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Streamlined LCA in product EHS

A case study of Sandvik Mining

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Acknowledgements

Growing up psysical education was always my favorite subject in school. Could there be anything better than to play sports on school hours? Not to me at least. This initial interest has by now evolved into a boarder line addiction to sports; although nowadays I might spend too much time watching it in comparsion to how much I take part in it my self. The point is that there are very few sports that I do not enjoy; either watching or playing my self. One of these rare exceptions has however always lied in long distance running. I guess that it has to do with my psysical settings have not being, nor will it ever be, sufficient to reap any glory within this sport. The process of writing this paper is perhaps the closest I will come to running a marathon. Do not get me wrong I like running, but maybe shorter distances and chasing a ball while running. I have come to realize that there are many obstacles to overcome even in a marathon; both psychological and psysical. Also, a marathon is not as straightforward as I suspected.

Mårten Karlsson, you have been both my mental coach and personal trainer in this race. When I thought I could run no more, you gave me just the right words to make me continue. When I thought I was lost, you reminded me that I was on the right way all along. You followed me from the side of the entire race cheering me on. I could not have done this without you.

A huge acknowledgement is given to Sandvik Mining for giving me the opportunity to take on this race. Being able to wear your running clothes is an opportunity I will never forget. Thank you for beliving in me although I have never ran a marathon before. It is amazing to me that you believed in me enough to enter me into the race and now when I have finished I hope that I have made you proud.

Johanna Wester, know how hard it is to limit these words of gratitude. Without you I would not have made it 10 kilometers. I feel as is you have run beside me for the entire distance being the one of us that never doubted my abilities. I will be grateful for that for the rest of my life.

I always heard about the special bond that is within the IIIEE Alumni but I could never have guessed the optimism I encountered when asking previous runners for advice. Your help was much appreciated; Douglas, Mary Ann, and Anna.

Für Anna: Wäre dies ein Marathon, dann wärest du das Ziel zu dem ich renne und du wirst es auch für immer sein. Du bist der Teil von mir, der immer gefehlt hat und mich erst wieder ganz gemacht hat. Ich werde dich immer lieben!

My dear Batch 17. This process has made it painfully obvious how much you managed to boost my confidence. The year with you made me accomplish things I would never have guess I was capable of. They say that you do not truly miss something until you lost it. I hope that I will never loose a single one of you guys even though I am missing all of you so much that I feel like I have.

Abstract

Life Cycle Assessment (LCA) is today an established environmental tool which allows companies to assess the environmental impact of its products. Considering all inputs and outputs that a product uses in its entire life cycle; an LCA study gives a quantified expression of environmental performance. Theory does however not always go hand in hand with practice and it is common that companies simply cannot justify the resources that an LCA study requires. Derived from LCA, Streamlining LCA (SLCA) offers companies a more manageable environmental assessment by deliberately excluding parts of an LCA study and still recieve results that are reliable and useful. There are however many ways to approach SLCA and a company needs to clearly understand its own unique requirements of using it. This research examines LCA and SLCA theory, and then it analyzes the case of Sandvik Mining, in order to describe how SLCA can be adapted and used as an environmental tool and incorporated into a company's existing new product development model. The methods include literature analysis, review of both internal and external documentation, and semi-structured interviews. The findings include that SLCA can be justified at Sandvik Mining based on their current requirements of using it. A recommended incorporation of SLCA into Sandvik Mining's new product development model is suggested. Overall, the findings are sensitive to the unique situation of the case study and these should be viewed as an initial effort to work with SLCA.

Keywords: streamlined life cycle assessment, life cycle assessment, Sandvik Mining, new product development, product EHS

Executive Summary

Introduction

Environmental life-cycle assessment (LCA) provides a company with a method which makes it possible to assess the environmental impact caused through-out the whole life-cycle of a product or a service. LCA aims to understand the entire life-cycle of a product; from its cradle to its grave. By doing so, a company can understand where in a product's life cycle the biggest environmental impact occurs. Additionally, LCA can also allow a company to choose between various product designs based on their sustainability. LCA gives a quantified assessment of a product's environmental performance. The increased knowledge that LCA provides a company can be utilized by focusing sustainability efforts towards the identified environmental 'hot-spots'. Furtermore, LCA allows a company to measure the improvements that their sustainability efforts have on their products.

LCA is however often critized by the business sector for being too costly and time consuming in relation to what they can provide the companies with. The assessment of the entire life cycle of a product can quickly become an overwhelming task for a company. The level of complexity of an LCA study is closely related to its set goal and scope. A complete LCA study aims to understand every single aspect and component of a product's life cycle and theory cannot always be applied on reality. Many companies struggle to find a balance between keeping LCA manageable and ending up with environmental information that is representative for their products. Moreover, companies are increasingly targeting their EHS efforts towards their products placing even more restrictions on the time that can be justified to spend on an LCA study. In order to keep up with the tempo of product innovation LCA needs to be made more manageable by the companies.

Streamlined LCA (SLCA) is a concept that offers companies ways to simplify their use of LCA studies without endangering the reliability of the results that they deliver. Clearly understanding the goal and scope of an LCA study can allow a company to identify parts of an LCA study that can be disregarded. All LCA studies are in fact argued to be streamlined to some extent and the concept of SLCA can be seen as the process of a company justify the streamlining activities that are fitting for their unique needs of using an environmental assessment.

Problem Definition

It is up to the LCA expert to decide *where* and *how* to streamline in an LCA study. Because SLCA is so closely related to the goal and scope of an LCA study there are no guidelines or frameworks that a company can utilize when approaching SLCA. This suggests that every SLCA study will be unique depending on who performs it. A company that has interest in using LCA as an environmental tool in order to improve its environmental performance will therefore face a problematic situation; should they choose the resource intensive full LCA that provides a more detailed result or the less resource demanding SLCA providing a less complex study?

With some experience of using LCA, Sandvik Mining wishes to expand their use of this environmental tool. It is the aim of Sandvik Mining to incorporate LCA into its existing New Product Development (NPD) model. Previous LCA studies increased Sandvik Mining's knowledge about the environmental impacts of one product's life cycle. However, as Sandvik Mining produces a wide range of products within many different categories of mining equipment. The possibility to perform LCA studies on each and every product that Sandvik Mining produces is currently not seen as applicable as the resources required are simply too high. Instead Sandvik Mining has expressed an interest in SLCA as this potentially could allow them to realize the benefits of using LCA studies and still be reasonable to carry out from a

resource perspective. Sandvik Mining wants to incorporate SLCA into its new product development model in order to establish a model that allows for a systematic approach to its environmental work and ensure that continuous improvements are accomplished over time. It is however unclear to Sandvik Mining if the use of SLCA can be justified and how it can be incorporated into their existing current processes.

Research Question

The defined research problem demands an understanding of how SLCA can be used by a global manufacturing company as an environmental tool. This will in turn require a solid understanding of SLCA and its linkages to LCA. Additionally, it is necessary to translate this understanding into recommendations for incorporation of SLCA into the existing NPD model. This formulates the following research question:

How can an LCA be streamlined, adapted, and incorporated to fit the specific purposes of a global manufacturing company?

Methodology

The research was carried out as a single case study investigation based on theory, interviews, e-mail correspondence, meetings, and documents. The defined research question required detailed insights into a global manufacturing company. Sandvik Mining was selected as the case study and followed a descriptive approach providing relevant observations, used to analyse against the theoretical framework of the paper. The theoretical framework was established with emphasis on SLCA, LCA, and product innovation.

The analysis of the paper aimed to find correlations between the established theoretical framework and the collected case study obeservations. The first part of the analysis aimed to identify and justify these correlations and the second part aimed to translate these correlations into recommendations.

Theoretical Framework

The creation of the theoretical framework followed a funnel approach where it was necessary to first understand the theory on LCA. This theory was seen as the foundation on which SLCA theory is build. Other theoretical concepts identified as relevant for SLCA were also included inti the theoretical framework including product innovation theory and EPD. For Theory on LCA was primarily based on the ISO 14000 series on LCA guidelines and framworks. SLCA theory was primarly derived from previous research of Mary Ann Curran. Overall, the theory was deemed as very comprehensive and it was necessary to identify and include parts most relevant to the research question into the theoretical framework.

Case Study of Sandvik Mining

The case study of Sandvik Mining included information gathering through; interviews, meetings, brainstorming sessions, presentations, and documentation reviews. Furtermore, the author was located at the Global Product EHS department at Sandvik Mining, Sandviken, Sweden. This allowed for daily interactions with the intended audience of the paper and access to internal documentation that proved to be valuable case study observations.

Also the case study followed a funnel approach initiaing in a wider context of Sandvik Mining as a company and an understanding of their operations. EHS policies and strategies for the entire company led into more specific EHS practices that can be separated into operational- and product EHS. The main emphasizes of the case study lies in the presentation of the NPD model with a focus on current product EHS practices. The case study observations made at Sandvik Mining as a whole allowed the paper to understand *why* SLCA can be justified within the company. The observations made from specific product EHS practices and the NPD model allowed the paper to understand *how* SLCA should be used within Sandvik Mining. Additionally, the case study gave an understanding of the current knowledge of LCA building on past experiences.

