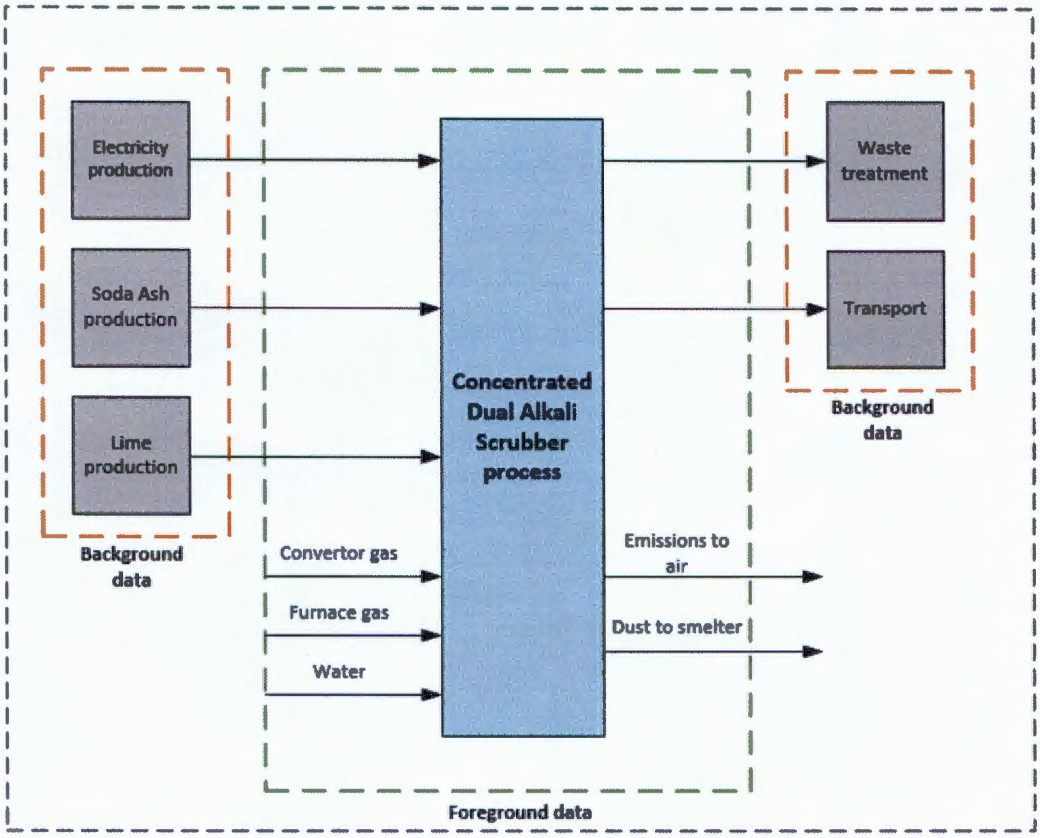


Figure 3-4: LCA system boundary for concentrated dual alkali process

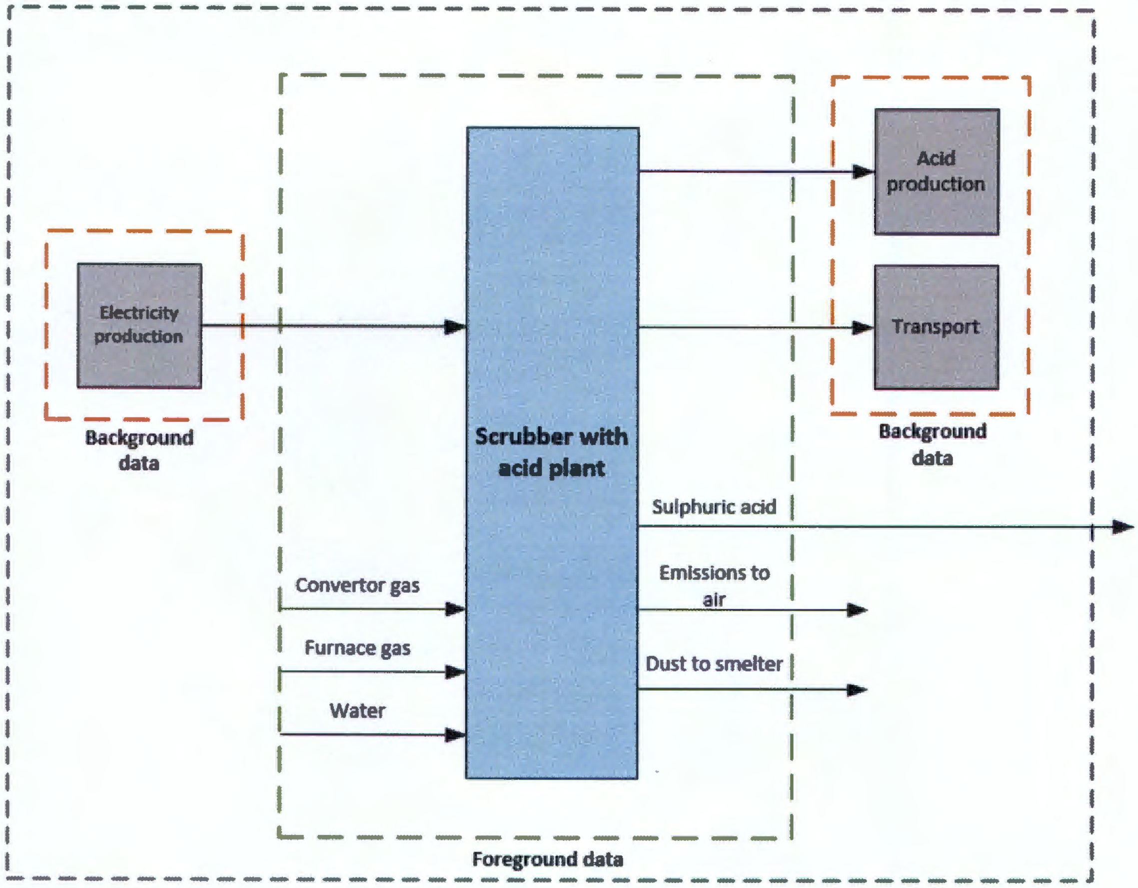


Figure 3-5: LCA system boundary for scrubber with acid plant

Life Cycle Inventory Analysis

Data quality requirements

The data used as part of the analysis can be classified as either foreground or background.

Foreground Data

These are mass and energy balance data for the different SO_2 abatement technologies. These primary data were acquired from a review of the published design documents for the different smelting processes ((Bezuidenhout et al. 2012; Sichone 2009; Westcott et al. 2007), supplemented by values obtained during the interviews done with experts from companies running similar processes. These data included: energy use, raw material inputs, and ratios of main products to co-products, environmental emissions and production rates.

Background data

This data describes how key raw materials or energy purchased from suppliers are produced; they were acquired from the Ecoinvent LCI database and published reports. In addition the waste treatment in the case of the concentrated dual alkali was also modelled as a background process.

The life cycle inventory results of the modelling of the two systems under consideration are presented in Chapter 4.

Life Cycle Impact assessment

There are quite a number of mid-point indicators that are used when performing life cycle assessments, however, for this study only 6 have been considered. The following impact categories are considered based on their relevance to the goal of identifying potential burden shifting induced by the SO_2 scrubbing process:

- ***Human toxicity:*** The scrubbers remove SO_2 and particulate matter – their main function is to protect human health around the plant. But it is also known that if the scrubber uses a lot of power, that this may transfer human health impacts to people living around power stations.
- ***Climate change***: Though the SO_2 abatement technologies reduce the amount of sulphur dioxide that is released into the air, they also tend to be energy intensive. In the South African context where energy supply is coal based this may lead to significant volumes of greenhouse gases being emitted from coal-burning which causes global warming and in turn causes climate change. Hence it is only through life cycle assessment that this concern can be traced; impacts are potentially shifted from local impacts to global impacts and hence becoming useful in decision making.
- ***Depletion of abiotic resources***: The scrubbing process that comes with the acid plant sees the generation of a by-product sulphuric acid. This therefore means that the acid produced can be sold to other processes requiring the acid as an input thereby eliminating the process of making the acid. This therefore means that there will no longer be need for such companies to make sulphuric acid from mined resources.

- ***Water usage***: The SO_2 scrubber makes use of water for the cooling of the gas stream and also produces liquid effluents that have the potential to contaminate freshwater. It is therefore very important to identify or rather differentiate between the water types and quality that are used and produced by the gas cleaning and acid plant, all of this in view of the eminent importance of freshwater shortage and regional variation in water quality since the availability of fresh water is of utmost importance to humans and the environment.
- ***Acidification:*** This category considers the potential of SO_2 scrubbing processes to reduce or shift the deposition of acidifying pollutants on soil, ground and surface water, and ecosystems mainly as a result of acid rain. Since the major contributors of this category are SO_2 and NO_x it is important to evaluate by how much the acidification potential of the process is reduced through the use of the scrubber, and to what extent burdens may be shifted to coal-fired power plants which also emit the same substances.
- ***Fossil fuel depletion:*** The two SO_2 abatement technologies that were analysed were seen to be energy intensive. In the South African context the electricity that is used is coal based hence it was important to investigate the depletion of fossil fuel as a result of the increasing energy demand.

The results of the LCIA are presented in Chapter 4, section 4.2.

Critical Review considerations

An LCA should undergo a peer or critical review, so as to facilitate the understanding and credibility of the LCA. Being contained in a dissertation, this LCA benefits from a critical review both by an external and an internal expert, familiar with the ISO requirements. An interactive review process was adopted in which internal reviews were carried out after each of the following steps: After the scope definition, after the data collection, after the generation of the LCIA results, and after the interpretations were written. This ensured that problems could be corrected at early stages, before resources were expended on work which would later turn out to be inadequate. The interactive review process was done by the main supervisor. The external review, on the other hand, is part of the external examination of the dissertation; the examination report is expected to contain a final review statement on the quality of the LCA.

3.3.2 Expert Design Interviews

Once the analysis of data had been carried out both on Aspen and in SimaPro a set of detailed expert interviews were carried out, so as to determine whether life cycle assessment could help inform design decision making in the minerals industry. The researcher opted for semi-structured but detailed face to face interviews with expert design engineers. Only seven interviews where scheduled as the main purpose was to get as much detailed insights as possible from the interviewees, who were part of the decision making process when most of the SO_2 abatements projects where implemented in the North West province.

The interviews were approximately one hour long. Informed consent was obtained for the recording of interviews. Interviewees were also notified on anonymity and confidentiality of the information that would be gathered from the interview. A set of the interview questions and the consent forms relating to the interviews are provided in Appendix D.

The interviews were structured in such a way that the session started off with the introduction of both the interviewer and the interviewee. The design expert was then given the consent form to sign after being briefed about what the project was all about. The first part of the interview then focused mainly on decision making in the minerals industry, with the researcher clarifying any responses that were not clear but refraining from guiding the interview on how to answer the question. Next, the results from the LCA were then presented to the expert, who was thereafter asked to comment on whether they thought incorporation of LCA into the specific design they had been involved in, and into minerals processing design decision making more generally, would be useful.

Two of the interviews carried out were then followed up by site visits of the plants that ran similar processes to the two main cases as way of deepening the understanding of how the processes work and linking theoretical information to the practical. The site visits also opened up a chance for the researcher to clarify some of the assumptions that had made in the Aspen simulation so as to determine how precise the conceptual models were.

Thereafter, the interviews were analysed based on a thematic analysis approach as detailed below which was adopted from (Braun & Clarke, 2006). Firstly the recorded interviews were transcribed into a written form in order to conduct the thematic analysis. This provided the first place of familiarisation to the data that was to be analysed. Initial ideas were noted throughout the process and patterns identified that were common among the design experts. Once transcription was done the ideas that had been noted were grouped and recurring areas of interest identified which were later put into themes. The interview results are presented in Chapter 5.

The interview results shown in Chapter 5 were then merged with the LCA results shown in Chapter 4 and used in the discussion in Chapter 6 of the dissertation.

The greatest advantage that was identified for using this form of analysis was that it could generate unanticipated results and also highlight any similarities and differences in information from the different sources. This meant that the key features of a large body of data were usefully summarized and discussed.

3.4 Ethics Conformation

Part of the data collection process for the research was conducting detailed design expert interviews with people responsible for different decision making steps in the mining company. This therefore meant that ethics approval had to be obtained from the Faculty ethics committee as way of ensuring that the research meets the highest ethical standards. As such, an ethics approval application was submitted to the EBE Ethics in Research Committee (EiRC) before the data collection commenced and was granted.

Informed consent was used to ensure that the interviewees' participation was voluntary and that they agreed to all the terms and conditions stipulated in the consent forms. In addition the consent forms also clarified how classified information would be handled and whether or not the participants wanted to be kept anonymous or not.

Samples of the questionnaires and the respective consent forms that were sent through to the Universities ethics committee have been as attached in the Appendix D including the approved form.

3.5 Summary

This chapter has provided the key questions which led to the formulation of a methodology that informed this study. The basis of the methodology was defining the goal and scope of the life cycle assessment to be carried out and also the procedure for the expert design interviews that were carried out. This therefore provides a background against which the results in the next two chapters will be interpreted.

CHAPTER 4. LCA FOR SO_2 ABATEMENT TECHNOLOGIES

This chapter of the dissertation will present the results of the case study that has been used to answer the first key question that was posed in Chapter 3. It starts off by presenting the results of the Aspen simulation that was used to model the selected SO_2 abatement technologies, viz. the concentrated dual alkali system and the SO_2 scrubber with acid generation plant. It then presents an LCA on the defined design decisions. The goal of this chapter is to identify whether there were design decisions that induced environmental burden shifting when platinum mining companies chose and specified SO_2 abatement technologies, by utilising the LCA perspective. The chapter will therefore present and discuss the results of the LCA study and will include the impact assessment and interpretation of the model outcomes – all conducted in accordance with the goal and scope as presented in section 3.3.1.

4.1 Mass and Energy balances

This section presents a summary of the overall input / output table based on the system boundaries outlined in Chapter 3, and the energy requirements for the different process options at different recoveries. The key design variables that were considered are provided in Figure 4-1.

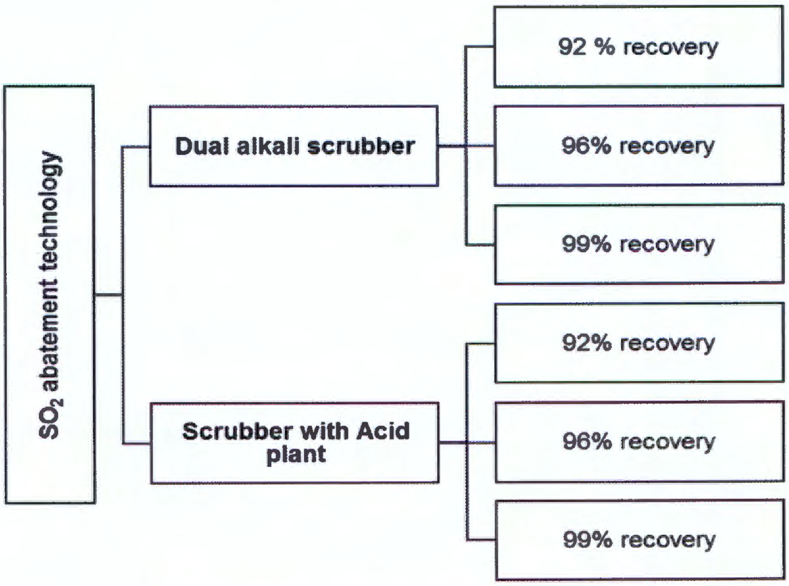


Figure 4-1: Key design variables analysed

4.1.1 Aspen Simulation

The gases to be treated were determined to be of the compositions shown in Table 4.1:

Table 4-1: Off-gas from convertor and furnace to be treated

Component	Convertor Gas (kmol/hr)	Furnace Gas (kmol/hr)
SO_2	169	22.9
O_2	371	425
N_2	4512	1690
H_2O	85.2	70.6
CO_2	27.95	0
SO_3	5.4	2.8
Dust Burden		
Silica	0.052	1.679
Alumina	0.008	0.282
Sulphides	0.004	0.139
Calcium Oxides	0.004	0.16

The two SO_2 abatement cases were modelled using Aspen Plus as a way of generating mass and energy balance data which would form the basis of the foreground data that would be used in the Life Cycle Assessment. The key flows were based on values averaged from literature and current plant operational data from one of the mining companies.

The key input and output data for the foreground systems are presented in Table 4-2 and Table 4-3.

Table 4-2: Input / output flows (per year) for concentrated dual alkali plant treating 1.66E+06 t/yr. of flue gas

Component			Units/yr.	92% recovery	96% recovery	99% recovery
Inputs	Raw Materials	Water, process	m³	1.1E+06	1.6E+06	3.1E+06
		Soda Ash	Tons	28490	65119	74887
		Lime	Tons	100670	105050	108338
	Electrical Energy		MJ	1.5E+06	1.9E+06	3.3E+06
Outputs	Emissions to air	Sulphur dioxide	Tons	7572	3785	945
		Oxygen	Tons	183486	177308	172796
		Nitrogen	Tons	1334623	1334623	1334623
		Water, vapour	Tons	1134159	1614505	3171809
		Sulphur trioxide	Tons	5062	5062	5062
		Carbon dioxide	Tons	21277	36487	40543
	Dust returned to smelter	Silica	Tons	1559	1559	1559
		Alumina	Tons	437	437	437
		Sulphides	Tons	168	168	168
		Calcium oxides	Tons	138	138	138
	Waste for disposal	CaSOx	Tons	208522	232771	250629

As can be seen in Table 4-2, the amount of raw materials required by the concentrated dual alkali process increase with increasing recovery. The amount of dust returned to the smelter is the same for all three recovery as the dust removal process was assumed to be the same for all key variables in the conceptual design. It is also evident from the table that the amount of CaSOx produced increases with increased recovery.

The concentrated dual alkali process sees an increase in the amount of CO_2 produced with increasing recovery, this is because the CaSOx production reactions release CO_2 which adds to the CO_2 that is already possessed by the gas stream that is being cleaned.

Table 4-3: Input / output flows (per year) for scrubber with acid plant treating 1.66E+06 t/yr. of flue gas

Component			Units/yr.	92% recovery	96% recovery	99% recovery
Inputs	Raw Materials	Water, process	m^3	9.3E+06	1.1E+07	1.3E+07
	Electrical Energy		MJ	4.5E+06	5.2E+06	6.2E+06
Outputs	Emissions to air	Sulphur dioxide	tons	7572	3785	945
		Oxygen	tons	202335	201400	200699
		Nitrogen	tons	1428419	1428419	1428419
		Water, vapour	tons	3115899	3150067	3217275
		Sulphur trioxide	tons	7069	8316	10567
		Carbon dioxide	tons	7281	7050	6567
	Dust returned to smelter	Silica	tons	1559	1559	1559
		Alumina	tons	437	437	437
		Sulphides	tons	168	168	168
		Calcium oxides	tons	138	138	138
	By-product	Acid	tons	126295	130506	132066

As can be seen from Table 4-3 above the amount of water and energy required in the foreground system increases with increasing recovery. The scrubber with acid plant option sees an increase in the amount of SO_3 released with increasing recovery, this is attributed to the unreacted gases released from the contact plant which would have converted SO_2 gas into SO_3.

4.1.2 Energy Requirements for the technology options

The results of the variation of energy consumption with the different key variables is presented in Figure 4-2 and Figure 4-3 for the concentrated dual alkali scrubber and the scrubber with the acid plant respectively.

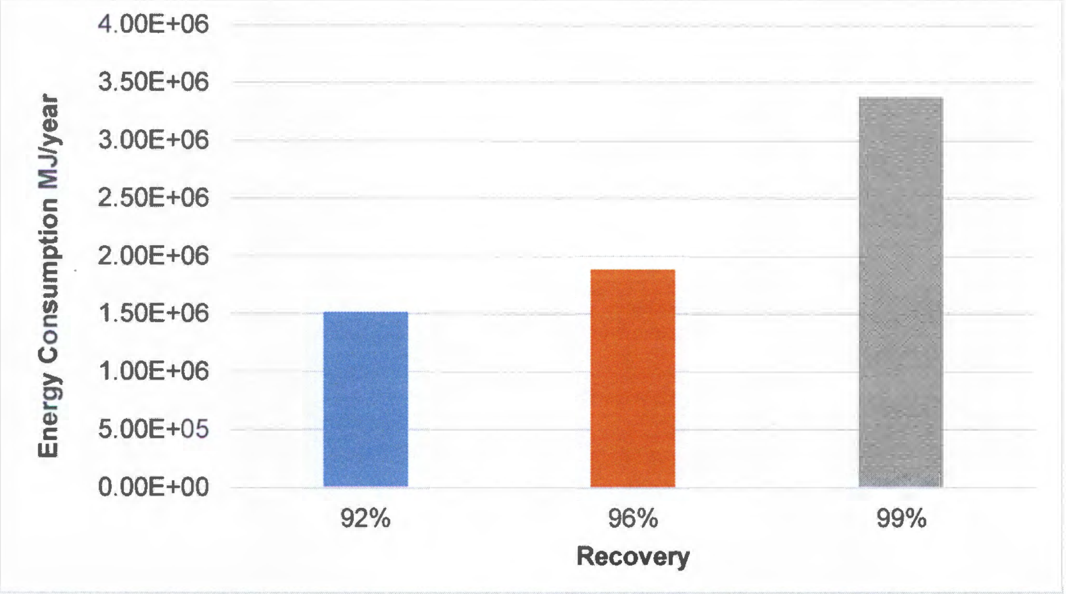


Figure 4-2: Variation of energy requirements with increasing recovery for concentrated dual alkali scrubber

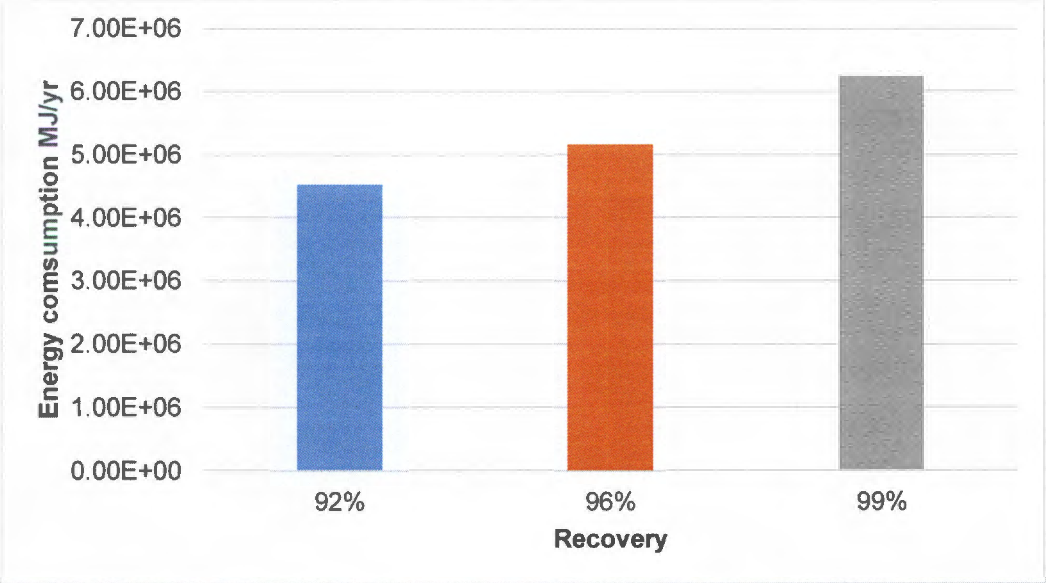


Figure 4-3: Variation of energy requirements with increasing recovery for the scrubber with acid plant

As can be seen from the graphs the energy requirement increases with an increase in recovery for both technology options. In the dual alkali case as it can be seen that one will require 4 times the amount of energy required to move from 92 % to 96 % if they are to increase recoveries from 96 % to 99 %. For the scrubber and acid plant a similar trend is observed in which the amount of energy required increases with increasing recovery.

The total energy consumption for the scrubber with the acid plant is greater than that of the concentrated dual alkali process at all recoveries. However, the energy requirements for the contact process were not considered as the process was determined to be auto thermal. The post absorption process which consists of reactors and thickeners negligible energy requirements as the energy requirements were way less than those of the pumps in the scrubber unit. The energy requirements that were considered for the systems was that associated with the pumping of the different solvents that would be required for the scrubber unit.

The trends observed are comparable to the results that were presented in Chapter 2 which showed how the Number of Transfer Units (NTU) changes with an increase in recovery. Comparing the energy requirements for the two technology options shows that the scrubber and acid plant requires more energy overall compared to concentrated dual alkali absorber.

In general the concentrated dual alkali scrubber offers better results in terms of energy consumption but see an increase in the amount of CO_2 that is released to the atmosphere as shown in the mass balance in Section 4.1.1 above.

4.2 Life cycle impact assessment (LCIA)

This section will evaluate the magnitude and potential environmental impacts for a process being analysed throughout its life cycle by presenting the results of the life cycle assessment modelling.

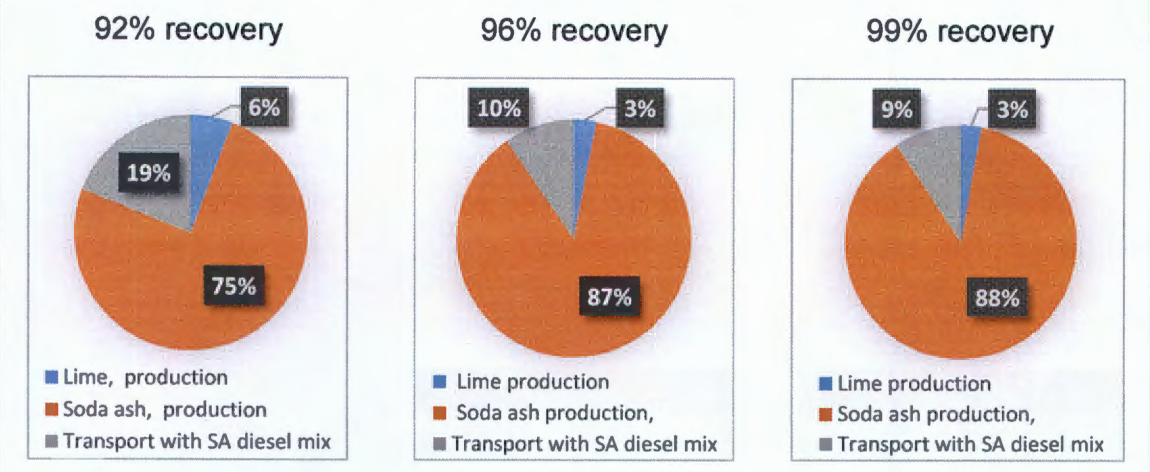
Table 4-4: Impact categories considered for the study

Impact Category	Scale	Method	Units
Abiotic resource depletion	Global	CML	kg Sb eq
Acidification	Regional	Recipe	kg SO_2 eq
Fossil fuel depletion	Global	Recipe	kg oil eq
Global warming	Global	CML	kg CO_2 eq
Human toxicity	Regional	Usetox	CTUh/kg
Water depletion	Local	Recipe	m^3

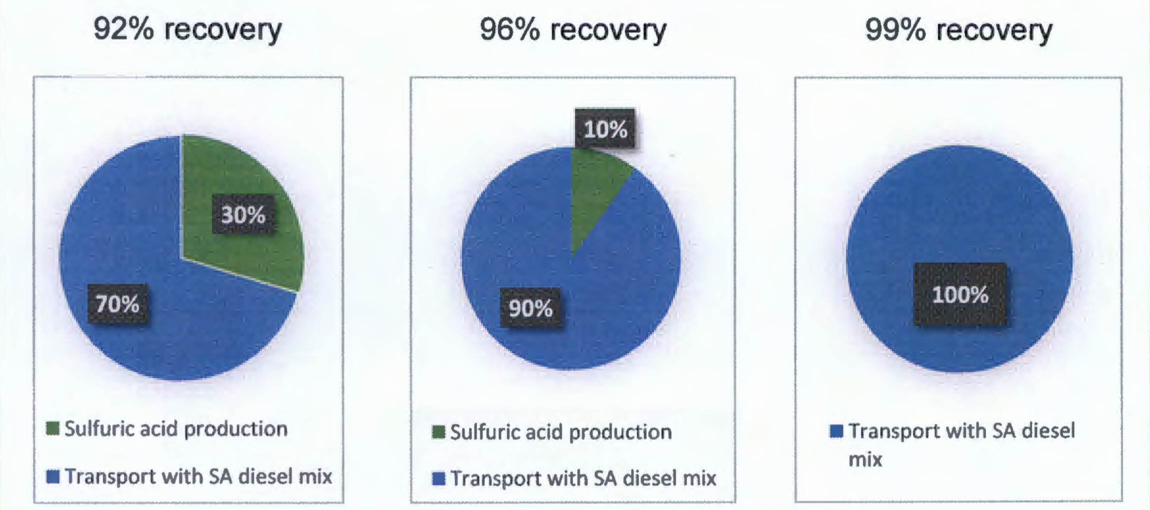
The following section presents the results of how the different environmental impacts vary with changes in the key variables.

4.2.1 Abiotic resource depletion

Abiotic resource depletion has a global impact and its potential was investigated in the study. Figure 4-4 shows the relative unit contributions to abiotic resource depletion for both the concentrated dual alkali scrubber and the scrubber with acid plant.



a) Concentrated dual alkali scrubber



b) Scrubber with acid plant

Figure 4-4: Unit process contributions to abiotic resource depletion for a) the concetrated dual alkali scrubber and b) the scrubber with acid plant

From Figure 4-4 it can be observed that the modelled background processes for the two technology options are the major contributors to abiotic resource depletion. For the concentrated dual alkali option it can be seen that the production of soda ash contributes 74% to the total impact followed by the transportation of the waste CaSOx product to the landfill which contributes 19% for the 92% recovery. However as recovery increases the transportation effects increase and the reagent contributions decrease. The scrubber and acid plant sees the transportation of the acid contributing 70% to the total resource depletion and the production of sulphuric acid which was used for the systems expansion contributing the remaining 30% for 92%recovery.

Similar to the concentrated dual alkali case, the transportation effects become more dominant with increasing recovery.

The abiotic resource depletion impact category is related to the extraction of mineral elements and fossil fuels associated with the input systems on a global scale.

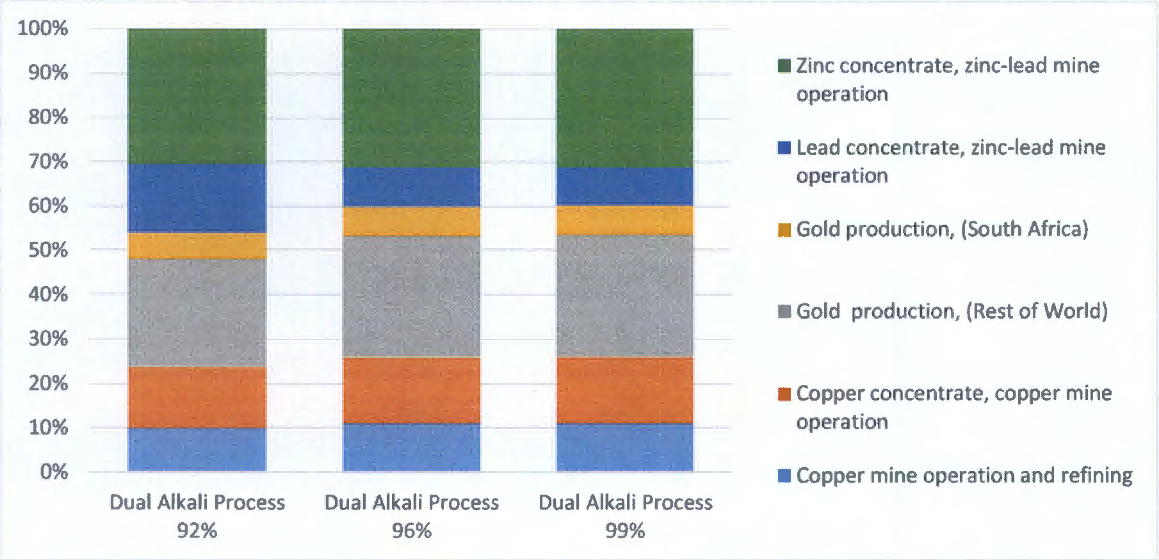


Figure 4-5: Process contribution (% of total) of inventory elements to abiotic resource depletion to the concentrated dual alkali scrubber

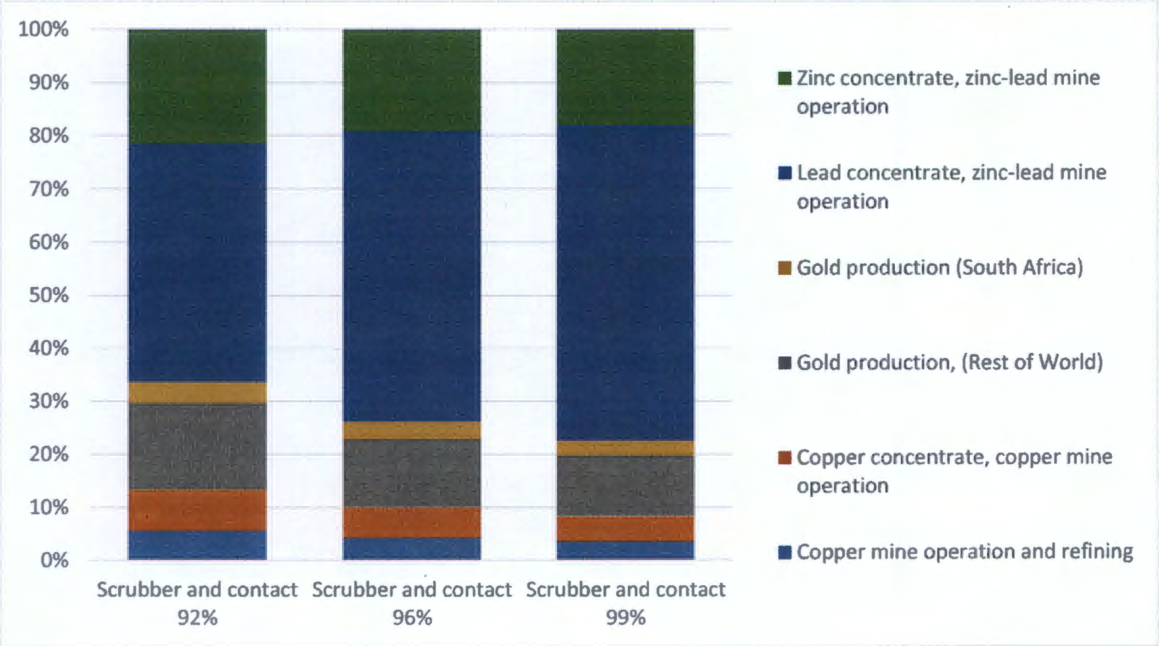


Figure 4-6: Process contribution (% of total) of inventory elements to abiotic resource depletion to the scrubber with acid plant

Figure 4-5 and Figure 4-6 provide a summary of the mineral elements depleted at the different recoveries based on the inputs to the two technology options analysed. Both figures clearly show the abiotic resources that are depleted with the zinc concentrate mining and gold mining dominating for both processes.

