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Life Cycle Assessment of Artisanal Mining: The Case of Sandstone Mining

By

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October 2017
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Urla Darlyne Moukita Koumba
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This study establishes the extent to which artisanal sandstone mining affects the environment. A review of literature on artisanal and small-scale mining (ASM) and environmental damages shows that studies focusing on the environmental impacts of ASM – including sandstone – are very scarce, in comparison to those on other mined commodities such as gold and diamond. The present study was undertaken in an effort to address this shortfall. Although most studies on the effects of artisanal mining focus on social, economic, human health and other aspects, the present study examines the environment – from a holistic point of view – and considers the overall environmental degradations resulting from artisanal and small-scale sandstone mining activities in QwaQwa, South Africa.

ASM is generally regarded as a means to support and improve local communities’ quality of life. In rural areas, especially, ASM is often the only activity that local communities have to sustain themselves. As such, it becomes important to understand the nature of artisanal sandstone mining and its associated environmental effects, so that informed decisions can be made regarding the management, licensing, and policy formulation in this particular sector.

Life Cycle Assessment (LCA) provides a very useful framework for analysing the environmental burdens associated with artisanal mining processes and products. So far, its various applications in the mining sector, though still minimal, show that the LCA is very much versatile and can offer great opportunities to the mining sector. It is for this reason that this study applied the general principles of the ISO 14040 series (which deals with LCA standards) to artisanal sandstone mining, to assess the overall environmental damages related to that activity. The study focussed on the following impact categories: resource depletion, global warming, ozone layer depletion, and acidification. Energy, land, and water usage as well as work environment were also considered.

The study revealed that the impacts of artisanal sandstone mining on the environment were minimal, when compared to those of other artisanally-mined commodities. For most of the impact categories selected, transportation involving the use of fossil fuel was the greatest contributor. The results also showed that the high physical demand of the work negatively affected the miners’ health and that the most significant negative impacts of sandstone mining were on the natural landscape.
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CHAPTER 1

INTRODUCTION AND BACKGROUND

This chapter provides a detailed description of the problem as well as the background and justification of the study, states the objectives of the research, and elaborates on the methodology used to analyse the environmental damages caused by artisanal mining. The chapter also explains the importance of the research and outlines the possible contribution of the study to miners, the government, the expert or the scientific world, and the general population.

1.0 Introduction

Mining plays an important part in the growth and development of various countries around the world – including South Africa. Indeed, the mining sector and its related industries are key contributors to the socio-economic development of South Africa. According to the Chamber of Mines (2014), the total contribution of mining to the GDP of South Africa is around 7.6%. However, although stone mining does not contribute significantly to the total income from the mining industry as the other mined commodities, such as coal and gold, it cannot be ignored. Ashmole and Motloung (2008a) noted that the stone mining sector is growing at a rate of 7% per annum – with a global turnover of around 60 billion US dollars per annum. The above figures demonstrate the need to pay attention to the artisanal and small-scale mining (ASM) sector, as warranted by its contribution to the total income of South Africa.

Despite all the goods that mining provides to the world’s economy (raw materials for industrial processes and resulting products or those directly derived from mining), the sector is still mostly perceived negatively because of the adverse environmental and human health issues associated with mining activities. The ASM sector in particular – which often operates outside the law and does not adhere to mining legislations or standards – is perceived as being illegal, unsafe, and extremely damaging to the environment (Naidoo-Vermaak, 2006). While the large mining sector which is quite well controlled and regulated is making visible efforts to reduce this negative perception by improving its environmental performances through the adoption of environmental management systems such as ISO 14001 (Naidoo-
Vermaak, 2006; Awuah-Offei and Adekpedjou, 2011), the ASM sector is still lagging behind regarding environmental management practices. Hence, this research study focuses on the environmental impacts of artisanal mining in South Africa.

With the mining sector’s growing adoption of environmental management tools and systems to evaluate and minimise the impacts of its activities on the environment, life cycle assessment (LCA) has emerged as a useful tool to achieve this objective. This is because it considers the impacts from the beginning to the end – entire life cycle – of an operation. Although the application of LCA in the mining industry is still quite limited, a number of LCA mining studies are traceable in the literature. However, they almost solely focus on large-scale mining.

Thus, this research study focuses on the application of LCA principles in the artisanal sandstone-mining sector in South Africa. The primary objective of the study is to apply LCA principles, adapting them when necessary, to estimate the “cradle to grave” environmental impacts of artisanal sandstone mining in South Africa. The research seeks to provide relevant data and reduce the deficiency in terms of the limited amount of available literature on sandstone mining.

1.1 Problem statement

For the past decade, the realisation that human activities can have damaging impacts on the environment and human health has compelled organisations to develop environmental sustainability tools. Those tools are mostly used to help organisations estimate the environmental impacts of their activities and identify areas for resources and energy optimisation. Among various environmental management systems, the Life Cycle Assessment (LCA) methodology is one tool that has proven to be successful in doing so because it provides a comprehensive evaluation of the environmental impacts of an operation or a system from the beginning to the end of its life cycle. The idea of engaging in environmental sustainability is increasingly growing in the mining sector. Unfortunately, most efforts on this front are made by large scale mining organisation while the artisanal and small scale mining (ASM) is still lagging behind. Therefore, it is important to promote the adoption and application of environmental assessment and improvement tools to the ASM sector to provide valuable data on the processes used and their consequences on the environment. Moreover, aside from its environmental assessment and improvement
capability, the LCA can be applied to achieve the process, energy and resources optimisation that leads to sustainability.

1.2 Background and justification

Over the past years, issues concerning the impact of mining activities on the environment and populations have increased. Noise, the destruction of the natural landscape, deforestation, the disruption of water drainage, the release of pollutants/greenhouse gases and/or malodorous substances, dusts, the generation of solid non-recyclable waste are but some of the environmental effects of mining activities. Ultimately, these effects lead to air, water, and soil pollution that, in turn, results in climate change, human and eco toxicity, as well as the disruption and destruction of the natural ecosystem. This public concern has prompted the mining industry and government legislators to take various steps to elaborate more environmentally-conscious legislations and standards (Hentschel et al., 2003). Therefore, it becomes imperative for the mining sector to quantify and analyse the impacts that its activities have on the environment, to identify opportunities for improvement and minimisation of the abovementioned impacts – in order to ensure sustainable development (Suppen et al., 2005). Although many other environmental management systems (EMS) such as ISO 14001 exist, the LCA methodology – because of its versatility in terms of application – is emerging as a tool that could benefit the mining sector. Indeed, it allows for the impact assessment and the efficient use of resources (Awuah-Offei et al., 2011). The large scale mining sector has made visible efforts to minimise its negative impacts on the environment and has been able to achieve sustainability through the adoption of more effective and efficient environmental management practices. In this regard, Hentschel et al. (2003) noted that large-scale, formal, mining organisations mostly adhere to well regulated environmental management practices and standards set by both legislators and the mining industry itself.

Conversely, the ASM sector remains mostly unregulated insofar as improving its environmental performance. It suffices to note that most often than not, ASM impacts on the environment often go unnoticed or are simply not addressed because its informal nature makes it extremely difficult to track or control its activities (Naidoo-Vermaak, 2006). In regions where ASM is often the sole means of subsistence, the lack of formal environmental management practices has proven to have adverse consequences on the environment and the surrounding populations.
A significant number of research studies that contain data that quantify the inputs and outputs to nature and assess the environmental damages caused to the environment by large-scale mining organisations can be found in the literature (Norgate and Rankin, 2000; Ditsele, 2010; Norgate and Haque, 2012; Ferreira and Leite, 2015). However, limited information and reliable data on ASM is available because this sector is still mostly informal or unregulated. A review of the available literature shows that research studies that deal with the consequences of ASM and other types of informal mining cover a vast array of environmental, social, and economic issues. However, most of these studies focus on the artisanal mining of such precious metals and minerals as gold and diamond (Hilson, 2002a; Hilson, 2002b; Hentschel et al., 2003; Tieguhong et al., 2009; Lichte, 2014). Very limited literature on the environmental impacts of the artisanal mining of construction materials or dimension stones like sandstone – particularly in South Africa – exists.

Artisanal sandstone mining in South Africa, like all other forms of artisanal mining, is characterised by the fact that miners use basic tools to extract the stone from the quarries. Moreover, the “informal” nature of this type of mining activity implies the absence of data that could help to quantify the inputs and outputs of the extraction process and its resulting effects on the environment. Since this method of extraction is so different from that used by larger sandstone mining organisations that use more complex techniques that are both more efficient and sustainable, it becomes important to determine how the artisanal mining of the sandstone may affect the environment.

Sandstone is a dimension stone, that is, a type of natural stone used in construction for ornamental or decorative purposes. One of its main characteristics is that, contrary to other mined resources, it is used in its natural state: it does not necessitate concentration and extraction from an ore (Ashmole and Motloung, 2008b). Its mining process mainly involves the careful extraction of large blocks or slabs of stone from the quarries (when large blocks are directly extracted, they are latter cut into slabs). This is followed by transportation to processing plants where the slabs are polished and readied for commercialisation (Borlini et al., 2012). The mining methods used in the extraction process range from basic technology to high-tech or advanced ones (Ashmole and Motloung, 2008a). Given that the extraction process must be executed in such a way as to preserve the integrity of the stone, the used methods must be engineered to have as little impacts as possible on the surrounding environment (Ashmole and Motloung, 2008b). Despite the fact that the mining of stones result in less environmental impacts than that of other minerals like gold or manganese, a
review of current literature on the subject suggests that the sandstone’s production process nevertheless brings its fair share of environmental costs (Ashmole and Motloung, 2008a; Borlini et al., 2012). This has been eclipsed by the fact that most of the available literature focuses on large-scale mining; little mention is made of sandstone.

Consequently, the LCA is undertaken in an effort to assess the environmental impacts of artisanal sandstone mining in South Africa. This is because the LCA is a comprehensive tool that could effectively assess the social and environmental impacts of artisanal sandstone mining within the boundaries of this research study. The outcomes of the study will be communicated to the dimension stone industry of South Africa and could be used by authorities to develop relevant laws and regulations pertaining to that sector. Additionally, the results should be used by stakeholders to identify potential challenges faced by ASM sandstone miners and assist in developing effective solutions.

1.3 Research goal and objectives

The primary goal of the study is to assess the environmental impact of artisanal sandstone mining in QwaQwa, South Africa – using the general guidelines of the ISO 14000 series. In order to reach this goal, the followings objectives should be fulfilled:

- Determine the processes involved in artisanal sandstone mining.
- Determine the inputs and outputs of each processes
- Assess the level of emissions associated with all inputs and outputs and categorise them accordingly.
- Identify areas-for-improvements.
- Promote sustainability and clean production in the ASM sector.

1.4 Research methodology

This research study is performed according to the general guidelines of the International Organisation for Standardisation (ISO) 14000 series (DEAT, 2004). According to the ISO, the LCA has four components, namely, goal and scope definition, inventory analysis, impact assessment, and interpretation.
1. Goal and scope definition

Goal refers to the statement of the aim of the research study and the provision of the reasons for conducting the study, the intended use of the research outcomes, as well as the targeted audience (Guinée et al., 2002).

Scope involves defining the limitation of the study; for instance, the temporal, geographical, and technological coverage boundaries (e.g. functions of the systems being analysed, the functional unit, and so on). This phase can also include the description of the products or services being assessed in terms of function, as well as the assumptions about the study (DEAT, 2004; Guinée et al., 2002).

2. Inventory analysis.

Inventory analysis involves identifying and quantifying the inputs (e.g. energy, water, material, and so forth) and outputs (e.g. emission to air, water, and soil) related to each stage of the product’s life cycle and weighting the gathered data to the functional unit. This helps to determine the overall environmental impact of the product (DEAT, 2004).

3. Impact assessment

This step involves interpreting the information gathered in the inventory phase and assessing it in terms of environmental and human health risks. This step also involves selecting impact categories and assigning them to the inventory outcomes (DEAT, 2004).

4. Interpretation

The last step of the LCA consists in the analysis of the results of the previous phases and the formulation of the relevant conclusions. It is in this phase that the limitations of the study are specified and recommendations are made. These are based on the outcomes of the study and the goal and scope defined in the first phase (DEAT, 2004).

1.5 Rationale for the study

This study is undertaken in an effort to promote sustainability in the artisanal sandstone mining industry in particular and the mining sector at large. Although almost all environmental assessment tools have some limitations, the LCA is selected for this study because it is effective in evaluating all the environmental aspects of a product or activity. While the benefits of such an environmental assessment can be multiple, the study hopes to provide valuable information regarding the environmental burdens associated with artisanal
sandstone mining. It is hoped the results obtained will inform the general public, the industry, and the government on the true impacts that this sector has on its surroundings. The outcomes of the study can also be used as a supporting tool for policy-making decisions in aspects where environmental and health improvements are necessary. Other benefits of this study of the artisan sandstone mining sector include:

- Evaluation of the true environmental and societal costs of artisan sandstone mining.
- Understanding the environmental impacts of the sector will encourage stakeholders to participate in the effort to adopt sustainability practices.
- Outcomes can be used in the development of policies and regulations for both the artisan mining sector and sustainability.