Overlaps between theory and practice

Comparing the results of the case study and the theoretical framework made it possible to identify a number of overlaps between theory and practice. The initial part of the analysis formed Sandvik Mining's current position of using SLCA based on the case study observations previously made. This allowed the analysis against the theoretical framework which identified where streamlining activities can be made, the level of opportunity to do these, and why these are justifiable. The intended use of SLCA results, the previous knowledge about dominant life cycle stages, and the internal SLCA audience were identified as the main factors allowing the use of SLCA. Furtermore, the accepted uncertainty, the current use of recycled or reused materials, the desire to establish SLCA according to product types, and previous knowledge about certain life cycle stages gave justification for some streamlining activitites. Derived from the fist part of the analysis it was then possible for the paper to translate the identified streamlining opportunities into actual recommendations of incorporation into Sandvik Mining's NPD model. The recommendations were suggested to complement the already existing product EHS activities.

Conclusions

The analysis of Sandvik Mining reached two major findings; that he use of SLCA can be justified at Sandvik Mining and a suggestion for how to incorporate SLCA into Sandvik Mining's NPD model. The research of this paper is however very specific and the choice to use a single case study of Sandvik Mining gave results that are useful for only them. Even for Sandvik Mining the findings of this paper must be treated carefully due to internal differences in LCA and SLCA requirements. Even so, the paper was able to answer its research question with findings that satisfy its intended audience.

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Abbreviations

LCT - Life Cycle Thinking

SLCA - Streamlined Life Cycle Assessment

LCA - Life Cycle Assessment

LCIA - Life Cycle Impact Assessment

LCI - Life Cycle Inventory Analysis

EPD - Environmental Product Declaration

ISO - International Standards Organization

NPD - New Product Development

1 Introduction

Life Cycle Thinking (LCT) has been an established way of thinking for a long time, applicable to many situations where the basic idea is suggested by its name; to consider the full life-cycle of a product or a service. During the 1960s researchers took the first steps in establishing an appropriate methodology concerning life cycle assessment (LCA) of a product's environmental impacts during its life-cycle. Environmental LCA provides a method for organizations to assess the environmental burdens that are caused through-out the full life-cycle of a product or a service. With a full life-cycle one usually considers a cradle-to-grave perspective, or sometimes cradle-to-cradle, if the product goes through some kind of recycling phase at the end of its life. An LCA compiles an inventory of inputs and outputs that is found in a product system and evaluates their potential environmental impacts. Commonly, the stages considered are; raw material, components, manufacturing, distribution, use and end-of-life management.

Broadly speaking, LCA can be argued to address two types of questions; which life cycle phase has the largest environmental impact or which product has a lower environmental impact over its life-cycle, depending if it is used to assess the life-cycle of one product or used to compare two products with the same function. The results of an LCA can support a company by increasing the knowledge regarding the environmental burden caused by the product. Business functions such as product development can translate the results of an LCA into action, leading to both a better performing product as well as increasing the awareness of other functions.

Although LCA has the potential of assisting a company it is often the target of criticism due to the level of complexity that it can reach. It can quickly become and overwhelming task to perform an LCA due to the share size of the system that is studied and the number of processes that takes place throughout the life of a product. A common criticism raised by businesses that are considering using LCA, is that it is too costly and time consuming in relation to the end result (Curran & Todd, 1999). An LCA study will always have to consider the relationship between the desired results and willingness to invest resources. One way to approach this dilemma is for the LCA expert to consider the scope of the LCA. It is possible to exclude certain parts of the life-cycle and/or look only at certain types of environmental impacts, if there are good reasons to do so. Another common problem is the amount of data that is needed to ensure reliability of the assessment. Often data is of poor quality or all together missing (Baitz et al, 2012). An LCA expert can solve this by actually recording necessary site-specific data, however can be time consuming. Instead average data that is commonly found in the industry, in the region or in the country, or perhaps even marginal data will often be used (Helman, 2012).

Curran (1996) argues that environmental issues have received increased attention from industries during the last couple of decades. Furthermore, LCA has been accepted by industry as an environmental tool that allows a company to work in an organized manner regarding its environmental performance. The development of the ISO 14040 framework for LCA has made more companies aware of the potentials of using LCA. However, companies often argue that an LCA study that follows the ISO 14040 framework often requires too many resources from the company. An ISO 14040 compliant LCA study aims to understand every single input and output of a product system, which in turn will require large amounts of data.

Instead many companies initiate work with LCA using compromises making the LCA studies more manageable and requiring fewer resources. This trend in industry showing an interest in less complicated ways to work with LCA have sparked the interest of LCA researchers. The Society of Environmental Toxicology and Chemistry in the U.S. formed a workgroup, consisting of LCA researchers, industry representatives, governmental representatives etc, in 1994 to further discuss the possibility of performing such simplified LCAs. The workgroup came to the agreement that it is not only possible to do so, through a streamlined life cycle assessment, but also that doing so should be seen as an inherent part of any LCA. Streamlining is done by any LCA expert when he/she defines the boundaries and data needs of the LCA. SLCA should therefore not be seen as a different approach or methodology as compared to LCA. However, they allow a LCA expert to simplify the reality while still delivering results that are reliable in relation to the set goal and scope of the LCA study (Curran, 1999).

According to Anna Bruun Månsson, consultant at WSP Environmental, there is currently a trend where industry has started to realize the potential of using LCA as an environmental tool. Lately many companies have started to target their sustainability work towards its actual products rather than its operations. Traditionally, environmental management systems (EMS) can be argued to have a higher focus on an organization's operations than specific products. This change of focus requires an environmental tool that allows companies to assess their efforts in a systematic manner and LCA is often used as the platform to achieve this (Bruun Månsson, 2012). The success of doing such a transition of moving EHS work from traditional operational EHS practices towards a higher focus on product EHS will of course depend on the complexity of the product itself. A B2C company has a range of environmental labeling programs that can enhance their environmental profile. However, a company that produces B2B products will not experience the same range of possibilities.

1.1 Problem definition

LCA is today an accepted environmental tool at both business as well as governmental level and it allows organizations to better understand their environmental performance of their products. Between initial raw material extraction and final end-of –life management is most often a long and complex system. LCA can be argued to be a 'black box' in which inputs are transformed to outputs. By systematically quantifying and/or qualifying the inputs and outputs that are passing through this 'black box', LCA aims to understand the environmental impacts that are caused over the entire product life-cycle. This will require resources in time, money and knowledge from anyone considering doing an LCA. Any LCA study needs to assess how much time and resources it will require in relation to the desired output one wants to achieve by performing it.

From a business perspective this is of high relevance as any corporation with stakeholders has to ensure an acceptable level of monetary returns to provide the business with capital. This often creates problematic situations where a company might have an interest in improving its environmental performance of its products by using LCA. However, the company might estimate that the resources the LCA study requires are simply too great in relation to the end result.

Curran (1999) suggests that streamlined life cycle assessment (SLCA) can provide a solution for such a situation. SLCA should be seen as a part of any LCA study and allows an LCA expert to make an LCA more manageable. An LCA will always to some extent be streamlined and it is up to the LCA expert to decide *where* and *how* to streamline. Streamlining is closely related to the scope and goal definition phase of an LCA and what will be streamlined in the study is decided in this phase. Curran suggests that there are a number of characteristics that should be in place in order to justify streamlining. However, there are no universal guidelines for SLCA that fit all. Every streamlined study will look differently depending on who performs it.

A company that has interest in using LCA as an environmental tool in order to improve its environmental performance will face a problematic situation; should they choose the resource intensive full LCA that provides a more detailed result or the less resource demanding SLCA providing a less complex study? Curran (1999) suggests that all LCA studies will end up on a continuum where a full LCA is one extreme at one end of the scale and a fully streamlined LCA lies at the other. It is not sufficient for a company to simply have an interest in using LCA as an environmental tool; the emphasis must be on the outcome of the LCA and what it should contribute to. For many companies increased knowledge of its products' environmental impacts throughout the life cycle is not enough to motivate the investment of a full LCA study. For these companies there is a need to ensure that the results of an LCA study can be translated into business advantages beyond that of increased awareness.

1.1.1 Sandvik Mining

Sandvik Mining is a global manufacturer of original equipment (OEM) for the mining industry. The company is one of five business areas under which Sandvik Group operates. As a leading supplier of equipment and tools, service and technical solutions for the mining industry, Sandvik Mining has approximately 13200 employees and operations in more than 130 countries. Sandvik Mining works to fulfill as well as go beyond environmental requirements by always striving to address the impacts of its activities. Sandvik Mining realizes the benefits of Life Cycle Assessment (LCA) as an environmental tool and wishes to incorporate it into its operations. Some experience from LCA already exists within the company. One of Sandvik Mining's product development centers in Tampere, Finland, developed 2008 a LCA study for a Sandvik Drill Rig using the ISO 14040 framework for LCA. The study provided much gained knowledge about the environmental impacts in the life-cycle. The LCA study also showed the potential benefits that LCA can contribute to and there is now an interest to incorporate LCA into existing new product development models (NPD).

Previous efforts regarding LCA have been done on a more case to case basis, and no common approach for LCA has been established within Sandvik Mining. However, there is a clear consensus that knowledge and capabilities regarding LCA exist within the organization, both within Sandvik Mining and the other business areas even if it can be seen as scattered. Sandvik Mining wishes to use LCA as an environmental tool, incorporating it into its NPD model but it is still under evaluation how this could, and should be done. It is important for Sandvik Mining that the outcome of doing so ensures that the results of using LCA can be translated into useful information, actions for R&D, as well as contributing to the overall environmental considerations in the product development process. The previous LCA study gave Sandvik benefits mainly by increasing their knowledge about the environmental impacts of one product's life cycle. Sandvik Mining produces a wide range of products within many different categories of mining equipment. The possibility to perform LCA studies on each and every product that Sandvik Mining produces is currently not seen as applicable as the resources required are simply too high. Instead Sandvik Mining has expressed an interest in streamlined LCA as this could allow them to realize the benefits of using LCA studies and still be reasonable to carry out from a resource perspective. Sandvik Mining wants to incorporate SLCA into its new product development model in order to provide a model that allows for a systematic approach to its environmental work and ensure that continuous improvements are accomplished over time.