Figure 4-7 presents results obtained for the abiotic resource depletion impact category from the assessment of the key variables with impacts measured in kg Sb equivalence.

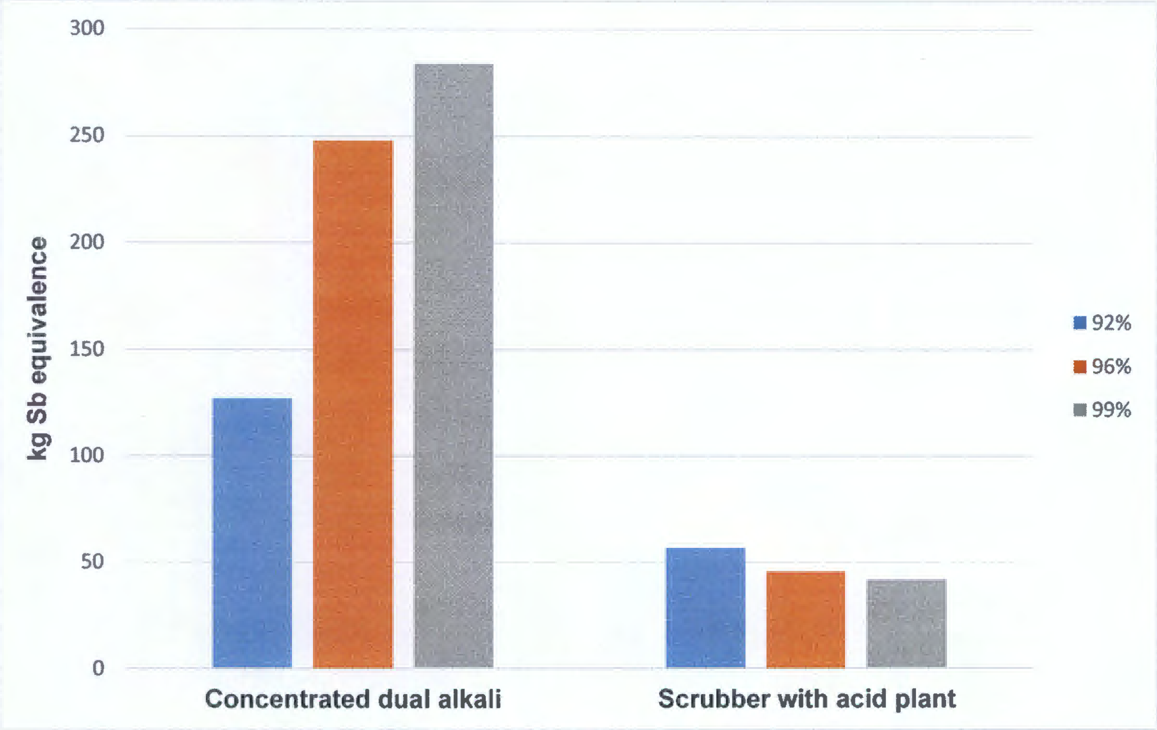


Figure 4-7: Variation of abiotic resource depletion with recovery

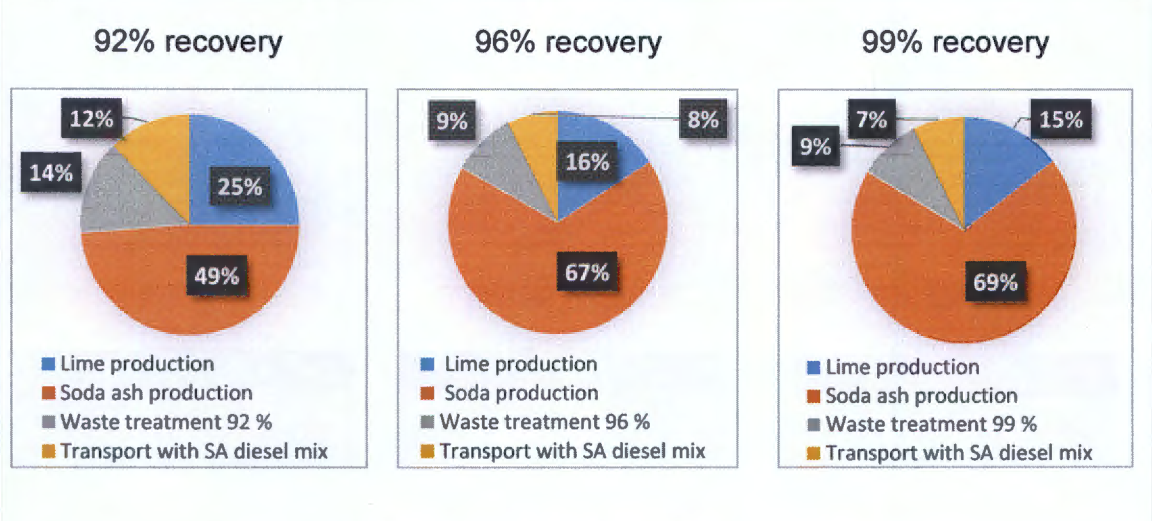
In the dual alkali option, the abiotic resource depletion increases by 95% when SO_2 recovery is increased from 92% to 96%, and by a further 14.5% when the recovery is increased from 96% to 99%. An inverse trend is seen for the scrubber with acid plant which sees a 20% decrease from 92% to 96% SO_2 recovery, and a further 8% decrease from 96% to 99% recovery.

The trend observed for the concentrated dual alkali process is directly linked to the soda ash requirements for the different recoveries which sees the solvent requirement doubling as you move from 92% to 96% as shown in Table 4-2.

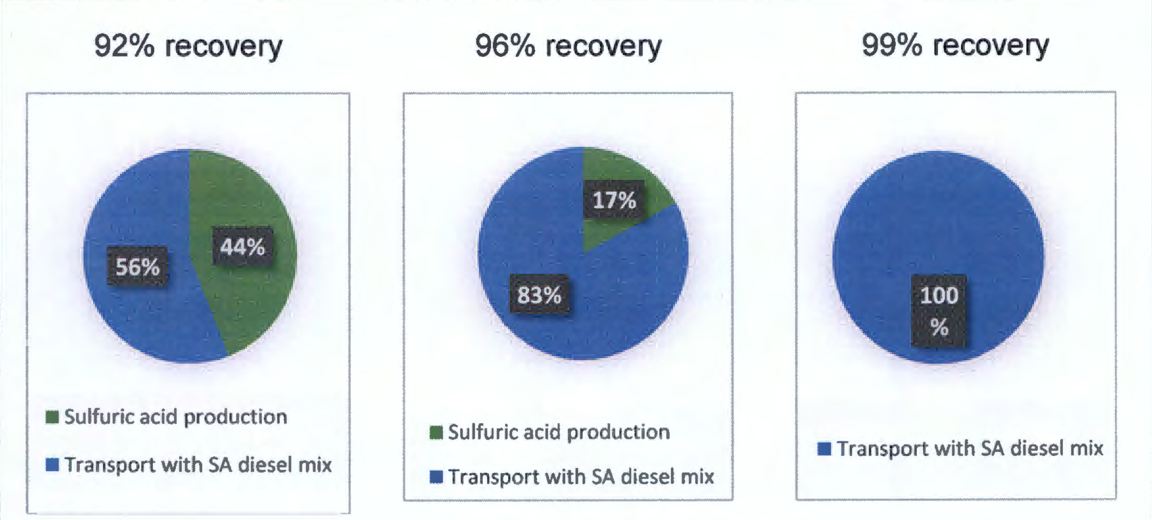
Although there is an exponential increase in the amount of electricity required for the scrubber and acid plant the decrease in resource depletion is attributed to the decrease in the amount of sulphuric acid that is required for the systems expansion as you move from 92% to 96% with the 99% not requiring the additional acid production. Therefore, by producing more acid, resource depletion is avoided elsewhere.

4.2.2 Fossil fuel depletion

The study also investigated the depletion of fossil fuels and its variation with the key design variables. Figure 4-8 shows the relative unit contribution to fossil fuel depletion at the different recoveries.



a) Concentrated dual alkali scrubber



b) Scrubber with acid plant

Figure 4-8: Unit process contributions to fossil fuel resource depletion for a) the concentrated dual alkali scrubber and b) the scrubber with acid plant

It can be seen in Figure 4-8 that the fossil fuel depletion impact is dominated by the modelled background processes for both the concentrated dual alkali scrubber and the scrubber with acid plant.

For the concentrated dual alkali case, the production of soda ash is responsible for 49% of the environmental impacts and the second largest contributor is the production of lime both of which are inputs to the system at a recovery of 92%. As the recovery increases it can however be noted that impacts of producing soda ash become more dominant. The scrubber and acid plant however, only has two major contributors which are impacts resulting from the transportation of the acid and the production of sulphuric acid contributing 56% and 44% respectively for the 92% recovery. The impact of producing sulphuric acid are directly related to the acid required for the system expansion hence decrease as one moves from 92% to 96%.

The fossil fuel depletion impact category is related to the amount of fossil fuels extracted based on the inputs to the system. Figure 4-9 and Figure 4-10 provide a summary of the main fossil fuels depleted by the two technology options.

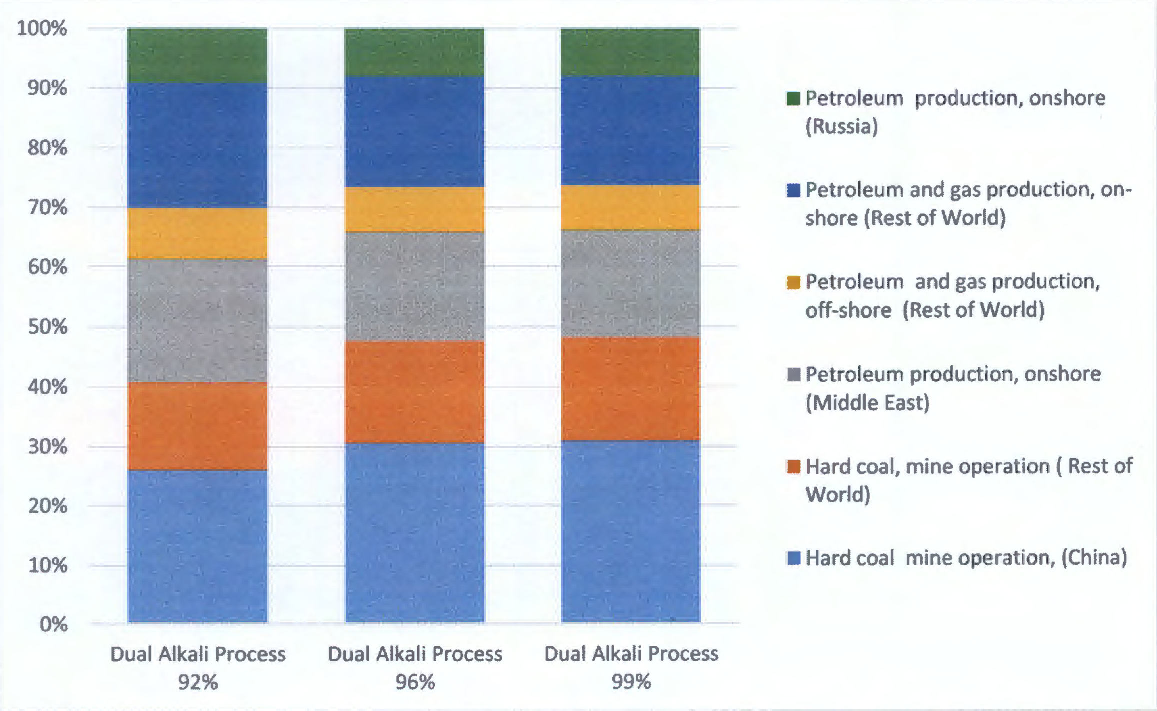


Figure 4-9: Process contribution (% of total) of inventory elements to fossil fuel depletion to the concentrated dual alkali scrubber

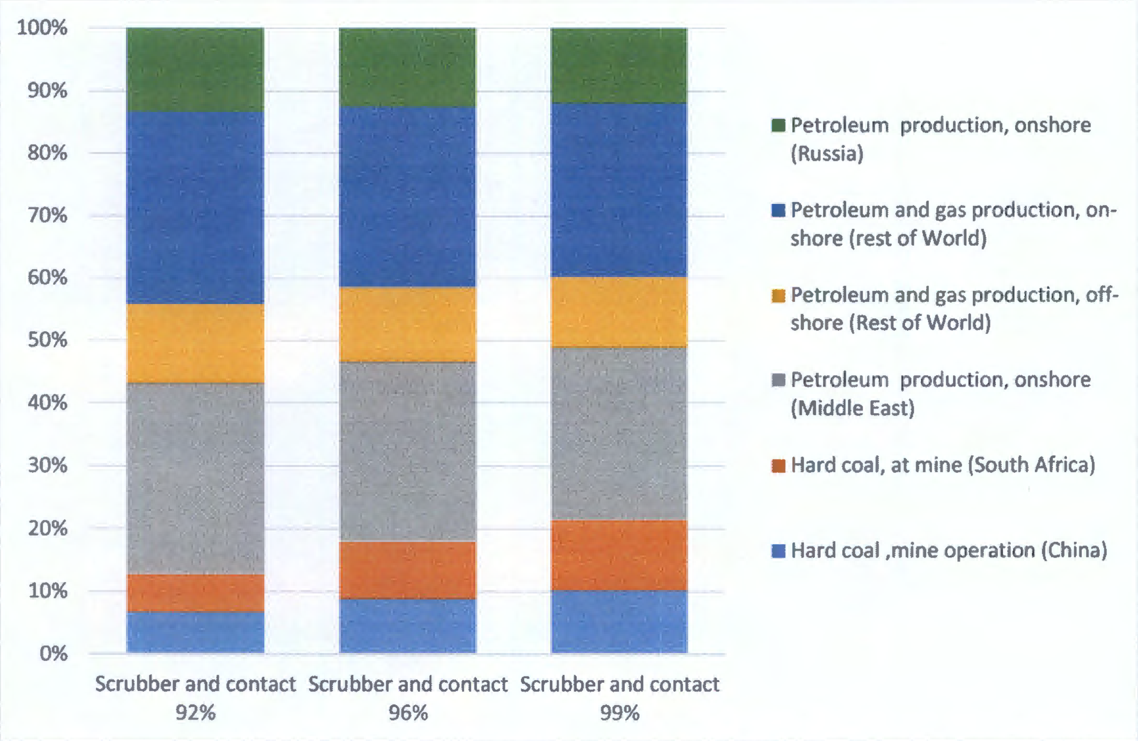


Figure 4-10: Process contribution (% of total) of inventory elements to fossil fuel depletion to the scrubber with acid plant

From Figure 4-9 and Figure 4-10 it can be seen that the actual processes that contribute to this impact category are the production of petroleum and the mining of coal.

Figure 4-11 reveals how the depletion varies with increasing recovery for the two technology options that were studied.

A similar trend to that seen in the abiotic resource depletion category was observed in the fossil fuel depletion category in which the environmental impacts increase with increasing recovery for the concentrated dual alkali scrubber and decrease with increasing recovery for the scrubber with acid plant. An increase in fossil fuel depletion is observed for the concentrated dual alkali scrubber option as one moves from 92% to 96% and from 96% to 99% with increases of 66% and 11% respectively.

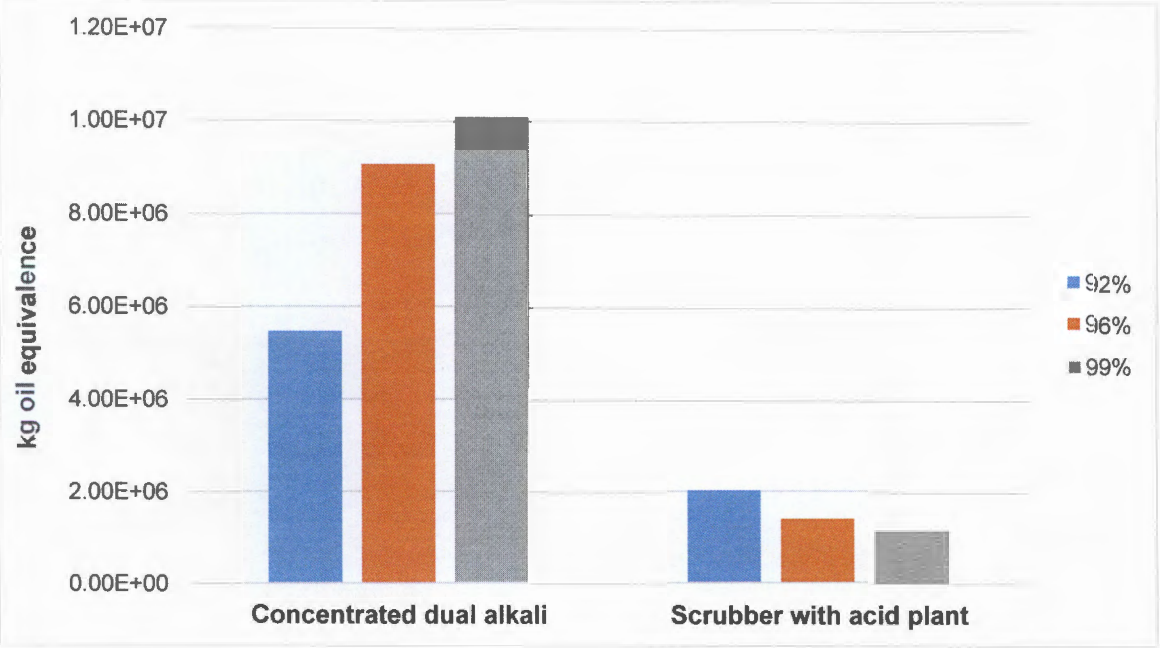


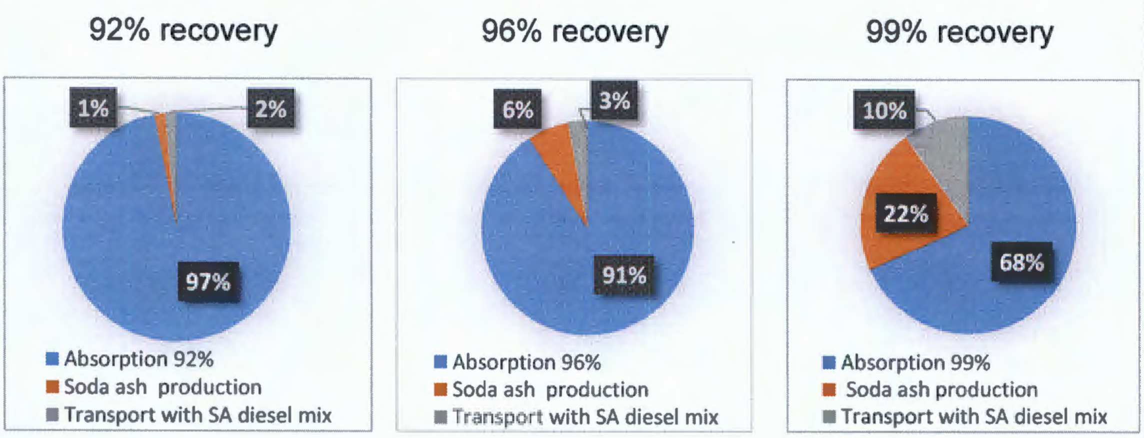
Figure 4-11: Variation of fossil fuel depletion with changing recovery

One would expect to see an increase in the impact as you move from a recovery of 92% to 99% since more acid is produced and more energy is required. The scrubber and acid plant however sees a decrease in the quantities of fossil fuels that are depleted. The decrease is attributed to the indirect impacts that are avoided as a result of the systems expansion that was made. It can be seen from Table B- 2 (in appendix) that the acid production required for systems expansion decreases from 5771 tons to 1560 tons as one moves from a recovery of 92% to a recovery of 96%. The 99% option has no extra acid production requirements associated with it. This decrease in additional acid requirement is more significant compared to the increase in transportation related impacts of the acid produced which increases by 3% from 92% to 96% and 1.2% from 96% to 99% .

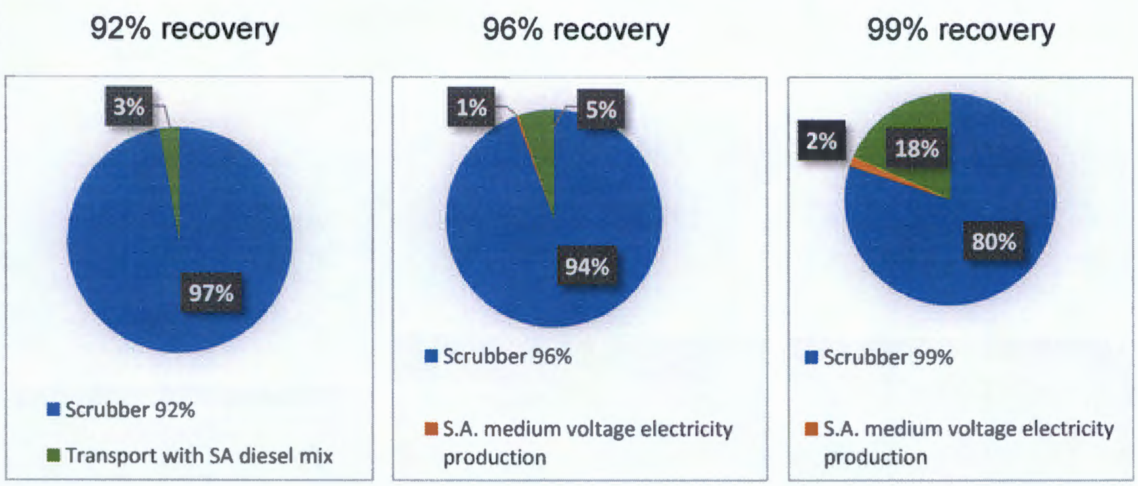
4.2.3 Acidification

Acidification is regarded as a regional effect. Based on the system emissions, it is the release of SO_2 that has the potential to cause acidification.

Figure 4-12 shows the relative unit contribution to acidification potential for both the concentrated dual alkali scrubber and the scrubber with acid plant at the different recoveries.



a) Concentrated dual alkali scrubber



b) Scrubber with acid plant

Figure 4-12: Unit process contributions to acidification potential for a) the concentrated dual alkali scrubber and b) the scrubber with acid plant

Figure 4-12 indicates that acidification potential impacts for both process technologies are dominated by the actual SO_2 removal process: both the scrubbing processes for the concentrated dual alkali scrubber and the scrubber with acid plant contribute 97% to of the total impacts. This is followed by the transportation of the waste product which contributes 2% and that of the acid contributing 3% for the 92% recovery. However background processes start being more dominant as the recovery increases for both technology options.

The acidification potential impact category takes into account the substances contained in input processes that have acidifying impacts on soil, ground water, ecosystems and organisms. Figure 4-13 and Figure 4-14 provides a summary of the different input system contributions to acidification potential for the key variables that were analysed.

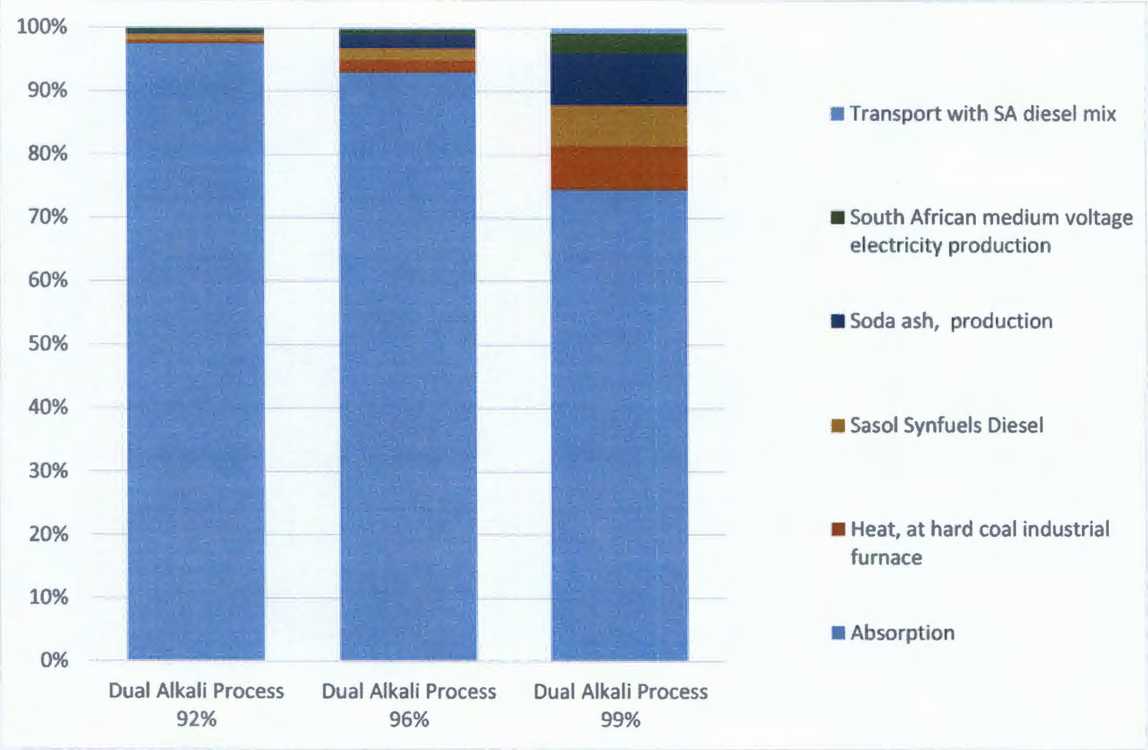


Figure 4-13: Process contribution (% of total) of inventory elements to the acidification potential to the concentrated dual alkali scrubber

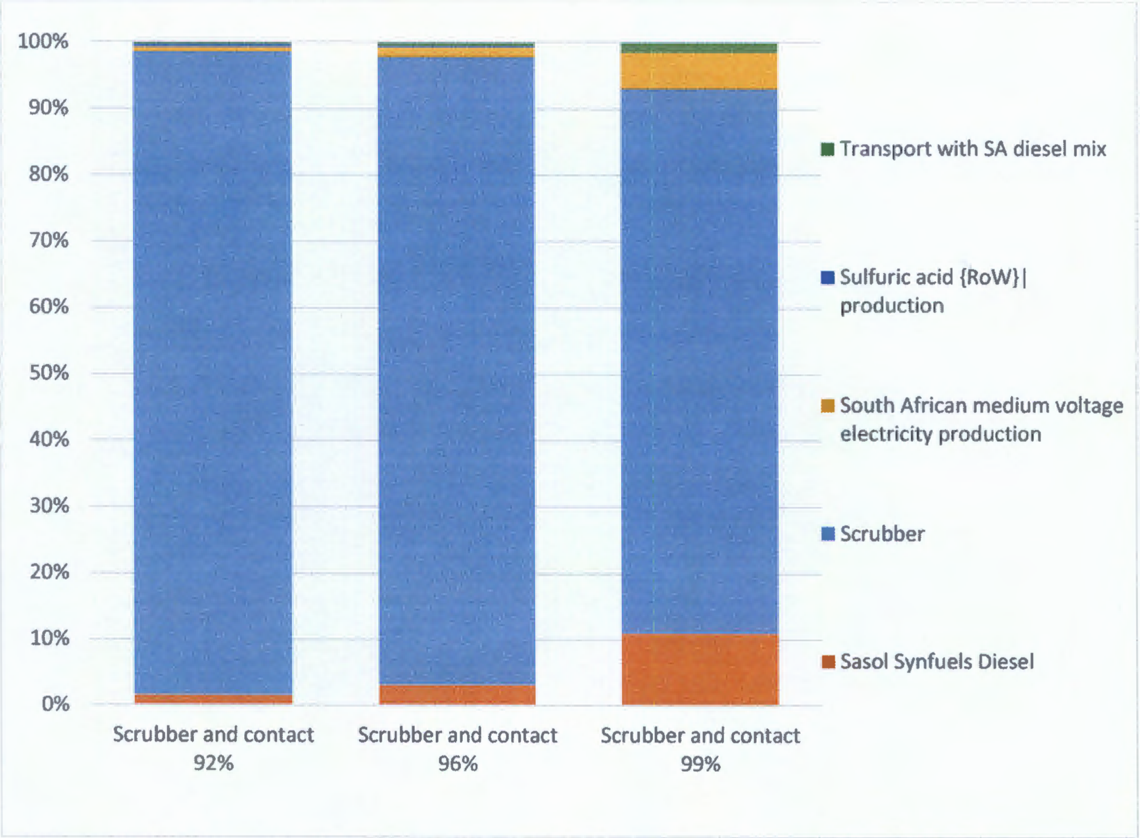


Figure 4-14: Process contribution (% of total) of inventory elements to acidification potential for the scrubber with acid plant

It can be observed from Figure 4-13 and Figure 4-14 that although the actual SO_2 removal processes are the major contributors to acidification potential as they release SO_2 into the air which is a major acidifying substance, the impacts associated with the background processes become more significant with increasing recovery.

Acidifying emissions for the different recoveries were evaluated and presented in kg SO_2 equivalence. The results obtained are presented in Figure 4-15.

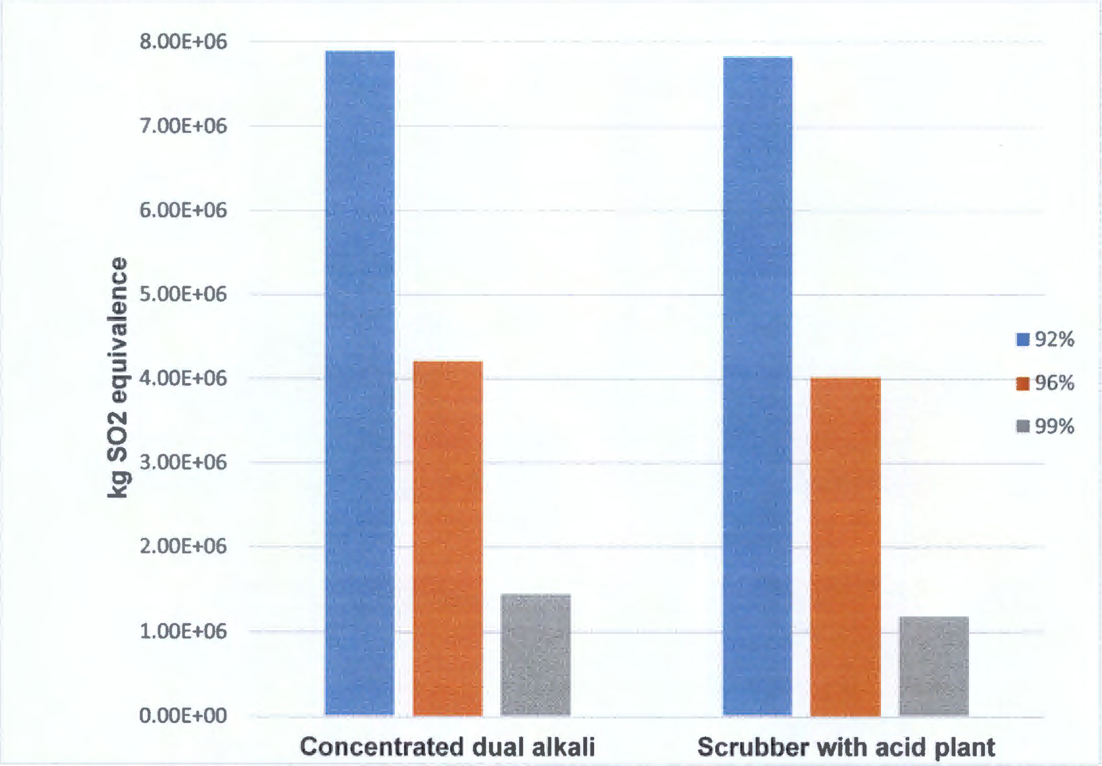


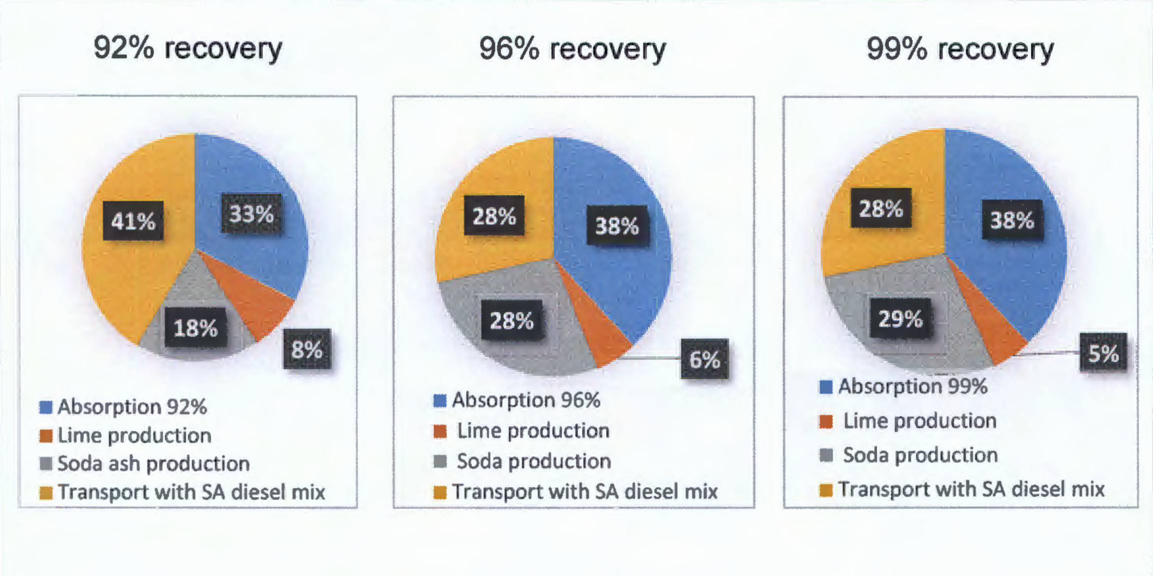
Figure 4-15: Variation of acidification potential with change in recovery

Both the concentrated dual alkali scrubber and the scrubber with acid plant show a similar trend in which the acidification potential decreases with an increase in the SO_2 recovery. The change as recovery is increased from 92% to 96% and then to 99% is the same for the two options. This is expected as this is directly related to the amount of SO_2 that is released to the air from the stacks which should decrease with an increased fixation of the sulphur.