1.6 **Structure of the study**

The second chapter deals with the literature review. The third chapter elaborates on the methodology used. The fourth chapter provides background information on the mining site that constitutes the case study in this research. The fifth chapter indicates the goal and scope definition and provides the inventory analysis. The sixth chapter covers the impacts assessment and result interpretation. The seventh chapter focuses on the improvement assessment and the issuing recommendations. Finally, the eighth chapter concludes the whole research study and provides directions for future research.
CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter reviews the literature pertaining to the application of the LCA in the artisanal sandstone mining. The subjects covered range from the principles of the LCA, the impacts of the mining industry on the environment, as well as the application of the LCA in mining and its potential challenges.

2.1 Sandstone and its uses

Sandstone is a type of sedimentary rock usually composed of quartz sand in a cementing material. The most common types of cement include calcite, iron oxides, silica, calcium carbonate, and clay. These can be found in higher or lower levels in stones, depending on the geographical location. Sandstones can virtually have any colour from tan, brown, yellow, purple, green, black, grey, tinted pink, to red and white (Ahmad, 2015).

Stones are categorised according to their texture, colour, and composition. The commercially available categories of stones include siliceous sandstone, calcareous sandstone, ferruginous sandstone, and argillaceous sandstone.

Natural stones like sandstone have been used as construction materials for centuries. Although the demand for natural stone faces increased competition from industrially-produced building materials such as concrete, bricks and glass, a great market for natural stone remains in domestic construction. The various applications of sandstone include paving, landscaping, tiling, and walling (Figure 2.1). Sandstone is also used for making housewares and for artistic purposes – to create monuments, tombstones, sculptures, and so on. However, the sandstones mined in the QwaQwa area of the Free State province of South Africa are mostly used for bricks and cladding. This is because the lack of advanced shaping tools prevents other applications (Mukuna, 2009). The figure below illustrates some of the applications of sandstone.
Figure 2.1: Application of sandstone in construction and architecture.

From left to right: sandstone tiles (www.mazista.co.za), sandstone bricks (www.owenwilson.com.au), and sandstone cladding (www.sandstone-pavers.blogspot.com).

2.2 Geological map of South Africa

The presence of sandstone is quite common in the South African rock formation (Figure 2.2). Indeed, this country holds some of the most spectacular “sandstone landscapes and landforms in the world” (Grab, 2015). One prime example of such impressive presence is the Golden Gate Highlands National Park, in the Free State, which is well known for its massive sandstone formation.

Figure 2.2: Simplified geological map of South Africa.
2.3 What is artisanal and small-scale mining (ASM)?

Dorner et al. (2012) affirm that there is no formal definition of artisanal and small-scale mining, yet. In the context of this study, the phrase artisanal mining is used to describe a type of activity performed by miners who are not formally employed by any mining organisations. These miners work in small groups of family members, relatives, cooperatives or friends – without any license or formal authorisation. Artisanal mining is mostly manual and very labour-intensive; the miners use inadequate and basic or simple tools (picks, shovels, and so forth) and techniques (Chakravorty, 2001; Dorner et al., 2012). Although artisanal mining takes place in every part of the world, it is most common in developing countries where it is generally a way of sustaining local communities. In other words, it is – in essence – a poverty driven activity (Buxton, 2013). Due to the informal nature of artisanal ASM and the fact that small-scale miners often move around, depending on the areas where work and resources are available. Consequently, there is no way of controlling and monitoring how their activity may affect the environment. Hence, many view artisanal mining as an environmental disaster in-the-making (Dreschler, 2001).

In South Africa, the presence of “informal” mining and/or the ASM is quite common and grew substantially for the past decades (Mutemeri et al., 2010). Informal mining is generally regarded as a poverty-related activity that helps to sustain poor communities. Nonetheless, in some cases, the ASM is used as a front for criminal activities (Dreschler, 2001). Providing an accurate picture of the spatial distribution of the ASM in South Africa is almost impossible, because of the lack of sufficient data on the subject. However, generally, the presence of the ASM in an area will depend on the geological presence of a commodity and the economic activity undertaken in the immediate geographic area (Mutemeri et al., 2010). The mined commodities – which include precious metals and stones (e.g. gold, diamond), industrial minerals (e.g. kaolin, limestone), and construction materials (e.g. granite, sandstone) (Mutemeri et al 2010), are varied. Benkenstein (2012) noted that in Africa, around 8 million people were engaged in ASM mining activities. In South Africa alone the number of workers in the ASM sector was estimated to be between 10 000 and 30 000. It was noted that although an exact number could not be provided, miners who operate outside a legal framework
significantly outnumber those with appropriate mining licenses (Ledwaba and Mutemeri, 2017).

The Mineral Bureau (1996) has classified small-scale mining according to the number of people operating the mine. This classification resulted in the following categories (Heath et al., 2004):

- Artisanal mining: operations involving 1 to 5 people.
- Micro-scale mining: activities involving 6 to 20 people.
- Very small-scale mining: mining operations involving 21 to 49 people.
- Small-scale mining: activities involving 50 to 99 people.

Quite a number of small-scale mining associations such as the Small-Scale Mining Chamber or the African United Small-Scale Miners exist and work towards fulfilling the needs of artisanal and small-scale miners (e.g. access to finance). The ASM sector is regulated by the Mineral and Petroleum Resources and Development Act of 2002, the Health and Safety Act of 1996, and the National Environmental Management Act of 1998. These acts provide standard guidelines on mining practices, as well as miners’ safety and environmental management practices. Generally, however, artisanal and small-scale miners do not adhere to these regulations and guidelines, because they find them burdensome or unrepresentative of their particular situation (Dreschler, 2001). Heath et al. (2004) mention that the Department of Minerals and Energy (DME) initiated the development of a National Small-Scale Mining Development Framework whose objectives are to provide assistance to small-scale miners regarding the compulsory regulatory and administrative procedures, reserve determination, business plans, and mining methods.

2.4 ASM and environmental sustainability

Defining sustainability is a difficult task as its meaning differs from one stakeholder to another (Ditsele, 2010). In other words, sustainability means so many different things to so many different communities that the concept itself is tainted with ambiguity (Ciegis et al., 2009). The concept of sustainability depends on whether it is used from an economic, environmental, ecological, social, ethical or governmental perspective (Ciegis et al., 2009; Ditsele, 2010). Nevertheless, today, it is generally accepted that sustainable development requires a balance between economic, environmental, and social aspects (Harris, 2003;
Soubbotina, 2004). According to the World Commission on Environment and Development, development is deemed sustainable when “present generations are able to meet their needs without compromising the ability of future generations to meet their own needs” (Harris, 2003).

Applying the concept of sustainability to the mining sector can be a complex task. Firstly, mining is by nature a non-sustainable activity, since it is based on the exploitation of non-renewable resources. Secondly the requirements of a large number of stakeholders need to be satisfied (Lins and Horwitz, 2007; Mudd, 2009; Ditsele, 2010). Thirdly, there are so many different views and issues related to sustainability in mining that variances exist in the various stakeholders’ priorities (Mudd, 2009). Nevertheless, concerns over the impacts of mining activities, such as environmental degradation and depletion of natural resources, have become so emphasised that the mining industry is increasingly embracing the concept of sustainable development (Ditsele, 2010). Some organisations are even moving beyond compliance to industry requirements – by incorporating sustainability into their management systems and by using environmental performance analysis tools – to improve both their environmental performance (EPA, 2006) and their public image.

Although the mining sector is making visible efforts to decrease the adverse impacts of its activities on the environment, the ASM’s contribution to sustainable development is still lacking (Dreschler, 2001). Hentschel et al. (2003) argue that this sector is mostly considered as fundamentally unsustainable, because of its high environmental costs and poor health and safety record. This may partly be due to the relationship between the level of concern for the environment and the community’s level of welfare (Ditsele, 2010). It can also be because artisanal miners are more likely to emphasise economic growth over environmental sustainability. For example, Dreschler (2001) noted that artisanal and small-scale miners rarely engage in land rehabilitation programmes. Moreover, instead of considering artisanal mining as a possible poverty-reducing and tool for sustainable development, governments, larger mining organisations and NGOs often focus on the negative impacts of artisanal mining. Consequently, they choose not to interact with this sector, that is, they do not address the challenges preventing artisanal miners to engage in sustainable development. As a result, ASM remains underfunded and neglected in most parts of the world (Buxton, 2013). Another issue is that, in instances where governments and legislators manage to elaborate legislations and standards pertaining to artisanal and small scale-mining, concerns are raised about the suitability of these legislations to the ASM sector (Mwakaje, 2012). In this regard, Dreschler
(2001) noted that miners often find ASM-related laws and regulations difficult to comply with and unrepresentative of their particular situation and thus chose to ignore them. A few international standards on industry requirements and policies on mining and sustainability deal with artisanal and small-scale mining as a sector (e.g. IFC Performance Standards); but, most of them do no mention ASM (Hentschel et al., 2003; Buxton, 2013).

2.5 Environmental impacts of stone mining

People have been mining stones and minerals since pre-historic times. Clearly, mining activities play an important part in the economic and social upliftment of society (Ditsele, 2010). This is especially true for artisanal and small-scale mining which remains the main livelihood of impoverished communities in various part of the world (Buxton, 2013). Nonetheless, the mining sector has many adverse impacts on the environment, the society, as well as the health and safety of the miners and the local community, in some cases (Kitula, 2006). The impacts of dimension stone mining on the environment are relatively small compared to those of other mined minerals and metals. Hazardous gas emission (e.g. carbon dioxide), which is relatively low, emanates mostly from oil-powered engines of trucks or pieces of mining equipment. Conversely, soil and water contamination, which is also very rare, is mostly caused by petrochemical spillage or poor waste management practices (Ashmole and Motloung, 2008b). Since the stone is used in its natural state and does not necessitate concentration and extraction from an ore, several environmental issues related to these two processes – which are directly associated with the metal extraction industry – are avoided (e.g. acid mine drainage) (Ash mole and Motloung, 2008b). Additionally, large blocks of stone are extracted as carefully as possible to avoid any damage to the stone. As it becomes evident, the mining and extraction methods used generally have minimal impacts on the surrounding environment (Ashmole and Motloung, 2008b). Recent developments in the dimension technology such as improvements in the diamond wire sewing efficiency have resulted in a reduction in the use of explosive in the extraction of stones and an increase in the recovery of usable blocks of stone. This has lowered the quantity of waste rock, the amounts of blasting gases emitted, as well as the noise and ground vibrations (Ashmole and Motloung, 2008b).
2.5.1 Land disturbance
Given that mining activities usually deal with large areas of land, landscape disturbance is one the most visible impacts of mining. In the case of dimension stone mining, large blocks of stone are directly extracted from quarries that the public can easily see (Ashmole and Motloung, 2008b). This results in a dramatic visual effect, as the quarries are usually in operation for long periods. People can see the gradual changes in the appearance of the land. The extent of the damages is usually related to the size and location of the quarry (Langer, 2002). In South Africa, poor mining practices and lack of industry requirements have led to such adverse visual impacts that the Department of Minerals and Energy considers the environmental impacts of dimension stone mining as being severe (Ashmole and Motloung, 2008b). Besides the negative visual effects, land use damages also affect the vegetation, animal life, as well as the quality of both ground and surface water. Ditsele (2010) warns that excluding land use impacts on the environmental assessment of products would be a mistake, as they contribute significantly to the changes in global biodiversity.

2.5.2 Destruction of habitat
The destruction of the flora and the fauna’s habitat is directly linked to the land use impact of mining. Most often than not, mining organisations have to remove the grass and vegetation that constitute the natural habitat of the local fauna. Furthermore, foreign presence, noise, and infrastructure related to mining operations (e.g. roads) can affect animals’ breeding and/or behaviour and effectively disrupt the ecosystem (GDACE, 2008).

2.5.3 Dust
One common complaint associated with any types of mining activity is the degradation of the air quality by dust. Dust is present in almost all forms of mining and it is the most visible, irritating, and potentially harmful type of pollution (GDACE, 2008). Dust can occur during land clearing, drilling, blasting or crushing of the stone, as well as during the transportation phase. Although its visibility often raises concerns that are disproportional to its impacts (Langer, 2002), dust is linked to a number of health and environmental issues. Miners and surrounding communities exposed to dust are at a greater risk of developing dust-born infections, respiratory diseases, and other related health issues. For example, it was observed in Tanzania that children who were exposed to dust for a long time had more chances of developing silicosis and silico-tuberculosis, and that the rate of miscarriage also increased with the presence of dust (Kitula, 2006). It is also noted that dust can retard the growth of
vegetation (GDACE, 2008) and alter ground water recharge by clogging the pores in the ground (Langer, 2002). Dust deposition is measured in units of g/m² per month of dust fallout and is usually measured against registered pre-mining dust levels (Saviour, 2012).

The different types of dust are described in Table 2.1 below.

Table 2.1: Dust classification and description (GDACE, 2008).