1.2 Purpose

The purpose of this paper is to understand how Streamlined Life Cycle Assessment (SLCA) can be used by a global manufacturing company as an environmental tool. Furthermore the paper will assess the concept of Streamlining LCA to understand how an LCA study can be simplified and still provide results that are acceptable to the LCA expert. It is also the purpose of the paper to understand how LCA can be incorporated into a global manufacturing company's existing product development model.

1.3 Research Question

How can an LCA be streamlined, adapted and incorporated to fit the specific purposes of a global manufacturing company?

2 Methodology

2.1 Selection of Topic

The topic selection for this thesis was set in collaboration with Sandvik Mining. The author approached Sandvik Mining with an interest to coordinate his research with their operations. A discussion with Johanna Wester, Product EHS Specialist at Sandvik Mining, led to an agreement to write a thesis within the topic of Life Cycle Assessment. A number of future projects that Sandvik Mining intends to initiate were considered and the final decision was set according to the interest of both Sandvik Mining and the student. Additionally, it was discussed which project that could ensure both an academic value as well as value for Sandvik Mining.

2.2 Research Design

The research of this paper was carried out in three parts; the creation of a theoretical framework, a case study, and an analysis. The first two ran simultaneously leading into the analysis of the results.

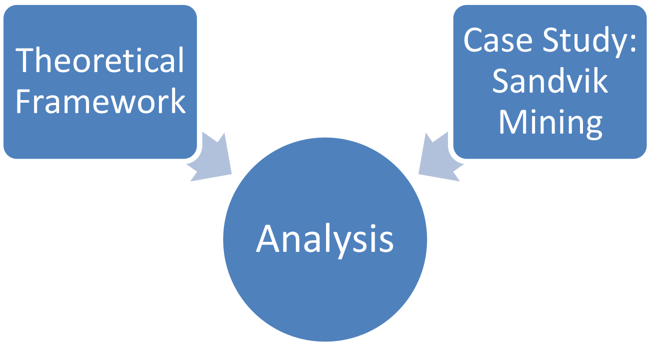


Figure 1 - Research Design
Source: Author

2.2.1 Research method for Theoretical Framework

A theoretical framework was formed that aimed to include theory deemed necessary to answer the identified research problem.

Literature review

A wide literature review was conducted to form the theoretical framework of the thesis. The theory that was reviewed focused on LCA and SLCA. The majority of the literature was accessed in Lund University's literature search engine Summon. During the thesis project this search engine was replaced with LibSearch. Publications issued by various LCA organizations were also reviewed. Additionally, specific literature was ordered and reviewed after discussions with LCA experts. ISO standards were available through Sandvik Mining's subscription to e-nav. The standards concerning LCA and environmental labeling were reviewed in particular.

Interviews

Four interviews were conducted with experts in LCA, SLCA, and EPD complementing the literature review. The list of interviewees can be found in the bibliography. The interviews followed a semi-structured method where the interviewees were initially presented with the research problem and the research question. The interviewees were then encouraged to provide their opinion on the matter from their perspective. Each interview was preceded with the preparation of some key questions written down to be used if the conversation started to steer off topic. The interview technique allowed for much variety in the discussion, the original intent of the researcher as it often gave suggestions for further theory and literature to consider.

E-mail correspondence

As a result of the conducted interviews the author was given the opportunity for e-mail correspondence with two of the interviewees. This communication allowed for follow-up questions of the interviews and gathering of new information. Correspondance was done with Douglas Helman, Senior Consulstant at PE International, Mary Ann Curran, LCA & Sustainability Consultant at BAMAC Ltd, and Anna Bruun Månsson, Consultant for Environmental and Sustainable Development at the WSP Group.

2.2.2 Research method for Case Study

This paper focused its research on a single case study of Sandvik Mining. The purpose of this paper required the student to gain detailed insights into a global manufacturing company. As the stated research problem was valid for Sandvik Mining the research format of a case study was an ideal approach for attempting to understand the issue at hand. Additionally, the case study allowed the student to apply findings to Sandvik Mining by developing a modified product development model.

Between November 2012 and February 2013 the author was placed at Sandvik Mining's offices in Sandviken, Sweden. The author was given an office in the global Global Product EHS department allowing for the close cooperation required of the research with focus on a single case study of Sandvik Mining. The members of the global Global Product EHS department are; Anna Gandal, Daniel Rosén, and Johanna Wester. The department's main working tasks include; product requirements identification, coordination of local product EHS engineers and advisors, development of processes, models and strategies, functional safety, and competence development.

According to Yin (1993) a case study refers to the phenomena of a case which is seen as an event, an entity, an individual or a single unit of analysis. Case studies are concerned with the questions 'why' and 'how' things occur in specific ways. Sandvik Mining served as the *subject* that was studied through *objective* of streamlined SLCA.

The case study of Sandvik Mining followed a descriptive approach presenting relevant information, necessary to compare it with the theoretical base of the paper. By selecting Sandvik Mining as a case study the student accessed internal data that might have proven to be difficult to access without the cooperation of the organization itself.

Throughout the case study of Sandvik Mining a number of data collection methods were used. These are described in greater detail below.

Interviews

The interviews followed the same structure as the interviews conducted for the theoretical framework as described above. But instead the interviews were conducted with employees at Sandvik Mining. The list of interviewees can be found in the bibliography.

Meetings
The student could benefit by being placed within Sandvik Mining for two months allowing for closeness to the organization. A number of internal meetings were attended which allowed the student to gain deeper insights to how Sandvik Mining operates.

Brainstorming sessions
A few brainstorming sessions were organized where the author was given the opportunity to sit down with members of Product EHS and provide short updates on the the research process and present thoughts and reflections. This caused reactions from the participants which in turn led to discussions regarding the research and new ideas to be considered.

Documentation review
The closeness to Sandvik Mining gave the author the opportunity to take part of internal documentation. Large amounts of documentation were reviewed, starting from a wider perspective regarding organizational strategies to later funneling this information down to sources more specific to the purpose of the paper.

2.2.3 Analysis
The analysis of this paper aimed to find correlations between the set theoretical framework and the observations that was made in the case study of Sandvik Mining.

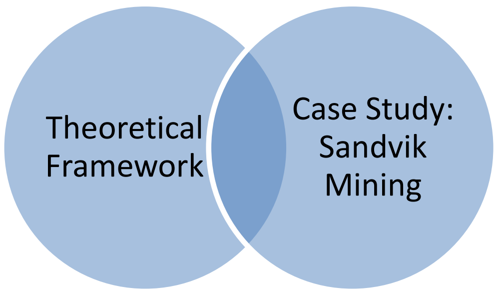


Figure 2 - Analysis method
Source: Author

The analysis can broadly be viewed as twofold where the initial part aimed to find opportunities for using SLCA at Sandvik Mining and the later part identifies applications of SLCA (recommendations) to be incorporated into the existing NPD model.

2.2.4 Intended audience
This paper was carried out in close cooperation with Sandvik Mining, and the global Product EHS organization, who is also the primary audience of the findings. The paper could also provide som value to readers from other global manufacturing companies operating within similar industries as Sandvik Mining. Additionally, the paper can serve as a valuable information source for other students interested in LCA and SLCA in particular.

2.2.5 Limitations
As the nature of the in depth case study focuses on a unique case the finding of the paper will not provide results that can be applied directly to other situations. Even so, it can be argued that many global companies share similarities in their structures and in ther product

development processes suggesting that the findings of this paper could provide valuable lessons for companies other than Sandvik Mining. The main strength of the paper is the chosen in depth case study that allows for a thorough understanding of the posed research problem at Sandvik Mining.

3 Theoretical framework

3.1 Life Cycle Thinking

Figure 3 below depicts the life cycle of a product with four phases; design/development, production/manufacturing, use, and end-of-life. During the initial phase of designing or developing a product one determines much of the product's environmental impacts. However, these environmental impacts are mainly occurring during the three latter phases of the life-cycle (Rebitzer, 2002).