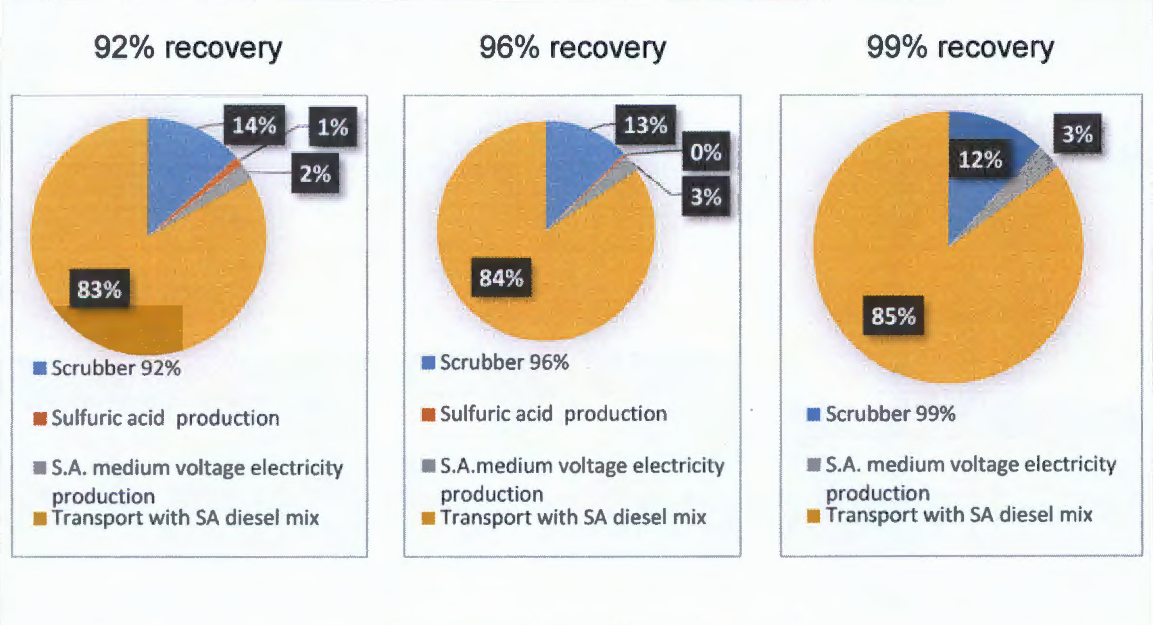
The slightly higher values for the concentrated dual alkali process compared to the scrubber with acid plant are attributed to the modelled background processes as presented in Figure 4-13 and Figure 4-14.

4.2.4 Global warming potential

The global warming potential is used to express the contribution of greenhouse gases emitted by the different processes to the environmental problem of global warming which eventually leads to climate change. Figure 4-16 shows the relative unit contribution to global warming potential for both the concentrated dual alkali scrubber and the scrubber with acid plant at the different recoveries.



a) **Concentrated dual alkali scrubber**



b) **Scrubber with acid plant**

Figure 4-16: Unit process contributions to global warming potential for a) the concentrated dual alkali scrubber and b) the scrubber with acid plant

It can be seen from Figure 4-16 that the major contributors to global warming potential for both the concentrated dual alkali scrubber and the scrubber with acid plant are the transportation impacts of the CaSOx and acid that is produced, this is then followed by the actual SO_2 scrubbing processes. The scrubbing processes contribute 33% of the total impacts in the concentrated dual alkali option and 14% in the scrubber with acid plant option at a recovery of 92%. However as the recovery increases, for the concentrated dual alkali process, the impacts for producing soda ash and the transportation of the waste increase. The contribution of background processes increases with increasing recovery for the scrubber with acid plant.

The global warning impact category is related to emission of greenhouse gases to air that can have adverse effects upon ecosystems, human health and material welfare. The process inputs contribution for the two technology options are shown in Figure 4-17 and Figure 4-18.

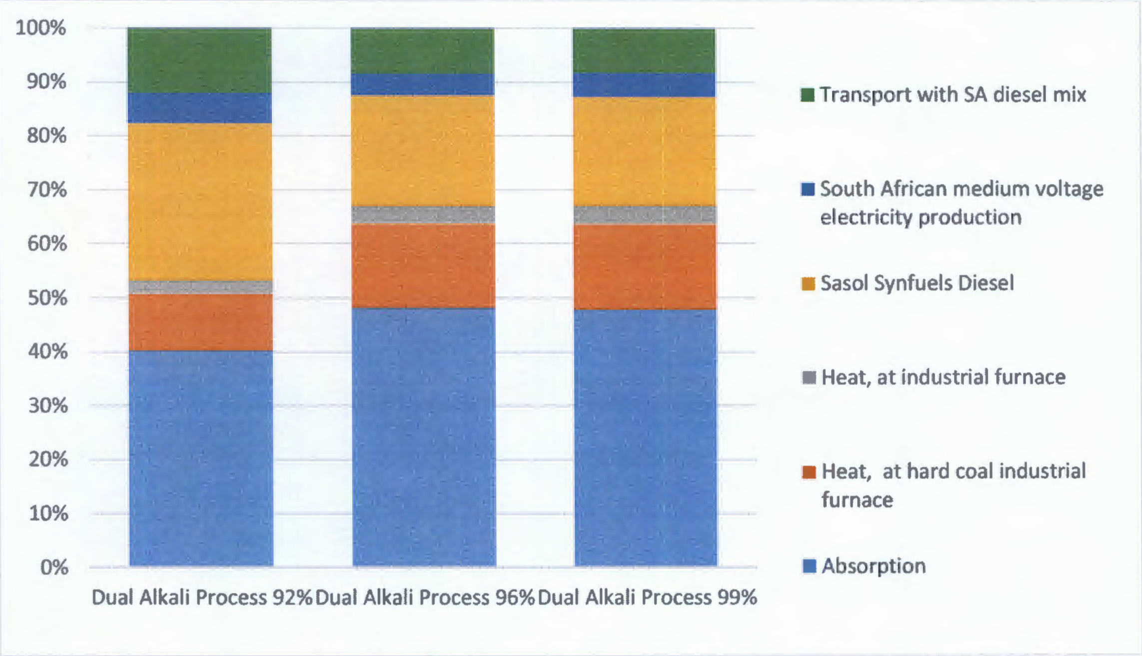


Figure 4-17: Process contribution (% of total) of input systems to the global warming potential for the concentrated dual alkali scrubber

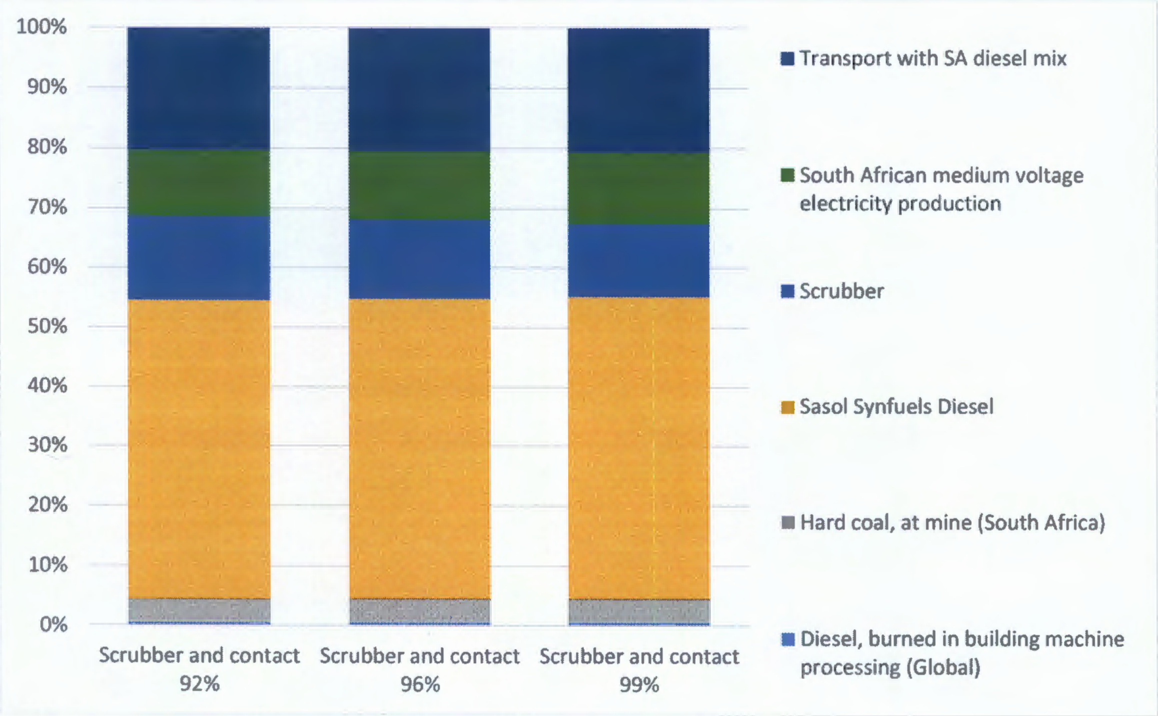


Figure 4-18: Process contribution (% of total) of inventory elements to global warming potential for the scrubber with acid plant

It can be observed in Figure 4-17 and Figure 4-18 that the processes contributing the most to this impact category are transportation, the fuel used and the specific process emissions directly related to the foreground systems for both the concentrated dual alkali scrubber and the scrubber with acid plant.

The global warming potential expressed in the present system as kg CO_2-equivalence is presented in Figure 4-19 for the key variables that were analysed.

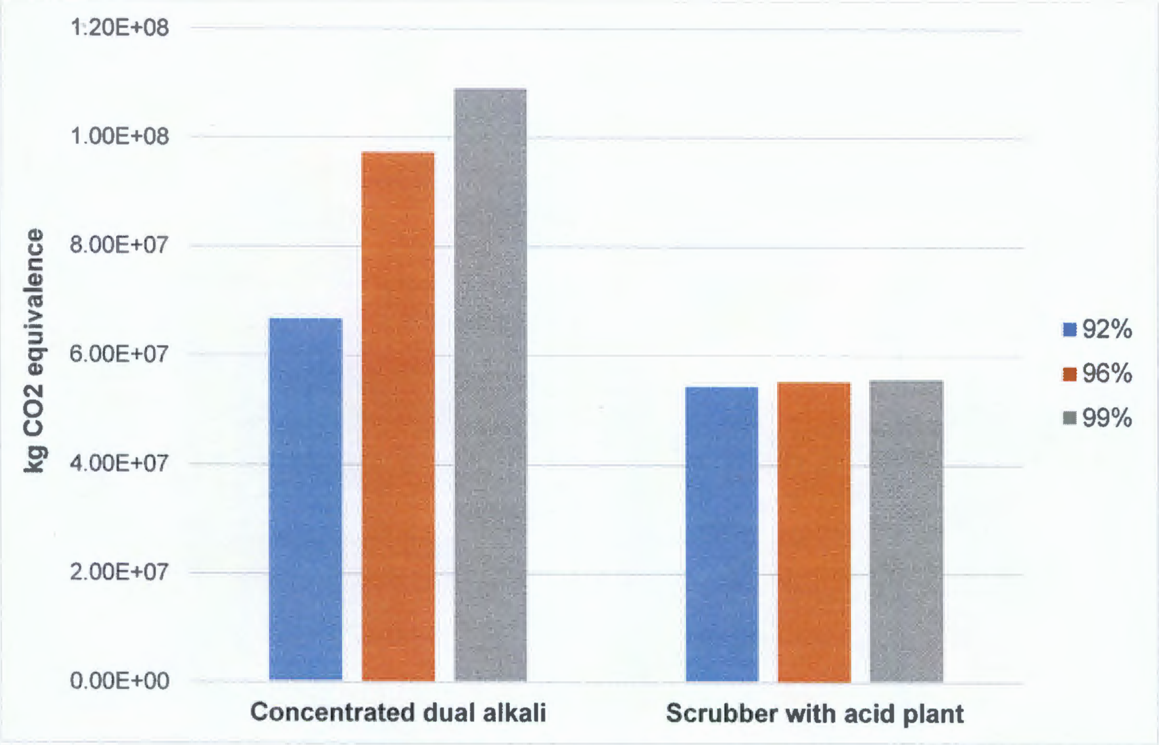


Figure 4-19: Variation of global warming potential with change in recovery

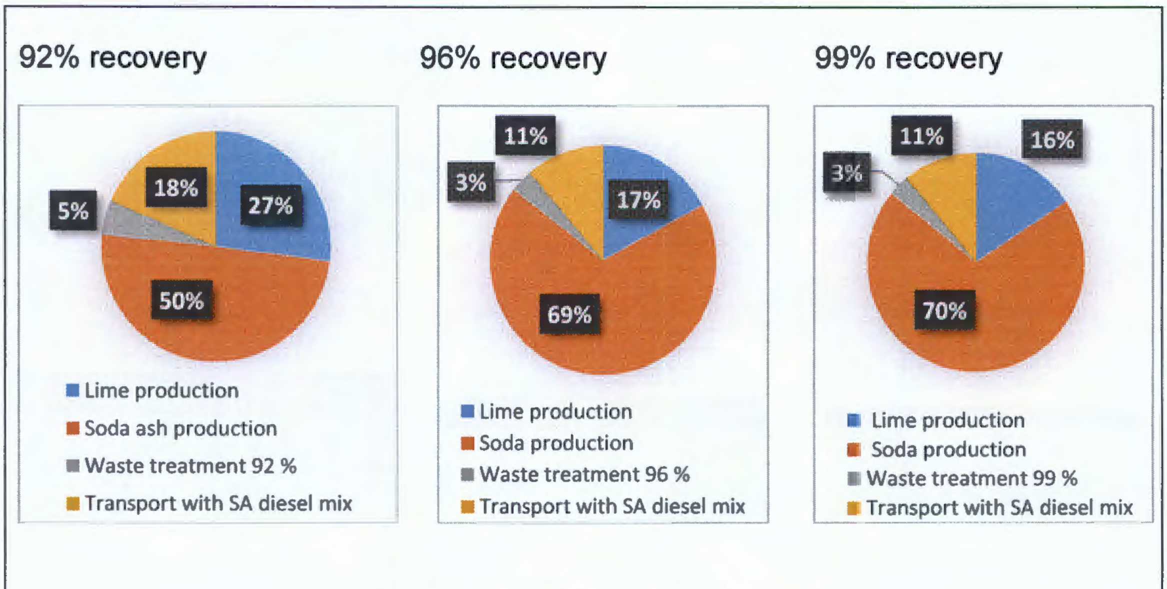
The global warming potential increases with increasing recovery for both the concentrated dual alkali scrubber and the scrubber with acid plant, however, the rates of increase are significantly different. Figure 4-19 reveals that the potential increases by 46% and 12% as you move from 92% to 96% and 96% to 99% respectively for the concentrated dual alkali scrubber. This can be attributed to the impacts associated with soda ash and lime production which increase significantly with increasing recovery compared to the slow increase in transportation impacts which is directly related to the CaSOx formed.

It should be noted that for the concentrated dual alkali process, when the SO_2 reacts with the dual alkali, the reactions in addition to forming CaSOx also release 0.5 mol of CO_2 per mol of SO_2 removed. This increases the total amount of CO_2 that is released by the dual alkali option.

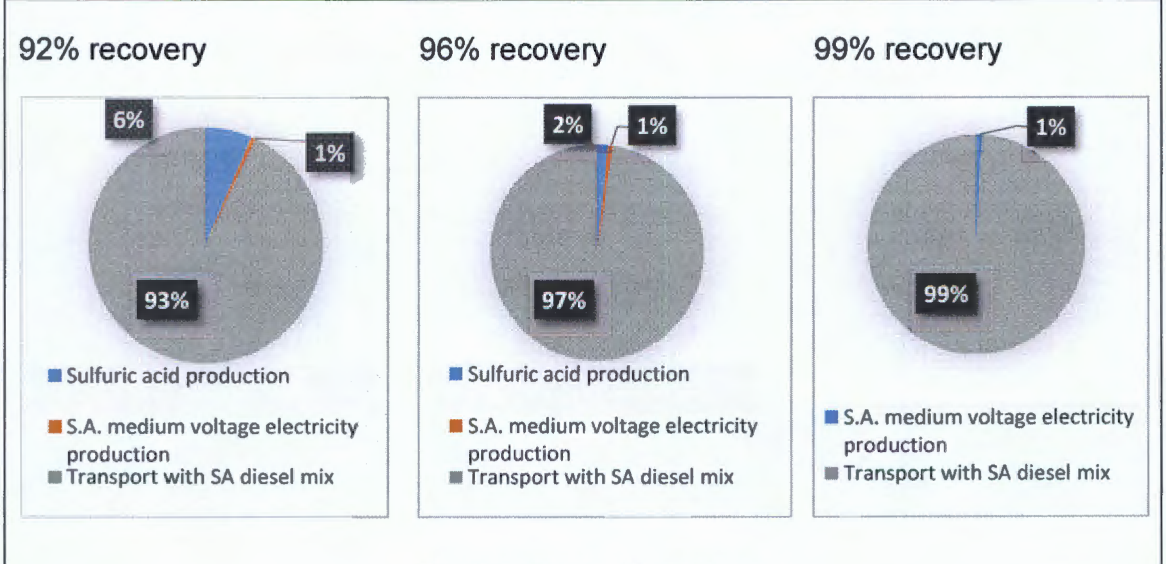
The scrubber and acid plant see a minor increase in the global warming potential of 1.8% and 0.3% as recovery increases from 92% to 96% and 96% to 99% respectively. This is attributed to the slight increase in fuel requirements for the transportation of the acid that is produced. Though it was revealed in Section 4.1 that there is an exponential increase in the amount of energy required with increasing recovery, it can be seen from Figure 4-16 that the energy requirements only account for 2% of the impacts. Therefore the exponential increase is overpowered by the changes in transportation requirements.

4.2.5 Human toxicity

The human toxicity potential reflects the potential harm of a unit of chemical released into the environment. Figure 4-20 shows the relative unit contribution to human toxicity for both the concentrated dual alkali scrubber and the scrubber with acid plant at the different recoveries.



a) Concentrated dual alkali scrubber



b) Scrubber with acid plant

Figure 4-20: Unit process contributions to human toxicity for a) the concentrated dual alkali scrubber and b) the scrubber with acid plant

Figure 4-20 shows that the production of soda ash and lime contributes the most to the human toxicity impacts of the concentrated dual alkali scrubber with contributions of 50% and 27% respectively at a recovery of 92%. It can however be noted that there is an increase in the contribution of the soda ash production to the impacts and a decrease in the contribution of lime production impacts. The transportation of acid produced contributes 93% of the total human toxicity effects associated with the scrubber and acid plant at a recovery of 92%. As the recovery increases the transportation with SA diesel mix become the dominant contributor.

The human toxicity impact category describes the fate, exposure and effects of chemical on human beings (i.e. substances present in input systems that have toxic effects on human beings) Figure 4-21 and Figure 4-22 present the process contributions of the input systems containing the substances with toxic effects for the two technology options.

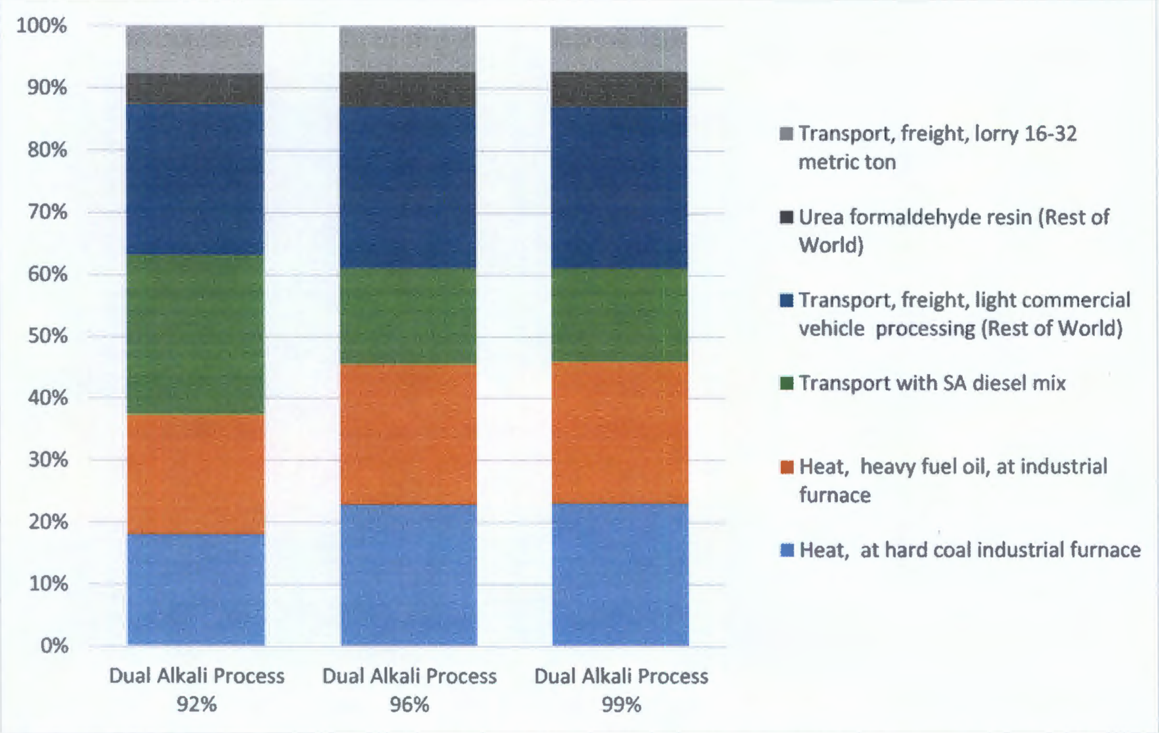


Figure 4-21: Process contribution (% of total) of inventory elements to human toxicity for the concentrated dual alkali scrubber

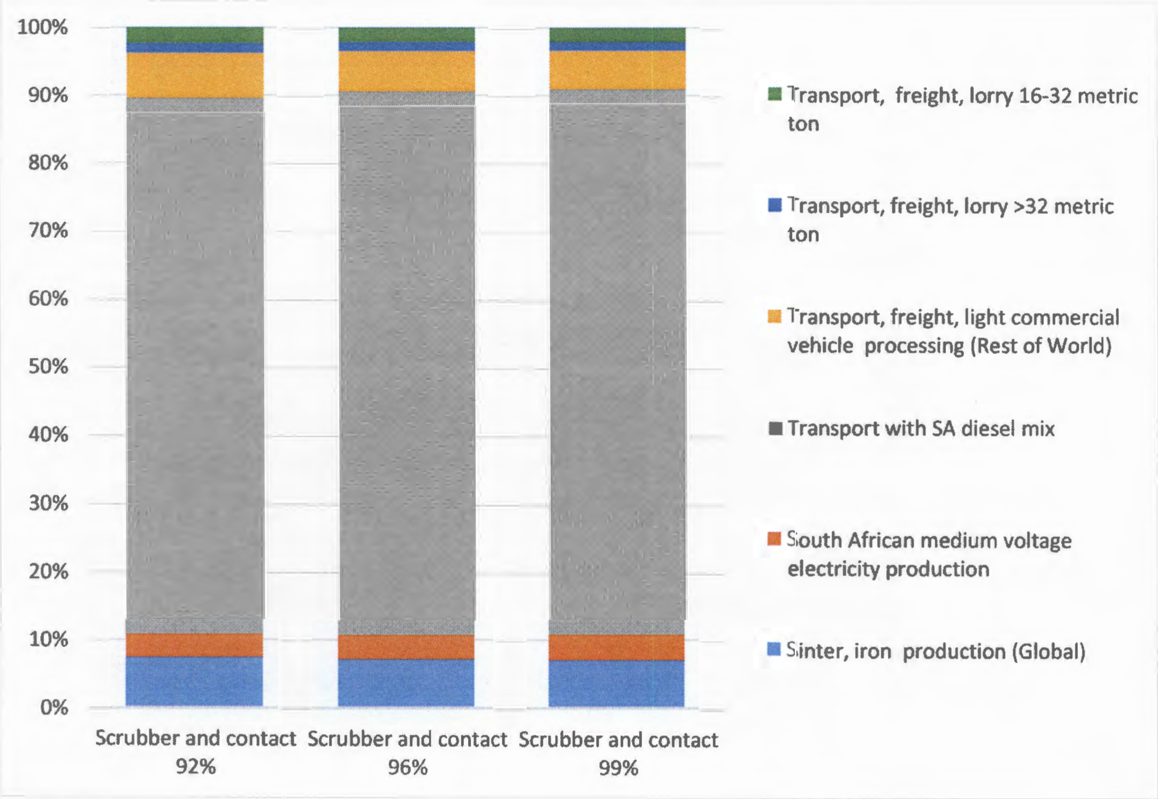


Figure 4-22: Process contribution (% of total) of inventory elements to human toxicity for the scrubber with acid plant

As can be seen from Figure 4-21 and Figure 4-22 the major process contributions are from heating and transportation for the concentrated dual alkali process. The scrubber and acid plant also see some contribution from the electricity production in addition to transportation and heating.

The effect of the different recoveries on human toxicity was also investigated and the variation is shown in Figure 4-23. The impact analysis conducted provided results for both the cancer causing and non-cancer causing human toxicity effects. For this study only the cancer causing effects were considered as the non-cancer causing effects were very negligible.

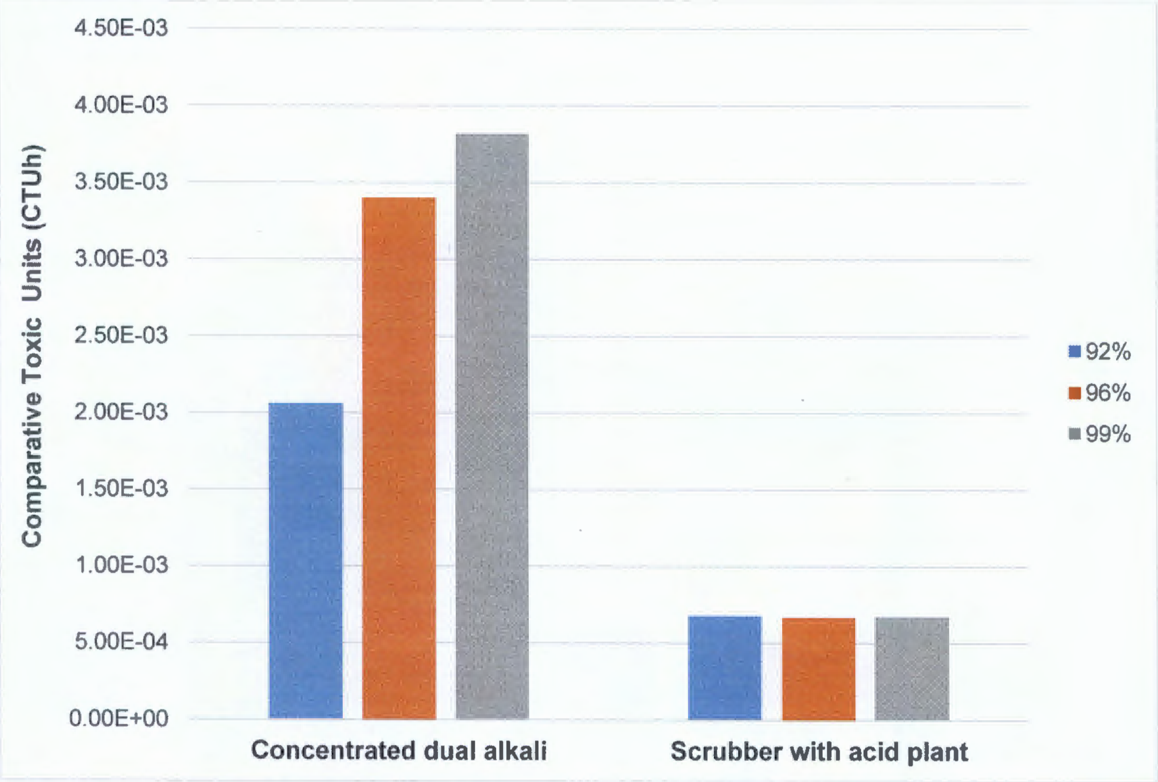


Figure 4-23: Human toxicity (cancer causing) impacts for the two technology options at different recoveries

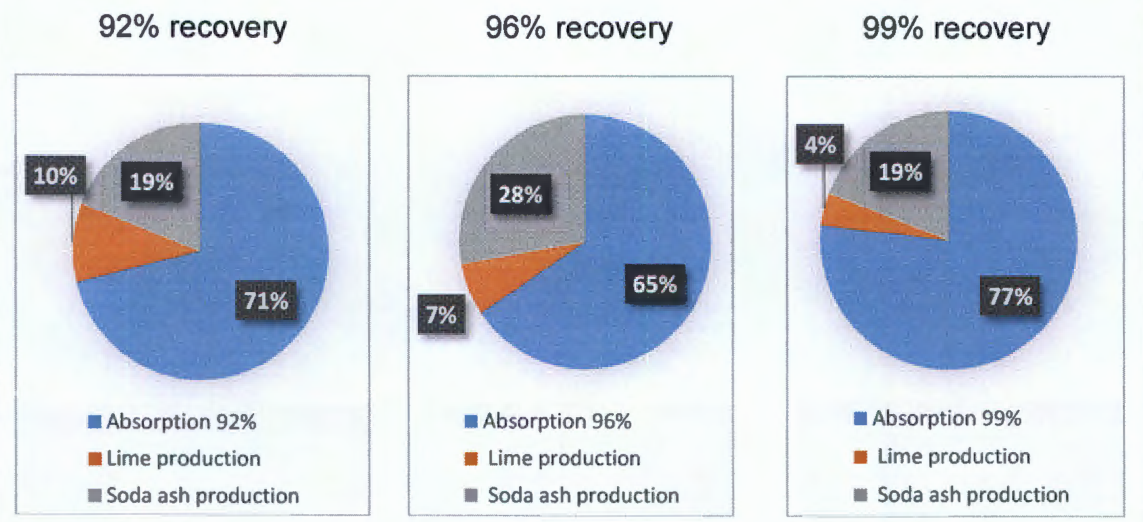
The concentrated dual alkali scrubber shows an increase in the human toxicity impact with increasing recovery, with the increase from 96% to 99% being 3.2 times more than that from 92% to 99%. This is attributed to the increase in amounts of soda ash and lime that are required to scrub off the SO_2 in the process.

As can be seen from Figure 4-23 the comparative toxic units slightly decrease with increasing recovery for the scrubber with acid plant option. This is attributed to the reduction in the amount of acid required for the systems expansion with increasing recovery which according to Figure 4-20 contributes 6% of the total contributions in the 92% case hence a decrease in acid formed will result in the slight decrease in the human toxicity impacts.

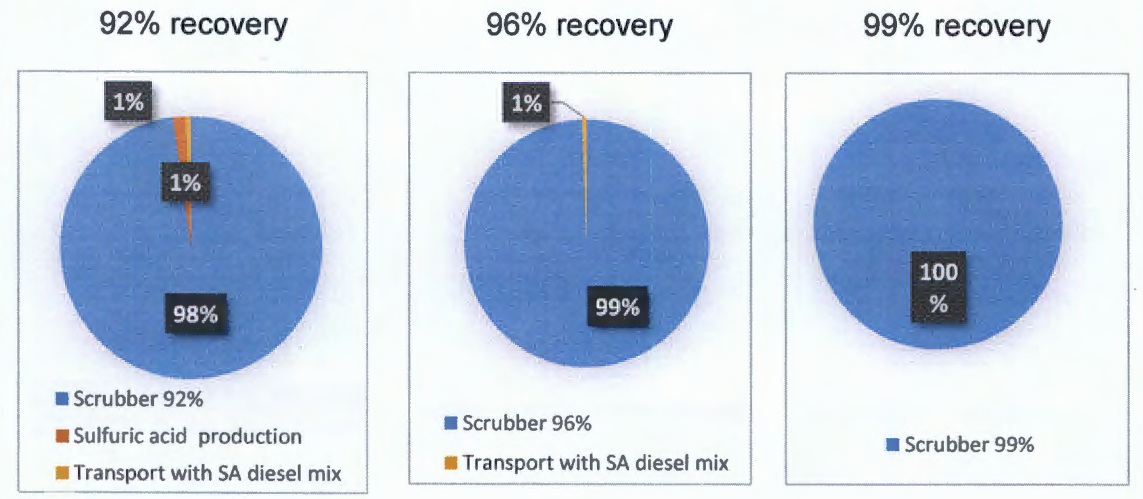
4.2.6 Water Depletion

The scrubbing processes for both technology options make use of water as the scrubbing agent and hence it was relevant to look at how the consumption would vary with changes in recovery.

Figure 4-24 shows the relative unit contribution to water depletion for both the concentrated dual alkali scrubber and the scrubber with acid plant at the different recoveries.



a) Concentrated dual alkali scrubber



b) Scrubber with acid plant

Figure 4-24: Unit process contributions to water depletion for a) the concentrated dual alkali scrubber and b) the scrubber with acid plant

Figure 4-24 shows that that dominant contributor to water depletion for the concentrated dual alkali process is the actual scrubbing process (foreground system) contributing at least 65% to the impact category. The other significant contributions are from the production of soda ash and lime. For the scrubber and acid plant the water used for the scrubbing process dominates this impact category with a 98% contribution for the 92% recovery and as the recovery increases to 99% the contribution of the foreground system increases to 100%. Sulphuric acid production for systems expansion and transport making a contribution of 2% at a recovery of 92%.

As can be seen from Figure 4-25 and Figure 4-26 the foreground process systems are mainly responsible for water depletion, with background process contributions being more significant in the concentrated dual alkali scrubber.