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nuisance dust</strong></td>
<td>Reduces environmental amenity without necessarily being harmful. It comprises particles in the 50µm to 1 mm size range and equates to the total suspended particles (TSP).</td>
</tr>
<tr>
<td><strong>Fugitive dust</strong></td>
<td>Derived from non-point, mixed source.</td>
</tr>
<tr>
<td><strong>Inhalable dust</strong></td>
<td>Particles commonly less than 1µm size range (PM10) (80% from 2.5-10µm size range) and inhaled into the trachea and bronchia section of the lungs.</td>
</tr>
<tr>
<td><strong>Respirable dust</strong></td>
<td>Dust less than 2.5µm (PM2.5) that penetrates the lung’s unciliated airways and lodges itself in the alveolar region.</td>
</tr>
</tbody>
</table>

2.5.4 Noise

Just like dust, noise is an inherent aspect of mining. The most common sources of noise are blasting, the extraction process, and earth moving equipment (Langer, 2002). For such stones as sandstone, blasting (using explosives to break stones into workable size) is infrequent and only occurs once or twice a year (Langer, 2002). This is because of the need to reduce the damages to the stone and preserve its integrity as much as possible. Although this helps in reducing the noise levels, the equipment used for the extraction process as well as the vehicles and trucks used to transport the equipment and the stones still create a range of noise levels that can negatively affect nearby communities.

According to the GDACE (2008), in 1992, Johnson published a very useful study of noise – from an environmental perspective. Given that noise measurement is reported according to
the frequency-weighted scale (A-weighting) and in dB (A), he asserted that communities would accept noise differences of 5dB, complain about differences of more than 10dB, and respond strongly to differences of 20dB and more. Simply stated, people would only object to a new noise level if it exceeds the background noise level they are used to (Langer, 2002). The effects of high noise levels on individuals can be both physical (e.g. hearing impairments) and psychological. In South Africa, regulations (GN R992 promulgated in terms of the Minerals Act 50 of 1991, Regulation 4.17.1) state that “When the equivalent noise exposure (...) in any place at, or in any mine works where persons may travel or work, exceeds 85dB (A), the manager shall take the necessary steps to reduce the noise to below this level”.

2.5.5 Climate change

Climate change is defined by the United Nations Framework Convention on Climate Change (UNFCCC) as “a change attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to the natural climate variability observed over a comparable period of time” (UNFCCC, 2011). The emission of greenhouse gases or GHGs in the atmosphere is cited as the main contributor to climate change. These gases, namely, carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O) are mostly released during the combustion of such fossil fuels as coal, oil, and natural gas, to produce energy (EPA, 2017). Ruttinger and Sharma (2016) noted that being extremely energy-intensive; the mining sector is one the major contributor to greenhouse gases emissions. Most mining activities entail the use of fossil fuels with an associated release of greenhouse gases. The latter are emitted by fossil-fuel-powered engines and machinery during the mining process (e.g. extraction) and the transportation of the mined commodity. Additionally, mining projects also often require the destruction of large and heavily forested areas that play a critical part in maintaining the balance by absorbing the carbon dioxide emitted by human activities. Moreover, toxic and or pollutant gases are often emitted during the processing phase. However, it is noted that the dimension stone mining sector’s impact on the environment is way less negative than that of other sectors of the mining industry. Its contribution to climate change is minimal, compared to that of the other mined commodities, because dimension stone mining uses less energy. This is true for artisanal mining, as this sector does not use heavy equipment or machinery that require fossil fuel to operate in the context of stone extraction. Thus, its emissions of pollutants or greenhouse gases that
contribute to climate change are minimal. They are mainly caused by diesel-powered vehicles during the transportation of the stones.

2.5.6 Energy use
As a general rule, the mining industry uses considerably large amounts of energy to mine and process minerals. Ditsele (2010) mentioned that energy sources, among which electricity and diesel, are important inputs in mining. They are ranked among the highest components of mining costs. In a country such as South Africa that relies heavily on fossil fuel for energy (around 77% of South Africa’s energy needs are met through coal), the environmental implications of using energy must be taken seriously. This country is ranked 14th in terms of greenhouse gases emissions. Since energy is a produced commodity whose environmental properties may vary depending on the producer or supplier, the choice of energy supplier can significantly influence the environmental impacts of a product’s life cycle (Mashoko, 2009). Determining energy use is particularly important because it can help identify energy efficiency areas. The commonly used energy parameters and their units are shown in Table 2.2 below.

Table 2.2: Energy parameters and their units (Mashoko, 2009)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Additional data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuel</td>
<td>GJ</td>
<td>Lower heat value; moisture, density, sulphur content, transport data</td>
</tr>
<tr>
<td>Bio fuel</td>
<td>GJ</td>
<td>Heat value (low), moisture, transport data</td>
</tr>
<tr>
<td>Heat energy</td>
<td>GJ</td>
<td>Energy carrier temperature</td>
</tr>
<tr>
<td>Electricity</td>
<td>KWh</td>
<td>Country or region, type and amount of energy carrier</td>
</tr>
</tbody>
</table>

2.5.7 Water quality
Surface and ground water quality is often affected by contamination by means of hazardous substances (e.g. oil and fuel), dust, and silt resulting from mining activities. In the case of dimension stone mining, Ashmole and Motloung (2008a) noted that the contamination of water sources does not happen regularly and that when it does, it is often the result of petrochemical spillages from equipment or storage facilities. Nevertheless, the effects of dimension stone mining on the quality of water cannot be neglected, as runoff water and
storm water can interact with waste, stockpiles and petrochemical spillages and create polluted fluids. The latter will contaminate soils, plants, water sources, and living organisms that come into contact with those fluids. Ground water can also be affected because once surface water is contaminated by polluting substances; ground water can quickly become affected due to infiltration. Moreover, mining activities can affect the natural ground water recharge by decreasing the permeability of the ground (e.g., dust can clog pores in quarries and nearby surface and alter recharge rate) (Langer, 2002; GDACE, 2008).

2.5.8 Solid waste
Traditional mining generates large quantities of solid waste (also called overburden) that is often discarded on site, in piles. Solid waste includes the rocks or soil removed to access the ore deposit or the rocks that contain an amount of minerals that is considered too low to be profitable and other types of waste such as construction waste, packing waste, and domestic waste (if there are camps on site) (Ashmole and Motloung, 2008a). In any case, the impacts of mining waste can be disastrous to both the economy and the environment. Firstly, productivity can be lost over the land that is turned into a waste storage area. Secondly, soil contamination often occurs when discarded soil and rocks contain polluting or potentially dangerous substances. For instance, waste rocks containing a high concentration of sulphide mineral have high chances of creating acid rock drainage formations. Another effect of waste rock is the negative visual effect it creates on the area being used as a wasteland.

In the case of dimension stone mining, the recovery of stones that are destined to be used in blocks is typically between 3% and 60%, depending on the extraction technique used and the stone’s desired physical properties (Ashmole and Motloung, 2008b). To minimise the negative visual effect of mining waste or overburden in South Africa, Regulation 72 of the Mineral and Petroleum Resources Development Act stipulates that “Granite off-cuts and related waste must be broken into manageable units to be recycled, crushed or disposed of and the applicable land must be rehabilitated …” The bigger concern is the disposal of domestic and construction waste, or its packaging. Poor waste disposal practices can have negative repercussions on the environment – even years after the closure of the mine.

2.6 Life cycle assessment framework

Life cycle assessment is a science-based tool used to assess the environmental impacts of a product system. It compiles and evaluates the inputs and outputs to the environment of a
product, a process or an activity – throughout its entire life cycle. It helps to assess the environmental burdens associated with all the stages of a product’s life cycle, from raw material extraction, product manufacturing, to use and/or re-use and/or recycling and waste disposal (Guinée et al., 2002).

The LCA differentiates itself from other environmental assessment tools by the fact that it performs a cradle-to-grave evaluation, taking into consideration all the inputs (energy) and outputs (emission and solid waste) during all the stages of the product’s life cycle, as they all contribute to environmental impacts (Figure 2.3). In LCA studies, it is not the product itself that is assessed but rather its function. This allows for comparisons between products, processes or activities – if they perform equivalent or very similar functions. The holistic approach of the LCA can virtually be applied to all product systems, to generate data on environmental impacts and bring them together into a consistent framework. The latter can facilitate comparison between product systems and can systematically identify environmentally “cleaner” alternatives and opportunities for improvement, to lessen the consequences of resources usage and environmental emissions (Guinée et al., 2002; Klöpffer, 2014).

Figure 2.3: Illustration of a cradle-to-grave flow diagram showing energy input and waste (emission)
This diagram, which constitutes the product system, helps to define the boundaries of the LCA.

2.6.1 LCA developments

The first studies performed on the life cycle of products or materials focussed more on optimisation of energy and resources usage than on pollution (Klöpffer, 2014). For example, in 1969, Coca Cola used LCA methods and principles to perform a study aimed at quantifying and assessing the energy, material usage, and environmental consequences of the life cycle of its packaging (Hunt and Franklin, 1996). Around the same time, in Europe, various studies dealing with energy, resources and waste associated with packaging materials were also undertaken (Ditsele, 2010). Economic reasons were the driving-forces of these studies. Because energy efficiency and resource usage are considered more important than waste and output, little distinction is made between inventory development (inputs) and the interpretation of the associated environmental impacts (outputs) (Jensen et al., 1997). Since the term Life Cycle Assessment was not yet used, those studies were performed under various names such as Resource and Environmental Profile Analysis (REPA), Energy Analysis, Product Ecobalance, Integral Environmental Analysis, Environmental Profiles, Product Line Analysis or Integrated Chain Management (Guinée et al., 2002; Ditsele, 2010).

When people started realising that the conveniences of modern life had disastrous impacts on the environment and human health, the LCA emerged. It was regarded as a tool that could address a wide range of environmental concerns such as hazardous and solid waste (EPA, 2006). Thus, at the UN earth summit of 1992, most people agreed on the idea that the LCA was a promising tool for a large number of environmental management tasks (Jensen et al., 1997).

Before the development of LCA rules and standards, many studies performed on similar products showed different outcomes and discrepancies, depending on the approach selected (Zamagni et al., 2008; Ditsele, 2010). This led to the questionability of the findings of some studies and to the subsequent decrease in the popularity of the LCA concept during the 80s and early 90s (EPA, 2006; Zamagni et al., 2008; Williams, 2009). The Society of Environmental Toxicology and Chemistry (SETAC) was the first international organ to work towards the harmonisation of the LCA methodology (Guinée et al., 2002). It developed a scientific platform for the enhancement of the LCA. It is during one of the first workshop
held on life cycle assessment that the SETAC created a code of practice for the LCA and presented the name by which to describe the method. The SETAC was also the first organ which provided a clear LCA with its triangle (Figure 2.4) (Guinée et al., 2002; Fava et al., 2014). From its initial involvement in 1989 until today, the SETAC continues to hold workshops aimed at improving the LCA concept.

After the development of a code of practice by the SETAC, the International Organisation for Standardisation (ISO) started working towards the development of standard procedures for the LCA in 1994 (Guinée et al., 2002). Under the ISO 14040 series (environmental management – life cycle assessment), the SETAC released a number of publications that deal with the technical and organisational aspects of LCA procedures as well as terminologies and methodological framework. The main documents produced under the ISO 14040 series include:


The United Nations Environmental Programme (UNEP) also plays an important part in the promotion of the LCA globally and particularly in developing nations. In 1996, the UNEP published a user-friendly and easy-to-read guide for the LCA, in an effort to encourage the use of the LCA worldwide (Guinée et al., 2002). Joining forces with the SETAC and other partners, the UNEP has been working towards the global adoption of LCA approaches – with the objectives of increasing resources usage efficiency and moving towards sustainable consumption and production (Sonnemann and Valdivia, 2014).
The first triangle made in 1990 only had three components: inventory analysis, impact analysis, and improvement analysis. Later on in 1993, this triangle was revised and now included four components: goal and scope definition, inventory analysis, impact assessment, and improvement assessment. The ISO standardization brought a small change to this structure by replacing the improvement assessment by interpretation, as the improvement phase was rather seen as a potential use of the LCA than a methodological step (Klöpffer 2014).

2.6.2 LCA methodology

The methodology of the LCA follows ISO standards and comprises of four components: goal and scope definition, inventory analysis, impact assessment, and interpretation (see Figure 2.5). This methodology was standardised to avoid inconsistencies in LCA studies and to enable comparisons and contrasts between study results.
1) **Goal and scope definition**

Goal and scope definition is the first step in an LCA study. It is the stage where all the initial choices and plans are made. This step guides the whole LCA process and every decision or choice made will have an impact on both the way the study is conducted and the relevance of the results (EPA, 2006). Defining the goal of a study involves stating the reason for conducting the study (what is the exact question that the LCA is trying to answer?), the intended application or use of the results, and the target audience. Conversely, defining the scope involves stating the characteristics of the study. The scope definition should identify the following (Guinée et al., 2002; Jungbluth et al., 2007):

- Function of the system.
- The functional unit (which will be used as a reference to which input and output data will be normalised).
- The system to be assessed.
- The system boundaries.
- Allocation procedure.
- The data requirements.
- The assumptions and limitations.
- Format for presenting the results and type of critical review.