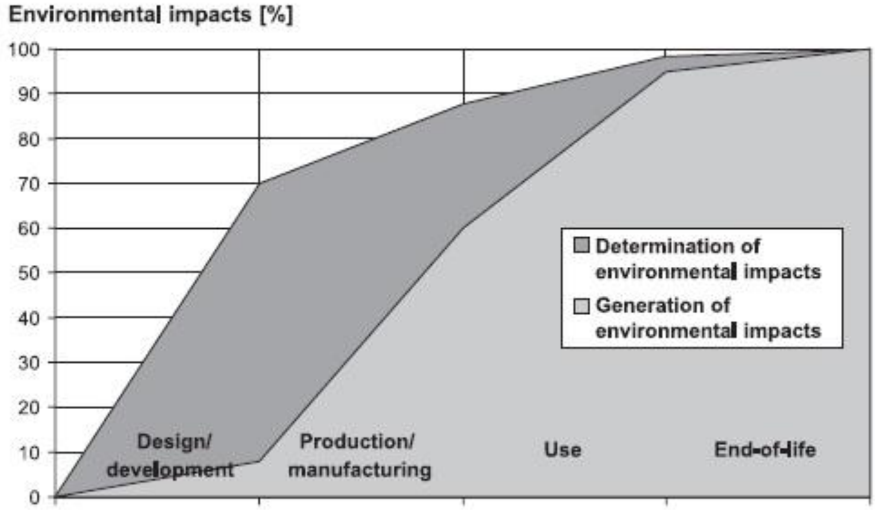


Figure 3 - Determination and generation of environmental impacts in a product's life cycle
Source: (Rebitzer et al, 2004)

Much like the name suggests LCA requires that life-cycle thinking is adopted to fully understand a product's environmental impacts over its entire life cycle. Rebitzer (2002) argues for a need to understand that every product has a life that consists of various phases. Commonly a product's 'life' starts with the development and design of the product, perhaps the most important phase where much will be decided regarding the coming phases of a product's life cycle. Considerations must be made to the needs that the product should satisfy and how these should be met. Choices of materials etc are decided and often one or more prototypes are developed until a design that meets all requirements of the product can be found. When a design has been set the next phase of the product's life cycle commonly is seen as the extraction of the raw materials necessary for the product or/and its components. Then follows the production (manufacturing) phase and the use phase where the product is placed on the market. Finally, the last phase includes the product's end-of-life which can look different depending on how the product is handled after its use. It can be collected, recycled, reused, or disposed of as waste. If the product is disposed as waste one considers a 'cradle-to-grave' approach but if the product is somehow collected, recycled or reused the life cycle expands towards a 'cradle-to-cradle' approach. In life-cycle thinking considerations must be made to weather a 'cradle-to-grave' or possibly 'cradle-to-cradle' (depending on the end-of-life management of the product) situation is in place. Commonly life cycle thinking includes these four major phases; design/development, production, use/consume and end-of-life activities (Rebitzer et al., 2004).

Life Cycle Assessment (LCA) has been defined by ISO 14040 as the: *"compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle"* (ISO, 2006a).

3.2 LCA in Product Innovation

Da Silva (2012) argues that LCA has gained increased interest from industry as companies realize the potential benefits that LCA can have on their product innovation. Many companies are currently realizing the benefits that sustainable innovation can give them and how LCA is an environmental tool that allows them to work with this in an organized, structured and methodological manner (Bruun Månsson, 2012). A common barrier for LCA lies in the budgetary costs and required time allocation. The ISO 14040 framework aims to harmonize businesses' efforts of using LCA. However, it often requires efforts from a business beyond their motivation for using it. In order for a company to successfully use LCA in its innovation processes they first must have; an understanding of LCA, an understanding of the innovation process it aims to support, and a certain level of creativity to find areas where LCA and innovation have common interests.

It is crucial that companies realize that they need to focus their work with LCA on areas where this will provide a high benefit I relation to the effort it will require from them. It is also of high importance that a company, wanting to incorporate LCA into its innovation processes, remembers that some types of products will be harder to improve from a sustainability perspective, than others. Not all products can be expected to be made more sustainable due to current societal and technical restrictions. In some cases products could possibly be made more sustainable, but to a cost that cannot be justified by the company. Companies needs to deal with the problem of creating models that can allow them to identify and improve innovations that makes the company's product portfolio more sustainable in terms of economy, environmental, and society (Da Silva, 2012).

According to Da Silva (2012) innovation aims to increase revenue and/or decrease costs. Sustainable innovation aims to achieve both these objectives while simultaneously reducing the environmental and social impacts caused by the product. Da Silva (2012) goes on to claim that: *"LCA in support of innovation does not aim at providing in depth, primary data based, with low uncertainty, highly researched and referenced environmental flow and substances, with high quality environmental models supporting its conversion into environmental impact categories. All those issues are of interest to LCA experts, and are essential basis for a sound LCA science. But, they are irrelevant to the R&D manager that only needs to know how to make their products more sustainable in a way that sells more products or reduces cost. Ideally, it will do both".* This suggests that a company needs to ensure that their efforts of using LCA provide them with knowledge that is useful for both their R&D as well as their LCA experts.

Da Silva (2012) argues that the process of incorporating LCA into innovation follows three major steps; **understand**, **improve**, and **succeed**. Initially a company must to develop a basic understanding of the environmental performance of the product. Secondly, product designers, engineers, and other members of the innovation team can test various design choices to improve the product to a desired environmental impact level. Finally, the innovation team can use the results of the environmental improvements as sales and marketing arguments. To accomplish these three steps Da Silva (2012) suggests a model that shows how LCA should be used in a company's innovation funnel. Naturally, innovation processes will look differently depending on how a company is structured, in which market it operates what products/services it provides etc. However, five main steps are commonly found in most of these processes (Da Silva, 2012). Figure 4 below shows these steps and the figure will be further explained in the coming sections.

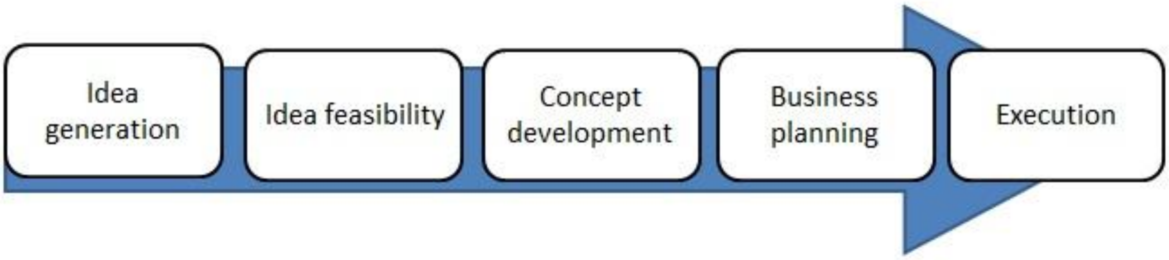


Figure 4 - The five main steps commonly found in innovation management
Source: Da Silva (2012)

3.2.1 LCA in the Innovation Funnel

Idea Generation

The initial phase in the innovation funnel focuses on the accumulation of innovation ideas. A company often has many ideas on how to improve a product already prior to initiating the innovation process and the main challenge lies in filtering these down to a few that are worth considering further. In this phase, LCA can provide such filters in terms of sustainability. Such filters can of course look very different but it is useful if these are related to specific product categories, since it is most often known by the innovation team that one type of product will have certain types of impacts. This is true also for environmental impacts. By incorporating a member in the innovation team with knowledge about LCA different ideas can be assessed in terms of their level of sustainability. If the company also has clear goals regarding what they want to achieve with their sustainable innovation, the innovation team will be able to do a quick initial screening of the ideas. Commonly, this type of innovation funnel will include some type of checklist to provide the basis for this initial filtering. The more knowledgeable the company gets regarding its products environmental profiles the easier it will be to form this type of checklist filters, based on set goals in terms of desired levels of sustainability (Da Silva, 2012). Basically, the idea in this phase is to simply consider the various ideas through their impacts on the sustainability of the product, using LCA. To fasten this process the company can set goals or levels that the innovations need to meet in order to be considered (legislative, customer requirements, business strategies etc). The filters can build on previous environmental assessments making it possible to understand if a new innovation will increase the sustainability of a product.

Idea Assessment

According to Da Silva (2012) this second phase of the innovation funnel has one key question that it needs to answer; **what is the feasibility of the innovation that is being considered?** Naturally, other factors such as the budget of the project, customer's willingness to pay and the technical capability of the company also needs to be a taken into consideration in an inoovation project. A LCA expert will start to consider life cycle calculations, set the concept of the product and also calculate the resources required to produce and launch the product. This will require collection of data often not available at this early stage of the innovation funnel. Therefore, a 'full' LCA study can seldom be justified here as it requires a lot of resources to carry out. Instead, the initial feasibility understanding can be attained using a generic product category LCA model aiming to consider materials, components, manufacturing processes and other industry average data considered characteristic for this particular product category. In theory, this would then allow an innovation team to perform a quick calculation of the environmental impact of any new product that falls under this product category. However, such an LCA model should always be flexible enough to be able to handle decisions to include new components, new design choices, and other changes that might come from a new innovation. Such changes will require the LCA expert in the innovation team to ensure that new data is found and incorporated into the LCA model. There are a number of tools that can aid this process such as GABI and SimaPro that offers an interface for the innovation team where single inputs can be changed to see how this will change the results of the LCA model. This will reduce the risk that the innovation team pursues innovation choices that in later stages of the innovation funnel cannot deliver the environmental performance that the product was intended to provide (Da Silva, 2012).

Concept Development

In this third phase the innovation team defines the product in its design and there is at this stage little possibility to make further changes. Components and materials that the product will consist of are set and decisions on how to source and manufacture the product are also decided. It is at this point of the innovation funnel that the innovation team should develop a more detailed LCA study that has a focus on the specific product that has been decided on. Often the innovation team will develop an LCA study that is more detailed than the once used in previous stages of the innovation funnel. This will ensure that the product later on can be marketed with justified results (Da Silva, 2012). It is important that the innovation team has an understanding of the coming marketing strategies that will be used to sell the product, already at this stage of the process. Da Silva (2012) argues that *"This is the time where marketing meets innovation. Where the work of LCA is to capture the specifics of the product to be produced and create the substantiation for the product marketing once it is released to the market".* Understanding of the marketing strategies will aid when defining the goal and scope of the LCA study, what effort the study will require, and the results it needs to produce.