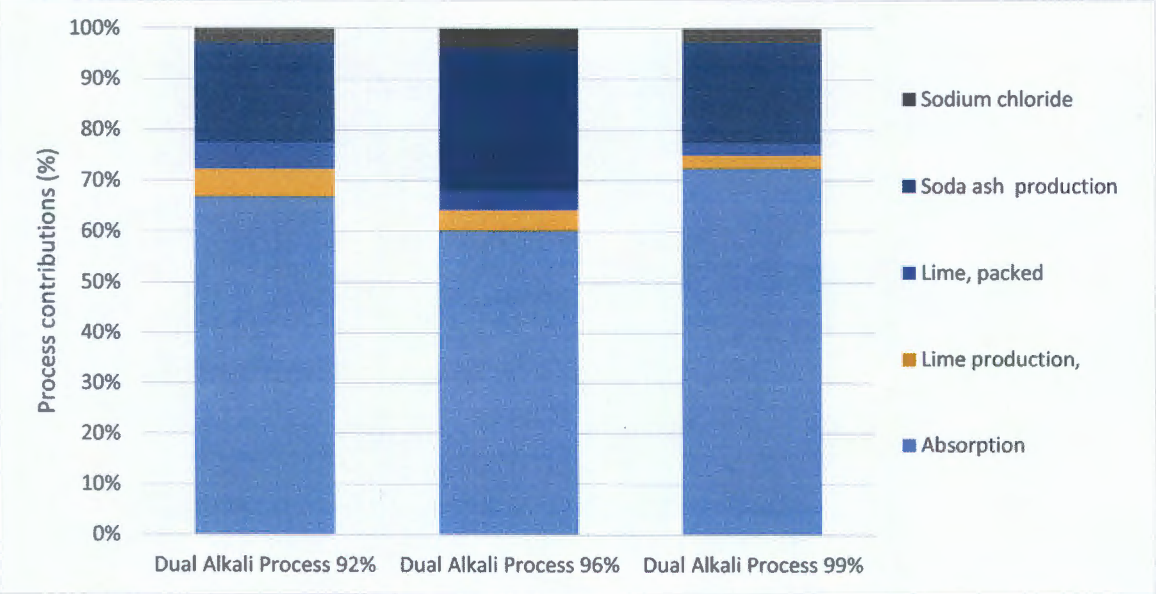


Figure 4-25: Process contribution (% of total) of inventory elements to water depletion for the concentrated dual alkali scrubber

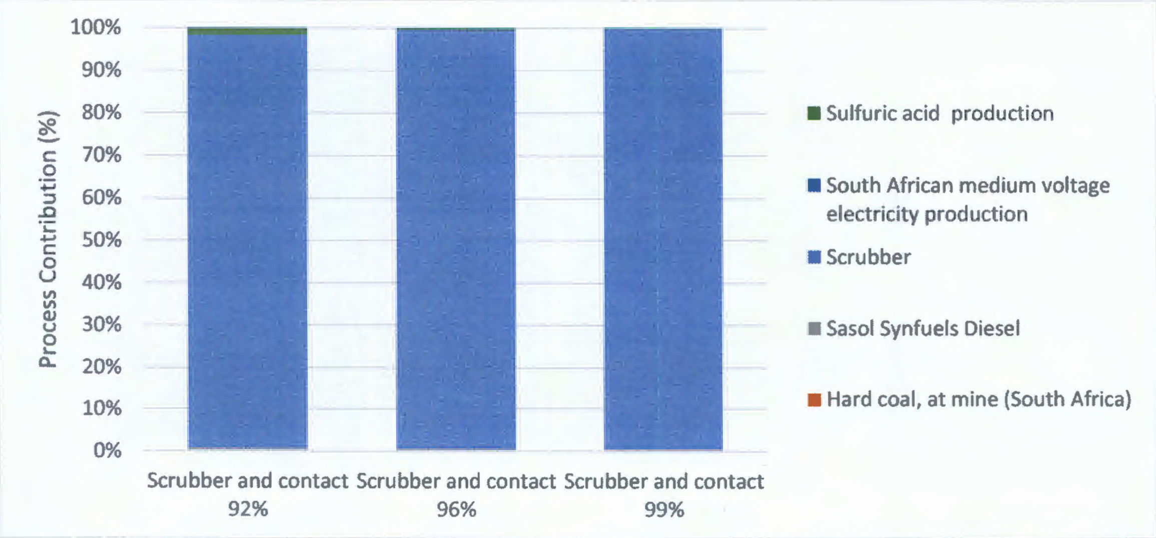


Figure 4-26: Process contribution (% of total) of inventory elements to water depletion for the scrubber with acid plant

The scrubber and acid plant which sees the impacts of the actual scrubbing process becoming more dominant with increasing recovery.

The results obtained from the analysis are presented in Figure 4-27.

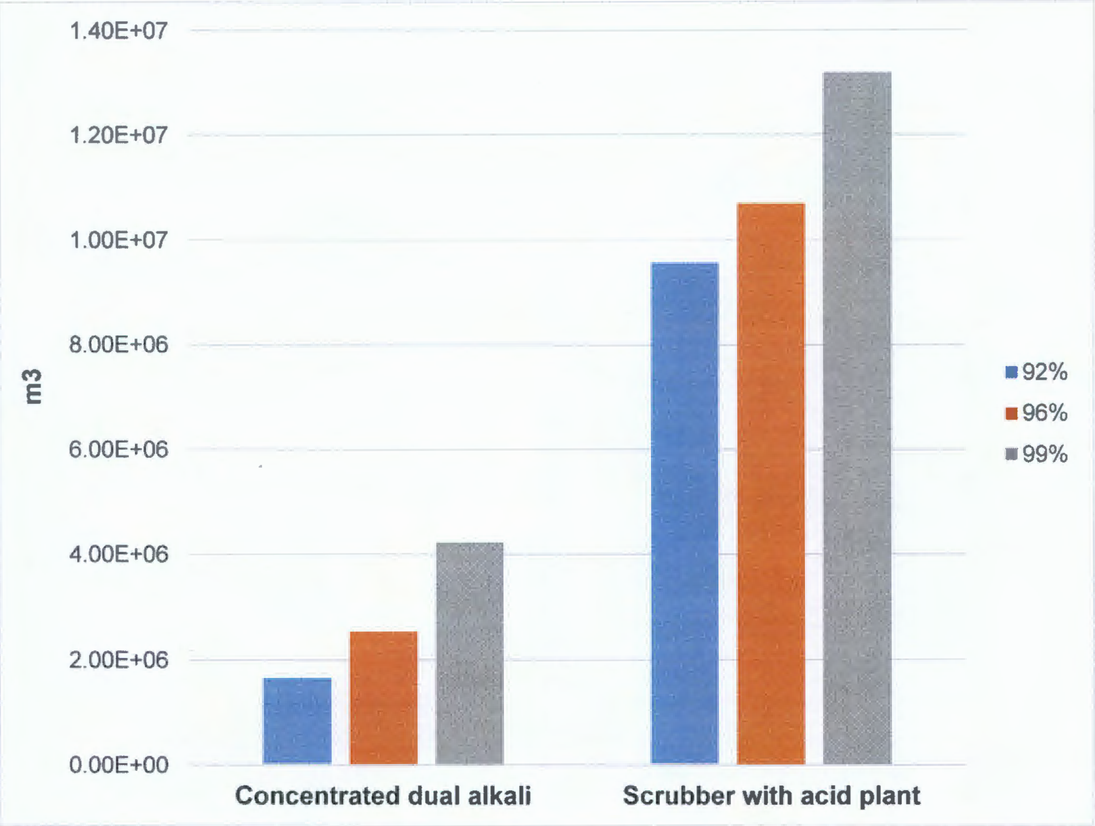


Figure 4-27: Water depletion for the two technology options at different recoveries

From Figure 4-27 it is evident that the amount of water required for both technology options increases with an increase in the recovery. This is expected as higher recoveries are associated with higher solvent quantities in scrubbing processes.

It can however be noticed that the scrubber with acid plant requires more water compared to the concentrated dual alkali plant. This is primarily because the scrubber with acid plant only relies on process water as the scrubbing agent whereas the concentrated dual alkali scrubber has water and hydrated sodium carbonate being used to scrub the SO_2 off. Water treatment and recycling were not modelled in the process. Therefore the amounts for the foreground system are purely indicative of once-through processes. Process contributions are from both foreground and background processes as presented in Figure 4-24.

4.2.7 Technology option comparison

Having explored how the environmental impacts vary with change in recovery, it was thus found that for a company that is producing a waste product, the environmentally ideal operation point would be a recovery that just allows them to meet the legal limits, which in this case would be 92 %. In the case where the company produces a useful by-product (H_2SO_4) it was found that with the lowest life cycle impacts in most categories would occur in the 99% recovery option. Table 4-5 provides a summary of the absolute scores of the two technology options.

Systems expansion was applied in the case of the dual alkali case to make it comparable to the scrubber with acid plant.

Table 4-5: Absolute scores for the two technology choices with systems expansion for the concentrated dual alkali scrubber

Item	Unit	Technology option		Scale
		Concentrated dual alkali scrubber	Scrubber with acid plant	
Abiotic resource depletion	kg Sb eq	510	41.7	Global
Fossil fuel depletion	kg oil eq	2.58E+07	1.18E+06	Global
Global warming	kg CO_2 eq	8.08E+07	5.56E+07	Global
Acidification	kg SO_2 eq	8.79E+06	1.18E+06	Regional
Human Toxicity	CTUh/kg	3.06E-03	6.71E-04	Regional
Water Depletion	m^3	5.04E+06	1.32E+07	Local

The LCIA results of this comparison between the two scenarios are presented in Figure 4-28.

Figure 4-28 shows the percentage of the impact as a function of the impact category considered. A 100% score in this case means that the specific process has the highest impact and the other score is calculated relative to the highest score. This helps to give an overall idea of the performance of the two technology options.

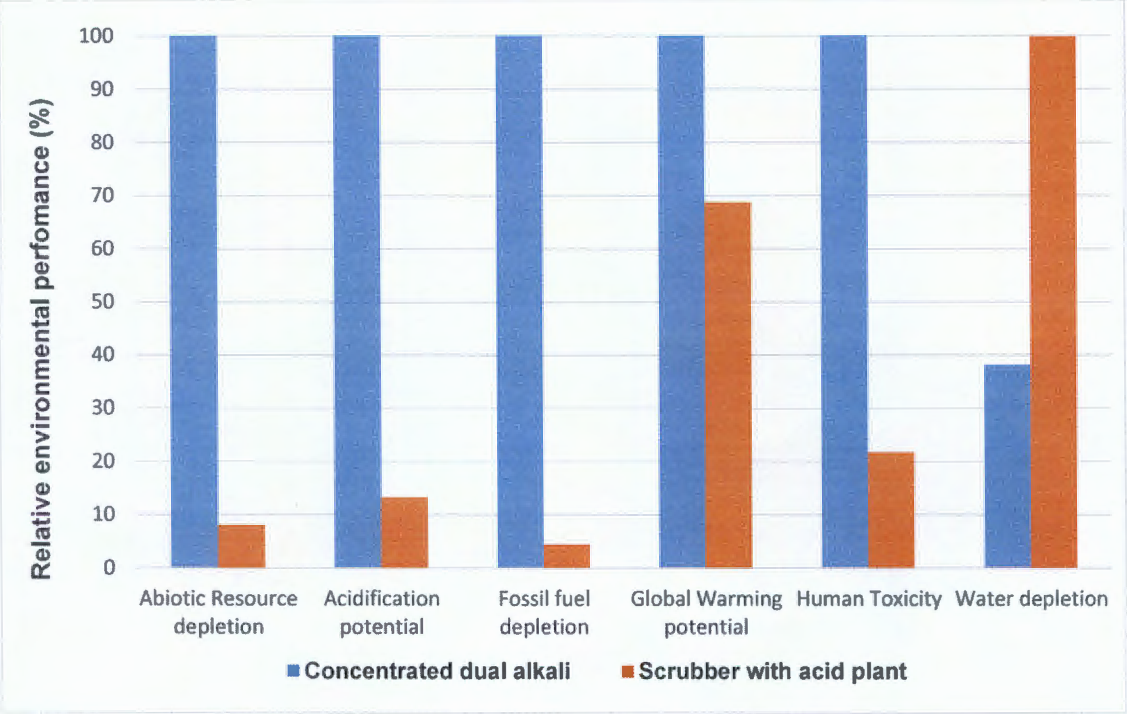


Figure 4-28: Relative environmental impact for the two technology options with systems expansion for the concentrated dual alkali scrubber

It can be seen from Table 4-5 and Figure 4-28 that overall the scrubber with acid plant performs better than the concentrated dual alkali scrubber, by 1 to 2 orders of magnitude for most indicators. Comparison between the two technologies without employing the system expansion is presented in Table 4-6 and Figure 4-29.

Table 4-6: Absolute scores for the two technology choices without systems expansion for the concentrated dual alkali scrubber

Item	Unit	Technology option		Scale
		Concentrated dual alkali scrubber	Scrubber with acid plant	
Abiotic resource depletion	kg Sb eq	127	41.7	Global
Fossil fuel depletion	kg oil eq	5.46E+06	1.18E+06	Global
Global warming	kg CO_2 eq	5.56E+07	5.56E+07	Global
Acidification	kg SO_2 eq	7.89E+06	1.18E+06	Regional
Human Toxicity	CTUh/kg	2.06E-03	6.71E-04	Regional
Water Depletion	m^3	1.65E+06	1.32E+07	Local

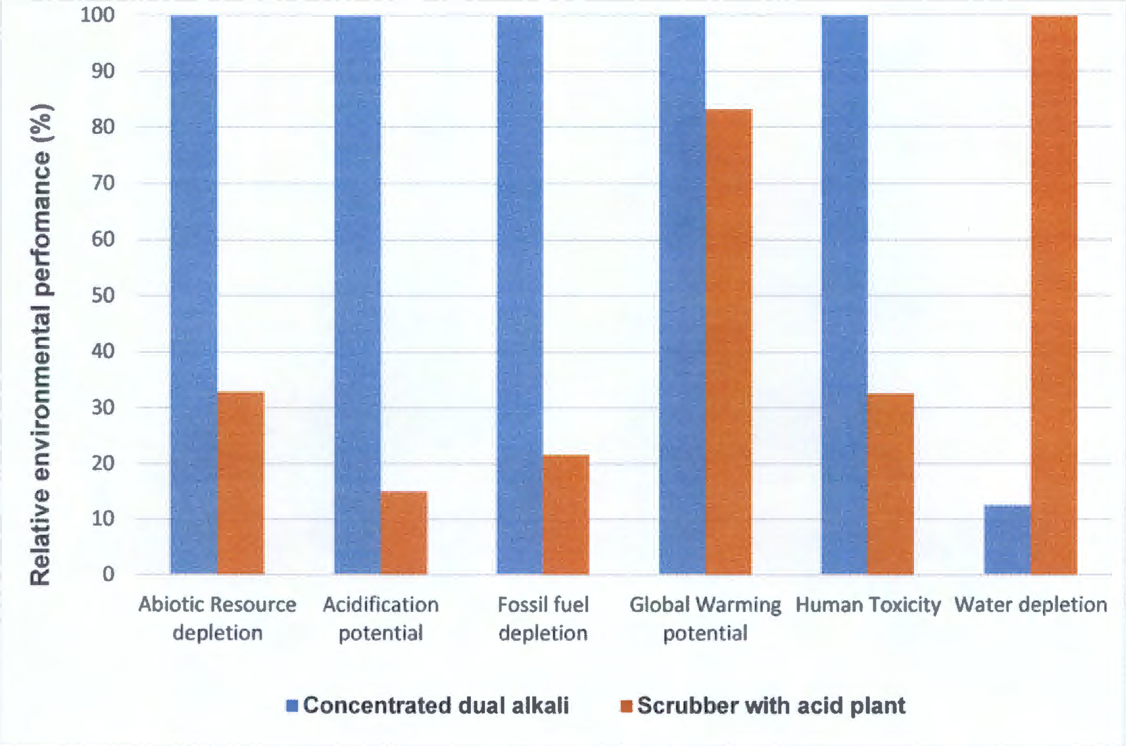


Figure 4-29: Relative environmental impact for the two technology options without systems expansion for the concentrated dual alkali scrubber

In both cases it is evident that in 5 out of the 6 impact categories that were analysed, the acid plant showed less impact with the only exception being the water depletion in which the acid plant proved to require a significantly larger quantity compared to the dual alkali.

4.3 Summary

This chapter presented the results that were obtained from both the foreground modelling and the LCIA of the key variables. The energy requirements are purely indicative of pumping energy requirements around the scrubbers. The foreground modelling showed that the scrubber with acid plant option was more energy intensive compared to the concentrated dual alkali scrubber. This was attributed to the fact that the scrubber with acid plant required more solvent in terms of volume which increased the pumping energy requirements.

Background process modelling dominated the abiotic resource depletion impacts for the concentrated dual alkali scrubber whereas the major contributor in the scrubber with acid plant case was the transportation impacts of the acid that was produced. The impacts increased with increasing recovery for the dual alkali case but decreased with

increasing recovery for the scrubber and acid plant. This slight decrease in the scrubber with acid plant option was attributed to the decrease in the additional amount of acid required for systems expansion for the different recoveries.

Fossil fuel depletion mimicked the abiotic depletion trends in which the background processes dominated this impact category. This was expected as both fossil fuel depletion and abiotic resource depletion are input indicators. The impacts increased with increasing recovery for the dual alkali case but decreased with increasing recovery for the scrubber and acid plant.

The acidification potential decreased with increasing recovery for both technology options. The major contributor to this impact category was the actual scrubbing process in both cases. Therefore it was expected that the impacts would decrease with increasing recovery as the amount of SO_2 being released was also decreasing with increasing recovery.

The global warming potential increased with increasing recovery for both the concentrated dual alkali scrubber and the scrubber with acid plant. The major contributors to this category were transportation and the scrubbing process in both technology options. The larger quantities for the concentrated dual alkali process were attributed to the extra CO_2 that is produced during CaSOx formation and the increase in the soda ash and lime requirements which had significant contributions to this impact category.

The concentrated dual alkali scrubber shows an increase in the human toxicity impact with increasing recovery, whereas the impacts decrease with increasing recovery for the scrubber with acid plant. This was also attributed to the contributions of the background processes that were modelled in both cases.

The water requirements for the actual scrubbing process dominated the water depletion impact category. The production of soda ash and lime also had significant contributions to this impact category in the concentrated dual alkali option. The high quantities for scrubber with acid plant were directly related to the foreground system as it required large amounts of water since it was the only scrubbing agent.

The conclusions that can be drawn based on this analysis are:

- The LCA shows that the scrubber with acid plant choice mostly has significantly lower environmental impacts.
- The magnitude of impacts increases with increasing recovery in the concentrated dual alkali case with the only exception being the acidification potential.
- The magnitude of impacts decreases with increasing recovery for the acid plant with the exceptions being the amount of water used and the global warming potential.

CHAPTER 5. INTERVIEW FINDINGS

Interviews were carried out with design experts to determine whether they would deem the incorporation of life cycle assessments into their design decision making process useful. The interviews were also used to get deeper insights on how decisions are made in the minerals industry and what is involved in the process of making design decisions. Results are presented and discussed in this chapter, with the detailed interview transcripts presented in Appendix D. The chapter starts by giving an overview of the people interviewed as way of setting context before presenting the actual interview findings.

5.1 Overview

This section gives an overview of the people who were interviewed and provides a brief summary of each interview.

5.1.1 Interviewees

Table 5-1 positions the participants in the mining industry and how they were involved in the decision making processes of SO_2 abatement installations which were put in place by some of the mining companies operating in South Africa's North West province.

Table 5-1: Overview of people interviewed

Participant(s)	Type of Company	Position
ME-SC	Minerals processing and Metallurgical Engineering company	Specialist Consultant
PC1-VP & PC1-LM	Platinum Company 1	Vice President of the Company and lead metallurgist
CF-C	Consulting Firm	Consultant
PC2-PL1 & PC2-PL2	Platinum Company 2	Process Leads at a Platinum mining company
PC3-TS	Platinum Company 3	Technical Superintendent
ECC-GC	Engineering Consulting Company	Consultant for gas cleaning processes
PC4-TS	Platinum Company 4	Lead technical Services

5.1.2 Interview summaries

Brief summaries of the design experts' interviews are given in this section as way of supplying more detail on what their backgrounds are, whether or not they have been involved in flue gas treatment projects and motivation as to why they were selected.

ME-SC

ME-SE is a specialist consultant who works for a Minerals processing and Metallurgical Engineering company. He has published multiple reports and a paper detailing platinum smelting operations in the South African PGM industry. The motivation for interviewing him was to get a deeper understanding of how the SO_2 abatement story evolved and also to get insights from him pertaining to the technologies that are currently in use, based on his numerous years of research within the minerals industry. The interview with him progressed in a very interactive manner and ME-SC answered all questions presented to him in great detail.

CF-C

CF-C is an independent consultant who has worked for one of the mining companies that implemented one of the technologies. He is currently consulting within the Rustenburg region and interacts a lot with the mining companies. The motivation to interviewing him was that as a person who had once been on the inside and was now working independently he would be able to give quite an interesting perspective of the adopted processes, which he did. The interview was quite interactive and at the end he also gave some suggestions which he thought would make the research better.

PC4-TS

PC4-TS works as a lead technical services person for one of the North West Platinum mines. Their mine has a similar process technology to one of the cases that was being investigated. He was able to give a different perspective as to why they had chosen that specific technology for their company. Most of the reasons he gave were very similar to the ones given by one of the people whose company had a similar technology. The interview with him was quite interesting in that for all the questions he was asked he kept stressing that as long as there is no value add then it's not worth considering.

ECC-GC

ECC-GC is a consultant at an engineering company and specialises in gas cleaning processes. The motivation behind interviewing him was to understand how they as a consulting company would help a client in choosing between technologies and also how they viewed the decision making process within the mining industry, as all the people interviewed mentioned that consultants actually played an important role within the decision making context. The interview was quite interactive and very informative.

PC3-TS

PC3-TS is a technical superintendent at one of the platinum mines in the North West. She has published articles on the operations of one of the technology options that was being investigated, hence the motivation to interview her. Interviewing her also allowed the researcher to do a plant visit which was good in terms of relating theoretical knowledge to practise. What was interesting about interviewing PC3-TS was that she was very open about why their company had chosen a similar technology to the one that was being studied. The interview session was also very interactive and helped clarify some issues that helped with the conceptual design.

PC1-VP & PC1-LM

PC1-VP & PC1-LM work for a junior mining company that is still being set up. They both have experience in working within the minerals industry. PC1-VP is the vice president for the company and PC1-LM is the lead metallurgist. The motivation behind interviewing them was to get insights on decision making from a new and junior company point of view. Their inputs interestingly were a bit different from the majors (senior companies) perspectives as they were placing emphasis on sustainable operations throughout the interview. The interview with both of them was strongly interactive.

PC2-PL1 & PC2-PL2[4]

PC2-PL1 and PC2-PL2 are part of the processing team at one of the major mining companies that has a similar operation to one of the technology options being studied. The motivation behind interviewing them was twofold. The first one was to get some input on the conceptual model that had been developed and get acquainted with the practical side of the process which would also help in justifying some of the assumptions that were made. Secondly, since PC2-PL1 has been leading the process team and contributed in a publication that one of the models was based on, the researcher felt that he would give important insights as to why their company chose the specific technology. Most of the responses were obtained from PC2-PL1, whilst PC2-PL2 only chipped in a few times just to add onto what PC2-PL1 was saying. What was interesting about these two in particular was that, because one of the cases that was being analysed, made them feel as though it was their company that was under scrutiny. This made the interview a bit different to the others as they often weren't that specific in their responses and at times they just preferred not to respond to some of the questions.

5.2 Design decision making

The following sub-sections present a synthesis of the findings from the interviews which were carried out. The sub headings have been grouped based on the questions that were asked.

5.2.1 Design decision making in mining companies

As a starting point, interviewees were asked to provide details on how design decisions were made in mining companies. All participants interviewed were in agreement that decision making within the mining industry is very complex as it involves many people from different departments within the mining operation, all of whom are involved at different stages of the process together with any interested or affected parties.

Team agreement in decision-making was one element identified. PC2-PL1 pointed out that in the SO_2 case, the team would usually involve the technical lead on the project,

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[4] Transcript not in appendix as requested by participants

the production manager, the automation people, the entire smelter team and the capital project team. In order for a decision to be made there would be need for unanimous agreement between all parties involved.

> *"Everybody makes the call. It's a shared thing and everybody likes to think that their part is the most important but unless they are all 'yeses' it doesn't happen."* **ME-SC**

The process would start off with metallurgical engineers identifying the need for either a new technology to be implemented or a change that needs to happen. They would be the ones who would be in charge of ultimately steering the whole process. However because they would not have enough manpower and expertise to do everything that need to be done they would then need to get people from other departments to consult with.

The engineers would first narrow down their options based on the quality of gas they would be treating and what they expect to get from the process (waste or by-product). This process alone has the potential to narrow down the options available from as many as 20 to 4 options.

> *"In our case, a single contact acid plant would not work due to the strength of the supply gas that we have"* **PC2-PL1**

Once they have narrowed down their options they would then consult with the companies supplying the different technologies to get detailed designs.

According to PC4-TS, a discipline such as the Human Resources would become part of the process and would have the responsibility of organising public participation meeting with interested and affected parties. In order to ensure compliance in the case of decision driven by regulatory measures, the legal department would also be very visible.

The project capital team would then look at the capital requirements of the projects together with the operating costs that would be associated with the project. According to PC4-TS they are then able to quantify the financial aspect of the project such as its Net Present Value and use this to evaluate the preferred option on a cost basis.

5.2.2 The drivers retrofitting, using new technologies

With regards to the retrofitting of new technologies in the minerals industry the respondents felt that there were three major drivers: not being able to meet design specifications, introduction of new regulatory limits and the surfacing of new and improved technologies.

a) Not meeting design specifications

One of the drivers to retrofitting was identified to be the case in which a new installation fails to meet the design specification. ME-SC identified the case in which a company had designed a plant based on a pilot scale, and then once the plant had been set up, it was not meeting the design specifications as expected. CF-C pointed out that in such cases companies would then have to go through redesigns; he used the furnace of one company as an example. In both cases the companies had to consider retrofitting their plant designs.

b) Regulatory limits

The other major driver that was pointed out was the introduction of new regulatory limits. In such instances, new regulatory limits are set and companies have to look for ways in which they can either redesign or retrofit to meet the new standards. One would classify this as a driver that is not negotiable and that companies are supposed to act to it, however, it became apparent that there were a few loop holes to it. ME-SC revealed that there were cases in which companies that were not in good financial standing were not necessarily given an exemption but rather an extension to the time in which they would be expected to adhere to the new regulations.

c) Improved technology

The surfacing of new technologies was also stated as major driver. Since all mining companies are "businesses", they need to ensure that they remain competitive. CF-C's opinion was that they always have to be on the lookout for new technologies that they can go for to improve their efficiencies which means increased profits and also to ensure that their cost per tonne remains competitive.

The SO_2 abatement case that was studied would then fall into the category where change is driven by regulatory limits. However, in that particular case not all companies retrofitted new technologies. According to PC4-TS there were some companies that just opted to increase the stack height and all this meant was that they would reduce the ground level concentration by achieving greater dilution, but they still emitted the same amount of SO_2. This shows that multiple solutions may be possible – introducing complexity to the design decision-making process

5.2.3 Choosing between two technologies that are meant to satisfy the same function

Interviewees were then asked how they would choose between two technologies that were meant to satisfy the same function. It was interesting to note that though there were different drivers to technology choice selection, they were all steering the decision to be based on value. However they did mention that for them to decide on the best option they had to look at the option that scored the most in their decision matrix which includes some of the factors discussed below:

a) Quality of gas to be treated

The interviews revealed that in the case of the SO_2 abatement case, the major factor that would help determine the technology choices to consider would be the quality of gas to be treated. This is because not all desulphurisation processes can be applied to the gas streams of different SO_2 strength. For example if you have a low strength SO_2 feed then you do not really have the luxury of making an acid as you would not meet the required acid strength that is of saleable quality. This would have serious cost implications for the company as generally setting up an acid plant is expensive and hence you would probably settle for the dual alkali scrubber.

b) Possibility of making a by-product

Once you have figured out the technology options that are available for your specific gas strength you then move on to consider the possibility of making a by-product. Ideally companies would want to go with the process in which they produce a by-product rather than a waste but it's not that simple. ME-SC puts forward the fact that not only is it about having the right gas quality that allows you to make a by-product but you need the right quantities. This then leads to the evaluation of the economics of the process

c) Economics of the process

All the participants agreed that the economics of the process played a huge role in deciding on which technology option a company would go for. So once the design team is left with 2 or 3 options they would then do a cost benefit analysis to determine the technology option that would make more financial sense. This would also be greatly driven by the company's financial standing.

In the case of the SO_2 abatement technologies for example, a company might see a lot of benefit in going with the acid plant route but if they cannot afford it and do not have enough investments to go through with it then they would have no option other than to go with the concentrated dual alkali scrubber. The acid plant option is seen to have a higher CAPEX and lower OPEX compared to the dual alkali scrubber. So a company would then have to decide on whether or not they are going to go with the higher CAPEX or higher OPEX.

The more senior companies that have strong financial positions often go with the high CAPEX low OPEX options. PC3-TS pointed out that in their case they chose their specific technology option because they wanted higher efficiencies for their acid plant. She points out that at the point in which they opted for the acid plant option it was very Capital intensive but with the continuous change in regulation specifically the ones coming through in 2020, it means that their company doesn't have to worry about retrofitting or introducing new technologies. So in the long run they are at an advantage as most companies that opted for the lower CAPEX routes are now faced with the challenge of improving their designs.

When asked about the notion of companies designing for future regulatory limits, ECC-GC felt that considering the current economic climate they would not advise a company to go down that route. They would rather advise them to focus on the current limits especially if the option that is going to meet future regulations produces a by-product in which little or no money can be recovered such as the acid the companies are producing. This is because companies do not know what the next limit is going to be so one would rather have a plant that has been designed to be expandable. In that way you meet the current limits but also know that if the limits are to change you can add maybe a tail gas scrubber in the case of an SO_2 abatement chase.

d) Risk involved

PC1-VP & PC1-LM pointed out that in the case where the technology is completely new, it is very difficult especially for junior companies to implement it. There is a lot of risk that is involved in installing a completely new technology and a company should not be willing to take the risk of setting up something that has no precedence at all. This is because there is the possibility of the technology failing to work completely so the investors or the banks where the funds are meant to be obtained for this are usually not interested in such risky investments.

So it is most likely that when new technologies that are assumed to have a very good environmental footprint are realised smaller companies would wait for the majors to try it out as they usually have more capacity to take on risks compared to small companies. Once they have proven to be successful then they can go ahead and try them out.

This shows that the financial stability of the company is a major contributor to what the company can and cannot do. Hence in most junior companies though being aware of newer and better technologies they might just end up settling for the option that lies within their budgets and ones in which their investors are willing to go with.

e) Complexity and skill set

An interesting point that was brought up by CF-C was that one thing that often stops some efficient technologies from being adopted is the availability of the skillset and the complexity of the process as a whole. The one thing that companies look at is the availability of skill set. In the event that you install a specific technology option you need to be sure that you have people within your region at least who are qualified to operate the system and also ensure that it is not too complex. This was echoed by PC3-TS who pointed out that you want to buy a technology from a place that is close enough such that in cases where the technology fails to work it is easy for you to get people to come and fix it because if the people selling the technology are on the other end of the world and something goes wrong it will cost the company a lot of money to stop operations while waiting for the people to come and sort it out. So most of the time companies end up going with local technologies.

5.2.4 Incorporating environmental concerns and choosing an environmental assessment method in the design phase

The design experts were then asked how environmental concerns were incorporated during the design phase and how they would decide on the environmental assessment that would be employed.

It was interesting to note that some of the experts felt that the EIA encompassed all the environmental concerns that would be related to specific designs.

> *"We wouldn't have any concerns because we would do an EIA which would involve public participation with interested and affected parties so that you would have all their opinions/perspectives/concerns"* ***PC4-TS***

However, some interviewees (PC3-TS and PC1-VP) expressed their view that companies do not do much to incorporate environmental concerns during the design phase. Often they just settle for the EIA because that is required by regulation. However PC1-VP felt that what has to happen is that companies should prescribe their own environmental assessment tools as EIA encourages the "download thinking" where companies just pick up the things that work and do an EIA because of its regulatory nature. Similar sentiments were echoed by PC4-TS who pointed out that the culture and ethical characteristics of a company also played a huge role in how far they would go to ensure that the technology option they choose was environmentally friendly and would not shift burdens within the process.

5.2.5 Dealing with trade-offs in cases where design is driven by regulatory standards

The design experts were also asked how trade-offs were dealt with in cases where design decision were driven by regulatory demands. Of particular interest was how they would decide on the extent to which they would push the recoveries once the regulatory limits had been reached. Again in this case some of the participants were steering towards the issue of value.

"Companies are not inherently philanthropic. Trade-offs would be cost-benefit based always" **CF-C**

The major determinant that was pointed out was that of the financial stability of the company. Initially a company would start of by designing just to meet the regulatory limits. Once limits have been reached they would then look for an option or a recovery that would ensure that they derive the most value out of the process. In so doing they would then decide on whether they want to settle for a high OPEX or high CAPEX option:

"So you take your legislative limits as your minimum limits and you design around which one is likely to give you the best value. So that would be looking at CAPEX vs OPEX' and then benefits vs sales etc." ***PC4-TS***

Applying this to the acid production case would mean that a recovery of 92% would allow the company to meet legislative requirements but chances are the acid they would be producing would not meet the minimum specifications of the industrial grade acid if they plan on selling it (acid produced will not be of high strength). In such cases they would then have to decide on whether or not increasing the recovery to 99% would be beneficial to them and whether or not the costs associated with the change from 92% to 99% would be worth such a sacrifice.

In addition, CF-C was also of the opinion that the trade-offs would mainly be dealt with on a cost-benefit basis. For him if a company were to be aware of any potential changes in the regulations it would be cost effective to start off with a process that can cater for high SO_2 removal. However he did mention that in cases where such information were not to be available overdesigning would then come at a cost.

The other major issue that decision makers would face would be that of deciding between quality and quantity. This was described as one of the major deciding factors by PC2-PL1 and PC2-PL2.

'" *It's a catch 22 that you sit with"* **PC2-PL2**[5]

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[5] The interviewee requested that the actual interview not be transcribed in the appendix

With the SO_2 case in particular one would have to strike a balance in deciding the point at which the effort spent to clean a gas is enough. PC2-PL2 pointed out that this was mainly due to the fact that the process of cleaning the SO_2 gas comes at a cost whereby one has to buy electricity and use water for the scrubbing process all of which have associated negative impacts.

5.3 LCA in design decision making

5.3.1 Usefulness of LCA during the design phase

The majority of the people who were interviewed felt that carrying out a life cycle assessment during the early stages of design would be useful. The key points that they gave were that it would be good to put numbers or rather quantify the impacts that are associated with the different processes. ECC-GC pointed out that having the impacts quantified would be of great value especially for incorporation into the company's decision making matrix. This according to CF-C would be most crucial in improving the scoring of the environmental aspect of the project which is currently not being given that much attention.