![Life Cycle Assessment Framework](image)
The ISO 14040 second edition states that the scope (system boundaries and level of details) of an LCA will depend on the goal of the study and intended use of the results (ISO 14040, 2006).

2) Life cycle inventory analysis (LCI):
Inventory analysis is the step at which all the inputs (energy, water, raw material, and any other type of resource) and outputs (atmospheric emissions, waterborne emissions, solid wastes, and other types of environmental burden) of a product, a process or a material are recorded and quantified. It is during this phase that the product system and its boundaries are defined. The following issues need to be addressed when doing an inventory analysis (Guinée et al., 2002; EPA, 2006):

- Develop the flow diagram of the product system being assessed.
- Develop a data collection plan.
- Collect data.
- Relate the data to the unit process.
- Validate the data.
- Allocate data for multifunctional processes.
- Complete final calculations.
- Assess and report the results.

3) Life cycle impacts assessment (LCIA)
The impact assessment phase evaluates the impacts of the inputs and outputs identified in the life cycle inventory. It is during this phase that the data collected during the LCI are further processed to determine the potential effects on human health and the environment, for every material or process used (William, 2009). All impacts are assessed based on the previously selected impacts categories (Ditsele, 2010). The LCIA has various steps, including the selection of impact categories, the classification, the characterisation, the normalisation, the grouping, the weighting, and the data quality analysis. The last four steps are optional, while the impact categories selection, the classification, and the characterisation are mandatory, as shown in Figure 2.6 (ISO 14042, 2000).
Selection of impact categories: involves selecting the impact categories that will be considered in the study. The main reason for doing so is that the results of the LCI are translated in terms of their contribution to such impacts categories as global warming, land use, and so on (Guinée et al., 2002). Below are listed some of the impact categories often considered for LCA studies.

- Depletion of abiotic resources.
- Depletion of biotic resources.
- Impacts on land use.
- Global warming (climate change).
- Stratospheric ozone depletion.
- Human toxicity.
- Ecotoxicity.
- Photochemical oxidant creation.
- Acidification.
- Eutrophication.
- Work environment/occupational health and safety.

Guinée et al. (2002) underscore that the list of impact categories distinguishes between baseline impact categories, study-specific impact categories, and other impact categories, as shown in Table 2.3.

Table 2.3: List of baseline and other impact categories. Source: Guinée et al. (2002).

<table>
<thead>
<tr>
<th>IMPACT CATEGORIES</th>
<th>Baseline Impacts Categories</th>
<th>Study Specific Impacts Categories</th>
<th>Other Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. <strong>Baseline Impacts Categories</strong></td>
<td>- Depletion of abiotic resources</td>
<td>- Impacts of land use</td>
<td>- Depletion of biotic resources</td>
</tr>
<tr>
<td></td>
<td>- Impacts of land use</td>
<td>Land competition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Climate change</td>
<td>- Human toxicity</td>
<td>- Desiccation</td>
</tr>
<tr>
<td></td>
<td>- Stratospheric ozone depletion</td>
<td>- Ecotoxicity</td>
<td>- Odour</td>
</tr>
<tr>
<td></td>
<td>- Climate change</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Freshwater aquatic ecotoxicity</td>
<td>Freshwater sediment ecotoxicity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Marine aquatic ecotoxicity</td>
<td>Marine sediment ecotoxicity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Terrestrial ecotoxicity</td>
<td>Terrestrial ecotoxicity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Photo-oxidant formation</td>
<td>- Acidification</td>
<td>- Malodorous water</td>
</tr>
<tr>
<td></td>
<td>- Acidification</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Eutrophication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. <strong>Study Specific Impacts Categories</strong></td>
<td>- Impacts of land use</td>
<td>- Impacts of ionising radiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Loss of life support function</td>
<td>- Odour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Loss of biodiversity</td>
<td>Malodorous air</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Ecotoxicity</td>
<td>- Noise</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Waste heat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshwater sediment ecotoxicity</td>
<td>- Casualties</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marine sediment ecotoxicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Terrestrial ecotoxicity</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. <strong>Other Impacts</strong></td>
<td>- Depletion of biotic resources</td>
<td>- Odour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Desiccation</td>
<td>Malodorous water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Odour</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The selection of impact categories must take the following various points into consideration (Jensen et al., 1997):

- The impact categories selected for the study must be relevant to the goal and scoping phase.
- The list must be complete enough to cover all the relevant environmental burdens.
- The list must contain a suitable number of impact categories.
- The impact categories must be selected in such a way as to avoid double counting.
- The selection of an impact category must take into account the availability of characterisation methods.

**Classification** is concerned with assigning inventory data to the selected impact categories based on their ability to contribute to environmental and health issues. LCI results that contribute to more than one impact category can be mentioned twice, as long as their effects are not dependant on one another.

**Characterisation** deals with selecting characterisation models to convert and quantify LCI outcomes into a common unit and allow the aggregation of results, within the impact categories, into a single score (Guinée et al., 2002). The modelling of inventory data can happen at mid- or endpoint level.

Midpoints refer to points in the cause and effect chain of a particular impact category that are between inventory data and endpoints, while endpoints refer to elements in the cause and effect chain that are of value to society and give a clear understanding of the final effects of LCI outputs (Barel et al., 2000; UNEP, 2003).

**Normalisation** comes after characterisation. The ISO 14042 defines normalisation as “calculating the magnitude of indicator results relative to reference information”. This means that the overall score obtained for each impact category is compared to a selected reference value by dividing the score by the reference (ISO 14042, 2000; UNEP, 2003). The main objective of normalisation is to provide a clear understanding of the relative magnitude of the environmental profile of a product system. Other objectives such as checking for inconsistencies, giving information on the relative significance of category indicator results, as well as preparing and presenting the results in a format that is suitable for subsequent steps can also be associated with the normalisation phase (Guinée et al., 2002; UNEP, 2003).
Grouping refers to sorting and/or ranking category indicators into one or more sets, after characterisation. Following two procedures, the category indicators could either be sorted on a nominal basis or ranked based on their level of importance (ISO 14042, 2000).

Weighting deals with the prioritisation of impact categories. It is a subjective process in which the indicator result of each impact category is assigned a numerical factor, according to its relative importance. The significance assigned to each impact category usually depends on the goal of the study and the general preferences or main concerns of the person or organisation conducting or requesting the study.

Data quality analysis is the last step of the LCIA. To get a better understanding of the significance, uncertainty and sensitivity of LCIA results, the data are analysed with specific techniques – to determine their reliability. The ISO 14042 lists three techniques that can be used for data quality analysis:

- Gravity analysis - Identifies the data that have the greatest contribution to the indicator results.
- Uncertainty analysis - Describes the variability of the LCIA data to determine the significance of indicator results within the same impact category.
- Sensitivity analysis - Measures the extent to which changes, in the LCI results or characterisation models, affect the indicator results.

Ditsele (2010) notes that, for Huijbregts et al. (2001), the source of data inaccuracy can be a lack of specific data. To address this uncertainty, he suggests that the following:

- Use economic input-output LCA models to estimate missing data;
- Replace lacking product data with those of main components or ingredients;
- Use uncertainty factors for non-representative data;
- Use quantitative uncertainty propagation methods to deal with data inaccuracy; and
- Use the sensitivity analysis to identify items that are important to the uncertainty of the LCA results.

4) Life cycle interpretation

The fourth and final step of the LCA is interpretation. Here the results of the analysis are evaluated, important issues are identified, and conclusions and recommendations are made to assist decision-makers (Jensen et el., 1997). The conclusions and recommendations should be
consistent with the goal and scope of the study. Guinée et al (2002) stress that, for the sake of transparency, the line between final the conclusions (analysis results) and recommendations (personal opinions) should be clearly defined.

The components or phases of the LCA and the LCA itself are iterative, meaning that they are done repeatedly as more information is gathered so that the results can be improved. It is also important to note that all the phases of the LCA are related to one another and that the interpretation phase is an integral part of all phases, as it is done after each phase is completed.

2.6.3 Strengths and weaknesses of the LCA

1. Strengths
The major strength of the LCA is its holistic approach in assessing the environmental impacts of products and services (Guinee et al., 2002). Compared to the wide variety of other environment assessment tools, the LCA offers a more comprehensive assessment of the materials, processes, and potential burdens of products – from the beginning to the end of their life cycle. It takes into consideration the natural environment, human health, and resource usage (Ditsele, 2010). The key advantage of the comprehensive nature of the LCA is that problem shifting can be avoided by tracking and documenting the transfer of environmental impacts between the stages of a product life cycle and from one medium to another (Reid et al., 2007). The capability to identify the transfer of environmental problems helps to fully characterise the environmental trade-offs associated with alternative materials, products or processes (EPA, 2006).

Furthermore, the LCA strives to be as quantitative as possible and uses scientific data and competences to support any type of decision-making, finding or claim (Jensen et al., 1997; Guinee et al., 2002). The LCA can also be a non-negligible cognitive tool for capacity building, because of the format in which the results are reported (e.g. diagrams, tables) (DEAT, 2004).

2. Weaknesses
Despite being a valuable strength, the holistic nature of the LCA is also a non-negligible limitation (Guinee et al., 2002). The large spectrum that the LCA covers in the assessment of the complete life cycle of a product raises the need for readily available and reliable data. However, data collection can be a very difficult task, because the volume of data generated is...
usually very large and difficult to obtain (Borlini et al., 2012). Although databases are developed continuously in many developed countries, there is a restriction in their usage. This is because they carry the specificities of their respective countries (Borlini et al., 2012). Another weakness is that the accuracy of some study results can sometimes be questioned, because the available data are often outdated, incomparable or of unknown quality (Guinee et al., 2002; EPA, 2006). Because of the scarcity of readily available and credible data, the number of LCA studies is limited (Ditsele, 2010).

Additionally, LCA studies are time-consuming and costly, because of the high level of expert knowledge required and the necessity to either purchase data from commercial databases or collect and assess data internally (DEAT, 2004). As a result, the use of the LCA is more frequent in developed countries – within large multinationals and companies – than in developing countries’ small and medium enterprises (Borlini et al., 2012). This is because the latter do not have access to adequate expertise or simply lack the necessary resources.

The LCA cannot deal with localised impacts, since it does not provide a completely developed framework for local risk assessment studies. Hence, it is unable to identify the impacts expected from the operations of a facility in a specific locality. It is possible to identify points of emissions; however, the way the potential environmental impacts will be distributed over place and time cannot be determined (Guinee et al., 2002; Ditsele, 2010). That is why environmental burdens are described as “potential”, since the time and space – and even the occurrence – of those impacts cannot be ascertained (Guinee et al., 2002).

The standardisation of the LCA and databases’ format has successfully avoided arbitrariness while conducting studies; but, because a few technical assumptions and methodological aspects are still left to subjective judgement and preferences, the final results can still be characterised by uncertainty (Guinee et al., 2002; Reid et al., 2007).

As it is, the LCA only deals with environmental dimensions of products: it does not consider non-environmental aspects (Guinee et al., 2002). Furthermore, it is unable to determine products’ performance or cost effectiveness (EPA, 2006). As such, the LCA should not be regarded as a complete assessment tool that is able to replace other tools that can assess economic or social dimensions (Jensen et al., 1997; Ditsele, 2010). Instead, it should be considered as a component of more comprehensive tools that have the capability to evaluate the trade-offs between performance and cost (e.g. Life Cycle Management) (EPA, 2006). Zamagni et al. (2008) observe that this shortfall has given rise to new developments aimed at
“deepening and broadening” LCA methodology so that it is able to include more mechanisms and can expend to economic and social aspects. In addition, more comprehensive tools modelled around the LCA framework are being developed every day (e.g. Life Cycle Value Assessment (LCVA), economic input-output LCA (EIO-LCA) and so forth) (Ditsele, 2010) to satisfy the need for a multidisciplinary assessment tool.

Furthermore, the LCA model which is at the heart of a steady-state and linear equilibrium (Zamagni et al., 2008) does not allow for variability in specific conditions or critical loads (DEAT, 2004). Ekvall et al. (2007) note that in waste management, for example, the typical LCA model cannot be used to identify optimal reuse and recycling rates, because of its linearity.

Finally, the LCA is an environmental assessment tool that provides information for decision-making; however, it does not replace the decision-making process itself (Guinee et al., 2002). This means that the results can be used to give more weight to a given decision but will not be a decision on their own. Moreover, decision-makers are free to decide whether to use those results in making their decisions.

2.7 Applications and benefits of the LCA

The LCA is an analytical tool that helps to understand and assess the environmental profile of a product system. It can identify the various benefits and liabilities associated with the life cycle of a product, service or process. It can be used in various ways, to support environmentally sound decisions.

**Product design, development and improvement:** the use of the LCA in the environmental management of products is growing each day. This is because of the multiple environmental concerns that are forcing organisations to find ways to develop more environmentally friendly products. The LCA is widely used by private organisations and industries because of its capacity to identify opportunities for improving the environmental profile of products at different stages of their life cycle (Ditsele, 2010).