Business Planning and Execution

The last two phases of the innovation funnel is when the decided innovation has been created and now enter the marketplace. At this stage the use of LCA will mostly be focused on providing guidance, validation and substantiation for the innovation team. The set goal and scope of the innovation project are assessed according to which level the can be seen to have been accomplished. The results of the LCA study are analyzed and presented in whatever form was decided on in the scoping and goal setting of the study. The LCA study will provide a quantified assessment with substantiated results that should provide the desired use functions that was considered already in the initial scope and goal setting of the study. Monitoring is another important factor to consider in this phase of the innovation funnel as various limitations in e.g. manufacturing, suppliers, customers, transport systems, technologies, etc that are realized only after the project reaches its final phase. These changes can potentially cause an undesired change in design of the innovation. Furthermore, it can be very important to validate the results of the LCA study in accordance to actual data from the field. This is especially true if the results of the LCA study depend on factors that are not controlled by the company producing the products (Da Silva, 2012).

3.3 Streamlined LCA

Streamlined LCA, or sometimes referred to as simplified LCA, can be argued to have the intention of making an LCA study more manageable for a company. Some recognized researchers describe SLCA as: *"In general simplifying or streamlining can be viewed as a way of 'cutting' whilst still meeting the study goal" (Todd & Curran, 1999: Eide & Ohlsson, 1998)* and *"a simplified variety of detailed LCA conducted according to guidelines not in full compliance with the ISO 14040 standards and representative of studies typically requiring from 1 to 20 person-days of work" (Guinée et al., 2001).*

In April 1994 the Society for Environmental Toxicology and Chemistry (SETAC) created a workgroup that developed a new concept at the time; SCLA. The goal was to suggest a definition for a process that allowed the performing of a simplified or streamlined LCA as a reaction to the cost and complexity issues regarding full LCAs presented earlier. The work group found that rather than a different approach to LCA, streamlining is actually a part of any LCA. All LCAs are in fact streamlined to some degree. The findings came to get growing recognition among LCA experts and rather than to separate a 'full' LCA from a 'streamlined' LCA it was suggested to consider a continuum where these two extremes are located on each end. Any LCA study would then place itself at some point of this continuum depending on to which degree it can be argued to be 'streamlined' (Curran & Todd, 1999).

Figure 5 - The LCA continuum
Source: Author

Curran & Todd (1999) argues that the process of streamlining an LCA study is closely connected to the process of setting the goals, scope, and desired use of the study. The various ways of streamlining an LCA study are most often found in this initial process where the LCA expert decides what absolutely must be included into the study to support its set application and decision. It is argued that many LCA studies devote to little time and effort into this stage. This argument is supported by Rebitzer et al. (2004) who states that many LCA experts fails to consider the design/development phase of the product. If the aim of an LCA study is to decrease the environmental impacts of a product over time, it is important to realize that decisions that are taken in the design/development phase of a product strongly affect its environmental impacts during its full life cycle.

To streamline an LCA study means to limit the scope of the study (Curran 1996). The scope refers to the system that the LCA expert chose to study, the level of detail of the data that is collected and used in the study, and the number of environmental impacts that the study aims to consider. A full (complete) LCA study is often very demanding of the amount and level of detail of data that it will require. In some situations it can therefore be beneficial to use the life cycle concept but avoid all of the requirements of a complete (full) LCA study (Christiansen, 1997). Curran & Todd (1999) argue that streamlining can take place at two levels within an LCA study. **Firstly**, one can streamline in the methodology of the LCA, deciding on 'what to do' or 'what to not do'. **Secondly**, one can streamline the process for how to perform the LCA, or the 'how to do it'. The first type of streamlining (in the methodology) often includes reducing the scope of the study, which in turn will limit the required amounts of data that is necessary to conduct the assessment. The second type of streamlining (in the process) is often accomplished by using LCA software that comes with Life Cycle Inventory (LCI) databases.

Christiansen (1997) and Graedel (1998) discuss a number of techniques that can be used to streamline an LCA study, where one can:

- Simply screen out options that e.g. a product designer or engineer knows are wrong, due to previous experiences and knowledge.

- Leave out processes in the product system that is considered to be of minor or low relevance the system as a whole.

- Limit the life cycle stages considered in the LCA study. For example a company can limit the product system between its own gates (gate-to-gate assessment) and by doing so understand its own industrial process. Ideally an LCA study should consider a full cradle-to-cradle product system. However, if there are parts in this product system that a company cannot affect it can be justified by the company to not include these in an LCA study.

- Use various types of indirect data instead of direct data in situations where direct data might be impossible to attain, or simply would be too costly to attain.

- Decide to leave out certain resources used, pollutants emitted, or environmental impacts caused in the product system. Some of these can possibly be argued to represent such a small fraction of total to be justified for removal in the LCA study.

- Focus on one or a few environmental impacts. A well-known example of this action can be found in e.g. energy efficiency studies. This focus will however always risk disregarding other important environmental impacts caused by the product system.

- Simply eliminate whole steps in the LCA study. An example can be an LCA study that leaves out an impact assessment of great detail in a situation where e.g. the study can be argued to have reached its stated goal and a detailed LCIA is not required.

- Use various cut-off criteria to reduce the amount of inventory data required for the LCA study. By defining threshold weights, volumes, etc the LCA study will then not consider e.g. raw materials and emissions that are not amounting to these levels.

- Replace or complement quantified data with qualitative data. Qualitative data can be attained by consulting experts providing justified estimations or even guesses. At occasions, qualitative data can be sufficient for an LCA study to e.g. highlight problems.

- Reuse data that can be argued to be equivalent for the purposes of the LCA study, when other data is not readily available. This could for example take form of a company establishing a data base from its LCA studies. If this company develops products that evolving in a slow pace and new models are much alike older ones it is then possible to reuse LCA data in new LCA studies.

Weitz et al. (1996) conducted research based on discussions with LCA experts and researchers of LCA, aiming to understand ways to streamline LCA. The findings suggested nine categories of approaches to streamlining LCA:

- Removing upstream components - where all processes e.g. raw material extraction and transport to the factory, up to material manufacture are excluded. Instead the LCA study focuses on internal manufacturing, consumer use, end-of-life management etc. (also called gate-to-grave LCA).

- Partially removing upstream components – where all processes before material manufacture are excluded. However, some upstream processes that are argued to be of high relevance for the result of the LCA study will still be included.

- Removing downstream components – when the LCA study's product system is defined to exclude processes that occurs after final material manufacturing (cradle-to-gate LCA)

- Removing up- and downstream components – where the studied product system is defined to only consider the activities taking place within a company's operations (gate-to-gate LCA).

- Using 'showstoppers' or 'knockout criteria' – where a company sets criteria before starting the LCA study with the aim that if these criteria are then encountered throughout the process this will require instant decision making of the company. This is commonly derived from past experience and knowledge already existing within the company.

- Using data of high quality – where the LCA study defines its data requirements to only consider values that already known to be dominant within the studied product system. Other values are seen as less relevant and excluded. Furthermore, data that is qualitative, and or have high uncertainty can also be excluded.

- Using surrogate process data – where some processes within the studied product system might lack data and could therefore be replaced with similar processes. The replacing processes must ensure physical, chemical, and or functional similarity to the processes that are replaced.

- Limiting raw materials – where raw materials that represents less than a defined percentage of total mass are excluded from the LCA study.

According to Rebitzer et al. (2004) a SLCA aims to make well informed, as well as justified, simplifications of an LCA study. These simplifications can either be done in a horizontal- or vertical manner within the set product system to be studied in the LCA study. A horizontally limited approach will on purpose disregard some life cycle stages and focus on a decided part of the full life-cycle of a product. In contrast, a vertically limited approach will include all life cycle stages but not analyze these in the depths required by a complete LCA study. Research suggests that both methods allow an SLCA to deliver satisfactory results but that this is closely related to the defined goal and scope of the LCA study. Christiansen (1997) argues that both the vertically limited - and the horizontally limited approach of SLCA are best used by a company for screening purposes. However, the vertically limited approach is to be recommended as it, to some degree at least, considers the full life cycle of a product.

These streamlining approaches have been assessed in relation to doing the same studies using a complete LCA. This assessment found that the streamlining methods that excluded the least amount of data or processes were closest to provide the same results as a full LCA study. Streamlining will present a risk of arriving at LCA results that are different from a full LCA study. However, if the LCA expert has good knowledge of the product system that will be studied this can aid in understanding where streamlining actions should be targeted. If a product for instance has one life cycle stage that requires large amounts of resources and produces much emissions; this suggest that the risk of removing upstream and downstream life cycle components is rather low (Curran & Todd, 1999).

Using SLCA will always risk losing information by 'cutting corners', which might lead the LCA expert to reach conclusions that are different to the ones that would have been found using a full (complete) LCA. Therefore, it is important to set the streamlining techniques based on the objectives of the LCA study. SLCA has great potential and according to Curran & Todd (1999): "*SLCA techniques are nevertheless potentially useful, particularly as screening tools in preparation for subsequent detailed LCA"*. Although simplified, SLCA can provide designers, innovation teams, and environmental experts with direction towards more sustainable product innovation (Christiansen, 1997).

According to Curran & Todd (1999) all LCA studies require some degree of streamlining in order to be feasible to manage. The benefits that streamlining can provide, through resource savings, should always be weighed against the ensuring of the result's reliability. The LCA expert needs to raise the question of what could be left out from a full-scale LCA and not threaten to compromise the study goals. As previously stated, every LCA study is to some degree streamlined and this suggests that there cannot exists an approach to streamlining that fits all purposes. However, some considerations that relates to the goal and scope definition of an LCA study are suggested. The considerations are argued to be common to most LCAs and should be considered when defining the goal and scope of the LCA study. Figure 6 summarizes these considerations. When the questions in the table are answered by an LCA expert this allows the realization of where and how the LCA study can be simplified (or streamlined). Figure 6 aids to understand to which degree a planned LCA can be streamlined and still deliver the desired results.