ME-SC and PC2-PL2 seemed to steer towards the fact that quantifying impacts would be more useful in cases where a company would have to justify why they did not go with a specific technology option. In such case they would then present the interested and affected parties with data showing the impacts associated with the other options that they did not go with.

On the contrary PC4-TS and PC2-PL2 did not seem to see the value that their companies would gain from performing a life cycle assessment similar to the one that the researcher presented to them. They felt that mining companies already had practices in place which were addressing all the impacts that were addressed by the assessment that was used for the study. They pointed out that the current risk assessments that their companies would do during the preliminary design stage already looked at impact like acidification and human toxicity. There would therefore need to be extra information other than the mere quantification that would help motivate for such a tool to be implemented.

A concern that was brought up by CF-C was that the SO_2 abatement case being a complex one, the life cycle assessment tool would need to be able to handle complexity. This is because for the different cases in the acid production route for example, it would not be possible to use the same process technology. So one would have a single contact acid plant for the 92 % recovery option and the 96 % option and then a double contact for the 99 % recovery. This therefore means that there would need to be a way of comparing across the variations that would be available within the technology options. And if this can be addressed then indeed the assessment would provide meaningful results.

To add on to the complexity was the issue of impact significance. According to ECC-GC, though it would be good to quantify the impacts, the major issue would be the significance of the particular impacts. So in order for such information to become a key drivers to decision making they would need to point out something very critical. For example, showing that a process is water intensive in a water scarce region would be a key driver to decision making, whereas just knowing that a process result in an increase in human toxicity alone would not be enough to drive change unless the impacts are severe. So basically the point was that it's one thing knowing the impacts and the potential of burden shifting but it will then depend on what issues the company values most and which impacts are the most severe ones. Note: essentially this comment points for the need to normalised impacts in a given setting – an optional step in LCIA. However it is still necessary to quantify all the impacts to determine those that are most severe to the company operations, not just the ones they might think might be significant.

5.3.2 Incorporating LCA thinking as part of the EIA process

There were mixed feelings among the participants as to whether or not incorporating LCA thinking into the EIA process would be a good idea. PC4-TS and PC2-PL2's sentiments were that companies already spend between 18 months to 24 months working on the EIA and often at times by the time they get to the end of the process the commodity cycle could have bottomed out and the company might actually be out of funds. They felt that introducing another aspect to it such as LCA would only prolong the process. According to PC4-TS there are more "company-critical, industry-critical" issues that would need to be addressed hence one would need to understand the impact of adding something like LCA to the process. However it is important to note that the LCA could inform and improve the EIA process and thereby curtail the overall process, not prolong it.

PC3-TS's point of view on the other end was quite interesting as she suggested that other than viewing it as an additional part of the EIA, the EIA should rather follow LCA thinking. This is because the EIA is basically a set of guidelines and hence incorporating LCA thinking will prompt the EIA to ask the right questions during all the stages of the design phase. Therefore in such an instance the EIA can still be carried out in the same amount of time with the only difference being the focus and the kind of questions that are asked.

5.4 Summary

This chapter synthesised the interview findings on decision making in the mining industry and the potential application of LCA as an environmental assessment tool. From the interviews it was gathered that the decision making process is not a one man job but rather requires input from different project teams ranging from the project engineers, via the legal department to HR. So before a decision is made they would all need to agree unanimously on a specific technology option which they would all deem beneficial after carrying out a cost benefit analysis.

The major drivers for the retrofitting of new technologies in the mining industry were identified to be the case in which design specifications were not being met, surfacing of new regulations or improved technology. Once faced with any of the three, companies would then need to explore retrofitting. With regards to choosing between technologies that satisfied the same purposes, the interviewees felt that the main determinant would be the quality of gas to be treated. Once this had been established the company would then decide on whether or not they wanted to opt for high OPEX or high CAPEX process depending on their financial stability.

It was interesting to note that most of the participants from the 4 platinum mines that were interviewed were focused more on value adding and felt that as long as the process was not adding any value it would be difficult to motivate choosing that option. The consultants on the other hand were more open to the idea of carrying out the assessment as long as it would not complicate the current system. They also felt that there was a need to have impacts quantified in such a manner and this would increase the weighting of the environmental aspects of the project in the company's decision making matrix.

Most of the interviewees expressed the view that companies did not do much to incorporate environmental concerns into their design apart from doing the legally prescribed EIA. Therefore once presented with the LCA results from the study they felt that such an assessment could be useful especially if it were to be incorporated during the early stages of the design, also to justify exclusion of some options, e.g. to interested and affected parties. By so doing the environmental aspects would gain more weighting in the decision making matrix that is used. However, some concerns were expressed as to the overlap with other environmental assessment tools, e.g. the site-specific risk assessment, and already lengthy timelines for environmental improvement. A key may be to incorporate life cycle thinking within other environmental assessment tools.

CHAPTER 6. CONCLUSIONS

This study set out to investigate whether life cycle assessment (LCA) would help inform design decision making if it were to be incorporated as an environmental assessment tool by mining companies. It builds up on earlier research (Guma, 2010; Basson & Petrie 2001; Forbes et al., 2000; Stewart, 1998) which looked at ways of incorporating sustainable development practices into the minerals processing design.

The previous two chapters have provided results based on the analysis that was done both quantitatively and qualitatively as way of addressing the problem statement and the key research questions. This chapter starts off by synthesising the results obtained in the previous chapters in section 6.1. Section 6.2 then looks into the degree of fulfilment of the research objectives that were set out for this study. Section 6.3 draws conclusions to the study. Finally, Section 6.4 gives recommendations for future research.

6.1 Synthesis of study

In an attempt to address the key questions that were set out for the study, two methodologies were fused. Within an identified case study, a quantitative research method in the form of a life cycle assessment was carried out to determine the environmental impacts that were associated with the key variables that were being analysed for the SO_2 abatement technologies. A qualitative methodology was then used to explore design decision making in the minerals industry and whether or not the incorporation of LCA as part of the environmental assessment would be of any value to the minerals industry. The research questions posed at the start of Chapter 3 will now be answered in the following sub-sections.

6.1.1 SO_2 abatement life cycle assessment

For the LCA part of the study two key variables were assessed: technology choice and recovery. The mass and energy balance data for this were obtained by modelling the different scenarios using the Aspen Plus software. The data that was used in the Aspen simulation was mainly based on literature values and the process data obtained from company publications. The different impacts based on the two key variables were then quantified and analysed.

The magnitude of impacts increases with increasing recovery in the concentrated dual alkali case, with the only exception being the acidification potential since more SO_2 is recovered. The principal contributor to the environmental impacts was identified to higher demand for materials such as soda production and lime for the concentrated dual alkali scrubber with the foreground system dominating acidification potential and water depletion. Though section 4.1.2 revealed that the energy requirements increased exponentially with increasing recovery the impacts of this increase were over powered by that of the background processes and shown in section 4.2.

Conversely, for the scrubber with acid plant, the magnitude of impacts decreased with increasing recovery for the acid plant, with the exceptions being the amount of water used and the global warming potential. The dominant contributor to most environmental impact categories was the sulphuric acid production used for the systems expansion (background process) and the transportation of acid produced by the foreground system (background process). The acidification potential and water depletion impacts were however dominated by the foreground system contributions.

Overall, the LCA revealed that the choice of key variables had a significant impact on the environmental impacts associated with them. The LCA shows that the scrubber with acid plant choice mostly has significantly lower environmental impacts compared to the concentrated dual alkali scrubber.

From this, it is evident that by carrying out a life cycle assessment on different key variables one is able to see how burdens can be shifted either within a technology option as determined by the recovery that one chooses or across technology options.

6.1.2 Decision making in the minerals industry

The interviews revealed that the decision making process is not a one man job but rather requires input from different project teams. So before a decision is made, the design team would all need to agree unanimously on a specific technology option which they would all deem beneficial after carrying out a cost benefit analysis. Key drivers such as the case in which design specifications were not being met, surfacing of new regulations or improved technology were identified to be the main reasons that usually prompted a company to consider retrofitting technologies within its operations.

The quality of gas to be treated in the case of the SO_2 abatement technologies was identified as the main determinant to the technology options that a company would consider in the first place as there exists different technologies for gases with different SO_2 strengths. This would be the first step in narrowing down the options available and then once this had been established the mining company would then approach a consulting firm to help reduce the options to 2 or 3 and for this in most cases would be achieved by scoring the different options in a decision matrix. From these options the company would then decide on whether or not they wanted to opt for a high OPEX or high CAPEX process depending on their financial stability. Once this had been established then a company would have 1 technology option that they would go ahead and put in place.

6.1.3 Life cycle assessment as a tool for informing design decision making

When asked what companies were doing to incorporate environmental concerns during the design phase, most of the interviewers felt that companies did not do much apart from conducting the prescribed EIA. Therefore once presented with the LCA results from the study they felt that such an assessment would be really useful especially if it were to be incorporated during the early stages of the design. By so doing companies would be able to justify why they excluded certain options, e.g. to the interested and affected parties during the public participation process.

6.2 Achievement of objectives

The research objective that was set out at the beginning of the research was to determine whether life cycle assessment could help inform design decision making in the minerals industry. This was achieved by firstly comparing and assessing the performance of SO_2 abatement technologies and the effect of efficiencies chosen on the broader environmental performance by using life cycle assessment modelling. This allowed the identification of areas of potential burden shifting that would arise depending on the key variables that were chosen. Once the results were obtained they were then presented to expert design engineers for their insights.

From Chapter 4 and Chapter 5 results it was evident that LCA has potential as a tool that can help inform design decision making.

6.3 Conclusions

The environmental comparison of the two technology options used to reduce the amount of SO_2 gas emitted by smelting processes at Platinum mines has been successfully demonstrated. From the results shown in Chapter 4 it is evident that one is able to identify areas of potential burden shifting that can occur when choosing key variables and technology options during the design phase. The energy requirements were identified to increase exponentially with increasing recovery for both technology options. It has also been shown from the LCIA that the concentrated dual alkali process, overall, has higher environmental impact compared to the scrubber with acid plant.

The design expert interviews have revealed that the incorporation of LCA as part of the decision making process will be more beneficial if its principles were to be used to guide the key questions asked in the normal EIA rather than adding it as an extra task. However, this would be more of a long term goal as the EIA is already very structured and has a lot of guidelines so changing that would take a while. A more robust approach that would find effective application in the short term would be to use LCA results during the public participation process to help justify to interested and affected parties why specific technology options were chosen.

In addition it was identified that it would be beneficial to normalise the LCA results obtained against a specific reference point so that one can actually see the significance of the different increases or decreases in the impacts.

Overall, it can thus be concluded based on the case analysed, that had the life cycle view been adopted during the design decision making process, it would have generated useful further insights to the design team on the technology and design variable choices. Additionally, as revealed by the interview findings, there would be some interest from design decision-makers to include such insights into design projects if this could be done without introducing significant extra work or delays to the current environmental assessment that is being carried out.

6.4 Recommendations

This study has been exploratory, and its evidence was generated for one particular case. Further research would thus help to firm up or nuance the conclusions arrived at.

- For this particular study published results were used for the process modelling. Therefore it would be interesting to see if different results would be obtained if the researcher were to use company specific data.
- Different acid plants may be more suited for the different recoveries, offering options beyond the use of a double contact double absorption (DCDA) acid plant. This would be more of a sensitivity analysis aimed at seeing if there would be significant change to the impacts for the scrubber and acid plant option.
- The design engineers might react differently if presented with the peer reviewed LCA results, or if interviewed in the presence of an LCA expert. It would therefore be useful to interview them again.
- It would also be useful to interview people with an environmental background like EIA practitioners who have experience working in project development and or design to see if they would have similar inputs to those presented by the technical experts.
- Case studies on retrofit designs done for reasons other than meeting new environmental standards, or even on grassroots designs, may provide different insights into usefulness of LCA.
- Further studies could be carried out to investigate ways of modifying the LCA process so that it is less time and resource dependent, this would make it more feasible for it to be utilised more effectively in the design decision-making process.

The need for normalised LCA scores, as noted in the conclusion, introduces a research need which will help solve the major problem faced by decision makers in industry of interpreting LCA results. Once normalisation factors have been determined they can then be used as reference points during the interpretation stage of the LCA. However, the major challenge that might arise in trying to normalise the LCA scores is the lack of reference points for specific regions. In such cases, one would have to use reference point for similar geographical regions as proxies which introduces uncertainty thereby distorting the results obtained.

In addition, even though further research as recommended above would be useful, it is recommended that PGM processing companies wishing to make environmentally superior design choices do proceed with a real project test case of using LCA at the pre-feasibility stage of a project. Specifically, in such a test case, practitioners should consider getting an LCA competent design engineer to be part of the design team who will guide them through the assessment and help justify design choices during the public participation process. Even in such a case there might still be potential problems with accessing the data required in its entirety even when working with the mining companies as some of the data required might not be reported in the available documentation. This will result in more time being required to carry out the assessment which might have implications on the actual design process.

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APPENDIX

APPENDIX A: BASIC CALCULATIONS

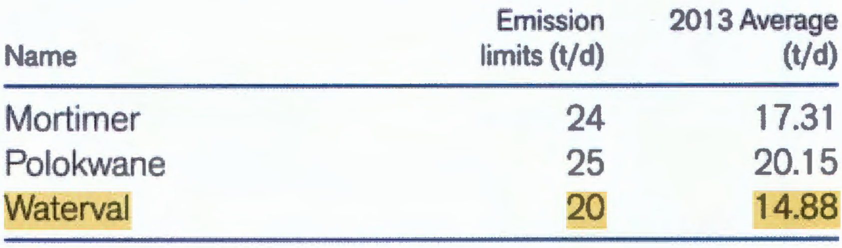
Feed Composition:

The feed gas that was used in the simulation is shown in Table A-1. These values were obtained both from literature and other company specific data.

Table A- 1: Gas feed composition

Component	Convertor Gas (kmol/hr)	Furnace Gas (kmol/hr)
SO_2	169	22.9
O_2	371	425
N_2	4512	1690
H_2O	85.2	70.6
CO_2	27.95	0
SO_3	5.4	2.8
Dust Burden		
Silica	0.052	1.679
Alumina	0.008	0.282
Sulphides	0.004	0.139
Calcium Oxides	0.004	0.16

The basis for the minimum tonnage per day required to meet the regulations was based the following:



Name	Emission limits (t/d)	2013 Average (t/d)
Mortimer	24	17.31
Polokwane	25	20.15
Waterval	20	14.88

Figure A- 1 Adopted from (Anglo American platinum, 2013)

Calculation of the minimum variable to be used:

Total gas flow rate per hour was 12320 kg which is equal to 12.3tons/hour. This was obtained by averaging the total gas flow rates of the 3 North West mines that were available (Bezuidenhout et al. 2012; Sichone 2009; Westcott et al. 2007))

Therefore to meet emission standards of 23 tonnes per day (average) based on the table above the minimum recovery will be:

$$Recovery = \frac{(12.3 * 24) - 23}{(12.3 * 24)}$$

= 92%

APPENDIX B: ASPEN SIMULATION

In order to obtain mass and energy balance data for the conceptual study a simulation was carried out using Aspen Plus Software.

Key outputs from the simulation

Table B- 1: Key outputs for concentrated dual alkali scrubber

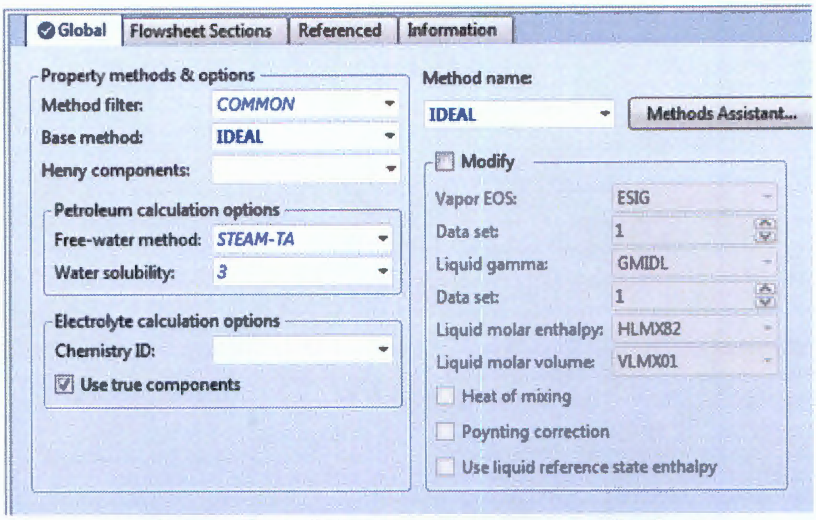
DUAL ALKALI			
Key Quantities	**92**	**96**	**99**
	tonnes/year		
Ca(OH)2	100672	105053	108338
NaCO3	28490	65119	74887
Water	1125939	1622420	3188603
CaSOx	208522	232771	250629
Emissions	**tonnes/year**		
SO2	7572	3785	945
O2	183486	177308	172796
N2	1334623	1334623	1334623
H2O	1134159	1614505	3171809
CO2	21277	36487	40543
SO3	5062	5062	5062

Table B- 2: Key outputs for scrubber with acid plant

Scrubber with Acid plant			
Key Quantities			
	tonne/year		
	92	**96**	**99**
Water	9345390	10608750	13103751
Acid	126295	130506	132066
Acid for Expansion	5771	1560	
Emissions	**tonne/year**		
SO2	7572	3785	945
02	202335	201400	200699
N2	1428419	1428419	1428419
H2O	3115899	3150067	3217275
CO2	7281	7050	6567
SO3	7069	8316	10567

B.1 Property Model used

The model filter that was used was Common with the base method being Ideal. The ideal base method was considered sufficient to model the simple solids simulation and was assumed to be very representative of the data that was given and also because very few reactions were taking place hence it would be a good approximation. Figure B-1 below is a snapshot of the property method selection.



Property methods & options

Method filter: COMMON

Base method: IDEAL

Henry components:

Petroleum calculation options

Free-water method: STEAM-TA

Water solubility: 3

Electrolyte calculation options

Chemistry ID:

☑ Use true components

Method name: IDEAL

☐ Modify

Vapor EOS: ESIG

Data set: 1

Liquid gamma: GMIDL

Data set: 1

Liquid molar enthalpy: HLMX82

Liquid molar volume: VLMX01

☐ Heat of mixing

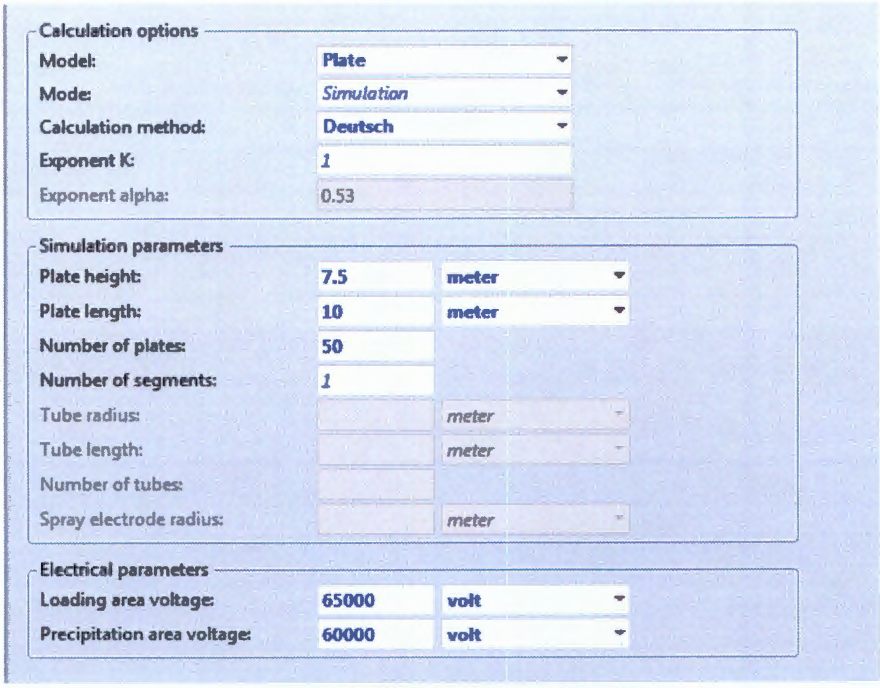
☐ Poynting correction

☐ Use liquid reference state enthalpy

Figure B- 1: Selection of property method

B.2 Electrostatic Precipitator

Both the concentrated dual alkali scrubber and the scrubber with the acid plant were assumed to have similar ESP which had the same specifications for ease of computation. The ESP unit on Aspen was set up with the inputs as shown in Figure B-2



Calculation options

Model: Plate

Mode: Simulation

Calculation method: Deutsch

Exponent K: 1

Exponent alpha: 0.53

Simulation parameters

Plate height: 7.5 meter

Plate length: 10 meter

Number of plates: 50

Number of segments: 1

Tube radius: meter

Tube length: meter

Number of tubes:

Spray electrode radius: meter

Electrical parameters

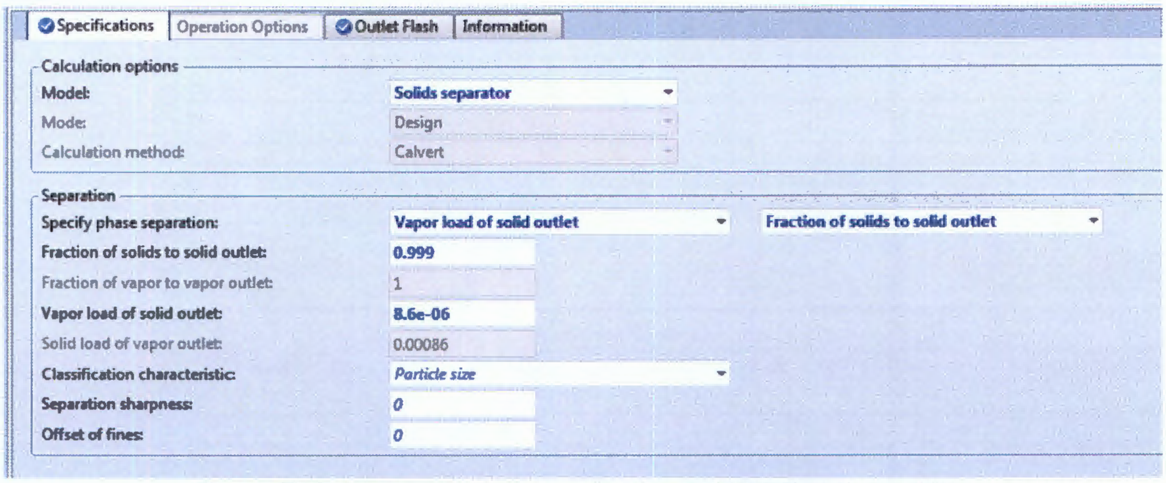
Loading area voltage: 65000 volt

Precipitation area voltage: 60000 volt

Figure B- 2: ESP input specification

B.2 Variable Throat Scrubber

The variable throat scrubber was also assumed to be the same in both scenarios and this is where the final solids removal was set to happen. The input specifications are shown in Figure B-3 below.



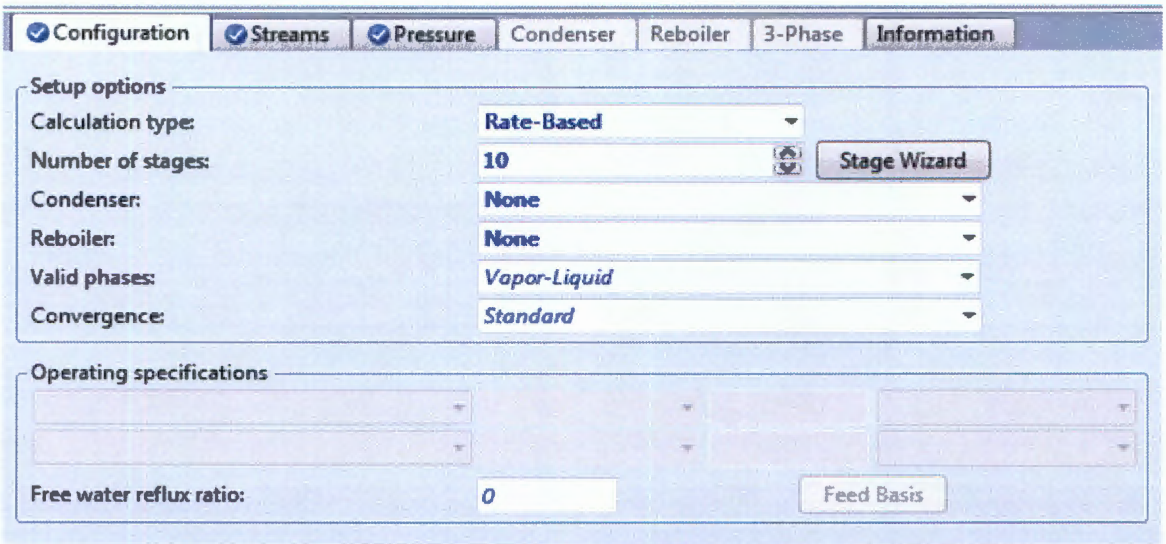
Calculation options
Model: Solids separator
Mode: Design
Calculation method: Calvert

Separation
Specify phase separation: Vapor load of solid outlet; Fraction of solids to solid outlet
Fraction of solids to solid outlet: 0.999
Fraction of vapor to vapor outlet: 1
Vapor load of solid outlet: 8.6e-06
Solid load of vapor outlet: 0.00086
Classification characteristic: *Particle size*
Separation sharpness: *0*
Offset of fines: *0*

Figure B- 3: Input specifications for the variable throat scrubber

B.4 Concentrated dual alkali scrubber and 2-stage scrubber

Both scrubber were modelled using the Radfrac unit in Aspen. This is a separation unit that allows you to specify the calculation type, number of stages and the stages at which the streams enter and leave the column. Because we were modelling a scrubber the unit was made to have no condenser or reboiler when the specifications were made.



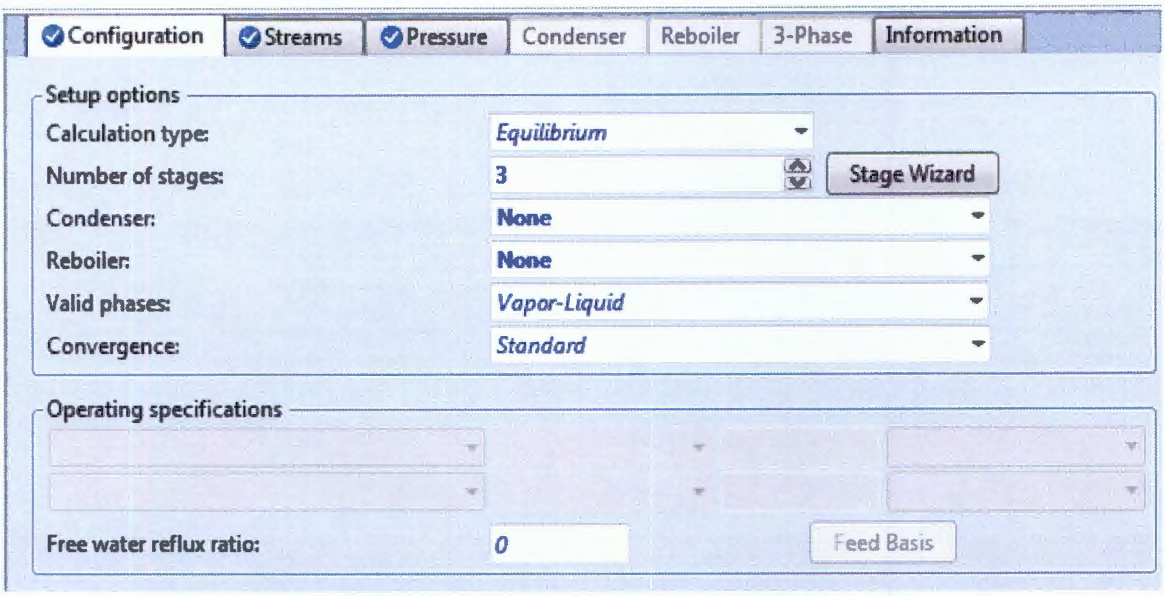
Setup options
Calculation type: Rate-Based
Number of stages: 10
Condenser: None
Reboiler: None
Valid phases: *Vapor-Liquid*
Convergence: *Standard*

Operating specifications
Free water reflux ratio: *0*

Figure B- 4: Sample scrubber input specification

B.5 IPAT, FAT Pre & Post drying Tower for acid plant

The above mentioned columns were also modelled using the Radfrac unit. A sample input specification is provided in Figure B-5.



Setup options

Calculation type: Equilibrium

Number of stages: 3

Condenser: None

Reboiler: None

Valid phases: Vapor-Liquid

Convergence: Standard

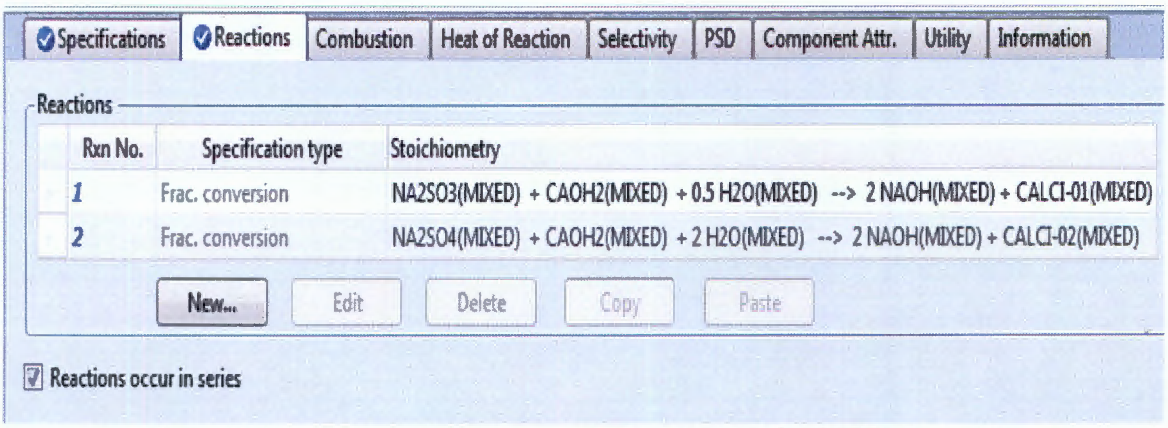
Operating specifications

Free water reflux ratio: 0

Figure B- 5: Sample input specifications for columns in the acid plant

B.6 Reactors for CaSOx formation

The reactors for the CaSOx production were modelled using the RStoic unit in Aspen plus. This allowed the researcher to input all the known reactions and either known conversions from literature or use the limiting reagent approach to determine conversions for the reactions. A sample input specification sheet for the reactors is presented below:



Reactions

Rxn No.	Specification type	Stoichiometry
1	Frac. conversion	NA2SO3(MIXED) + CAOH2(MIXED) + 0.5 H2O(MIXED) --> 2 NAOH(MIXED) + CALCI-01(MIXED)
2	Frac. conversion	NA2SO4(MIXED) + CAOH2(MIXED) + 2 H2O(MIXED) --> 2 NAOH(MIXED) + CALCI-02(MIXED)

☑ Reactions occur in series

Figure B- 6: Input specification sample for reactors for CaSOx formation

B.7 Aspen Flow Diagrams

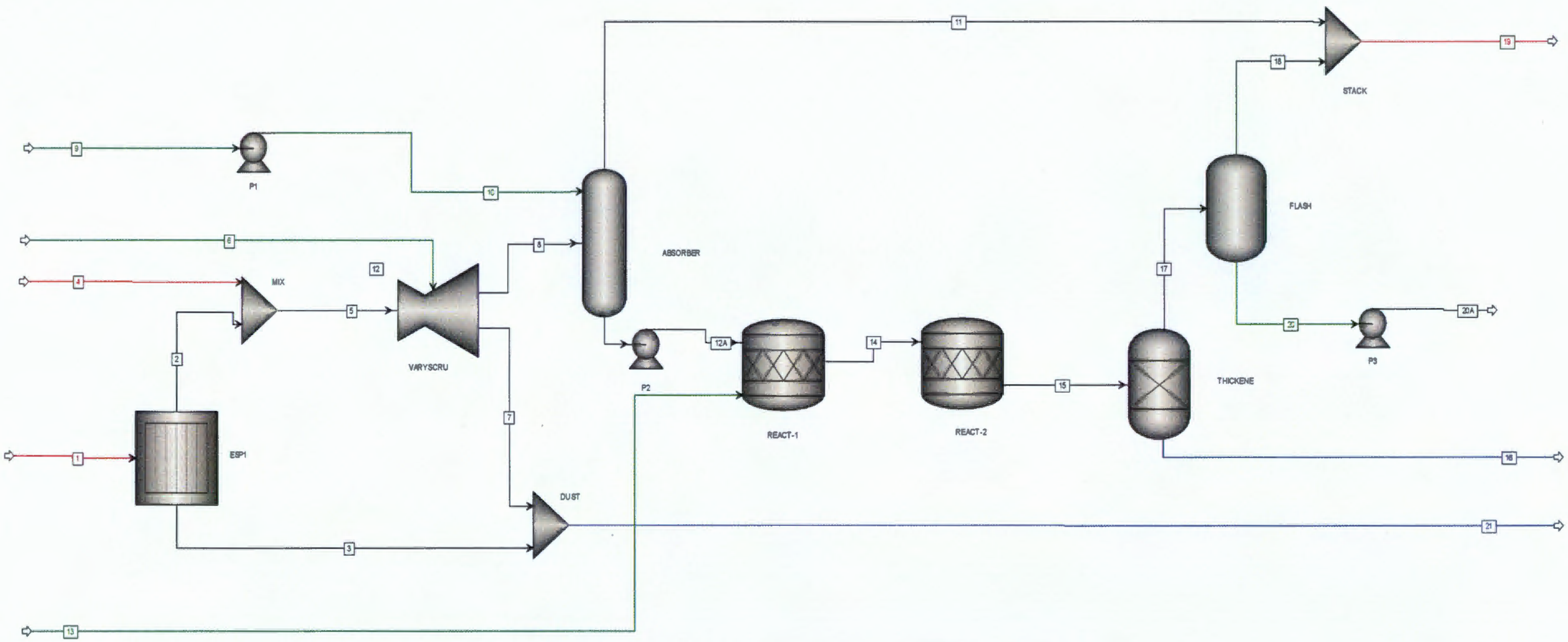


Figure B- 7: Aspen flow diagram for concentrated dual alkali plant

Table B- 3: Sample mass balance for concentrated dual alkali scrubber

Stream #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	20A	21	CaSox
Mass Flow (kg/hr)	64234	63939	296	152355	216293	9008	4.53	225296	146509	146509	194826	176980	14078	191057	191057	28120	162937	154937	349763	7999	7999	300	36120
SO_2	1467	1467	0	10853	12320	0	0	12320	0	0	981	11339	0	4.93	4.93	0	5	4.93	986	0	0	0	0
O_2	13615	13615	0	11877	25491	0	0	25491	0	0	23838	1653	0	53.3	53.3	0	53	53.3	23891	0	0	0	0
N_2	47357	47357	0	126422	173779	0	0	173779	0	0	169453	4326	0	4326	4326	0	4326	4326	173779	0	0	0	0
H_2O	1272	1272	0	1536	2809	9008	0	11816	137599	137599	380	149036	0	150900	147297	0	147297	147297	147677	0	0	0	0
CO_2	0	0	0	1230	1230	0	0	1230	0	0	173	1057	0	2597	2597	0	2597	2597	2770	0	0	0	0
SO_3	227	227	0	432	659	0	0	659	0	0	0.628	658	0	658	658	0	658	658	659	0	0	0	0
Silica	201	0	201	3.10	3.10	0	3.09	0.003096	0	0	0	0.00310	0	0.00310	0.00310	0.00310	0	0	0	0	0	204	0.00310
Alumina	56.7	0	56.7	0.864	0.864	0	0.863	0.000864	0	0	0	0.000864	0	0.000864	0.000864	0.000864	0	0	0	0	0	57.5	0.000864
NA_2S	21.2	0	21.2	0.324	0.324	0	0.324	0.000324	0	0	0	0.000324	0	0.000324	0.000324	0.000324	0	0	0	0	0	21.5	0.000324
CaO	17.3	0	17.3	0.252	0.252	0	0.252	0.000252	0	0	0	0.000252	0	0.000252	0.000252	0.000252	0	0	0	0	0	17.5	0.000252
Na_2CO_3	0	0	0	0	0	0	0	0	3710	3710	0	3710	0	0	0	0	0	0	0	0	0	0	0
NA_2SO_4	0	0	0	0	0	0	0	0	0	0	0	0	0	14204	0	0	0	0	0	0	0	0	0
CALCI-01	0	0	0	0	0	0	0	0	0	0	0	0	0	9934	9934	9934	0	0	0	0	0	0	9934
CALCI-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17217	17217	0	0	0	0	0	0	17217
$CaOH_2$	0	0	0	0	0	0	0	0	0	0	0	0	14078	8378	969	969	0	0	0	0	0	0	969
NaOH	0	0	0	0	0	0	0	0	5200	5200	0	5200	0	0	7999	0	7999	0	0	7999	7999	0	7999