The LCA is mainly used by organisations in the design and development stages of their products. It is during those stages that the various choices regarding the materials and resources to be used for manufacturing the product are made. The LCA can help to ensure that environmentally sound alternatives are selected, as any decision made during the design
and development of the product will doubtlessly affect all the following stages of the product’s life cycle (Menoufi, 2011).

The LCA can also be used for product improvement. When it is the case, Menoufi (2011) suggests that the focus be on those materials and resources that have the greatest impact on the product. Product improvement can either be motivated by economic reasons such as maintaining or creating a competitive advantage in the marketplace. This is achieved by offering cutting edge or “less-costly to manufacture” products, or by addressing environmental concerns by using alternative materials or resources that will improve the environmental performance of products.

**Strategic planning:** in order to handle environmental issues efficiently and effectively, it is now common practice for businesses, industries, and governments to include environmental aspects in their strategic planning. In this regard, the LCA can provide useful information in such areas as pollution prevention, resource conservation, waste management, or packaging requirements (Guinee et al., 2002; Ditsele, 2010).

**Policy formulation:** the LCA can assist in the development and improvement of organisations’ internal polices (DEAT, 2004). It can successfully provide insight in various environmental issues and improvement opportunities that can affect an organisation’s strategy on specific areas. For example, LCA results can guide a business in selecting or avoiding certain materials or chemicals because they could prove difficult to handle or could attract negative publicity (DEAT, 2004).

The LCA is also used as a regulatory tool by government and municipalities. Its applications extend to such areas as subsidies and taxation, promotion and/or adoption of different energy sources (DEAT, 2004), deposit refund schemes, product-orientated and general policies (Jensen et al., 1997). The LCA also applies to construction. A case in point is the Netherlands where the construction of new buildings requires the use of materials selected based on their LCA and which meet minimum environmental requirements (Guinee et al., 2002).

**Marketing:** it involves delivering products or services that meet or exceed consumers’ expectations. When using the LCA as a marketing tool, organisations mostly use its results in product certifications and/or marketing declarations (Ditsele, 2010) and in eco-labelling (Jensen et al., 1997). The purpose of the LCA in environmental marketing is to increase an organisation’s market share by attracting environmentally conscious buyers and/or by
encouraging the selection of alternative products that have less damaging impacts on the environment. Consequently, product certifications and eco-labelling are used to attest that a given product is environmentally friendly. One good example of the use of the LCA in green labelling is the European Union Ecolabel (The Flower) which promotes the production and usage of goods that have minimum environmental impacts throughout their life cycle (Jensen et al., 1997).

**Learning and education:** another application of the LCA is the communication of information about significant environmental issues (Joachimiak-Lechman, 2013). Some LCA studies are conducted for the sole purpose of learning about a particular product system. Nevertheless, even those conducted for specific goals such as product improvement or policy making still offer some sort of knowledge or learning points (Ditsele, 2010). In addition, LCAs can be used to educate the general public, organisations, and governments on key environmental issues and sustainability (Jensen et al., 1997).

**Support Environmental Management System (EMS):** the EMS aims to improve the environmental quality of an organisation’s operations through the management of its significant environmental impacts. Combined with the LCA, the EMS can result in product, process, or manufacturing changes that can successfully minimise the effects of organisational activities on the environment (EPA, 2006).

If properly conducted, LCA results offer various benefits that include:

- LCA helps understand the environmental burdens associated with organisational activities.
- It can effectively assist in reducing the environmental profile of products or processes through eco-design and by identifying areas for improvement in their life cycles.
- LCA application leads to resources and energy usage efficiency – by identifying inefficiencies or waste in a product system.
- LCA can help identify the environmental trade-offs of given materials, products, or processes.
- LCA results can be used to gain stakeholders’ support and acceptance of new policies or planned action.
- LCA provides useful information in organisational buying – by helping decision makers to select products, processes, materials, or equipment that have the least impacts on the environment and result in low costs.
LCA supports strategic business planning and environmental management.

LCA can assist with business growth – by identifying environmentally benign products to be developed for specific market segments and/or by creating competitive advantage through product or process improvement.

In policy-making, the LCA gives access to valuable data relating to the development of policies and programmes that deal with resources usages and environmental releases and therefore aim to achieve sustainability. It can also be used as a decision support tool for the adoption of regulations on materials use (e.g. packaging, building sector), energy sources, and so on.

LCA helps to educate the public on the impacts of resources usage and environmental releases associated with products, their production processes, and human activities at large.

2.8 Application of the LCA in the mining sector and its associated challenges

Most products and systems require inputs that are directly or indirectly derived from mining. As the LCA is used to evaluate the environmental impacts of these products and systems, it is important for the mining sector to provide relevant information regarding the inputs and outputs of its activities, so that the full spectrum of the environmental burdens generated by a product can be effectively assessed (Lesage et al., 2008). In most LCAs, the mining system is simplified: it is represented as a black box, not lending itself to the interpretation of different processes used in the materials production (Durucan et al., 2006). Lesage et al. (2008) underscore that in LCA studies of mining, such aspects of the industry as extraction and waste handling, are often overlooked or downplayed. As a result, most of the available LCIs cannot provide an accurate account of mining environmental burdens of products or systems. The shortage of mining LCA studies is alarming because it does not only undermine current LCI databases (Awuah-Offei et al., 2011), but also hinders the quality of life cycle assessment results (Lesage et al., 2008). Thus, it is important for the mining sector to provide updated, quality data on its activities, so that an accurate evaluation of its environmental impacts and those of most primary materials may be performed.

The application of the LCA to artisanal and small-scale mining is also very limited. Since there is no formal way of monitoring the effects of ASM’s activities, more effort to promote
the application and the adaptation of the LCA framework to ASM activities should be made, to gain a better understanding of their impacts on the environment.

Despite the aforementioned shortage, different applications of LCA in the mining sector can be found in the literature. Lesage et al. (2008) mention various authors who have used the LCA in the mining sector to compare the environmental impacts of various production methods. The LCA has also been used to identify stages in the mining, treating, and marketing of red clay that have the greatest impacts on the environment (Bovea et al., 2007). It has also been used to identify appropriate surface area metrics in land use impacts (Spitzley and Tolle, 2004). This shows the versatility of the LCA methodology and the possible advantages that the mining sector could gain form systematically adopting life cycle thinking. The LCA can provide valuable insights on a number of issues and options of interest to the mining sector (Awuah-Offei et al., 2011). Moreover, Stewart (2001) notes that the LCA can be used as a decision-making tool, to support environmental sustainability.

The challenges associated with the application of the LCA to the mining industry are multiple. Some of them are discussed below.

The availability of quality data is the major concern pertaining to mining LCAs (Stewart, 2011). Just like LCIs of other products, mining LCIs are drawn from readily available sources (Spitzley et al., 2004). The usefulness of these data is very limited for a number of reasons. For example, the collection bases (e.g. system boundaries, functional unit) can vary from one study to another (Stewart, 2001). It suffices to note that generic databases cannot address site-specific conditions and impacts (Durucan et al., 2006). Furthermore, the data collection method is not always transparent (Stewart, 2011). Because of the existence of different mining methods and systems, the best option would be to collect data directly on site. However, this is not possible because mining organisations are reluctant to disclose environmental information pertaining to their activities (Awuah-Offei et al., 2011).

Normally, the LCA methodology aggregates environmental impacts over time and space. This means that for a given material or mineral, environmental impacts are assumed to be the same, regardless of temporal aspects or location (Stewart, 2011). In mining, however, this aggregation is more likely to be accurate for global impacts (e.g., global warming potential) than for regional or local impacts such as eco-toxicity or land use (Lesage et al., 2008). This is due to the fact that mining impacts may vary according to the region and depending on such factors as local climate, soil quality, or waste management practices. Environmental
impacts may also manifest years before the mine starts operating. For instance, deposit discovered during the exploration phase can stay dormant for years, while still having negative impacts on the environment (Stewart, 2001). Moreover, after the mine’s closure, bad waste management or rehabilitation practices can contaminate the local surroundings for centuries. Hence, it is important to integrate temporal aspects and spatial variability in mining LCAs, as the lack thereof brings technical issues that undermine LCAs’ results.

The generic list of impact categories is normally used to assess the environmental impacts of the mining sector. However, since mining operations occur in places where environmental conditions and concerns significantly differ from one another, a number of voices argue that this list of impacts cannot effectively address that variability (Stewart, 2001). Awuah-Offei et al. (2011), for example, contend that the standardised list of impact categories alone cannot fully describe the environmental impacts of mining and provide additional impacts. Examples of the latter include land, water, and energy use impacts as well as resource depletion. These should be considered when undertaking mining LCAs. To assess land use’s potential impacts, Spitzley et al. (2004) proposed the evaluation of the average lifetime disturbed land per unit of material produced. One shortfall of this method is that it cannot account for the long-term impacts of land use. The effects of land use are of a diverse nature (biodiversity, degradation of soil quality, changes in water regulation, and so forth). Including all these effects in mining LCAs can be a difficult task, because there is no consistent framework that states the land-use impact indicators that should be included in the impact assessment (Lesage et al., 2008). Noise and vibration are inherent aspects of mining; however, it has been proven that exposure to disturbing levels of noise negatively affects both humans and animal life (Cucurachi et al., 2014). As such, the effects of noise should be included in mining LCAs. Nonetheless, to date, most LCA studies have not included noise and vibration in the list of impact categories. This is because there is no formal recommended approach to addressing noise and vibration (Cucurachi and Heijungs, 2013). So far, several efforts have been made to incorporate noise and noise indicator factors in the LCA framework (Cucurachi and Heijungs, 2013; Cucurachi et al., 2014). Those studies emphasise the need to only incorporate into the LCA framework the impacts that are of interest to the local community but have been given little or no attention.
CHAPTER 3

METHODOLOGY

3.0 Introduction

The methodology adopted for this study follows the standard recommendations of the International Organisation for Standardisation (ISO). In accordance with these recommendations, the LCA was divided into four stages: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation.

3.1 Goal and scope definition

The goal of a study refers to the reason for conducting it, the intended use of the study’s results, and the targeted audience. The present study was conducted to determine the environmental effects of artisanal sandstone mining. The results of the study will be communicated to the mining sector, the government, and other parties interested in understanding the effects of artisanal mining and finding ways to minimise the potential environmental impacts of artisanal sandstone mining through the elaboration of relevant laws and policies as well as the adoption of sustainable mining practices.

Scope definition involves the following areas: system function and boundaries, functional unit, impact assessment method, data requirements, assumptions, and limitations (Guinée et al., 2002; Jungbluth et al., 2007). The artisanal sandstone mining system to be studied includes the following activities: stone extraction, transportation, and cutting or/and processing. Some stages of the life cycle of the stones are not included in this study, because of various reasons that include the unavailability of data or the fact that their environmental contribution is too minimal to have any real impact on the LCA results.

3.2 Inventory analysis

Inventory analysis is the stage where the raw material, energy inputs, and the consequent environmental outputs associated with the life cycle of a product are quantified. Inventory analysis entails collecting data on raw material and energy consumption, related atmospheric, waterborne, soil-borne emissions, and solid waste. Because of time and resources limitations, the inventory analysis conducted in this study did not include some phases of the mining
process that precede the extraction phase and those that follow the delivery of the final product to the consumer.

The calculation of energy usage mainly considered the fuel used during the transportation of the raw stones to the warehouse as well as water and electricity consumption for the operation of the heavy machinery used to cut and polish the final product.

1. Data quality

The quality of data significantly influences the quality and accuracy of any LCA results. The LCA study used both primary and secondary data. Primary data were collected in the Free State province – directly at the mine. The data of interest related to land use, extraction, processing, and transportation inputs (water, energy, fuel, and so forth). The main concern was to determine whether operational and mining practices were generic enough to enable the generalisation of the results to the whole artisanal sandstone mining sector. Secondary data were obtained from readily available sources and studies such as industry or government publications, journals, books, and other types of published literature (refer to Table 3.1).

Table 3.1: Nature and quality of data

<table>
<thead>
<tr>
<th>Data</th>
<th>Data Requirements</th>
<th>Nature of collected data</th>
<th>Geographical coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone extraction</td>
<td>Materials and energy inputs and emissions</td>
<td>Primary</td>
<td>QwaQwa, South Africa</td>
</tr>
<tr>
<td>Stone processing</td>
<td>Materials and energy inputs and emissions</td>
<td>Primary/secondary</td>
<td>QwaQwa, South Africa</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td>Primary/secondary</td>
<td>QwaQwa, South Africa</td>
</tr>
</tbody>
</table>

2. Uncertainty in LCA and Ethical issue

Ditsele (2010) mentioned that data uncertainty emanates from two factors: (1) a complete lack of data or absence of parameter values (data gaps) and the use of data that are unrepresentative of the item under study, and (2) data inaccuracy. This was also the case for this study. Primary data were collected for electricity use and miners’ health and in some
instances, such as diesel and water usage, a certain number of assumptions had to be made because primary data could not be obtained in order to take into consideration main sources of potential impacts. Even though assumptions help in eliminating data gap in LCAs, they also contribute to uncertainties in the study outcome. In the case of this LCA study, it is believed that deviations from actual host mine data are not important enough to invalidate the study findings. Furthermore, these results should provide a reasonable idea of the environmental performance of the case study mine and help identify biggest contributors to potential impacts.