Goal and Scope conciderations	More opportunity for streamlining		Less opportunity for streamlining
How will results be used?	Scoping, screening, identify hot spots	Estimate relative difference	Marketing, labeling, public policy
Is there a dominant life-cycle stage?	Very dominant	Somewhat dominant	No dominant stage
Who is the study audience?	Internal	Internal and external	External
What is the threshold for uncertainty?	High uncertainty	Moderate	Low uncertainty
To what extent are recycled/reused materials used?	Recycled/reused materials	Virgin and reused materials	Virgin and recycled materials
How narrowly is the product defined?	Generic product	Product type	Specific product
How much is already known about the product?	High knowledge of all life-cycle stages	High knowledge of some life-cycle stages	Low knowledge of all life-cycle stages

Figure 6 - Goal & Scope considerations for SLCA
Source: Curran & Todd (1999)

3.4 Life Cycle Assessment

LCA is defined in ISO 14044 as: "*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, 2006b).* LCA is a methodology that allows a LCA expert to analyze these negative impacts in a quantitative or qualitative manner, resulting in the possibility to take appropriate action to mitigate them. Environmental impacts have a direct relationship with environmental aspects, connected through natural causality. For example; when we drive cars those combust fuels and this is an environmental aspect. The combustion of fuel creates emissions that affect global warming, making it an environmental impact (Giudice et al., 2006). An environmental impact has been defined as: "…*any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services" (ISO, 2006a).*

Heijungs & Guinée (2012) argue that LCA has been changing over time. However, during the last decade there has been growing acceptance towards that a number of set principles should exist within an LCA framework. The LCA framework developed by ISO, as shown in Figure 7 below, can be argued to be most accepted LCA framework in present day.

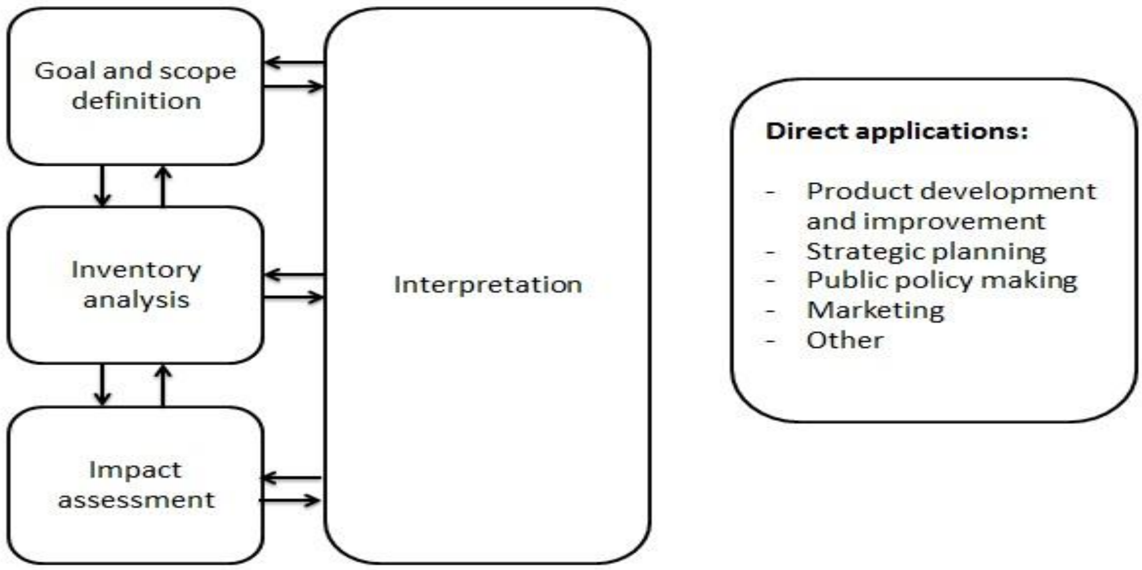


Figure 7 - Methodological framework for LCA
Source: ISO (2006a)

As shown in Figure 7 above, every LCA study should consist of four different phases:

- Goal and scope definition
- Inventory analysis
- Life cycle impact assessment
- Life cycle interpretation

Most commonly the LCA study's phases will follow this order. However, it is important to remember that an LCA study is a very iterative process and it might be necessary for the LCA expert to go back to previous phases. The phases of the model are interrelated. Although the LCA methodology is described as a rather linear process it is not uncommon to jump back and forth within it. This can be justified by many factors such as; requirements of new boundaries setting, lack of data/findings of data etc (ISO, 2006a).

3.4.1 Goal and Scope Definition

According to Heijungs & Guinée (2012) the initiating phase of an LCA study is when the LCA expert defines the scope and goal of the LCA study. No data is collected in this phase and there are no calculations regarding results. Instead, the LCA expert needs to plan the LCA study and define the precise question that will be addressed in the study. A number of factors need to be considered when setting the goal of the LCA study such as:

- Intended application of the study
- Reasoning for carrying out the study
- Intended audience of the study

- Whether the results of the study are going to provide a basis for a comparative statement issued to the public.

The choices that are made in this initial phase will influence the remainder of the LCA study and it is crucial for the LCA study that the goal is clearly defined. Depending on how the above topics are considered in relation to the LCA study the goal will decide on the level of complexity the study reaches. If the goal is straightforward e.g. to understand the energy impacts that are associated with production of a single product, and the information is strictly for internal use the complexity of the LCA will not be that high. However, if the goal to make comparative claims regarding environmental performance of a range of competing products, this will present a much more complex LCA study (Heijungs & Guinée., 2012).

Sauer (2012) argues that every LCA study, no matter how it looks, can be placed within one of four major categories of LCA studies. The categories are suggested based on the goal(s) of the LCA study and are:

1. Single system – Internal use of results
2. Single system – External use of results
3. Comparative analysis – Internal use of results
4. Comparative analysis – External use of results

One quickly realize that Sauer (2012) separates types of LCA studies based on whether these are considering a single product system or are aiming on comparing two products. Also the intended use of the study's results (internal use or external use) is separated. (1) An LCA study that studies a single product system and use the results internally can allow a company to assess a product's current performance as well as possibilities for enhancement of this performance in terms of environmental impacts. This also allows a company to establish a baseline of a product's environmental performance which can be used as an indicator to assess improvements that are made in the future. (2) An LCA study that focus on a single product system but instead aims to use the results externally can instead allow a company to use the results for informative purposes. This could e.g. be targeted towards a customer that requests the environmental performance of a product. If the results instead are used for marketing purposes a company can pursue the realization of an environmental product declaration (EPD) based on the LCA study. However, this would place strict requirements on how the LCA study is carried out. (3) An LCA study aimed to compare two or more products and use the results for internal purposes allows a company to compare various design choices for its products, both internally as well as against competitor's product already on the market. (4) Finally, an LCA study that does a comparative analysis and uses the results of the study for external purposes can allow a company to attain data derived from a scientifically accepted methodology. This data can be used to protect a company from public criticism the environmental performance of its products. Furthermore, such reliable data can provide a strong basis on which marketing claims can be backed up; claims that perhaps are comparing a company's product against competitors.

The most important factors to consider in the scoping phase includes; to define the product system (or systems if performing a comparative analysis), the functional unit, the reference flow, the boundaries of the system that will be studied (life-cycle stages, time, geographical), various methodological problems such as allocation procedures, deciding which impact categories that should be considered in the study, the method to assess these impacts, and deciding on the necessity of adopting some kind of critical review (Sauer, 2012). These factors will be further explained below.

When scoping the LCA study, an important step is to decide on which impact categories that will be included in the results (that later will be collected in the life cycle inventory analysis (LCI). Depending on which impact categories that the LCA expert decides to include, there will be different requirements on the actual data gathering. An LCA study that chooses to only consider e.g. a product's carbon footprint over its life cycle will have a relative low complexity in its data requirement. However, an LCA study that wants to understand all of a product's environmental impacts over its life cycle will experience data requirements to be much more complex (Sauer, 2012). It is important to remember that LCA should always be seen as an estimation of potential impacts on human health or the environment, not an absolute environmental impact. LCA can never go beyond being a model of reality that illustrates the environmental significance of the actions throughout a product's life cycle (Margni & Curran, 2012). Examples of the most commonly used LCA impact categories include; global warming, ozone depletion, acidification, eutrophication, photochemical smog, terrestrial toxicity, aquatic toxicity, human health, resource depletion, land use, and water use (ISO, 2006a).

The functional unit is defined in the ISO 14040 framework as: *"the functional unit defines the quantification of the identified functions (performance characteristics) of the product. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results"* (ISO, 2006a). Derived from the functional unit an LCA study also includes a reference flow which describes the quantified amount of the product (including product parts) that the studied product system requires to deliver the performance set in the functional unit.

A reference flow is needed in order to fairly compare two or more product on the same basis when doing an LCA study. A functional unit can differ in its complexity depending on the type of LCA study that one wants to achieve. If the goal of the study is to only understand the environmental profile of a single material the functional unit would naturally be rather simple, e.g., output of a mega joule (MJ) of a fuel type. When one instead wants to consider a comparative analysis, the functional unit must consider the differences in the properties that might exist in the two products that should be compared. If these properties are the same for the systems that one wants to analyze then of course the LCA expert could use the same functional unit for both systems. However, this is often not the case and the LCA expert would then need to consider the differences in the product systems when deciding on the scope and functional unit of the analysis. In other situations, an LCA expert may run into problems due to lack of data that allows to accurately quantifying the functional differences between product systems. Other times there can be problems with products that deliver the same functional service but come in different volumes of packaging related to the form of the actual product (Sauer, 2012).