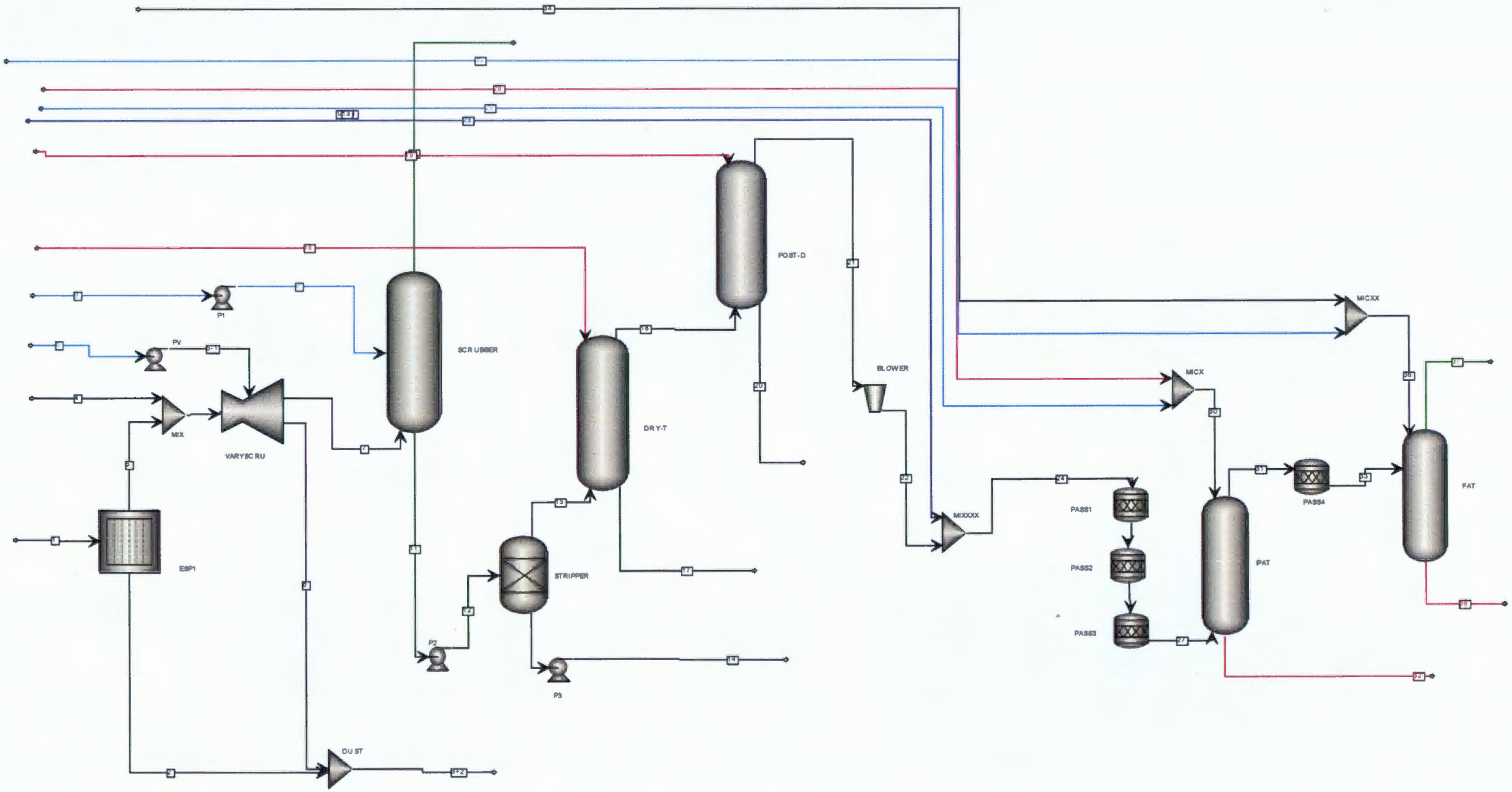


Figure B- 8: Aspen flow diagram for scrubber with acid plant

Table B- 4: Sample mass balance for the scrubber with acid plant

	1	2	3	4	5	6	6-2	7	8	9	10	11	12	13	14	15	16	17	18	19
Mass Flow (kg/hr)	64234	296	63939	152355	9008	4.531765	300.2473	225296	1207840	1207840	216571	1216560	1216560	1045330	1045330	171234	19190	151613	38811	8328
SO_2	1467	0	1467	10853	0	2.13E-06	2.13E-06	12320	0	0	976	11344	11344	0	0	11344	0	146	11198	0
O_2	13615	0	13615	11877	0	4.41E-06	4.41E-06	25491	0	0	24751	740	740	0	0	740	0	0.0675	740	0
N_2	47357	0	47357	126422	0	3.01E-05	3.01E-05	173779	0	0	171769	2010	2010	0	0	2010	0	0.0847	2010	0
H_2O	1272	0	1272	1536	9008	2.04E-06	2.04E-06	11816	1207840	1207840	18127	1201530	1201530	1045330	1045330	156198	6716.502	138551	24364	333
CO_2	0	0	0	1230	0	2.13E-07	2.13E-07	1230	0	0	948	282	282	0	0	282	0	212	69.9	0
SO_3	227	0	227	432	0	1.14E-07	1.14E-07	659	0	0	4.98E-05	659	659	0	0	659	0	284	376	0
Silica	201	201	0	3.096	0	3.093	204	0.00310	0	0	0	0.00310	0.00310	0.00310	0.00310	0	0	0	0	0
Alumina	56.7	56.7	0	0.864	0	0.863	57.5	0.000864	0	0	0	0.00086405	0.00086405	0.000864	0.000864	0	0	0	0	0
Na_2S	21.2	21.2	0	0.324	0	0.324	21.5	0.000324	0	0	0	0.00032402	0.000324019	0.000324	0.000324	0	0	0	0	0
CaO	17.3	17.3	0	0.252	0	0.252	17.5	0.000252	0	0	0	0.00025202	0.000252015	0.000252	0.000252	0	0	0	0	0
H_2SO_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12473.5	12419.71	53.8	7994

Table B- 4: continued

	20	21	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	59	GAS1
Mass Flow kg/hr	7926	39213	15862	55074	55074	55074	55074	96879	900764	997643	201185	851532	201185	91950	1801530	1893480	404337	1690330	620908	216293
SO2	0.084	11198	0	11198	3471	1076	334	0	0	0	332	1.66	9.96	0	0	0	9.83	0.123	986	12320
O2	0.000141	740	3648	4388	2459	1861	1675	0	0	0	1675	0.00491	1595	0	0	0	1595	0.153	26345.72	25491
N2	0.000152	2010	12214	14224	14224	14224	14224	0	0	0	14224	0.0470	14224	0	0	0	14223	0.600	185992	173779
H2O	13.2	24684	0	24684	24684	24684	24684	270	900764	901034	183252	742466	183252	1379	1801530	1802910	387589	1598570	405716	2809
CO2	8.36E-05	69.9	0	69.9	69.9	69.9	69.9	0	0	0	5.34E-17	69.9	0	0	0	0	0	0	948	1230
SO3	0.0192	376	0	376	10032	13025	13953	0	0	0	1702	12251	2104	0	0	0	920	1184	920	659
SILICA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.10
ALUMINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.864
NA2S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.324
CAO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.252
H2SO4	7913	135	0	135	135	135	135	96608	0	96608	3.73E-05	96744	3.73E-05	90571	0	90571	0.00169	90571	0.00169	0

APPENDIX C: SIMAPRO

C.1 Inventory Analysis

C.1.1 Foreground data sets

Table C- 1: Input / output flows (per year) for concentrated dual alkali plant treating 216.5 t/h of flue gas

Component			Units/yr.	92%	96%	99%
Inputs	Raw Materials	Water, process	m^3	1.1E+06	1.6E+06	3.1E+06
		Soda Ash	Tons	28490	65119	74887
		Lime	Tons	100670	105050	108338
	Electrical Energy		MJ	1.5E+06	1.9E+06	3.3E+06
Outputs	Emissions to air	Sulphur dioxide	Tons	7572	3785	945
		Oxygen	Tons	183486	177308	172796
		Nitrogen	Tons	1334623	1334623	1334623
		Water, vapour	Tons	1134159	1614505	3171809
		Sulphur trioxide	Tons	5062	5062	5062
		Carbon dioxide	Tons	21277	36487	40543
	Dust returned to smelter	Silica	Tons	1559	1559	1559
		Alumina	Tons	437	437	437
		Sulphides	Tons	168	168	168
		Calcium oxides	Tons	138	138	138
	Waste for disposal	CaSOx	Tons	208522	232771	250629

Table C- 2: Input / output flows (per year) for scrubber with acid plant treating 216.5 t/h of flue gas

Component			Units/yr.	92%	96%	99%
Inputs	Raw Materials	Water, process	m^3	9.3E+06	1.1E+07	1.3E+07
	Electrical Energy		MJ	4.5E+06	5.2E+06	6.2E+06
Outputs	Emissions to air	Sulphur dioxide	tons	7572	3785	945
		Oxygen	tons	202335	201400	200699
		Nitrogen	tons	1428419	1428419	1428419
		Water, vapour	tons	3115899	3150067	3217275
		Sulphur trioxide	tons	7069	8316	10567
		Carbon dioxide	tons	7281	7050	6567
	Emissions to technosphere	Silica	tons	1559	1559	1559
		Alumina	tons	437	437	437
		Sulphides	tons	168	168	168
		Calcium oxides	tons	138	138	138
		Acid	tons	126295	130506	132066

C.1.2 Background data sets

This section presents the input and output data for the background processes that are associated with the two technology options.

Table C- 3: Electricity production input/output table for concentrated dual alkali scrubber

Description			Units	Flows per MJ Electricity produced	Concentrated Dual Alkali Scrubber		
					92 % recovery	96 % recovery	99 % recovery
Inputs	Materials/ Resources	Water, process and cooling	m3	0.192	288000	364800	633600
		Coal	kg	0.187	280500	355300	617100
Outputs	Emissions to Air	Carbon dioxide, fossil	kg	3.54	5310000	6726000	11682000
		Sulphur dioxide	kg	8.00E-04	1200	1520	2640
		Nitrogen oxides	kg	1.20E-03	1800	2280	3960
		Ammonia	kg	1.27E-05	19.1	24.1	41.9
		Carbon monoxide, fossil	kg	4.23E-05	63.45	80.4	139.6
	Emissions to water	Phosphate	kg	1.03E-05	15.45	19.6	34.0
		Aluminium	kg	9.83E-04	1474.5	1868	3244
		Boron	kg	2.09E-06	3.135	3.97	6.90
		Chloride	kg	5.3E-09	0.00795	0.0101	0.0175
		Suspended solids, unspecified	kg	7.38E-06	11.064	14.0	24.3

Table C- 4: Electricity production input/output table for scrubber with acid plant

Description			Units	Flows per MJ Electricity produced	Scrubber with Acid Plant		
					92 % recovery	96 % recovery	99 % recovery
Inputs	Materials/ Resources	Water, process and cooling	m3	0.192	288000	364800	633600
		Coal	kg	0.187	280500	355300	617100
Outputs	Emissions to Air	Carbon dioxide, fossil	kg	3.54	5310000	6726000	11682000
		Sulphur dioxide	kg	8.00E-04	1200	1520	2640
		Nitrogen oxides	kg	1.20E-03	1800	2280	3960
		Ammonia	kg	1.27E-05	19.1	24.1	41.9
		Carbon monoxide, fossil	kg	4.23E-05	63.5	80.4	140
	Emissions to water	Phosphate	kg	1.03E-05	15.5	19.6	34.0
		Aluminium	kg	9.83E-04	1475	1868	3244
		Boron	kg	2.09E-06	3.14	3.97	6.90
		Chloride	kg	5.30E-09	0.00795	0.0101	0.0175
		Suspended solids, unspecified	kg	7.38E-06	11.1	14.0	24.3

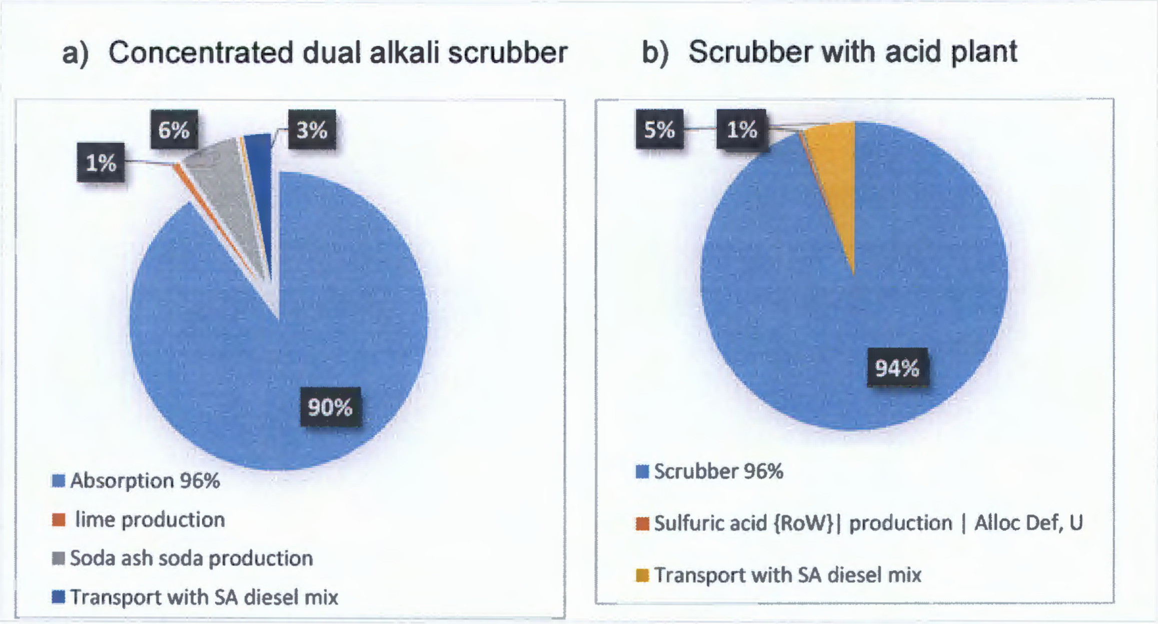
Table C- 5: production input/output table for soda ash requirements at different recoveries

Description			Units	Flows per ton Soda Ash produced	Concentrated Dual Alkali Scrubber		
					92 % recovery	96 % recovery	99 % recovery
Inputs	Materials/ Resources	Water, process and cooling	m3	295	8401663	19203800	22084370
		Lime, packed	ton	343	9778	22351	25703
		Sodium chloride	ton	429	12222	27936	32127
		Ammonia	ton	0.5720	16.3	37.2	42.8
Outputs	Emissions to Air	Ammonia	ton	0.5720	16.3	37.2	42.8
		Water, process and cooling	m3	11.6	330481	755386	868694
	Emissions to water	Phosphorus	ton	0.0149	0.424	0.970	1.116
		Cadium	ton	0.0000495	0.00141	0.00322	0.00371
		Copper	ton	0.000472	0.0134	0.0307	0.0353
		Lead	m3	0.0116	0.121	0.277	0.319
		Solids, Inorganic	ton	28.4	809	1849	2127
		Nickel	ton	0.000328	0.0093	0.0214	0.0246
		Nitrogen	ton	0.0529	1.51	3.44	3.96
		Chloride	ton	68.6	1956	4470	5141
		Water	m3	18.8	534468	1221641	1404888
		Mercury	ton	0.000000500	0.0000142	0.0000326	0.0000374
		Calcium	ton	28.6	815	1862	2142

C.2 Life Cycle Impact assessment

C.2.1 Acidification

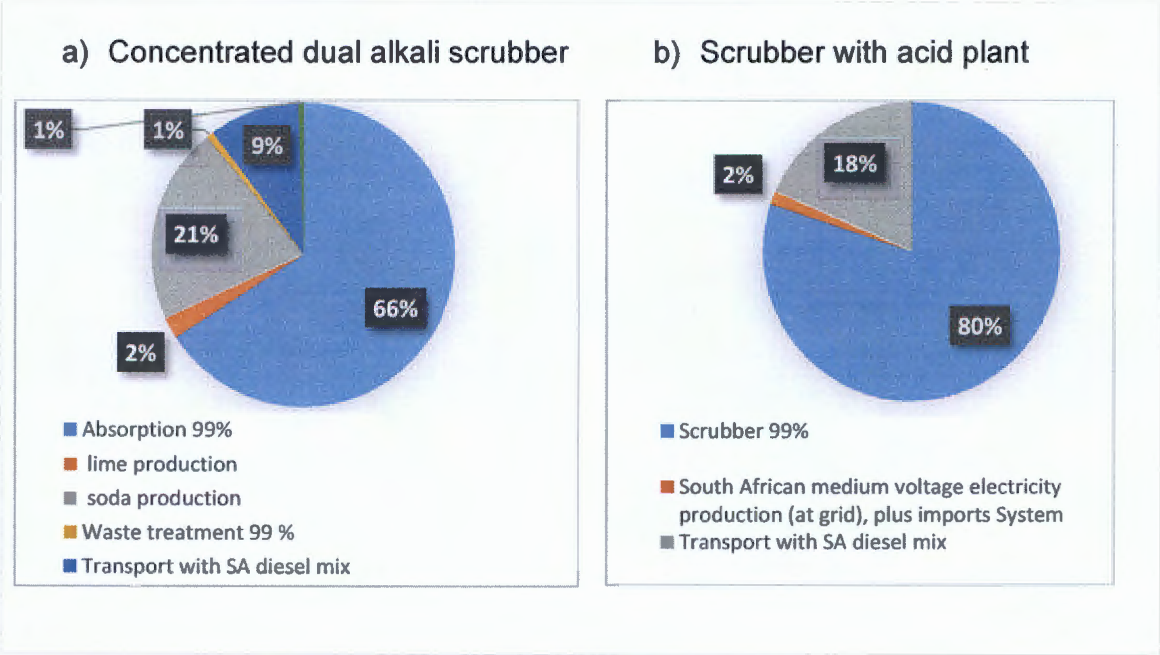
Table C- 6: Unit process contributions for the two technology options at 96% recovery



a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

Table C- 7: Unit process contributions for the two technology options at 99% recovery

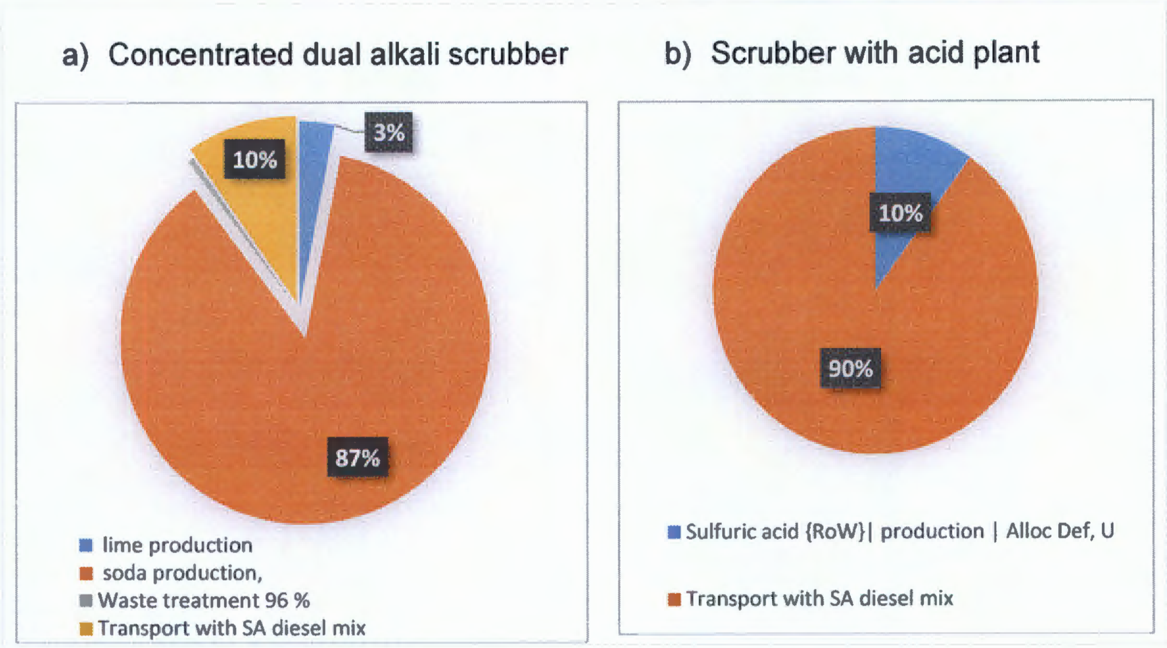


a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

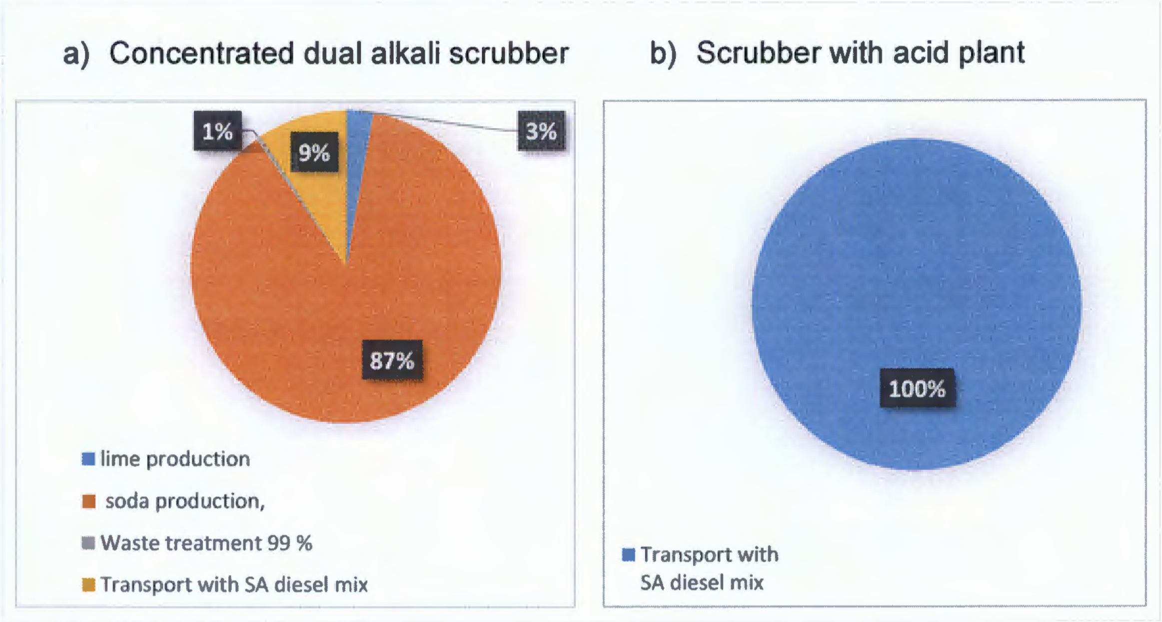
C.2.2 Abiotic Resource Depletion

Table C- 8: Unit process contributions for the two technology options at 96% recovery


a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

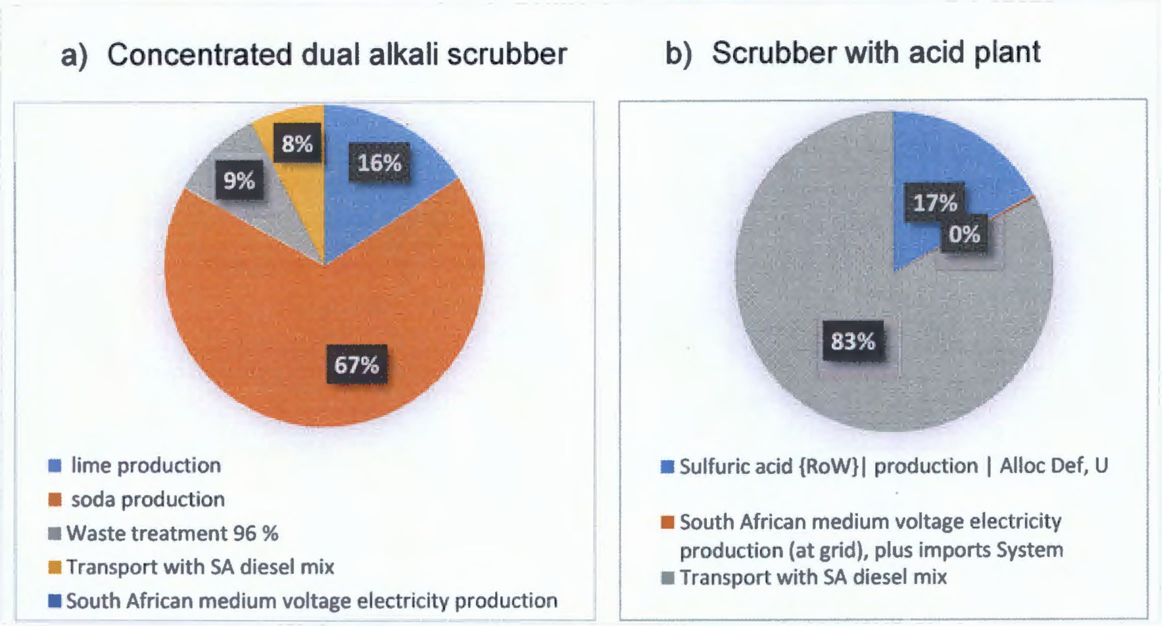
Table C- 9: Unit process contributions for the two technology options at 99% recovery


a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

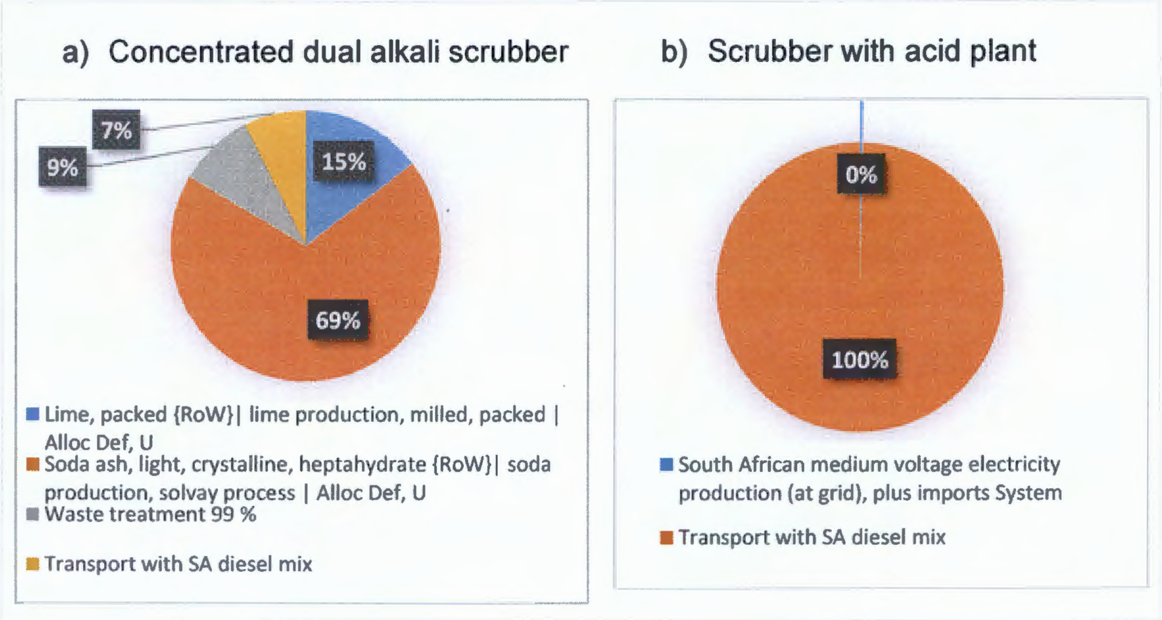
C.2.3 Fossil Fuel Depletion

Table C- 10: Unit process contributions for the two technology options at 96% recovery


a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

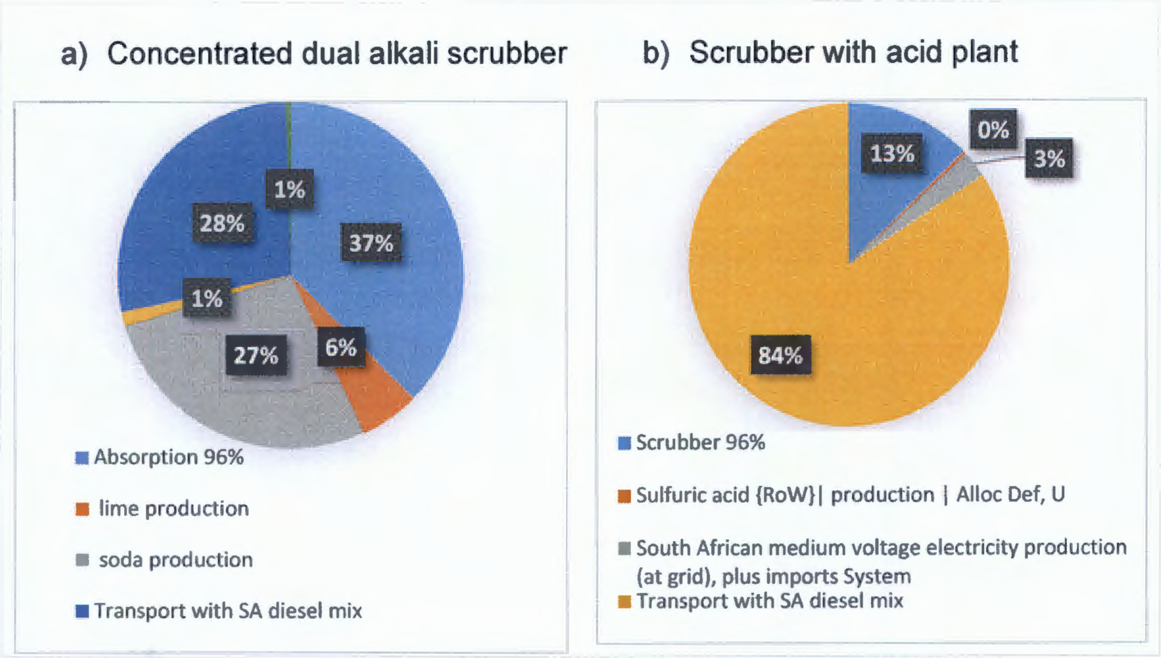
Table C- 11: Unit process contributions for the two technology options at 99% recovery


a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

C.2.4 Global Warming potential

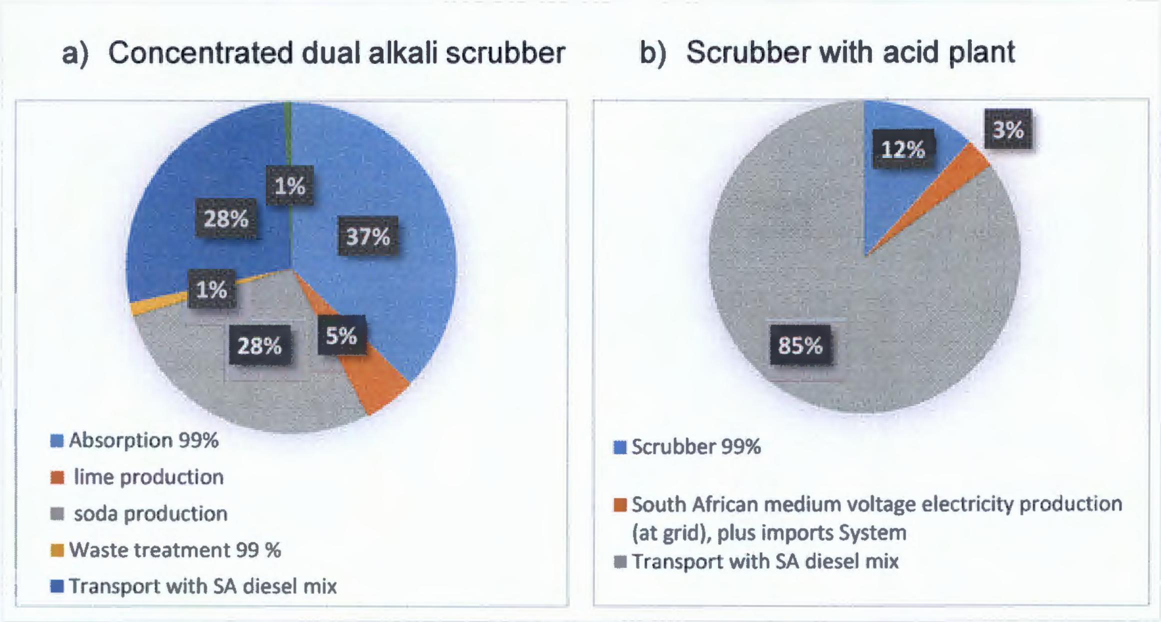
Table C- 12: Unit process contributions for the two technology options at 96% recovery



a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

Table C- 13: Unit process contributions for the two technology options at 99% recovery



a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

C.2.5 Human Toxicity

Table C- 14: Unit process contributions for the two technology options at 96% recovery