3.3 Life cycle impact assessment

The impact assessment phase involves interpreting the results of the life cycle inventory phase to determine the potential effects on human health and the environment (William, 2009). It is also during this stage that impact categories are selected and assigned to LCI results. In this study, the impacts assessment was conducted using the Sima Pro software.

3.4 Interpretation

The last stage of the LCA is where the results of the life cycle impact assessment are interpreted. This is the stage where possible areas for energy and material inputs improvement are identified and recommendations on how to improve the overall environmental impact of the system under study are made. Final conclusions and the interpretation of the life cycle inventory analysis have to be aligned with the objectives or goals of a study. To avoid confusion, the line between final conclusions (analysis results) and recommendations (personal opinions) must be very clear (Guinée et al., 2002).
CHAPTER 4

BACKGROUND ON THE CASE STUDY

4.0 Introduction

For the purpose of this LCA study, data from one mine were used to assess the impact of artisanal sandstone mining on the environment. The host-mine is located in the QwaQwa region, Free State province, South Africa. QwaQwa is widely known for its massive rock formation, as seen in Figure 4.1. The local economy relies heavily on sandstone mining; hence, several artisanal sandstone mine quarries and/ or dealerships exist in QwaQwa.

The small mining company that constitutes the object of our study has been operating for 15 years and employs less than seven people on a full time contract. These miners work on an order basis. This means that they only operate when an order for sandstone is placed by a customer. When this happens, independent miners are called in as an additional workforce, depending on the size of the order. Hence, the annual mining production varies significantly from one year to another. The data collected for this LCA study were based on the production from 01 January 2016 to 01 November 2016. The production for that period equalled 50 000 kilograms or 50 tons of sandstone. Because of the inferior quality of the tools used, the company only extracts its stones from opencast mines such as the one seen in Figure 4.2 below.

Figure 4.1: QwaQwa sandstone rock formation.

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Figure 4.1: QwaQwa sandstone rock formation.
The mining company operates with a mining permit delivered by the local authorities. However, the owner confessed that he was unable to give the exact size of the land area from which his organisation was extracting sandstone.

4.1 Sandstone processing in the artisanal mining sector

This LCA did not include the phases prior to the extraction of the stone, namely, the exploration phase where sandstone deposits are identified and classified according to their particular characteristics and the development phase that consists in making the necessary preparation for the extraction phase. The development phase was especially overlooked because, unlike the large-scale mining, the small-scale or artisanal sandstone mining does very little to no preparations before extraction. This is because there are no pieces of equipment or machinery to be transported to the extraction site, nor are there special facilities built on site. Thus, the study focuses on the extraction of the stone, its transportation to the warehouse, and its cutting into the final product that is ready to be delivered to the customer.

1. Sandstone extraction

Sandstones are extracted from mountains that are 12 km away from the warehouse. Large blocks of sandstone are removed from an identified sandstone deposit – using hammers and chisels. As shown in Figure 4.3 (1), large pieces of stone are hammered until cracks appear. Later, these cracks are enlarged by inserting chisels and hammering until the block separates from the deposit. The pieces of sandstone are then mined and transported to the warehouse for further processing. During the extraction phase, only human generated energy (human
power) is used for the tools (chisels, hammers, shovels and so forth). It was assumed that the emission of pollutants or toxic substances at this stage was non-existent, although a little dust is often generated during the process.

2. Sandstone transportation

Although the host-mining organisation extracts its stones from various sites, all are significant distances away from the warehouse. This LCA study focuses on one extraction site called site A which is 12 km away from the warehouse. Preference was given to this site because, according to the owner, most of the yearly production emanates from site A.

The business owns a small truck used to transport the large blocks of sandstone from the quarries to the warehouse. The truck is diesel-powered and uses around 18 liters per 100 km for a total payload of around 6 tons.

3. Stone processing (cutting and shaping)

Once the large pieces of stone (Figure 4.3 (2)) have been transported to the warehouse, a machine is used to cut and shape them into small bricks. The latter differ in size, depending on the customers’ needs. Small hammers and chisels can also be used to shape the bricks for cladding. The owner of the mine noted that after cutting and shaping, the total waste or overburden amounts to around 30% for about 1000 kg or 1 ton of bricks produced. The overburden or waste is usually brought back to the mining site to fill up holes created by miners’ activities and erosion furrow.

The business has two cutting machines (see Picture 4.3 (3)) used simultaneously. They are powered electrically and use water to cool – as constant flow of water over the cutting blade is necessary to dissipate the heat created in the cutting process.
Figure 4.3: 1) Large blocks of stone are extracted from the sandstone deposit – using a hammer and chisels; 2) Raw blocks of sandstone after extraction; and 3) Machine used to cut large blocks into small bricks.
CHAPTER 5

GOAL AND SCOPE DEFINITION AND LIFE CYCLE INVENTORY

5.1. Goal and Scope Definition

5.1.1 Goal

The goal of this LCA study was to determine the environmental impacts of artisanal sandstone mining in South Africa. The specific objectives of the study included:

- Identifying the different processes involved in artisanal sandstone mining and collecting relevant data on energy and material inputs.
- Conducting an inventory assessment of the inputs and emissions and determining their contribution to selected impact categories.
- Identifying improvement areas in terms of environmental performance and suggesting improvement measures.

1. Intended use and target audience

It is hoped that this study’s results will contribute towards addressing the lack of data on artisanal sandstone mining and the dimension stone mining in South Africa. The study’s outcome will be communicated to the South African dimension stone industry and public policy-makers who could use the generated results to develop and adopt policies and strategies that aim to minimise the environmental impacts of sandstone and ASM in South Africa. Finally, the LCA community can use the results of this study to improve the application of the LCA to the ASM sector.

5.1.2 Scope

1. Functional unit (FU)

Mila et al. (2008) define the functional unit as “the reference measure to which the environmental burdens are expressed” (p10). In this study, the functional unit (FU) is based on the mass or quantity produced. One advantage of representing the functional unit on the basis of the mass is that comparing the results of LCA studies becomes easier and much clearer, since most mining organisations report their production in terms of mass (Ditsele,
2010). In the context of this study, the functional unit will be the production of 1 ton (1000 kg) of sandstone bricks processed at the warehouse.

2. System boundaries

The system under study deals with the artisanal mining of sandstone. Because handling data regarding all unit processes involved in the artisanal mining of sandstone – from the beginning to the end of the material life cycle – would not be practical, due to resources and time limitations, the boundaries of the system were scoped to ensure a manageable data load. As a result, some stages of the life cycle were not included in the study. While selecting the boundaries of the system, care was taken to ensure that critical stages in the life cycle of artisanal sandstone mining were included. The main concern was to ensure that processes and stages whose inputs and/or outputs significantly contribute to the environmental performance of artisanal sandstone mining were not overlooked.

The scope of the study covers processes of the mine’s life cycle and associated environmental impacts below the black line, as shown in Figure 5.1 below.
Figure 5.1: Processes involved in the life cycle assessment of artisanal sandstone mining.

The subsystems that were considered for the LCA are:

- Energy and materials input during the extraction and processing phase.
- Transportation of the sandstone to the warehouse.

The following subsystems were excluded:

- Energy and material inputs during the exploration and development phase of the mine’s life cycle.
- Transportation of the sandstone to consumers and its usage.
- Re-use and final disposal.
5.2. Life Cycle Inventory

Data were collected for the life cycle inventory stage. Although most of the data were primary, some assumptions had to be made to calculate the inventory values. For each step of the sandstone process, various types of datum were collected – mainly through questionnaires, personal interviews, and observation.

5.2.1 Land use
The calculation of the total land surface area that could potentially be disturbed by mining activities was impossible, because the owner of the mining facility was unable to provide any numbers regarding the land surface area from which he was extracting the sandstone. One viable assumption concerning land use disturbance is that it is confined to extraction and waste disposal areas, because of the lack of supporting facilities (offices, processing plants, and so on) at the extraction sites.

5.2.2 Water use
Water consumption data were obtained for the processing phase of the sandstone. This is the only phase of the production process where water is used. The owner of the mine could not give the quantity consumed in kilolitres or litres; instead, he provided the total amount in South African rand (R) that he had paid for water usage to the municipality. Water consumption was calculated by dividing the total rand amount paid for the year by the price of 1 kl of water.

5.2.3 Energy use

1. Diesel fuel use
Diesel consumption for transportation serves two purposes: (1) transportation of the miners to and from the extraction sites, and (2) transportation of large blocks of sandstones to the warehouse. The owner of the mine was unable to provide numbers pertaining to the fuel usage for the period over which the study took time. Assumptions had to be made to determine the quantity of fuel necessary to transport 1.3 tons of sandstone to the warehouse – to produce 1 ton of sandstone bricks. Fuel consumption was calculated by considering the trip distance and the number of travels that would be necessary to transport 1.3 tons of sandstone (1000 kg plus the assumed 30% overburden) to the warehouse.
2. Electricity use

It is estimated that around 77% of South Africa’s energy is provided by coal and that most of it is used towards electricity generation (Department of Energy, 2015). There was no indication that the business uses a diesel-powered electricity generator at the warehouse. The electricity is delivered by the municipality. So, the assumption was that the electricity used by the mine was coal-generated. The electricity consumption for the period from January to November 2016 was obtained from the mine register.

Data on electricity, water, diesel consumption and transportation distance, collected from the mine, are summarised in Table 5.1 and the datum assumptions for the production of 1 ton of sandstone are presented in Table 5.2.

Table 5.1: Summary of data on production and resources consumption collected from the mine

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone production (kg)</td>
<td>50 000 (50t)</td>
</tr>
<tr>
<td>Electricity consumption (kWh)</td>
<td>74 958.15</td>
</tr>
<tr>
<td>Water consumption (kl)</td>
<td>2 790.675</td>
</tr>
<tr>
<td>Diesel consumption for transport</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Transportation distance (km)</td>
<td>12</td>
</tr>
<tr>
<td>Consumption of diesel fuel</td>
<td>18 litres / 100 km</td>
</tr>
</tbody>
</table>

Table 5.2: Data assumptions for the production of 1 ton of sandstone

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity consumption (kWh)</td>
<td>1.49</td>
</tr>
<tr>
<td>Water consumption (litres)</td>
<td>9.87</td>
</tr>
<tr>
<td>Diesel consumption – to and from – (litres)</td>
<td>4.32</td>
</tr>
</tbody>
</table>

5.2.4 Emissions

1. Waterborne emissions

No surface or ground water was present at or near the mining site or warehouse. The latter uses water from the municipality. Water is used mainly with the cutting machines – to dissipate the heat and for dust control during the extraction process. These two activities have
little to no contamination potential; thus, the impacts or emissions to water are quasi non-existent.

2. Airborne emissions
The calculation of greenhouse gases (GHG) released during the use of fossil fuel was done using the carbon content, oxidation factors, and emissions factors for fuels. These were obtained from the Environment Protection Agency (EPA). As for the emissions data, they were secured from Eskom.

- **Carbon dioxide (CO\(_2\)) emissions:**
CO\(_2\) emissions from sandstone transportation were calculated using the carbon content determined by the EPA. The diesel carbon content per gallon is 2.778 kg or 0.734 kg per litre, while CO\(_2\) emissions are 10.1 kg/gallon or 2.67 kg per litre of diesel (EPA, 2005). The carbon content and CO\(_2\) emissions being standards for diesel fuel, these numbers were maintained in this study.

\[
\text{CO}_2\text{ emissions from transportation (CO}_2\text{)}^1 = 2.7 \times 4.32 = 11.664 \text{ kg}
\]

Since the warehouse uses coal-generated electricity for the operation of the cutting machines, coal usage (0.55 kg per kWh) and CO\(_2\) emissions were calculated using Eskom data. CO\(_2\) emissions per kilowatt-hour (kWh) in South Africa are equal to 1.01 kg (Eskom, 2015).

\[
\text{CO}_2\text{ emissions from sandstone during electricity use (CO}_2\text{)}^2 = 1.01 \times 1.49 = 1.505 \text{ kg}
\]

The total carbon dioxide (CO\(_2\)) emitted for 1 ton of sandstone = (CO\(_2\))\(^1\) + (CO\(_2\))\(^2\)

\[
= 11.664 \text{ kg} + 1.50 \text{ kg} = 13.169 \text{ kg}
\]

- **Sulphur dioxide (SO\(_x\)) emissions:**
Sulphur dioxide emissions for transportation were calculated using the amount of diesel necessary to transport 1 ton of sandstone. The sulphur content in diesel in South Africa was reduced from 3000 parts per million ppm to 500 parts per million ppm. The sulphur content for our study was taken as 0.05% (Department of Energy, 2015).

\[
\text{SO}_2 = Q_f \times \text{concentration of pollutant} \times \frac{MW_p}{EWp}
\]
Where: \( Q_f \) = fuel use per kg

\[
MW_P = \text{Molecular weight of pollutant emitted (64)} \]

\[
EW_P = \text{Elemental weight of pollutant (32)} \]

\[
\text{SO}_x \text{ for transportation (SO}_x^1) = 4.32 \times 0.0005 \times \frac{64}{32} = 0.00432 \text{kg} 
\]

Sulphur dioxide emissions for electricity consumption were calculated using an emission factor of 8.25g per kWh consumed (Eskom, 2015).