System boundaries must be considered when setting the scope of the LCA study including; to decide which life-cycles of the product that should be included, to set the time- and geographical boundaries of the analysis, and to set which flows and impact categories to be included (ISO, 2006b).

Life Cycle Stages

The LCA expert needs to decide on which life cycle stages that will be included in the scope of the study and this is a very important step as it will affect the outcome of the whole study (Sauer, 2012). According to Douglas Helman, Senior Consultant at PE International, it is important to understand that the decisions that the LCA expert takes here will have very high impacts on what the en results of the study will tell him/her. It is allowed to leave a life cycle out of the study, but then the LCA expert needs to remember that the study in itself should not be considered to be a full LCA study. However, if a company have good reasons to do so (lack of data etc), they make sure to be transparent, and they motivate the reasoning for, it is acceptable (Douglas Helman, Personal Communication, 2012-12-20). ISO 14044 states that the decision to not include one or more life cycle stages is only permitted if it can be argued to not change the overall conclusions that are drawn from the study (ISO, 2006b).

Figure 8 below shows a basic picture of the stages that are included in a full LCA.

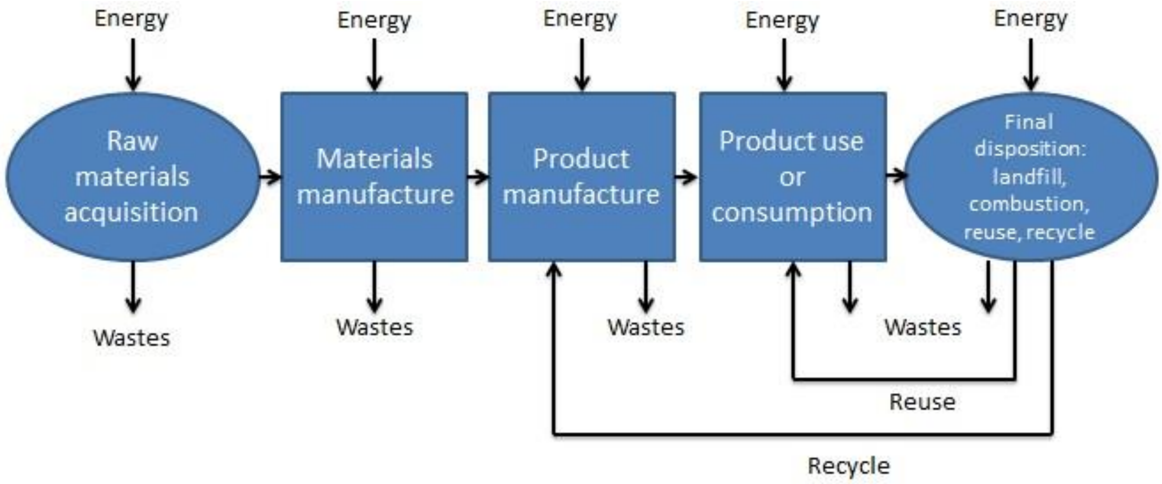


Figure 8 - Simplified life cycle flow diagram
Source: Sauer (2012)

The life cycle starts from raw material extraction and goes on until reaching end of life management of the finished product. The LCA creates an inventory that quantifies the incoming flows of materials and energy from the nature and the techno sphere at every life cycle stage. Additionally, the outputs from each life cycle stage (useful products, co-products, and wastes) are also quantified and handled in the life cycle inventory phase of the LCA study. The outputs usually consider solid wastes and emissions into air and water. It is important that the decision to exclude a life cycle stage in the LCA is preceded with careful consideration by the LCA expert (ISO, 2006b).

Geographical and Time Boundaries

When deciding on the life cycle system that is to be studied through the LCA the expert needs to consider the geographical boundaries of the system. These boundaries will depend on regional factors that can differ between different geographical areas. Common factors that are considered here are the type of technology used, the electricity mix, transport capabilities and distances, raw materials sourcing etc. One can think of certain materials that have global supply chains in order to attain their raw materials. Other energy-intensive processes might require specific geographical location that allows for efficient energy supply. Other processes might have very different logistical operations connected to how wide their distribution channels are stretching. Considering end-of-life scenarios, geographical boundaries can be different as recycling rates can often be very different compared on a country or regional level. Factors such as legislation, recycling systems in place, and consumer behavior can be hard to assess when deciding the scope of the LCA study (Sauer, 2012).

Time boundaries are similar to geographical boundaries in that they also can have effect on the relevancy and accuracy of the results of the LCA. Technology- and energy mixes can change over time, making it more complex to account for these changes if studying a product (with its product system) that is long-lived. It is expected that the LCA expert uses the technology mix that is of relevancy for the region in which the product is produced, at the time which it is produced. Furthermore, a long-lived product that has a high energy impact in its use phase can be hard to assess as the energy mix at the market in which it will be used might change over time (Sauer, 2012).

Product system

An LCA study aims to analyze the environmental impacts of a product by looking at it through its product system. The product system is further broken down into a number of unit processes that are linked to each other either; through; the flows of waste for treatment or intermediate products, through flows directly to the environment, or to other product systems through product flow. By thinking of a product's system in this manner it is possible to easier understand the inputs and (ISO, 2006a). The idea is to simplify reality in order to take a view on the product system that is manageable to understand and analyze. Any product system can quickly become very complex and it is necessary to make these simplifications in order to perform an LCA study.

Figure 9 from ISO 14040 presents a product system which has been scoped with geographical- and time boundaries as well as decisions connected to the number of life cycle phases to be included to meet the goal of the study. The inputs and outputs of the product system are thought of as flows categorized by their destination. Elementary flows refer to the product system's inputs and outputs that have a natural causality with nature such as; crude oil, air emissions, water discharges etc. Intermediate product flows occurs when a product system gets input from (or provides output to) another product system. This could e.g. be raw material that is used by a company to produce more than one product or subassemblies. Additionally, an LCA study will encounter product flows either entering or leaving the product system. These often take the form of recycled materials and/or components that can be used as either input for the studied product system or as input for another product system.

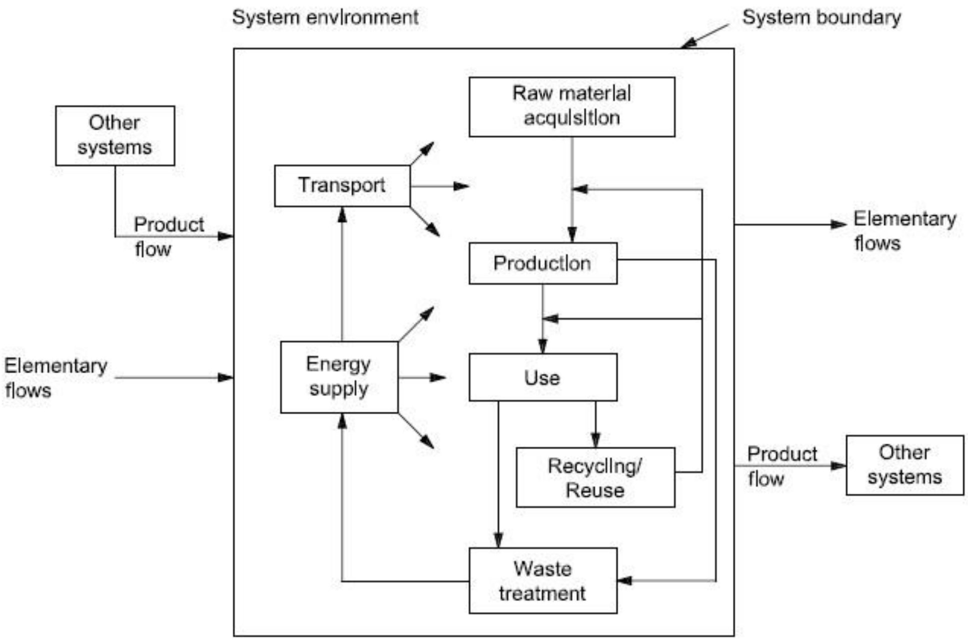


Figure 9 - Simplified product system for LCA
Source: ISO (2006b)

As previously stated, the product system needs to be further broken down into the specific processes that each life cycle stage will consist of. For example in the production phase it is necessary to not simply treat this whole life cycle stage as a single 'black box' where inputs are converted into various outputs. Instead one need to break down production into the different unit processes that is consists of. In a company's production you might for example find processes such as drilling, sawing, grinding etc that all of them would be considered as unit processes. Not before the entire product system for a product, with its entire unit processes, are decided the LCA expert can start to collect data for the inputs and outputs of it (ISO, 2006b). By just thinking of a product around you, one quickly realizes that a product system for any product really will get very complex if it considers including all the inputs and outputs for all the unit processes that makes up the product system of this product. This shows how any LCA study will have high dependence on the data is will require, and how the LCA expert can satisfy this data requirement.

Cut off criteria

Another way to limit a LCA study is to establish cut-off criteria that exclude components, materials, or processes that do not amount to the level as defined by the critera. These critera might be necessary to change throughout the study as some data typically will not be available or proves to resource demanding to attain. Prior to deciding on what is to be excluded it is important that the LCA expert understands what effect this will have on the LCA study as a whole. Some commonly used cut-off criteria includes; product mass, processing steps, estimated impact, and common processes (ISO, 2006a). Mass is perhaps the most commonly used cut-off criteria where an LCA study might aim to include a minimum of 95 percent of a product's total mass. Additionally, inputs that make up less than 1 percent of total mass are excluded using cut-off criteria. This will arguably make the LCA study more manageable and require less time to conduct. However, it will also present uncertainaty as some disregarded inputs can represent a large part of the product's total environmental impact (Sauer, 2012).