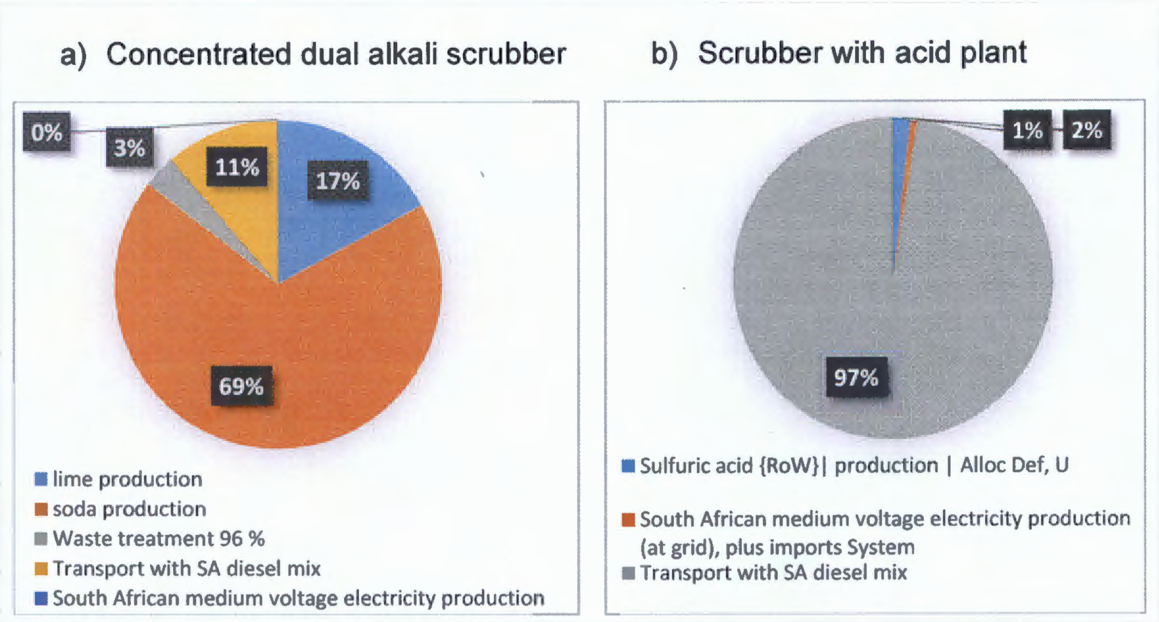
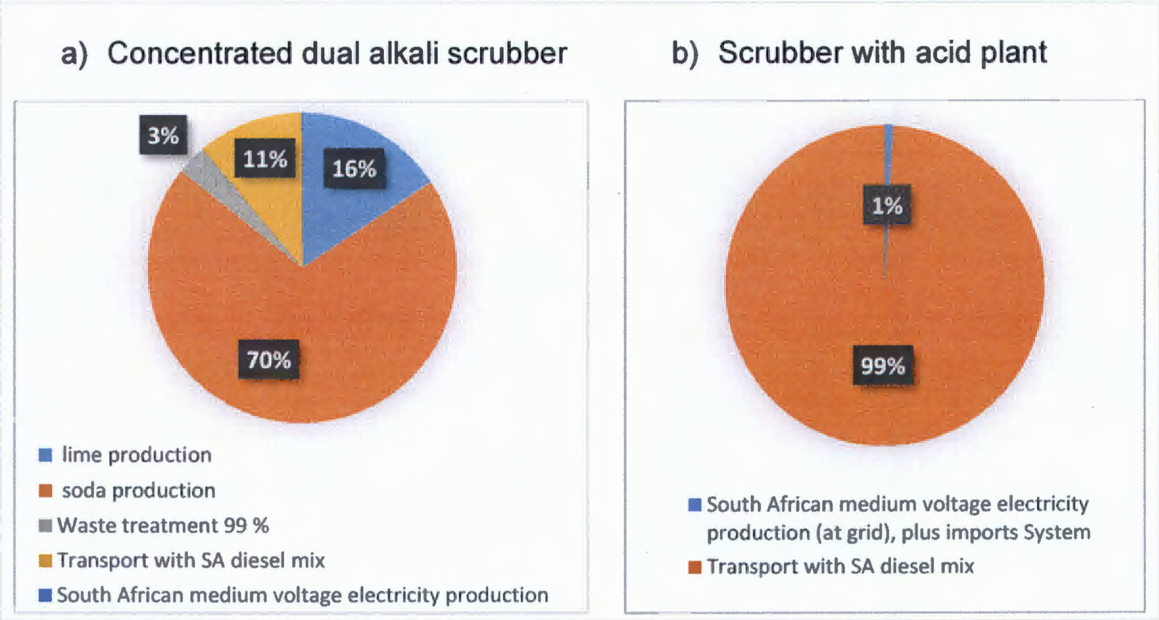
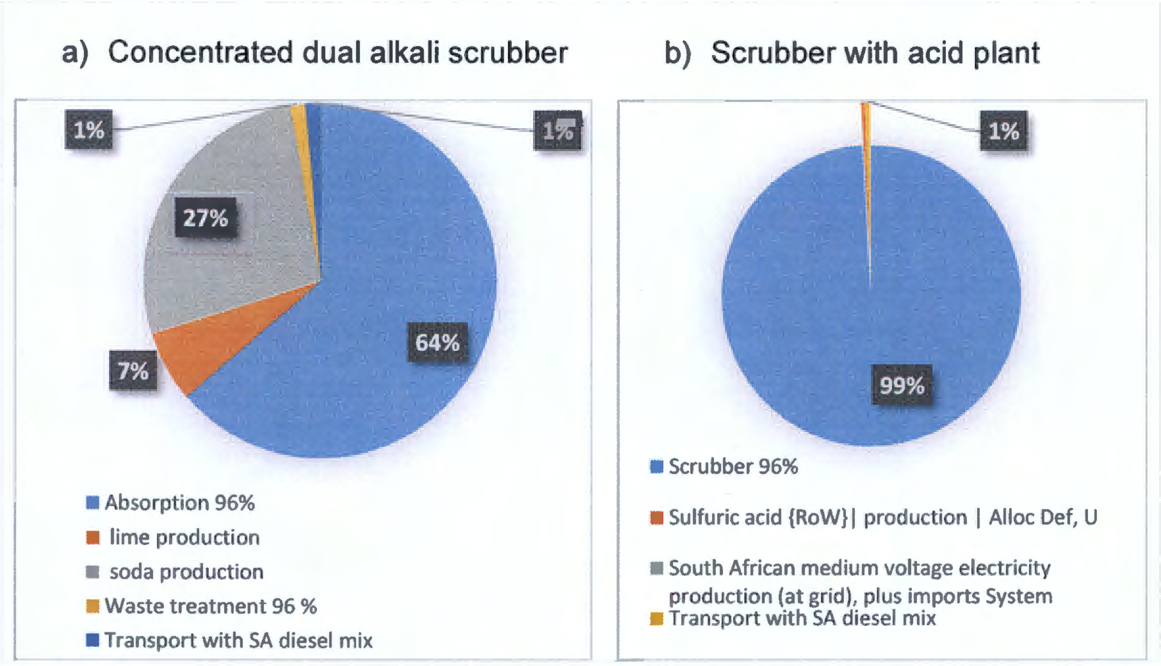


Table C- 15: Unit process contributions for the two technology options at 99% recovery



C.2.6 Water Depletion

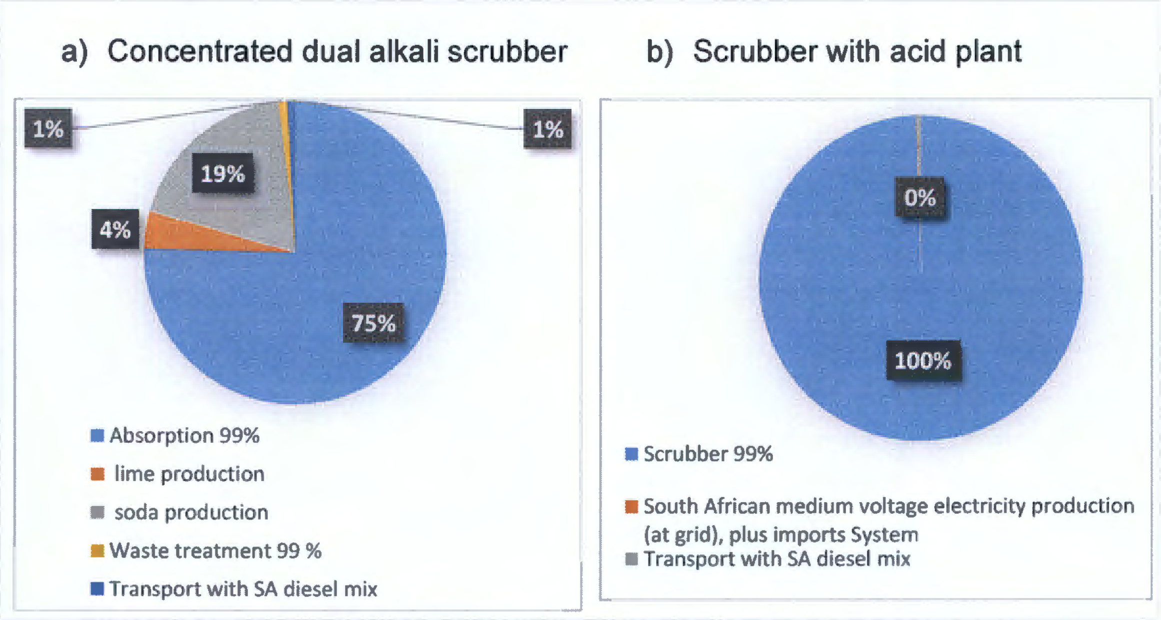
Table C- 16: Unit process contributions for the two technology options at 96% recovery



a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

Table C- 17: Unit process contributions for the two technology options at 99% recovery



a) Concentrated dual alkali scrubber

b) Scrubber with acid plant

APPENDIX D: EXPERT INTERVIEWS

D.1 Email Draft for interviews

Dear Sir / Madam

SUBJECT: INTERVIEW REQUEST

I am a Masters student at the University of Cape Town. Following my first degree in chemical engineering, I am now studying towards an M.Phil. specialising in the interplay of the minerals industry and sustainable development. For my dissertation, I am studying the possible use of life cycle assessment in mineral industry design decision-making. I am investigating this around platinum industry contexts, particularly by reviewing design choices made by different companies for SO_2 abatement technologies. To achieve my aims, my research includes conducting a small number of in-depth interviews with decision makers in those projects.

I am kindly requesting your participation in this study. As a published or noted design expert in SO_2 abatement in the minerals industry I believe that you would be able to provide some important insights.

Ideally the interview would entail a briefing session in which I would explain to you what the project is all about and what we aim on achieving by doing this research. Thereafter we would then engage in a discussion where I ask for your insights on the keys questions I would like to get your input and you can also ask any questions you might have for me.

If you are willing to participate, please let me know when you would be available for a 1-hour interview. I will be in Gauteng/ North West Province from 21-26 July 2015.

Please feel free to contact me or my supervisors, Prof von Blottnitz and Dr Jennifer Broadhurst, who are copied here.

D.2 Information sheet & consent form

An investigation of usefulness of life cycle assessment to inform design decision-making in the mineral industry: Case studies on SO_2 gas removal

Research Investigator:	**Supervisor**
Veronica Munyongani	Professor Harro von Blottnitz
Chemical Engineering Department	Chemical Engineering Department
University of Cape Town	University of Cape Town
mnyver002@myuct.ac.za	harro.vonblottnitz.uct.ac.za

Dear Participant

My name is Veronica Munyongani and I am conducting research towards a Master's degree in Sustainable Mineral Resource Development. I am investigation of usefulness of life cycle assessment to inform design decision-making in the mineral industry. I have approached you since I believe that you may be able to contribute significant insights to the project.

What the project is about

For my dissertation, I am studying the possible use of life cycle assessment in mineral industry design decision-making. I am investigating this around platinum industry contexts, particularly by reviewing design choices made by different companies for SO_2 abatement technologies. To achieve my aims, my research includes conducting a small number of in-depth interviews with decision makers in those projects.

Expectations from participant

I am kindly requesting your participation in this study. As a published or noted design expert in SO_2 abatement in the minerals industry I believe that you would be able to provide some important insights.

Ideally the interview would entail a briefing session in which I would explain to you what the project is all about and what we aim on achieving by doing this research. Thereafter we would then engage in a discussion where I ask for your insights on the keys questions I would like to get your input and you can also ask any questions you might have for me.

As a result of time constraints I would also appreciate if I be allowed to record the interviews and then transcribe afterwards so that I can get as much information from you as possible in the short time that you would have availed yourselves.

Anonymity and Confidentiality

The information that will be gathered from the interviews will be used for academic purposes only in the preparation of my dissertation and you will not be personally identified in the write up. The raw data identifying you will be kept confidential and not passed on to 3rd parties' i.e. it will only be available to the University of Cape Town staff.

There is also a possibility that the information provided may be used within the University for future unspecified research projects and if this happens to be the case the decision will still need to pass approval by our Research ethics board.

Once the interviews have been transcribed, I would send them to you for confirmation that you have been correctly understood

Consent Form for design decision makers

Please Initial Box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason. ☐
3. I agree to take part in the above study. ☐
4. I agree to the interview / focus group / consultation being audio recorded ☐
5. I agree to the interview / focus group / consultation being video recorded ☒
6. I agree to the use of anonymised quotes in publications ☐

Name of Participant	Date	Signature
Name of Researcher	Date	Signature

D.3 Detailed expert interview structure and questions

The following are general questions that were asked in the interviews though in some cases there were slight deviations based on the information that the interviewee would have highlighted to the researcher.

1. ***Personal introduction by researcher***

2. ***Personal Information from interviewee***

- What is your current position?
- How long have you been working as a design engineer?
- Have you been involved in any flue-gas treatment projects?

3. ***Brief overview of study (excluding LCA part)***

4. ***Design decision making***

- Who is involved in making design decisions in a company?
- What drives the retrofitting of new technologies such as the SO_2 abatement case?
- How do you choose between two technologies that are meant to satisfy the same function?
- How do you assess and incorporate environmental concerns in the design phase?
- How do you decide on which environmental assessment method you will use?
- How do you deal with trade-offs in cases where design is driven by regulatory standards?

5. ***Present LCA results***

6. ***LCA incorporation***

- Based on the results I have shown you, do you think carrying out a life cycle assessment would be useful during the design phase?
- Do you think mining companies would be willing to adopt LCA thinking in design decision making as part of the EIA process?
- What would you identify as the barriers that could be faced in trying to incorporate LCA for use by decision makers

7. *Closing of interview*

- Is there anything else you would like to add?

D.4 Ethics Clearance

EBE Faculty: Assessment of Ethics in Research Projects (Rev2)

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791). **NB: A copy of this signed form must be included with the thesis/dissertation/report when it is submitted for examination**

This form must only be completed once the most recent revision EBE EIR Handbook has been read.

Name of Principal Researcher/Student: **Veronica Munyongani** Department: **Chemical Engineering**

Preferred email address of the applicant: **mnyver002@myuct.ac.za**

If a Student: Degree: **Master of Philosophy** Supervisor: **Professor Harro von Blottnitz**

If a Research Contract indicate source of funding/sponsorship: **NRF**

Research Project Title: **Can Life Cycle Based indicators enhance eco-efficient processing of Platinum Group Metals (PGMs)**

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	[✓ NO]
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	[✓ YES]	NO
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	[✓ NO]
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	[✓ NO]

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate. Ensure that you refer to the EIR Handbook to assist you in completing the documentation requirements for this form.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	Veronica Munyongani Munyongani	18/11/2014
This application is approved by:		
Supervisor (if applicable): H. von Blottnitz		18/11/2014
HOD (or delegated nominee): *Final authority for all assessments with NO to all questions and for all undergraduate research.*		
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.		30/01/2015

D.5 Interview Transcripts

Interview 1: ME-SC

Background to the SO_2 abatement story in the SA context

Historically platinum smelting was done without any form of sulphur capture at all. Effectively tall stacks were built and the SO_2 that got emitted simply just got out to the atmosphere. Even fairly recently, like 10 /15 years ago ,if you drove into the Rustenburg area you could clearly see the effect of it and you could clearly see exactly where it was coming from.

The air pollution regulations got set up because of the public complaints that were being raised and everything that was happening in the vicinity of the smelters in Rustenburg particularly, which is where most of them were located.

Going back to that period that would have been the smelter at Waterval, which is the Anglo smelter, which is the biggest one and the earliest one. We also had dating back to about 1970,give or take a few years, the Phokeng one which is for Impala platinum and then closer to Marikana area the Lonmin Smelter.

Most of them simply pumped the gases into the atmosphere and obviously the gases would come from two primary sources: the main smelter where they would take the ore concentrate and simply melt it to form a matte and slag that obviously had high sulphur content. So even though there wasn't that much chemical reaction happening there would be reaction with the air and SO_2 will get emitted in the case of *Peirce-Smith* convertors which they used to use to take out the sulphide matte like copper iron sulphide. They would oxidise that primarily to remove the iron into the slag and at the same time remove a large amount of the sulphur and that is a much more intermittent process it's a batch process so the concentrations tend to be a lot higher but they spike.

So it's a challenging problem to deal with as you have steady emission of low concentration SO_2 and spiking, very fluctuating concentrations of high concentrations SO_2 from the convertors. So the net effect is they said we will make the stack high and just pump it out into the atmosphere but obviously that was not sustainable.

We have seen it echoed in countries like Canada were they have large nickel copper sulphide smelters and in Sudbury (Northern part of Ontario) and in that area it was initially used by the early astronauts to simulate the moons landscape because everything had been completely obliterated by SO_2 and there was no vegetation in the area and the rocks were all blackened but over a period of about 30 years they changed the situation completely by addressing the problem in a number of ways.

Why this is relevant to South Africa is that the smelting even though it doesn't have as much pgm content basically the same technology used in both cases hence the experiences are quite analogous just that they had environmental clamp downs way earlier than South Africa.

Basically the law kind of changed in steps and in parallel with that they made certain technical changes. The very first one that they made was to reject the pyrrhotite from the ore, so you've got a high iron containing a low nickel and copper and PGM containing part of the ore that has a lot of sulphur associated with it so they said its more acceptable to lose a little bit of recovery in the base metals in the interest of not processing a whole lot of sulphur. So with that they were able to make a step change in the sulphur emissions in the smelter simply by not processing the pyratite portion of the concentrate.

The next step they took was to say how can we avoid the sulphur emissions from the furnace and the convertor and they said the first step would be to remove it in a controlled fashion upfront of the smelter. The way they did it was through partial roasting in which they put it in into the fluidized bed reactor which is well enclosed so that you do not have fugitive emissions and also that you can operate it in a continuous manner which is always better to design a process around continuous flow when having spiky concentrations. And so they were able to get to about 60-70% removal through the partial roasting of the concentrate before putting it in the smelter. So the smelter still made sulphide matte and the convertors still emitted SO2 but the overall values were now much lower.

They then realised that they had optimised as much as they could and they started investigating other processes which is where I worked together with Estrata. We did work in the late 1990s on the ConRoast process as applied to nickel because they believed that the only way to remove it further would be to dead roast i.e. remove all the sulphur upfront of the smelter and then basically do iron collection where you reduce some of the iron oxides into metallic iron alloy that then collects into base metals and the platinum group metals instead of them collecting from the sulphide matte. So that was their thinking but obviously a lot has changed in the world.

In 2008 the world credit crunch and all the associated financial crisis meant that a lot of spending plans took a back seat. We've seen similar things happening in the last year or two as well. So let's put a hold on a whole lot of technical developments. So that doesn't talk about what you do with the SO_2 other than how you try and alter the process to reduce the quality of SO_2 that needs to be handled.

Who is involved in making design decisions in a company?

The way it usually gets done is that somebody at the plant, probably consulting metallurgists would say look we need to make some changes to the way this plant works, so they would initiate the process and be in charge of steering it. Typically they wouldn't have the manpower or the resources to do all of the evaluation so they would probably go to an engineering company to say to them please do a pre-feasibility study on the following options and let's look at the scrubbing process and acid plant and compare that to making our stack say 50m taller or compare that to nothing which will be more of a baseline.

So in that sense it is being driven by somebody in a technical position within the plant, but there is lot of opportunity for the engineering companies to say but are you aware of this latest acid plant technology or this latest scrubbing technology. So they would then bring in that aspect of it, but the person on the plant makes the broad selection of the process options then the engineering company will focus that down and say we want to consider this one by this manufacturer using this and this piece of equipment. And they would flesh out the flow sheet and put it together, cost it and then send that back to the plant.

At that point they would then say yes this looks like a good idea or bad idea, we will keep option 1, 5 and 7 open because those look like reasonable ones. Also note that you cannot take to financiers 7 options, it is not feasible to do that so rather you go with 2 or 3 maximum. So you then say let's go and do a more detailed cost study on those, get something that is actually credible to say yes if we actually do this we have engineered it to the point that we now know with reasonable amount of certainty within 20% of the capital costs and what the running costs will be and we've got a good idea as to what's involved. Once you get to that point it would then go typically to the board of the mining company and the board would then say yes we've looked at this these are the pros and these are the cons of the different options, yes we recommend that we spend a billion dollars on putting up an acid plant.

But it very unusual for the company to have a billion dollars floating around that they can just use, so typically what would happen is that they would then have to go to their investors and persuade either the investors or the bank depending on how they choose to fund it. So it would be somebody with a financial background who would finally say yes we are going to give you the money or no we don't think this is a good business case we are not going to give you the money. Which is what happened during the time of the credit crunch, there was actually nobody to give out the money so even if it had been approved by the plant and engineered by an engineering company and approved by the company's board, and it still wouldn't go anywhere because the money just wasn't there.

So ultimately who makes the call? Everybody makes the call. It's a shared thing and everybody likes to think that their part is the most important but unless they are all yeses it doesn't happen.

In terms of the number of options you would take to the investors, It depends on the nature of the funders but by that time you would have gotten to the point of having one option on the table because the cost of the bankable feasibility study, you would have probably spent, for example if an acid plant was a hundred million rand, you would had have probably spend ten million on just doing the engineering study to find out what it would cost because you would have done all the engineering work already. So yes you haven't actually gone and bought the materials and constructed it but you've already done designs and you've already done drawings, layouts and all the instrumentation. So there is a lot of costs and a stack of work that goes into the bankable feasibility study and so at that point you have spent a lot of your money already and to get the remaining bit you now have to go and convince the financiers to put in the money. So you probably wouldn't go all the way to a bankable study with more than one option.

But in the early stages say the concept you can probably have 10 different options but by the time you get to the pre-feasibility study you would have narrowed it down to say 3 or 4 and by the time you get to the actual feasibility study you would have narrowed it down to 2. And by the time you get it to a bankable study then you would have 1simply because it is too expensive to do it.

So it depends on the size of the project. So you go through each one of those stages in that much detail but for large company or large plant that would be how it would be done.

How do you choose between two technologies that are meant to satisfy the same function?

That's why I tried to give you the long background because I am not sure that they are framing their questions in a way that you are framing your questions. I don't think that they are looking at say what recovery or what emissions should we tolerate they are looking at saying practically what can we do. So first of all what are the technologies depending on the gas stream and then it's a case of well if there is no market for sulphuric acid then producing the acid isn't on the table it's not we like to do it but rather you can't do anything with it. So sometimes I say the decision making process is not a nice smooth thing.

It says you look at this way, if you were to make this product could you do something with it? If you can't do anything with it then that option is just scratched out. That the way that I would see that, when I talk to people who are part of the decision making process that's my impression of it. I am honestly not party to it when they are doing it. I often just hear a summarised version of it. And that's the way that I read the situation.

Now first of all if you have a stream of SO_2 that you could treat now whether that's from your smelter or from your *Peirce-Smith* convertor or fluidised bed roaster, whatever it is you need to ask the question: Is the gas in a form that we could treat it? In other words you need to ask whether you have got a reasonable concentration to do something with it. If you can answer yes to that question then you need to ask yourself have you got enough of that gas. In other words you are more interested in quantity and not just concentration.in order to justify doing something with it. If you are a very small producer it certainly does not make any sense to put it in an acid plant simply because you are going to spend millions upon millions in putting up the capital only to make a product that gives you no money because there simply isn't enough of it.

Obviously you also need to try and determine the economics of the sulphuric acid market because that traditionally is tied very closely to the base metals industry so we see interesting things happening in Zambia in the copper industry for example where existing producers that use solvent extraction in the Electrowinning process of recovering copper and they say actually one of our big cost elements is sulphuric acid which you need for the whole hydrometallurgical part of the process. They say actually we've got an ore body that has got sulphur in it why don't we pull up a copper sulphide smelter where we can capture the gas using one of the smelting techniques either flash smelting or top-blown lance smelting and make sulphuric acid for our own consumption in our own plant. So in that case you have got a market for the sulphuric acid.

Sulphuric acid is not such a high value commodity it is very corrosive and is subject to all kinds of transport regulations so it's pointless to produce it very far from where it is going to be used. So very often you have got to look at it holistically and say is there actually a market for the acid. If there is no market for it or it's already saturated by other producers, then it is pointless producing the acid because what are you going to do with it? You can't stockpile it and it's very expensive to transfer and transport around. So that's one of the critical elements, so do you put up an acid plant or don't you because not everybody is going to be in a position to put up an acid plant. So you cannot look at it in isolation and say that for this smelter should they put up an acid plant or shouldn't they. It depends on where they are located and what the market is for sulphuric acid around them, are there industries that could consume sulphuric acid and if not then it's a real problem. It's not like gypsum which you can put up in a heap somewhere and it's not going to go anywhere and it's not going to change. Acid you simply can't stockpile it's just not a practical thing to do.

So that is one of the big decisions that need to be made, so have you got enough gas at the right concentration and have you got a market for the acid, then if you can answer yes to all of those questions then finally the big crunch is can you actually get the capital?

So I think that is where a lot of plants sit saying that well we would love to clean up our act and put in some technology and we can't afford to do it so they don't. And sometimes legislation forces them to do it in such cases they don't have a choice but it is very unlikely that legislation is going to force a company out of business in the current political or economic environment that we are in. So you are going to be so punitive to a company and say look we see you are not making much money but we can't expect you to shut down because you can't afford to put up a scrubber or an acid plant so we will condone it for a little bit longer but you really need to do something going into the future studies. So then they commission studies and look at it but it doesn't really go anywhere. So in the big scheme of things obviously they have to clean up their act and obviously have to do something about it but it may not happen in a short time frame.

What is the purpose of carrying out an EIA?

Usually the EIA is not that you get a licence its more of saying if you want to make a process change then you have to do the EIA. So the way I would understand the chain of events is that the law gets published and somebody from the regulators picks up the phone and says to the big operating company are you aware of the law, you guys need to get your act together. So the company then says alright we will do something so they commission a study and go through the whole process and then as part of the whole process, that kind of consultation process they say we have now narrowed it down to this option.

Now before they actually go ahead and get the permission to build, and before they even ask for the money. You can't even ask for the money unless you've said yes we've already got the designs done and we've got the permission from the regulators and we've got the consultation from the community, all of these things are clear Mr Banker can we now have the money.

So all of those things must be in place first. So once you have engineered the chemical process that is, your next step would then be to take it to the community in terms of an EIA to kind of get buy in from them and permission to take it to the next level. So you wouldn't go to the community and say can we have your permission to clean up our act, that's too vague, that's not what you are asking for. You go to them and say we want to build an acid plant so that it would be cleaner but what we are saying is that the change we are going to make on our plant is to build a new acid plant is that ok? That is what happens when you do the EIA. So the EIA isn't we want to comply with the legislation but rather we want to build and make the following changes is that ok.

Would companies still do EIAs if they were not required to do so by the law?

So in the event that companies were not required to get buy in from the community, I still think they would go ahead and do the EIA. I think it is part of responsible engineering that you would consider all of the impacts that a process has. You would look at the economics and you would look at the safety, you would even look at the products that are made and the environmental impacts. I am sure you would do it but the EIA and the community consultation part: I don't think anybody would do the community consultation if they didn't have to because it's hard work. But I am sure they would look at the impacts at least to some degree.

Based on the results I have shown you, do you think carrying out a life cycle assessment would be useful during the design phase?

So to have numbers that tell you what those impacts are would be a useful thing but I am not sure if it will directly drive the decision making process. It would however feed into it just to say look it's not a practical option and we can't make and stockpile sulphuric acid, there is nothing we can do. So somebody will then say well have you thought of installing a sulphuric acid pipeline and you say no it wouldn't work because the acid would be corrosive plus pipelines are very expensive. It's also impractical to have a pipeline of say 1000km going to the nearest area that would consume it for example. And so most reasonable people at that point would then say ok that's not on the table you can't go for that, then they would say what about having trucks to take the sulphuric acid and drive that then somebody would need to calculate and say well if you were to have a thousand trucks a month driving on your little road the impact would be enormous and it would destroy your roads and there would be hazardous material being transported and besides which the cost would be X and this would be completely not feasible. Those are the kind of arguments you would have to give back and say yes we have thought it through and these are the impacts it would have so it's not just the impacts to the gaseous environment it's also the impacts associated with it. So if you are producing acid it's not just, that's a nice thing to do and your air is going to be cleaner but now your roads are going to be destroyed and people are going to get involved in hazardous spills on the highways or whatever.

So you would have to look at it very broadly and say what the costs of the options are. So to answer your question it is a worthwhile thing to do to quantify what the costs and impacts are

Do you think mining companies would be willing to adopt LCA thinking in design decision making as part of the EIA process?

I would say it's of value because they would have to justify the decisions. I think part of the environmental impacts consultations with the public is to go to them and say look this is the process we are planning to put in place and the questions usually come back and say ah but we have a heard that there is a technology that does this better, have you considered that technology? You would then have to be able to answer that question and you will have to give them for example if you were producing small amounts of gas in a very sparsely populated area you might say well there is no outlet for sulphur acid so we have decided to not go with that route because technically it is not feasible.

Then someone might come up and say well tell us what are the costs of such a decision in terms of environmental impacts and how much power you consume or how much coal you are burning, the emissions directly of SO_2 into the atmosphere.

Interview 2: PC1-VP & PC2-LM

There were two interviewees who sat in on this interview and the responses have been presented with Edward being **P1** and Bridget being **P2.**

What drives the retrofitting of new technologies such as the SO_2 abatement case?

P2: My background is minerals processing so I can tell you for a general mineral processing plant. If a concept is simply not working and the required design specification is not achieved, then you have to retrofit. So I would assume the same would apply to the smelter as well, if it's a regulation change or for operational purposes a retrofit may be required. There are very few smelter operations in the platinum industry and these have been running for a number of years and I think are at an optimal stage. I don't know if this regulation is new but I think it has been around for a number of years and they have already met those targets, because it is quite strict in this country in terms of achieving that.

I know when I lived in Rustenburg you could actually smell the SO_2 and at times they would actually shut down that smelter because it was really bad so they were very strict about it.

How do you choose between two technologies that are meant to satisfy the same function?

P1: First of all if it's a new technology then mining companies are always reluctant to apply new technology for a couple of reasons:

Number one is if there is a new technology out now, for example the Kell process that we are looking at, I don't know if you have heard about it. It's a new way of smelting which is obviously a lot more environmentally friendly. Now that hasn't been applied commercially, and from what we have heard the capital intensity is very low so for us that is a good thing. But if we had to go and apply that kind of process, the risk involved in applying that kind of new technology is huge because if it doesn't work then we would sit with something that is not operating, and we can't get it to work, obviously that then affects our revenue stream and the company as a whole.

And if you don't have the money, so obviously we are a junior company just developing now and say for instance if you are a major company, those are the kind of guys that can ty these kind of things on a smaller or pilot scale because they can put the money towards that and say alright we going to this and see if its working then we can commercialise it obviously at a later stage. But for us, if you don't have the capital and you are going to look for finances from the bank. So if you are going to go to a bank and say look we are considering applying this new technology, they will say to you look we cannot lend you this money based on this risk and the fact that it's not proven. So if it's not proven then it's very difficult.

P2: Yes the thing is with the Kell process it would be so fantastic in terms of the sulphur abatement because it's a hydrometallurgical process there is no smelter you know. The whole thing is hydrometallurgical so the whole route will be optimal in terms of the environmental perspective but then the risk associated with it is so high for us to implement something like that you know. So we watch on the side-lines and wait for somebody else to do it who has the money and has existing operations to fund that kind of thing and then we see how it goes from there. But that's basically the way to go.

So what we do is that we start off with an order of magnitude study and then we look at the viable options. You also have to test the concepts whether it's in a laboratory or somewhere just to prove that it would work and that would basically apply for any aspect of metallurgy. Then you would have to scale it up to either a mini pilot plant or a pilot plant especially if it's a new technology because you have to prove the success of the performance at every step and so if you can't you are very limited. So as we said with the Kell process there is a pilot plant but it requires so much concentrate feed and we can't get it from the sample that we have. So we wait for somebody else to do that sort of test work and see how it goes

P1: so to answer your question that's basically the first part of it. The second part is if you do have the cash and the risk appetite and you are a major. Then I don't think it is up to the engineers, it's up to management and goes up to board decisions, looking at sustainability and how to make or create a sustainable business and then drive those kind of technologies out to the engineers because you must understand that when you work with design engineers who have been in the field for a long time, they don't like to look at new technologies.

To get them to think out of the box is to think that it has to be driven by the leaders from the top down.

How do you assess and incorporate environmental concerns in the design phase?