The (SO\(_x\))^2 emission for electricity use amounted to 12.229 grams or 0.01229 kg.

The total sulphur dioxide content SO\(_x\) emitted for 1 ton of sandstone = (SO\(_x\))^1 + (SO\(_x\))^2

\[
= 0.00432 + 0.01229 
= 0.01661 \text{ kg} 
\]

Nitrogen oxide (NO\(_x\)) emissions for electricity consumption were computed using an emission factor of 4.22g per kWh consumed (Eskom, 2015). The NO\(_x\) amounted to 6.2878 grams or 0.00629 kg.

The total energy content related to the input was also calculated. For electricity, it was 3.6 MJ/kWh and for diesel 38.7 MJ/litre (Hofstrand, 2008). The calculation of the total energy content was done as follows:

Energy for electricity use = 1.49 x 3.6 MJ = 5.4 MJ

Energy for diesel use = 4.32 x 38.7 MJ = 167.2 MJ

Total energy input = 172.6 MJ

The summary of the mine’s inputs and outputs for the production of one ton of sandstone is provided in Table 5.3.
Table 5.3: Material and energy input and output

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs from technosphere</strong></td>
<td></td>
</tr>
<tr>
<td>Electricity (kWh)</td>
<td>1.49</td>
</tr>
<tr>
<td>Diesel (litres)</td>
<td>2.16 (one way)</td>
</tr>
<tr>
<td>Energy input (MJ)</td>
<td>172.6</td>
</tr>
<tr>
<td><strong>Inputs from nature</strong></td>
<td></td>
</tr>
<tr>
<td>Land area</td>
<td></td>
</tr>
<tr>
<td>Sandstone kg</td>
<td>1300</td>
</tr>
<tr>
<td>Water (litres)</td>
<td>12</td>
</tr>
<tr>
<td>Coal (kg)</td>
<td>0.8195</td>
</tr>
<tr>
<td><strong>Emissions</strong></td>
<td></td>
</tr>
<tr>
<td>CO₂ (kg)</td>
<td>13.169</td>
</tr>
<tr>
<td>CH₄</td>
<td>n/a</td>
</tr>
<tr>
<td>N₂O</td>
<td>n/a</td>
</tr>
<tr>
<td>SOₓ (as SO₂) (kg)</td>
<td>0.01661</td>
</tr>
<tr>
<td>NOₓ (as NO₂) (g)</td>
<td>0.00629</td>
</tr>
<tr>
<td><strong>Product output</strong></td>
<td></td>
</tr>
<tr>
<td>Sandstone bricks (t)</td>
<td>1.00</td>
</tr>
</tbody>
</table>
CHAPTER 6

LIFE CYCLE IMPACT ASSESSMENT AND INTERPRETATION

6.0 Introduction

This chapter focuses on the life cycle impact assessment. In other words, in this chapter, the results of the life cycle inventory are analysed and translated into contributions to pre-selected impact categories. It must be noted that the impact assessment can only be made after the interpretation of the data collected in the inventory phase.

6.1 Energy use

The total energy consumption for the artisanal production of one ton of sandstone is 172.6 MJ/t (see Table 6.1). Energy intensity values were used as indicators of energy consumption.

Table 6.1: Energy consumption in MJ/t

<table>
<thead>
<tr>
<th>Energy type</th>
<th>Values (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>5.4</td>
</tr>
<tr>
<td>Diesel</td>
<td>167.2</td>
</tr>
<tr>
<td>Total</td>
<td>172.6</td>
</tr>
</tbody>
</table>

The host-mine only uses energy for two phases: (1) the transportation of the extracted sandstone to the warehouse (diesel fuel), and (2) the processing of the large pieces of stone into smaller bricks (electricity). The proportions of contribution for each energy source are shown in Figure 6.1. The biggest contributor to energy use is the transportation phase, accounting for 96.9% of all the energy consumed; whereas the processing phase only accounts for 3.1%.
6.2 Water use

Ditsele (2010) noted the lack of a standardised characterisation method for water usage in the LCA framework. In this study, no characterisation factor was used to assess the potential impacts of the mine’s water consumption. Instead, the water consumption determined in the inventory analysis was used to measure the water use impact. For the production of 1 ton of sandstone, the water use amounted to 12 litres.

6.3 Land use and destruction of habitat

The impacts of mining activities on the land are very limited. The host-mine is situated in an area that is far from any habitation, where the vegetation is sparse, and with no water bodies. Before the mine opened, the population – except for occasional livestock grazing – seldom used the land and no significant trace of animal life was recorded. After the mine’s closure, the land is to be rehabilitated and returned to its previous state. The most significant impact associated with land use for mining is the perceived negative visual effect on the natural landscape.
6.4 Working habits and human health

To assess the impact of sandstone mining on human health, personal interviews were conducted with 31 of the miners working at the facility. Only the answers of those who had been working as miners for more than 12 months were considered in the analysis. The questionnaire essentially covered three sections: (i) general health before working at the mine, (ii) mining practices, and (iii) general health since working at the mine. Most of the respondents stated that they were in good health before they started to work as miners (65%). Fewer respondents admitted that they had a fair health (35%). None of the respondents confessed to having bad or poor health (Figure 6.2). Although some bias is assumed in the responses given, the results of the interviews were taken as an indication of the potential impact of artisanal sandstone mining on the miners’ health.

The results showed that the majority of the respondents had suffered from musculoskeletal problems that included back and muscle pain (these miners do not have sophisticated equipment and have to rely on their own strength for extraction and heavy lifting of the stones). The other significant health issue noted was respiratory in nature and could be attributed to the inhalation of dust particles during the mining process. Table 6.2 provides a summary of the data collected for health impacts and work environment. A look at the results of the interviews shows that there was a slight decrease in the percentage of miners who maintained that they had good health (55%), while the percentage of miners who indicated that they had fair health had increased (45%) (Figure 6.3). In both instances (general health before and after working at the mine), none of the respondents acknowledged poor or bad health. This could be due to the fact that some miners may be reluctant to admit to being in poor health for fear of being stigmatised by their co-workers or becoming unemployed.
Table 6.2: Summary of data collected on miners and health issues

<table>
<thead>
<tr>
<th>Type of health issues</th>
<th>No. of respondents</th>
<th>% of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory diseases or problems</td>
<td>21</td>
<td>68%</td>
</tr>
<tr>
<td>Musculoskeletal problems</td>
<td>25</td>
<td>80%</td>
</tr>
<tr>
<td>Skin infection</td>
<td>15</td>
<td>48%</td>
</tr>
</tbody>
</table>

6.5 Airborne emissions

Artisanal sandstone mining only contributes to emissions of CO₂ gases by using coal-generated electricity and diesel fuel for transportation. Most of the carbon dioxide emitted during the process results from the transportation phase – with 11.664 kg of CO₂ emitted in the process of transporting the stones from the mining site to the warehouse, whereas only 1.505 kg of CO₂ were emitted as a result of electricity use.

In total, the whole process of the production of 1 ton of sandstone emits 13.169 kg of CO₂ gases. Calculations of greenhouse gases emissions for the present study only covered carbon dioxide emissions into air. Since the global warming potential (GWP) of CO₂ is 1, the total CO₂ gas emitted for the whole process amounts to 13.169 kg.

The transportation of the stones from the mining site to the processing warehouse accounts for most of the emissions of sulphur dioxide (SOₓ). SOₓ emissions resulting from the
processing phase and the subsequent electricity consumption only amount to 22% of total emissions.

Nitrogen dioxide (NO\textsubscript{x}) emissions were mainly attributed to the processing phase and the related electricity consumption.

6.6 Impacts assessment

The SimaPro Software for Life Cycle Assessment was used to analyse the results of the inventory analysis. Two assessment methods were used for the impact assessment, namely, IPCC 2013 GWP 20a and IMPACT 2002+. The network for the production of artisanal sandstone is shown in Figure 6.4 below.

![Figure 6.4: Process network diagram for artisanal sandstone bricks.](image_url)

This network is graphical depiction of the artisanal mining model. It shows the energy sources for both phases of artisanal sandstone production; namely diesel fuel for transportation and electricity for sandstone production. The diagram also illustrates the contribution, in percentages, to potential impacts of both phases. It should be noted that the extraction process is not included in the process network because the techniques used do not
result in the emission of any type of pollutant and does not require any other energy source beside miners’ physical work.

6.6.1 Global warming potential

The potential impacts of global warming are associated with the release of carbon dioxide during the transportation and processing phases. The transportation phase – with the use of a fossil-fuel-powered vehicle – has the highest contribution to the total emissions (88%). Carbon dioxide releases related to the processing phase are significantly lower than those emanating from the transportation phase that involves the use of coal-generated electricity (Figure 6.5).

The contribution of each phase to climate change is similar to its contribution to global warming. Thus, to assess the contribution of each process/phase to climate change, one can refer to the results of the global warming potential.

Figure 6.5: IPCC global warming potential for 20 years.
6.6.2 **Ozone layer depletion**
The ozone layer depletion solely results from the transportation of uncut sandstone pieces to the warehouse. Hydrocarbons are emitted during the combustion of the fuel in the truck (Figure 6.6).

6.6.3 **Acidification**
The road transportation of the sandstones to the warehouse – for processing – contributes the most to the acidification. This is because of the amount of sulphur dioxide emitted when the diesel fuel burns in the truck. The contribution of the processing phase to this impact is due to the use of electricity and the related release of sulphur dioxide when the heat generated by the combustion of coal is converted into energy (Figure 6.6).

![Figure 6.6: Results of the characterisation.](image)

6.6.4 **Non-renewable resources use**
The transportation of the stone to the warehouse is the process or phase that contributes the most to the use of non-renewable resource (i.e. fossil fuel). Sandstone itself does not fall into the category of non-renewable resource. This is because it is virtually inexhaustible (natural
bedrock underlying all continents). The other process that contributes to non-renewable resource use is the processing phase which uses coal to generate electricity.

![Figure 6.7: Normalisation results](image)

The normalisation of the results is presented in the Figure 6.7. The latter shows the extent to which the phases of artisanal sandstone mining, namely, transportation and processing, contribute to human health, climate change, and non-renewable resource use impact. The objective of normalisation is to provide an idea of the relative magnitude of the environmental profile of a product system.

### 6.7 Conclusion

Based on the results obtained in the inventory analysis and the impact assessment phases, the following conclusions can be drawn regarding the contribution of each phase to the total life cycle of artisanal sandstone mining:

- Artisanal sandstone mining uses energy inputs that result in emissions in two phases, namely, the transportation of the stones to the warehouse and the processing of the
stones into bricks. The extraction phase that only requires human power does not involve any gaseous release.

- Impacts on land use are limited, because quarrying takes places in areas where the vegetation is sparse and the biodiversity is limited.

- Quarrying methods have negative impacts on the physical wellbeing of miners, because of the excessive human power required.

- The transportation phase is the greatest contributor to energy consumption and non-renewable resources use.

- The transportation phase contributes the most to global warming, climate change, and ozone layer depletion.

- Acidification is mainly caused by the release of sulphur dioxide when fuel combusts inside the truck engine.
CHAPTER 7

DISCUSSION OF RESULTS AND RECOMMENDATIONS

7.0 Introduction

This chapter summarises the findings of the study and makes recommendations that could help improve the environmental performance of the artisanal sandstone-mining sector in South Africa. All recommendations are based on the findings of the inventory analysis and the impact assessment phases. The recommendations for performance improvement consider what can reasonably be done by the mining company.

7.1 Discussion of study’s results

The main reason for conducting this study was to determine the impacts of artisanal sandstone mining on the environment. The goal was to identify areas in the life cycle of the stone that could be improved, to reduce said the identified impacts. The results of the study are as follows.

- Artisanal sandstone mining, essentially, has three phases: the extraction of the stone, its transportation to the warehouse, and the processing of the stone into readily-usable products (bricks, cladding, and so forth). Only two of these phases of the product’s life cycle result in emissions (transport and processing). It is assumed that during the extraction phase, no emissions occur because only human power is needed. The quarrying method does, however, impact the health of miners. The silicoses caused by dust inhalation and musculoskeletal problems are experienced because of the intensive nature of the work are among the health concerns.

- The transportation phase is the greatest contributor to energy use and fossil fuel use.

- Global warming, climate change, and ozone layer depletion are mostly a result of the release of carbon dioxide (CO₂) and hydrocarbons in the air, during the transportation of the extracted stones to the processing warehouse.

- The transportation phase is the main contributor to acidification.
The results of this LCA are only valid within the boundaries of the system studied and its related assumptions. In the present study, the transportation of the extracted stone to the processing warehouse was the greatest contributor to emissions and impact categories. The contribution of the processing phase was significantly the lowest (less than 15% in some cases); whereas the extraction phase registered no emissions and only impacted the environment through land use. However since this research focused on the system rather than the product itself, it is important to keep in mind that variations in the system could deliver different results.

The outcome of this LCA showed that the overall impact of artisanal sandstone mining on the environment is relatively benign, if compared to that of the whole mining industry. This is due to the fact that the artisanal sandstone mining sector does not necessitate as much energy input as other sectors. Additionally, the fact that the final product does not require extraction from an ore significantly reduces potential emissions into air, water, and soil.

7.2 Recommendations

7.2.1 Working habits and human health

Miners have complained of various health issues associated with work practices at the mine. Respiratory diseases related to dust can be reduced by adopting the use dust masks to reduce the amount of dust inhaled during extraction and stone handling. Extreme tiredness and musculoskeletal problems are the other major issues in artisanal sandstone mining, because the miners rely heavily on their personal strength and energy to extract and handle the stone (loading the stones into the truck). Using a mechanised mining process would significantly reduce the physical exertion required from the miners and the associated health impacts. Another benefit of adopting a mechanised extraction process would be the reduction of stone waste; thus increasing the mine’s productivity. Although less than 11% of the respondents acknowledged that the hammering noise was an issue, the distribution of ear protectors to the miners would be advised.
7.2.2 Land use

Not many changes could be implemented to reduce the impact of the artisanal sandstone mining activities on the land, without negatively impacting the productivity of the mine. Indeed, reducing the extraction area would also diminish the amount rock extracted. The major concern in land use is its rehabilitation so that it is returned to its previous state – if possible. Although the mine does, to a certain extent, engage in land rehabilitation (as a general practice, waste rock is used to fill up holes created by erosion and mining), a lot could still be done to minimise the effects of mining on the land. Hydro-seeding can be used to revegetate areas where vegetation would have been removed to enable extraction.

7.2.3 Energy use

The study revealed that the diesel fuel used for truck engines was the main energy source in artisanal sandstone mining, followed by electricity for stone processing. The use of fossil fuel is directly linked to the ozone layer depletion, global warming, and climate change. Improvements in energy use can address these three impacts categories. In the context of this study, it was shown that transportation was the most energy-consuming phase. Reducing the impacts associated with the consumption of diesel fuel could be achieved through the adoption of alternative biodiesel and by increasing the quantity of stones transported. The latter suggestion would reduce the number of trips made by trucks from the warehouse to the mine to a minimum. Increasing mine productivity could help achieve energy efficiency, as small-scale operations are often inefficient in the use of energy.
CHAPTER 8

CONCLUSION

The artisanal mining sector plays an important role in the economic upliftment of local community throughout the world. This informal sector is not well organised and, therefore, difficult to accurately assess in terms of the quantities of commodities extracted every year, or even to get a clear picture of the potential impacts of this sector on the environment. A review of the current literature reveals that a certain number of studies have been conducted on the effects of the artisanal mining of such commodities as gold and diamond on the environment, while almost none that consider construction or building materials such as limestone or sandstone exist.

Hence, this life cycle assessment was conducted to clearly establish the environmental impacts of artisanal sandstone mining and to correct the apparent lack of data on artisanal sandstone mining. The study was intended to provide useful information to artisanal miners so that they understand the impacts of their activities on the environment and identify areas where changes could be made to improve their environmental performance; and public policy-makers to enable the development of suitable environmental management strategies, policies, and regulations to reduce the adverse environmental impacts of artisanal sandstone mining.

The goal of this study was to apply the general principles of the ISO 14040 series in the LCA of artisanal sandstone mining, to determine its environmental impacts in the QwaQwa region of South Africa. The functional unit selected for this study was defined as one ton of sandstone processed at the warehouse. The potential impacts were selected for the following categories: global warming, ozone layer depletion, acidification, and non-renewable resource usage. Water, land and energy use, and the work environment were also considered. An artisanal sandstone mining company located in QwaQwa, South Africa, was used as host for this study. The main contributors to the different impacts categories were identified and recommendations were made to improve the overall environmental performance of the system under study. The conclusions drawn from the study are summarised below.

- Artisanal sandstone mining has a relatively low contribution to climate change and global warming. Nevertheless, it is important to ensure that effective environmental
management systems are adopted by this industry to ensure resource usage optimization and reduce impacts on both human health and the environment.

- Artisanal sandstone mining has a global warming and climate change potential of 13.169 kg CO$_2$ per ton of sandstone produced. Diesel fuel is the greatest contributor to global warming and climate change.

- The potential impact of artisanal sandstone mining on ozone layer depletion is caused by the release of hydrocarbon when diesel fuel is burnt in trucks’ engines during transportation.

- The potential impact of artisanal sandstone mining on acidification is 0.01661 kg SO$_2$ per ton of sandstone produced. The transportation phase is the greatest contributor to that impact category – with more than 60%.

- The impact of artisanal sandstone mining on the non-renewable resource use category is mainly due to the use of fossil fuel during the transportation phase. However, the processing also contributes to that category through the use of coal-generated electricity.

- The energy use impact per ton of sandstone produced is 172.6 MJ. Diesel fuel contributes the most in that category – to an extent of 96.9%.

- Water use impact of the production of artisanal sandstone mining was determined to be 12 litres per ton of sandstone produced. The assessment for this impact category was not performed because the LCA framework has no standardised characterisation method for water use.

- The potential land use impact could not be assessed, because the mining company was unable to provide data on the total land occupation for the duration of the mine. However, the assumption that land use impacts would only be dominated by the land affected by the extraction process can be made.

- Work environment and working habits negatively affect the health of miners. Silicosis and musculoskeletal problems were noted as the most common health-related issues.
• Recommendations for improving the environmental performance of artisanal sandstone mining include the adoption of a mechanised mining process, to increase productivity and reduce the work strain on miners and thus reduce musculoskeletal issue; the distribution of protection masks, to prevent dust inhalation; and the provision of ear protectors to neutralise the noise. Increase in mine productivity is important in the endeavour to improve energy use efficiency, to reduce non-renewable resource use, global warming, and ozone layer depletion impacts. The impacts on land can be minimised by engaging in land rehabilitation practices.

The results of this study also showed a lot of shortcomings with the overall management of the host mine. These shortcomings are often associated with a lot of ASM. Although the host mine is registered and has a land mining permit, management was unable to provide a clear number or any other measurement of the area of land in which they extract their stones. The same issues were encountered with water consumption in litres (l) and electricity use in kilowatt hour (kWh) where the manager of the mine could only provide the amount of money spent for both but not the exact quantity in the unity of measurement. The unavailability of specific numbers for some data essentially means that various assumptions had to be made to pursue the study.

This lack of clear records on land, water and electricity usage clearly illustrated some of the grievances associated with artisanal and small scale mining regarding the fact that it is often difficult to conduct proper studies on their impacts on the environment because records on inputs and outputs of their activities are often not up to date or readily available like in large scale mining. It clearly raises the need to encourage the adoption and promotion of good management training in the ASM sector through government or industry sponsored workshop for example.

In addition, the fact that no formal environmental management system (e.g. there is no clear procedure on how to deal with waste water) is adopted by the host mine also serves to reiterate and enforce the importance of the promotion of environmental sustainability and the adoption environmental orientated tools in the ASM sector.

Another important point that was noted in the host mine was the lack of proper knowledge on miners’ health and the necessary actions required to prevent accidents and/or health related
issues. Here as well, it highlighted the importance of providing small scale miners with the proper information regarding the negative impacts that their activities can have on their health and that of the surrounding communities as well as the necessary information or training that would assist in minimising said impacts.
REFERENCES


DATA COLLECTION QUESTIONNAIRE

(STAHELDERS QUESTIONNAIRE)
My name is Urla Koumba, a student at the University of Johannesburg, doing a Master’s in Operations Management. I am doing a study on the environmental impacts of artisanal sandstone mining. You are invited to participate in the mentioned study by providing the required information in order to complete this study. All the information you provide will be used strictly for academic purposes. Participation in this research is voluntary and your confidentiality will be safeguarded as the analysis will only focus on the patterns in the data provided by a number of informants. No names or information about any individual will be published.

1. Mine description and location:
   Specify the location and characteristics of the mining site ----------------------------------
   -------------------------------------------------------------------------------------------------------
   -------------------------------------------------------------------------------------------------------

2. Mine contact person:-----------------------------------------------------------------------------------------------

3. Occupation/position in the organisation:--------------------------------------------------------------------------

4. Do you think that artisanal sandstone mining has positive impacts on people:
   Yes □ No □

5. Are you aware of any environmental damages and health issues resulting from artisanal sandstone mining?
   Yes □ No □
   If yes, please name them:----------------------------------------------------------------------------------------
   -------------------------------------------------------------------------------------------------------
   -------------------------------------------------------------------------------------------------------

6. Do you think that there is way to minimise the damages and issues named in (4)? (please explain answer)------------------

7. Do you think that artisanal sandstone mining has disturbed the local ecosystem?
   Yes □ No □
If yes, please specify to what extent:

8. Do you think that artisanal sandstone mining has had a negative impact on the local visual landscape?
   Yes  No
   If yes, please indicate to what extent:

9. Are there any governmental policies and regulations that regulate artisanal sandstone miners’ activities?
   1. Yes 2. No 3. Don’t know
   If yes, specify: ________________________________________________________________

10. Are artisanal sandstone miners involved in these policies and regulation?
    Yes  No

11. Are you involved in these regulations and policies? (explain answer)-------------------
     ________________________________________________________________
     ________________________________________________________________

12. Do you engage in any land rehabilitation activities?
    Yes  No
    If yes, list them ________________________________________________________________

13. Who implements these rehabilitation activities?------------------------------------------

14. What challenges do you place in implementing the rehabilitation strategies?-------
    ________________________________________________________________
    ________________________________________________________________
    ________________________________________________________________

INPUTS AND OUTPUTS

15. Sandstone production:
    a) Indicate annual sandstone production for the last four years:
       2012----------------------------------------
       2013----------------------------------------
       2014----------------------------------------
       2015----------------------------------------
b) Specify if a special event occurred during any of these years  

Land use:

How long has the mine been in operation?  

<table>
<thead>
<tr>
<th>Name</th>
<th>Unit</th>
<th>Quality of Data (calculated/ estimated/measured)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilities area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overburden disposal area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total land use</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16. Transportation distance:

<table>
<thead>
<tr>
<th>Transport</th>
<th>Unit</th>
<th>Quality of Data (calculated/ estimated/measured)</th>
<th>Average distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>On site transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

17. List of equipment and energy type:

<table>
<thead>
<tr>
<th>Equipment/ vehicle</th>
<th>Energy source</th>
<th>Number of units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

18. Input:

For the production of ________________ of sandstone.

<table>
<thead>
<tr>
<th>Name</th>
<th>Unit</th>
<th>Quality of Data (calculated/ estimated/measured)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil fuel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total fossil fuel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Water

| Surface water |  
| Paid water    |  

**Total water usage**

| Labour |  
| Person |  

---

#### 19. Labour.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employees</td>
<td></td>
</tr>
<tr>
<td>Management/owners</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

---

#### 20. Emissions

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Quality of data (calculated/estimated/measured)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Data Collection Questionnaire

Workers Questionnaire

My name is Urla Koumba, a student at the University of Johannesburg, doing a Master’s in Operations Management. I am doing a study on the environmental impacts of artisanal sandstone mining. You are invited to participate in the mentioned study by providing the required information in order to complete this study. All the information you provide will be used strictly for academic purposes. Participation in this research is voluntary and your confidentiality will be safeguarded as the analysis will only focus on the patterns in the data provided by a number of informants. No names or information about any individual will be published.

1. How long have you been working in mining? ------------------------------- (if less than 12 months, the respondent do not qualify)

2. Age: ---------------------------

3. Gender: Male □ Female □

4. Indicate the approximate quantity of sandstone that you extract on a daily basis: ---------------------------------------------

5. Life status: (tick the appropriate answer).
   Leaving alone □ Having with family □

6. Household location (tick the appropriate answer)
   Leave in the nearby village □ Leave in miners camps □

7. How many hours do you work on a typical day? ---------------------------

8. Do you smoke? (tick the appropriate answer)
   Yes □ No □

9. Alcohol consumption: (tick the appropriate answer)
   1. Great consumer □ 2. Low consumer □ 3. No alcohol □

10. How would you describe your general health before starting to work as a sandstone miner?
1. Good 2. Fair 3. Poor  

11. Please tick the adequate box if you have experienced the following health issues since you started working at the mine:

<table>
<thead>
<tr>
<th>Respirator problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortness of breath</td>
</tr>
<tr>
<td>Cough</td>
</tr>
<tr>
<td>Chest pain</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Musculoskeletal problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back pain</td>
</tr>
<tr>
<td>Muscle pain</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General tiredness</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Hearing problems</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Vision problems</th>
</tr>
</thead>
</table>

| Skin infection            |

12. How would you describe your general health since you started working at the mine?

13. Good 2. Fair 3. Poor