P2: look its actually difficult to take into consideration from the onset, we do an EIA from when we do the studies and all of that is taken into account so we make sure that we adhere to whatever regulations there are from the design phase essentially. There are a lot more regulations that surround the smelter. .

P1: I think to answer your question I would say the company does very little, we do our EIAs but that is just required by the regulations and we have to do that. But I think what you have to do or what has to happen is that the company should prescribe the kind of technology they want to use. And that is the change that I see in the mining business and obviously all those, where your policies and sustainability practices drives your design. Because when I tell you to go look at say a flotation process I am not telling to go look at in these kind of parameters say from the environmental or social aspect. That must happen, because we just go to the whole download thinking were we just pick things that work and then we do the EIA because it's a regulatory requirement.

So if you turn around and say so we have policies in the business that are very specific and that drives them then that would be a different approach.

P2: At the moment I would say that most of design is driven by cost, the capital cost is the biggest driver not the environmental aspect, fit for purpose is what you want. Or you want the version that caters for all these things.

P1: We are currently doing a feasibility study for our project and we are kicking it off now and one of the biggest things when it comes to pricing and tenders, we now talking of people who are going to supply prices to us, we are going to weight the adjudication of these things based on sustainability as well. That is what these companies do in terms of sustainability. Which is probably the first, I don't know if any there are any juniors out there who have considered doing that.

How do you decide on which environmental assessment method you will use?

P1: From a smelter point of view especially a smelter in the BMR obviously because it has a whole lot of environmental impacts than just a processing plant or a concentrator and what normally happens is when you do get your environmental and social consultants in you will tell them what it's about and then they are certain environmental triggers that will trigger something like an EIA and normally smelters and BMRs usually have their own EIAs. And when it comes to the location study of where the smelter will be based that is vital because people don't like these kind of things.

P2: Yes because there are communities nearby so yes you have to take all of that into account

P1: So yes, that is regulatory and I am coming back to that, once you have done the EIA I think there is a lot of things that I am not happy with. A lot of the public or interested parties will comment or ask questions and what we do is just answer them for example if they ask about what will happen to the CO_2 or SO_2 produced then all we tell them is that we will put the measure in place to make sure that it is within the regulatory limits. That's the answer and it's a very short answer.

P2: The smelter design and operation is ten years away so we are not looking at it in too much detail at this point. But we will look at it.

P1: I know we will look at it but I am just saying if we look at it from an environmental and social consultant's perspective, they are also used to just answering whatever the interested and affected parties want to hear and always come back to policy and regulation. But where is the answer to say that we will better it or we will do it definitely?

Do you think mining companies would be willing to adopt LCA thinking in design decision making as part of the EIA process?

P2: I think your bigger companies have money to pay people to look at all of this, but your smaller and junior companies would just be looking at more fit for purpose minimum regulation designs unless it's a company like ours where we are very socially responsible you know. Plus I also think junior companies are not really looking at building smelters.

But I think generally in the platinum industry the senior companies are generally more responsible and would definitely be considering this. I would say that my experience with Company A is that they would definitely implement it and have it help inform decision making and not just focus on cost driven decisions. Even the other companies would do the same but some just not now.

Interview 3: CF-C

Background

I am a metallurgical engineer, with a PhD from Stellenbosch in metallurgical engineering and my current position is principal consultant at a small consulting firm. I am consulting mostly into the pyro metallurgical industry. At the moment I am a consultant and have been one for the last year and a half. Before that I was a process specialist at Company B. I was involved in many flue gas treatment projects at Company B. It has an existing dual alkali system and at that time they were looking to increase production and also to achieve new emission limits. In that time they were also looking at alternate technologies as well so I was the process leader on that study

Who is involved in making design decisions in a company?

So if you have a large project that need to run, typically the company would in-house to a conceptual study. In other words they would look at what the current emissions are, what the legal requirements are that you would need to achieve and then what would be the different technology options that would be available to help you achieve what you want to achieve from where you are currently positioned and of course taking into account any future prospects for the company in terms of where you want to be in the next couple of years.

So typically a conceptual study is done in-house and that would be done with a decent capital person and processing person and a financial person. They say typically the accuracy is 50%. So it's not that accurate but at least it shows you or rather gives you a feeling of what the total impact of a process you want to put in place would be and also to limit the number of options that you consider going forward. If you have say 5 technologies it's very expensive to take all five into the next step because now you need to start quantifying them so typically you would want to go down to say 3 options to take forward. And then obviously there are still a lot of variables that are still uncertain which you will list out.

From the conceptual phase you then enter the pre-feasibility stage. There you typically engage an engineering design company that would have sufficient experience in the specific processes that you want to study. You would basically draw up a design premise, and you would quantify the different options to about a 30% accuracy.

After the pre-feasibility stage and typically from your company you would have a finance person, processing person and capital person as a minimum involved but also you would have potentially maybe a mechanical person and an instrumentation person involved in the team because typically a pre-feasibility study without going into detail would require you to complete things like the Hazop.

So depending on what your standards are you would at least do the Hazop 1, 2 phase and you would at least have to draw up you basic flow diagrams and mass and energy balances for the plant.

So after a pre-feasibility study you would start taking you project seriously and you would draw up the budget for the next couple of years. You would also sign up a full project team manager from the company side to it and also supporter functions from process, instrumentation and mechanical areas.

So when you enter the feasibility study, the feasibility study has to go down to at least a 10% accuracy level at this point you almost complete 30% of your total design package. So it something that is a least bankable and you can take to your board to get approval for your process going forward.

At the end of the feasibility study you would quantify everything for the process you have chosen. The pre-feasibility study usually takes you down to one option because it's expensive to quantify it. But it definitely possible to take two options forward. And that the final stage. So after your feasibility study is completed then you enter your final design commissioning and construction which is the whole package to actually build the plant.

So there from the company side you can then decide from which basis you do it and you would appoint certain people to finalize it.

What drives the retrofitting of new technologies such as the SO_2 abatement case?

There is obviously more than one thing, and I will just list them as we go.

The first one is if you don't meet your design specs which happens a lot. You design a plant and everything seems perfect, but then you get a reality check when this plant starts operating and you are not achieving what you thought you would. So you go through redesigns, the furnace from Company A is a good study which has gone through 6 or 7 major redesigns after it was constructed as state of the art furnace of its kind in the industry. The reality check was a very nasty one. So that the first thing is if you don't achieve your targets.

Secondly, when plants become old or dilapidated maybe if you get new legislative requirements that impact on the plant or for some reason it's not efficient anymore.

The other thing is if new technologies start surfacing, because as a company you need to remain quite competitive at the end of the day. You are a processing facility and you need to ensure that your cost per tonne or per final product remains competitive. So if a new technology emerges that changes the playing field, very often it's possible to justify implementing that technology simply by the saving that you are going to achieve. Or if you have a major failure which can happen and at that point you will need to reconstruct.

How do you choose between two technologies that are meant to satisfy the same function?

Typically how the evaluation works is that once you have finalised your prefeasibility study, and you have two or three options left, if you have to make a decision on the one you take forward you would have to have a weighted matrix. That matrix would need to include the different aspects of business.

So certainly cost is one, then you have something like complexity and skill set. If it is a very complex system which you know there is only a couple of people in the world who know how to operate it and you have no idea of how to operate it, that would be a problem.

Risk would also be another aspect that is risk with regards to meeting the legislative targets, risks to failures and risk to social health environment and impacts. In other words you don't want to put up a system which when it has a leak people may die or something like that.

So you would preferably consider an option that produces a by-product, something that you can sell on and something that has an established market. But unfortunately those markets have inherent risks in them for example if the market is flooded you also need to pay people to take it away. So I think the other thing would be an existing market to actually produce a by-product rather than a waste product.

If you do produce a waste product then you would need to establish what would be the storage impact and what the environmental impacts would be of the storage and also long term recommendations if you have to and things like that.

I think it's not a complete life cycle assessment but at the end of the day at least any responsible company would draw up a matrix system in which they establish all of this. So it's your capital requirements and your OPEX requirements. So you would have a weighting as a panel with your management and then specific specialists in the field. As a panel you would then review each option and assign it a certain score and then at the end of the day you add them up and see what the weighting score comes up to. So the one that comes out at the top should be the option that you take forward. So at least it's an objective evaluated way of determining what to take forward.

How do you assess and incorporate environmental concerns in the design phase?

I would say primarily inadequate, it depends on whether or not you have good representation of environmental specialist on the panel that is doing the review. For instance if you have to accommodate spills and let's say you have to store it and there could be potential leakage or seepage and things like that, you design of the storage facility and if something were to go wrong how you would respond to that.

Things like energy requirements unfortunately in my experience is evaluated very much on a cost basis rather than what the addition carbon and other footprints would be. So it does not take into account what the total footprint of your process would be and also it does not look into the impacts of producing lime or the transport costs of getting lime to your plant. But rather it is evaluated from a cost perspective. And only serious incidents like ensuring that you don't have any ground water contamination or maybe dust pollution and things like that, but if you can either contain it or store it in a safe way then its deemed as acceptable think that's one aspect where something like an LCA would definitely add value because the footprints of the process are not optimally calculated.

How do you decide on which environmental assessment method you will use do you just go with the EIA because that is what is required by law?

Normally you would only engage your EIA when you enter your feasibility study. So in other words you can't approach government and get permission to construct one of the certain types of plants you have to narrow it down to a single plant and you have to have your design specifications, your final emissions, your production rates and things like.

So your EIA process would typically kick in at the end of your feasibility study before you start with your engineering package, in other words your final design construction phase. At that point in time for your EIA of course, you would then assess your emission rights to make sure your process complies and what you would also have to do especially in the case of SO_2 abatement options would be to look at your displacements. Here you would engage companies that do dispersion modelling to determine things like your stack height and if things go wrong what would be the impacts. So you have a certain number of ppm values that you have to comply to so that would be a specialist study.

If you are not producing acid as an example, and maybe you are neutralising some of the acid and you are producing waste product you would also do a specialist study with respect to the design of the facility to make sure that it is fine and safe and also that it complies, because you don't want to be hiding costs. The problem is that if you make a temporary solution and you have to go for a rehabilitation later on and those costs need to be accounted for upfront.

So I think depending on the process that you choose, you would do specialist studies to make sure that there are no hidden costs. So that typically works on a legal compliant basis. So you would get an environmental person mostly from the company itself involved and they would guide you with respect to what you need to do to achieve compliance and all this data then rolls up.

In other words all your specialist and design package with all your inputs and outputs to the plant then rolls up into the EIA process.

How do you deal with trade-offs in cases where design is driven by regulatory standards?

Companies are not inherently philanthropic. Trade-offs would be cost-benefit based always. In other words if you overkill or overdesign it comes at a cost. So if it makes sense from a cost perspective or in other words if there is the risk that legislation might increase in the future then that would have a certain benefit to choosing a technology type that can achieve better recovery so its seen as a risk in the future if you cannot.

So if you can only achieve 96% with your technology of choice and there is an expectation that in the future emission standards would increase then that becomes problematic. Would you be able to add another plant? So these would be things that you would actually think of.

But plants would design to meet the current emission standards that are applicable and then rather leave space for additional equipment pieces to be added onto it at a later time that is emission standards are to increase.

Plants would not overdesign because there is a massive cost associated with it. The jump between 98% and 99 % is phenomenal. If you need to achieve 99% it requires quite a few extra equipment pieces and often at time it requires a fundamental design change with regards to the sizing of your initial design equipment.

And from a cost benefit equation mostly that would not make sense. So I think people would primarily assess what we need to do now, what do we need to comply and what are the chances that compliance would change in the future. Once this has been considered, then rather design a plant that is fit for purpose for the moment, allow space and at least when you make a decision based on your matrix at least benefit a technology option that can increase in the future so I think that would be a way that people view it.

But I must warn you that it is extremely difficult in the SO_2 environment specifically because you technology types run into limitations. For a number of aspects; the way that you feed your plant, how consistently you feed your plant, what you feed your plant, things like that is very sensitive. So choosing a technology type and running through all the scenarios, different inputs and potential problems that you need to sort out. Because your acid plant becomes your driver at the end of the day. For you to comply you need to ensure that this is running sand it needs to sit with a constant input of gas.

So what I am trying to say is that it's not an easy choice on SO_2. For example if you look at acid plants, there are different kinds of acid plants that you can do. So once again of you needed to achieve 99.9% you would use the Cansolve if you needed to achieve 99% you would do the dry acid plant. If you needed to achieve 97% or 98% you would go for a wet acid plant and things like that. So it is fundamentally different depending on what your expectations are.

In the case where you have the 99.9% option having a huge impact in terms of cost you would not choose it but what you would do is that could put in that technology type like I said but simplistically in other words you would design it fit for purpose for now bur allow yourself to add an additional step of contact or an additional step to achieve your later stages.

It is also possible that you have your primary gas cleaning equipment and you leave that in place and what you do is that you add a second step of secondary gas cleaning equipment or SO_2 fixation plant treating the tail gas from this first step. And what is even possible with some plants is that they run a primary acid plant then they run a secondary tail gas scrubber and then they run a tertiary tail gas scrubber to achieve that recovery so of course this is costly. So if you wanted to achieve a 99.9% recovery then you would say, so I built an acid plant that can achieve that recovery from the word go or say I built three different plants at different phases to achieve the same thing.

Therefore, if you have a long term view you might just build the expensive acid plant right up instead of then differing costs to the future. Companies, in the current position in South Africa, are very capital constrained. The platinum price is the lowest it has been for the last 5 years and the industry has been shrinking constantly over the last almost 15 years. Labour relations are really tough and there is almost a very poor investment climate in the country and legislation is constantly increasing. Hence you actually get to a point where things like consolidation becomes an option because it's easy that you would be adding 15% of your total smelting costs by adding very high emission standards.

What I am trying to say is it's a major cost driver and it's a major decision and its one of those decisions that can actually kill a plant. So this is inherently an expensive process. And off-gas treatment from a smelter is one of those things that is very important to get right.

Based on the results I have shown you, do you think carrying out a life cycle assessment would be useful during the design phase?

It can be of value, and I believe there is a space from an environmental perspective at least. So if you remember that weighting matrix that I mentioned earlier where you have all the different aspects of your business being environmental, safety, health etc. You want to quantify them because all of them carry a weighting and environmental is not properly quantified so of course if you add an additional tool it will assist with the objective quantification which will help you to achieve your scoring

Therefore, I believe that there is an application for it and that it can add value. But it mainly depends on whether or not it can actually handle the complexity. Unfortunately the SO_2 abatement case is a very complex system since you processes for the different scenarios are fundamentally different in both cases.

So the results that you obtain would have to be representative of what actually happened if I were to incorporate it into the matrix if I were the environmental practitioner. So it needs to handle complexity otherwise it would just add data and not real information and nothing for decision making.

So from a business perspective I would want to know how that program functions in order for me to take these results as adding value. And because these are big decisions they are scrutinized by many people and for you to really add value you would need to make sure that it is representative of the specific scenario that you are working with. Ultimately I would say the devil is in the detail in such cases, how you approach it and how you make decisions.

It's very difficult to take an off the shelf package and feed a couple of values to it and it produces a number. One needs to put that number into perspective, what does that number mean and what am I gaining. In other words because you can quantify the costs, everything comes at a cost you can quantify it and say what's the real benefit.

So in other words let say there is a carbon tax, one would then look at what the cost for that carbon tax would be as an example so that you can actually bring all of that back into your financial statements. At the end of the day you need to generate more than just a percentage, you need to give people something to work with because people on a high level think rands and cents.

So yes the inventory results would be useful but in the case were a carbon tax is promulgated try as much as possible to quantify it, what will be the impact of that CO_2 equivalent because reality is until the carbon tax is promulgated it's a value that you manage and talk about from a sustainability perspective but in all honesty it's not really costing you more apart from the electricity costs going up. So it's still one of those things were if it becomes one of the major cost drivers in the future people would take it more seriously.

I am not saying that they are irresponsible but what I am saying is that they must also understand what it implies.

Do you think mining companies would be willing to adopt LCA thinking in design decision making as part of the EIA process?

Any tool that will provide additional information to companies in quantification of difficult projects will be adapted. As long as it doesn't only complicate the matter and generate values that are difficult to interpret.

You need to make it available in such a way that it actually generates valuable information that is applicable to the process. And yes there is no doubt that the environmental drive has become more of a concern or rather more of a driver in the last couple of years and it will continue to do so into the future. And the tools that are currently available to do the environmental assessment is a lot less than the tools that are available to do a process financial assessment or other assessment. So people would definitely be interested in adding it. But if you are adding complexity then you are not adding any value. Complexity helps no one

What would you identify as the barriers that could be faced in trying to incorporate LCA for use by decision makers?

Complexity, applicability and representativeness. So in the case of complex systems like gas cleaning if LCA is not able to quantify the assumptions made and sensitivities around those assumptions then it won't add value. If it can meet those criteria I think it would work.

Interview 4: PC3-TS

Background

I am a production superintendent. I have held this position for a year but prior to that I was a technical superintendent for 3 years. So I wouldn't really say I am a design engineer per sae but what I can say is that you can be involved in projects were decisions are made.

For example I work at one of the smelting operations that the company has and we are the only ones making acid but you will find that with the 2020 regulations coming into play the other operations are going to have to implement SO_2 abatement technologies. In such instances you will then find yourself being part of the meetings.

Therefore, even though the major decisions would be done at the head office, we have a team there and they would then come here and gather information on what is existing and say is it still the best? Do we just cut and paste or should we consider newer technology options.

How are design decisions made in the mining industry?

Look it will start from the head of refining technology and he would have two team leaders, they call them lead process engineers. So they are the ones who would then run around and gather data. With our company being so big we have acid plants even in South America. So this company gathers data even from other operations within the same company and see the recoveries that could be obtain and the current performance.

But what I have also seen is that our company really works hand in hand with other Original Equipment Manufacturers (OEMs). Very often you then get the OEM of your acid plant and say fair enough you have given me this double contact or single contact technology options, but what other technology options are available for the weaker gas?

Another good source, which option we almost went for, was getting technology options from seminars. So at the seminars you get people presenting plant experience and then you have companies that do technologies that also present. So for example there was a company from Canada that were selling ***Cansolve*** which is a technology that uses a resin to extract SO_2 to collect it, strip it and then come back and use it again.

Hence once you have decided on the technologies you would then sit and do a SWOT analysis. So you look at what are the pluses and minuses of the different options. So you wouldn't want to decide based on what's happening today but you would want to consider what is going to happen in the next 10 or so years. And again I think that one thing that our company does very well.

For example if you look at the convertors that most platinum mines use that is the *Peirce Smith* convertors, we had them until 2003. The decision was made and it was expensive but chances are now we would be the ones laughing when we go to the bank because 15 years later when other companies are now trying to upgrade because of the upcoming regulations, we've been there for the last 10 years

What drives the retrofitting of new technologies?

In the case of our acid plant we were looking for efficiencies. But there is also the issue of government regulations. So as I mentioned before this single converter we had the *Peirce Smith* convertors and with those we would exceed our limits and eventually you government stops being so tolerant. Therefore, I think when you couple government regulations with a need to operate more effectively you will then consider retrofitting.

We are a business so effectively we need to run things that make us a lot of money. So those two things coupled together is what then made our company go for this option.

How do you choose between technology options that satisfy the same objective?

Cost is normally one of the first things that you would consider. But our company would normally go for the best option that is available and then cost will come second.

Sometimes location is also a factor so say if we put a weak acid plant in Polokwane and there is no market for weak acid in Polokwane then what would you then do with it? So in the case were you are producing a product you would then need to ask yourself what it is you are going to do with the product. It's fine for us here to have a weak acid plant because all we do is feed that weak acid into the strong acid and there is a market for strong acid. So it would definitely be easy for us because we have a convertor.

With regards to cost you would need to determine how easily the product you are producing can be sold. And if you are to put up the absorber option you would need to consider how easily you would get the lime and soda ash that would be required.

You would also want to consider the location of the technology providers. So you don't want to buy a technology from the other side of the world because every time you have a challenge you would need to bring those people in.

How do you incorporate environmental concerns during the design phase?

I think we do incorporate them from the get go. Just like what you have shown me were you have a 92, 96 and 99% option. So if you have 10 options available and you do your SWOT analysis it is all about what you want. So if you want a 99% recovery already it eliminates whatever options gives you the 92% or 96%.

You would then go ahead and see from the options that give you the 99% which ones are cost effective, and which ones meet your regulatory requirements and can still be in place in the next 20 or so years.

How do you decide on an environmental assessment method to use?

I don't think it's any more specific than any other company and we generally have a huge environmental assessment division. So when you do an environmental impact assessment you will need some expert who then guides the rest of us. So I may know consequences of things but it doesn't mean that I can do a whole environmental impact assessment.

So we generally just do a basic EIA.

How do you deal with trade-offs in cases where design is driven by regulatory standards?

I am sure it will bow down to cost because cost is a huge factor. But also as I said, when you decide don't decide for now because it's one thing to spend millions of rands today or rather not and then in 5 years you need to upgrade or even restart when you could have done it 5 years ago at a fraction of the cost.

Hence cost is a factor and sometimes if you get yourself something that is more expensive it will pay off in the long run. So for us come 2020 when the new regulations are put in place we are not going to have to do much because already we are meeting those limits as is.

So we will not have to look at a billion rand more because we have already done than 20 years ago and money 20 years ago would be cheaper than what it is today. So you really need somebody who sits and looks at what will be happening in the next 50 or so years. So that allows your decision making to be further ahead and not just focus on the now. So it does help if you have money as a company.

Would use of LCA be useful during the design decision making phase?

Yes it is. For me it feeds into what I call the SWOT analysis. The more aspects you look at the better. So it is one thing to go for a specific technology but if it means you are say going to burn more and more coal and 10 years ago nobody used to speak about CO_2 emissions but now it's there so using such technologies allows you to take a look at the broader picture of things. It allows you to move from 10 technology options and helps you narrow down the options that you have.

This would be because the three would have looked at the impact on the environment. Would I have to rely on Eskom and would I have to truck in diesel every day, would I be gassing the little community down the road? So I think such an assessment would work though it won't tell me the exact option to go with it will help narrow it down to maybe three options.

Would mining companies be willing to incorporate LCA as part of the EIA process?

I think that they would. So it wouldn't come in as an extra to the EIA process but rather your EIA should follow that kind of thinking. So the EIA has guidelines that prompt you the questions to ask so I think it should be incorporated into that. So that right at the beginning you say that fine as we look at the new technologies have we considers the impacts on say fossil fuel depletion and acidification. And if it's really at the beginning it allows you narrow down the options that you have

What would you identify as the barriers?

Most likely there is already similar or existing technologies. And sometimes people don't want to change. So you have got an existing impact assessment template that works for you so adding 50 more things to the person doing the environmental assessment would definitely come with some resistance attached to it.

Interview 5: ECC-GC

Background

I have been working here for 8 years in the gas handling group where we deal with smelter off-gases. As an example, in the platinum industry we would look at SO_2 gas and how to clean it, especially to target the legislative standards. For the ferrochrome industry we would look at dust and CO emissions along with tars and other possible pollutants.

Choosing between technologies and the decision making process from a consultant point of view.

When we do a technology trade-off we always do a screening and ranking exercise. To prepare for the workshop, we develop the process in terms of mass flows, energy requirements and capital and operating costs. Once we have these numbers defined, we do the workshop with the client to determine the key criteria to screen the technologies. These criteria may include capital and technical risks and opportunities, safety, environmental and logistics.

In the workshop we assign certain weights to the selected criteria and then score each category. The technology (ies) with the best score will be further developed for implementation.

Environmental is always one of the key criteria to assess technologies. We will look at environmental impacts associated with the technologies such as wastes generated, energy consumed, water requirements, etc. Many times the study is usually performed in parallel with the EIAs so the findings of the EIA are not immediately available.

Do you have a specific environmental assessment method that you use?

No, it may be project and/or client specific. As mentioned, as engineers we would look at the process impacts on the environment such as wastes generated, energy requirements, etc. A detailed analysis as illustrated are not performed, especially not during the initial project phases

Based on the projects you have worked on how has the environmental aspect of the project been weighted?

If it is an environmentally driven project like SO_2 abatement, meeting the legislative standards is a key criterion. So we start off by doing our own screening so say we start off with 40 technology options we then ask ourselves if it meets the emission criteria. If not, we can already exclude 35 technologies. For the remaining 5 we would then need to ensure that the process is designed to meet the stack.

A key consideration between these two technologies is the production of a by-product (acid) or a waste that needs to be disposed of.

The dual alkali option might be more cost effective but the client may not want to produce a waste, in which case an acid plant is selected as preferred SO_2 abatement technology. The converse is also true where a company would not want to produce acid because the market may be saturated. It is a big problem if you have an acid producing facility and you don't have a market for acid.

If a company were to come to you with the option of making acid but then you realise that the dual alkali process is actually better in terms of the environmental impacts do you think telling them this info would make them change their minds?

It depends on how much the benefit can improve the environmental impact of the project. As an example, a marginal increase in carbon emissions between the two SO_2 abatement options is not considered a significant improvement on the environment and would not hold as strong argument to change the proposed technology. Not meeting the legislative emission criteria would be a good reason to recommend a change in technology

The capital and operating cost of implementing technology is also a big consideration to recommend a change in selection:

As an example, the dual alkali process may have lower capital costs during start-up but have higher operating costs in the long run. A sulphuric acid process might be the opposite in terms of capital and operating cost. This therefore becomes an important trade-off.

In some cases however, the implementation of SO_2 abatement is rather considered as an instant purchase to comply with the legislation immediately and operating cost becoming a concern that will be managed later.

Not producing a waste will be a great benefit to client but may be second as a decision criterion for selecting a technology when considering the capital and operating costs.

How do you deal with trade-offs?

As mentioned, a workshop is conducted to weigh and screen the technologies based on predetermined criteria relevant to the project and client.

Optimal operating efficiencies for the two technology options

If there is a positive market for the acid then producers might want to capture as much SO_2 as possible. In most cases we deal with, acid production is the result from SO_2 abatement and the plant will be operated with the target to meet the environmental limits only. In such a case a plant efficiency will be targeted to achieve the required environmental emission limits and not lower.

New plants will also be designed to the required efficiency set by meeting the environmental standards as a maximum to save capital and operating cost.

Would you design for future changes in regulations?

In the current economic climate the advice to a client will be to company to current emission limits only, especially if little money can be recovered from the by-product (such as the selling of acid).

Current projects in South Africa have mostly been based on 2020 standards as these are the only standards currently relevant.

The SO_2 abatement plant can also be designed to be expandable to achieve better efficiencies should the legislation become more stringent. As an example, in the case were you have the single contact acid plant, space can be allowed for future expansion a double contact acid plant. An alternative would be space for the installation of a tail gas scrubber at a later stage.

There is also other factors involved because single contact vs double contact isn't just dependent on outlet concentrations but it is also dependent on inlet concentrations. A 4% SO_2 inlet gas would allow a single contact plant to operate auto thermal but at higher concentrations a double contact acid plant option would be a better technology choice.

Based on the results that I have shown you do you think LCA would add value to decision making?

I am sure companies would be willing to see the results from the LCA as it will eventually go into their technology decision making and they could also report the results in their sustainability and annual reports. Showing the public that you have chosen a technology that has low environmental impacts on, for example global warming, would be beneficial.

We are however of the opinion that the results will not necessarily be a key driver in the technology selection. It will be dependent on the severity of the impact on the environment. Human toxicity, as an example, will have to be assess to determine the differential impact between technologies

Water demand, another example, might be a significant impact especially if you are in a water scarce area. In one our projects water scarcity was a key requirement, and we had to design for low process water requirements. The LCA results that highlight which a key impact early on will be beneficial. The results can then be used as input into the ranking that mentioned previously.

Do you think mining companies would be willing to incorporate it as part of the EIA process?

Capital and operating costs are mostly the key drivers but company policies may play a part. South African based companies may only target South African emission limits as a maximum but European based companies investing in a plant in Africa may set World Bank standards as a design criteria or would like to see more environmental benefits be added to the technology selection criteria.

Interview 6: PC4-TS

I am the Group executive of technical services at Impala Platinum Limited. I have worked as a design engineer but not necessarily on SO_2 but I have had to sporadically have involvement in plant design associated with sulphur emission and capture.

How are design decisions made?

Everyone with involvement across myriad disciplines is involved in decision making. So say for example you were talking about the selection of a technology then you would have a discipline like HR Involved with the public participation meeting s with the Interested and Affected Parties, you would involve the Legal Department on the compliance side, you'd involve engineering in the maintenance of systems and so on.

From a financial perspective we do these things not necessarily on a life cycle analysis but rather we do it on a value analysis. So you take your legislative limits as you minimum limits and you design around which one is likely to give you the best value. So that would be looking at CAPEX vs OPEX and then benefits vs sales etc.

Upfront it process engineers would be the most involved, but then after that it basically involves everyone who is in the decision making framework of the company.

What drives the retrofitting of new technologies and how would you choose between technologies that satisfy the same option?

Value. It's a cost benefit analysis, you put in what your assumptions are and you put in what your legal limits are, you look at the CAPEX, you look at the OPEX and you look at what the benefits are and you look at what the optimal solution to the company is.

So for example you require a solution to sulphur fixation. There are possibly two solutions: A scrubber and an acid plant. You will do a cost benefit analysis of the scrubber and find that it has a gypsum by-product that has a significant disposal cost but its CAPEX is significantly cheaper than the acid plant even though its net OPEX might be more expensive.

If you then look at an acid plant you see that the CAPEX is enormous, but the OPEX because it's an exothermic reaction is reasonably low. And let's say you can sell the acid or at times you are going to have to assume that you can just give it away because the market for it is very volatile. A Net Present value for both projects is calculated and on that basis you make a decision on which technology to advance.

And deciding on what the company values the most in terms of CAPEX and OPEX depended on where the company is financially. In a commodity down turn, cash flow may well be the defining parameter. So CAPEX is very difficult to come up with so at times you might end up favouring a low CAPEX cost and take accept the higher operating costs. But by in large when you are working out a Net Present Value over a number of years the operating cost has a greater impact and the CAPEX has less sensitivity to the NPV.

For this reason, you may elect to implement a technology that had a higher capital cost and but a lower operating cost. These are just two of the elements considered. There are other things that feed in as well like your social obligations and your local community and the products that you may need to source. So it's not just CAPEX and OPEX.

How would you then incorporate environmental concerns during the design phase of a project?

We wouldn't have any concerns because we would do an EIA which would involve public participation with interested and affected parties so that you would have all their opinions/perspectives/concerns. Many of these issues may come back to you through the department for certain stipulations on the record of the decision and those stipulations then get fed into the design. In conjunction with the legislated limits the design is completed.

If you are a company that is JSE - listed and is in the top 40 companies, you are morally obligated to do what's best for your stakeholders.

For companies not listed it would then be the outlook and the ethical characteristics of all the stakeholders at that particular company. By in large I think most companies do what is right.

How do you choose between two technologies that satisfy the same function?

Again I am going to say “VALUE”. So we look at the trade-off between having to dump the gypsum because there is very little that you can do with calcium sulphate. You also cannot dump it together with your tailings waste so you would need to dump it on a lined facility which is a hazardous lined facility. So that has a significant cost attached to it.

If you decide you can sell the acid say for R100 per tonne, generally when we design acid plants we tend to zero value the acid because the bottom line is that there are periods in which there is a surplus of the acid in the acid market and you cannot sell your acid. So if you cannot sell the acid and no one is prepared to take it away then your smelter stops. You definitely cannot afford for that to happen so you often decide to value the acid at zero saleable value and take the upside if prices are above that..

But on the other side of the equation the dual alkali plant is most likely to cost you a lot less capital and the acid plant option is going to cost you an arm and a leg. The dual alkali case is definitely going to cost you some money for disposal and the acid option probably not. So it is just the value proposition between the two.

Companies would probably produce the acid as a way of lowering their operating costs. So in our case our company has an acid plant but it's not because we saw a future in the acid market but rather in terms of the value proposition that was the better bet at the time.

In the event that you had to choose between a technology option with lower environmental impacts but produces a waste and one that produces a product with value how would you deal with the trade-offs?

We would have to put value on the impacts. You need to have some form of matrix for measuring what the value is or the benefit of making less environmental impacts.

How do you deal with trade-offs once legislative limits have been reached?

On "VALUE". If a plant costs less than another plant and is less to run and on a balance of CAPEX to OPEX the benefits to stakeholders are high then that is the option that you usually go for.

So how then do you factor in the impacts associated with the different recoveries for example the cost of energy that will be required. Is it purely on a cost basis or do you look at the environmental aspects?

Again I would say we look at the value. Because what we would do is that we would say for example this option cost us so much amount of energy to get the last 7 %. The cost of that energy is say 95c per kWhr plus the indirect carbon tax that we would pay to Eskom to produce that energy. So we take that in as a cost or non-cost whichever it will be and we decide on which one is the better value.

It might sound as though we are only interested in money but all we are doing is using value or money as a measure for whether we are going to do something or not.

But for instance at the moment we are busy looking at putting some fuel cells in as an alternative to the Eskom grid. Now those are always going to be more expensive than buying kWhr's from Eskom but if we take into account potentially what we might end up paying as a carbon tax which is say a R100 per tonne and you build that into the financial model, hen that would be something you would not pay if you had a clean gas going into the fuel cell. You build it into the model and it allows you to pay more for your power in the fuel cell and still come up with something that is more beneficial than buying Eskom at a lower tariff.

So we just use value as a metric for measuring all the things that influence a project.

Do you think the LCA results I have presented to you would help inform design decisions?

To some degree we already look at the impacts of the different processes in our risk assessments. So you would have things like human toxicity and acidification being taken into account. And in your risk assessment you would assess the life cycle of the project through the conceptual study, pre-feasibility study, feasibility study, the final design before going into the implementation. At the pre-feasibility study you would be looking at the various options and assessing which of them is best taken into the feasibility study.

At that stage you would do a risk assessment and you would look at the various processes and you would have a look at the impacts of thing like for instance toxicity and the impact on global warming. We have in our sustainability report a section were we have to report on our impacts. And so there is an understanding that we must minimise our impact on global warming. To some extent that is taken into account within the pre-feasibility study. But not necessarily as a life cycle assessment.

I doubt at the moment we would base decision - making on something like this.

Would mining companies be willing to incorporate LCAs as part of the EIA process?

EIA's are now on the critical path of any new technology implementation project.

You are going to spend a minimum of 18 months to 2 years doing an environmental impact assessment. By the time you finish it, the commodity cycle could have bottomed out and you maybe no longer have the funds to build that acid plant.

So there are far more company - critical, industry - critical issues. If the LCA is going to prolong the EIA process, you would have to understand the impact of that. Interested and affected parties with have a significant amount of detailed information and there's every chance that the process is prolonged.