Data requirements

According to ISO 14044 (2006) the LCA expert needs to define the data quality requirements in a way that ensures that the goal and scope of the study are met. If the LCA study is to be used in a comparative manner, disclosed to the public, the following requirements must be addressed by the study; time-related coverage, geographical coverage, technology coverage, precision, completeness, representativeness, population of interest, consistency, components of the analysis, reproducibility, sources of the data, and uncertainty of the information.

3.4.2 Life Cycle Inventory Analysis

Curran (2012) argues that data drives an LCA study and to complete the life cycle inventory analysis (LCI) the LCA expert usally needs massive amounts of it. Both production- and process data are required in the form of; raw materials, energy use, relation between main product(s) and co-product(s), the rate of production, as well as environmental emissions. All these must be quantified and include all processes in the studied system. According to Sauer (2012) it is beneficial to collect as much data, in as great detail, as possible. Even data that is not relevant for the LCA study in question should be collected as it might be useful to future assessments that considers the product system in greater detail.

If it is possible, it will always be preferable for an LCA study to use industry data taken directly from its processes. As manufacturing systems tend to change over time, becoming more efficient through e.g. technology advances this type of direct industry data will ensure that the results of the LCA study becomes accurate. There are many ways for an LCA expert to establish the data that will be used in the LCI. One way is to use a software tool such as GABI or SimaPro. However, these are often very costly to get access to and might not meet the specific data requirements of a certain LCA study. An alternative approach is to instead craft one's own LCI database by gathering data from a range or various data sources. Commonly, some of the data sources that are used (but not limited to) include; plant documentation, national statistics, operation logs, meter readings from equipment, technical journals, laboratory reports, governmental documentation and databases, industry data reports, trade associations, previous LCA studies, equipment specifications etc (Curran, 2012).

Curran (2012) suggests that it is crucial for the LCA expert to develop the LCI first and foremost to meet the set goal of the study. This might sound obvious, but many LCA studies tend to forget the reason for why they are done in the first place and risk ending up with reliable results that however are not useful for the purposes of doing the LCA study in the first place. To minimize the risk of ending up in such a situation it is important that the LCA expert decides on the most suitable data source for each point throughout the LCA study considering; the life cycle stages, the unit processes, and the types of environmental release. When deciding on where to access the data required of the LCA study an LCA expert needs to decide whether to use already established datasets or to develop data from 'scratch'. Some factors that are important to consider when taking this decision are; the size of the product system, the set impact categories, the technology of the product system, the time period that is considered, the geographical area that the study considers, the set cut-off rules of the product system, preferred databases of high relevance to specific unit processes, and the overall intention of use of the dataset.

By deciding on the required data sources already in the goal and scope of the LCA study, prior to the actual data collection, the LCA expert can decrease investments in both time and cost of the study (ISO 1404, 2006). Curran (2012) argues that there are overall two types of data sources, either primary or secondary. Primary data comes directly from the source and includes e.g. questionnaires and surveys, interviews, bookkeeping, on-site measurements, and various data collection tools. Secondary data most often comes from reports from e.g. databases, various statistics, and other open literature. Furthermore, data can be classified judged on their origin including; site-specific data, non-site specific data, modeled data, non-LCI data, and vendor data.

When forming the LCI database for the LCA study the LCA expert has many data categories to find his/her data from. The most common data categories considered are:

- Individual process- and facility-specific data – which is taken from a specific operation within a certain facility.

- Composite data – where data from one operation or activity is combined with the respective operation or activity at other locations.

- Aggregated data – data that combines two or more process operation.

- Industry-average data – referring to data that is representing sample of locations that statistically reflects an entire population.

- Generic data – that often cannot be argued to be representative but still is giving a qualitative description of a certain technology or process.

The list goes from lower degrees of aggregation in process-specific data to highest aggregation in generic data (Curran, 2012).

Unit processes and aggregated processes

The foundation of the LCI database is made up from the identified unit processes in the product system. According to ISO 14044 (2006): *"A unit process dataset is obtained as a result of quantifying inputs and outputs in relation to a quantitative reference flow from a specific process"*. A unit process is considered by an LCA study as the smallest element for which inputs and outputs are quantified. Alternatively, the LCA expert can to instead group a number of unit processes by taking data from similar unit processes or other aggregated datasets. Again, it is the goal of the study that should decide if the data that is used in the LCI represents one process or several aggregated processes (Curran, 2012). One factor to consider when setting the goal of the LCA study is what the intended use of the results is. LCI at the unit process level can be argued to be the most accurate to achieve reliable results of the LCA study. However, if the results are intended to be used externally, e.g. marketing purposes, it might be sensitive to provide that detailed data as it could potentially disclose sensitive information about company operations. If instead the results of the LCA study are intended for internal use, such issues concerning confidentiality will not be as relevant to consider. This reluctance of disclosing possible confidential information can also become a barrier for a company that wants to find LCI data on their inputs from various suppliers, as this data might be sensitive for the suppliers to provide. Aggregated data will present a possible solution for these problems (Curran, 2012).

Private or Public Data

When forming the LCI the LCA expert needs to weigh the sensitivivity of its data, in terms of business confidentiality, against how complete and detailed the LCA study needs to be. If the results are mainly used internally, and do not reveal sensitive information about the company to anyone outside of the company, private industrial data will serve as a good place to find ones data. Some sources of private industrial data includes; company reports, periodic measurements, specific measurements, machine specifications, and accounting or engineering reports. This data is however often missing or can be hard to translate into LCI data. If private industrial data is considered as too, there are alternative data sources to consult. Public industrial data are available in various forms such as; conference papers, published articles, external reports, and technical books. In reality however, businesses are often experiencing difficaulties in finding useful data. This has allowed for the creation of many LCA databases prodviding LCI data. These range from publicly available or private ones, requiring a company to for access. Some databases are termed dedicated LCI databases and do, as their name suggests, provide LCI data. Other databases instead provide other data than LCI data. This data can be used to extract useful LCI data for an LCA study but will often run the risk of being too general for the purposes of the study. Currently, the demand for LCI data exceeds its supply. Public databases need to be improved to provide easier access to reliable data. Additionally, converting non-LCI data resources into useful LCI data will also be crucial to increase the supply. Better coordination between owners of LCI databases and increased accessibility of data will be a key challenge in getting more companies to consider LCA in their operations (Curran, 2012). When all of the inputs and outputs have been quantified and compiled into the LCI, for the set product system, the inventory results are expressed as per functional unit, and then aggregated, based on the various environmental impacts that are throughout the product's life cycle. However, the LCI does no more than this. It is hard, if not impossible, to realize the environmental impacts of a product system by simply looking at the mass that is extracted or released by it. Therefore it is necessary to carry out the next phase of the LCA study, the impact assessment, in order to better understand the actual results of the study (ISO, 2006a).

3.4.3 Life Cycle Impact Assessment

The life cycle impact assessment (LCIA) is the phase of the LCA study that evaluates potential environmental- and human health impacts of the identified natural resources and environmental emissions in the previosuly done LCI.

ISO 14044 (2006b) defines LCIA as: *"phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product"*. The LCIA does this by modeling possible environmental impact pathways, to make it understandable how the life cycle of the product links to its environmental impacts (Margni & Curran, 2012). As previously mentioned the results of a LCI provide a lot of information to the LCA expert, but information that might be hard to make something of. Therefore, the main purpose of the LCIA is arguably to relate the results of the LCI in relation to their environmental significance.

According to ISO 14044 LCIA have three mandatory steps. **First**, the LCA expert needs to select and define the impact categories that will be the focus of the assessment. The **second** step is the classification where the LCI data is assigned to the chosen impact categories of which they relate to. The **third** step is characterization where every data set in the LCI is converted into a value that expresses its potential impact within the impact category e.g. carbon dioxide and methane both affect the impact category global warming (ISO, 2006b). Depending on the goal and scope of the LCA study it might be necessary for the LCA expert to also apply a number of optional elements in the LCIA; normalization, grouping, weighing, and data quality analysis (Margni & Curran, 2012).

3.4.4 Life Cycle Interpretation

ISO 14044 defines life cycle interpretation as the *"phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations"* (ISO, 2006b).

The life cycle interpretation phase is interrelated to the other phases of LCA and can be done at any time throughout the assessment. ISO discusses a number of elements that can be included in this phase such as;

- The identification of environmental issues that are seen as very significant
- A number of evaluation techniques to assess the completeness, the sensitvitity, and the consistency of the assessment
- Drawing conclusions and recommendations from the assessment
- Assessing the appropriateness of the defined functional unit, system boundaries, and system function
- Identifying and assessing data limitations

ISO does not provide any narrowly defined guidelines for a company on how to approach the life cycle interpretation and much is up to the LCA expert to decide. Arguably there are two approaches that a company can use; either a procedural- or a numerical approach. The former analyze the results with other readily available information, expert opinions, intuition etc. The latter is analyzing the results with statistical and mathematical tools (Heijungs & Guinée, 2012). As part of the life cycle interpretation it is important that the LCA expert considers various sensitivity analysis defined by ISO 14044 as: *"…procedure to determine how changes in data and methodological choices affect the results of the LCIA" (ISO, 2006b).* The idea is for the LCA expert to assess the reliability of the LCA study's results in relation to how the study was designed. A sensitivity analysis can assess the choices made at earlier stages of the LCA study. By changing certain data or methodological choices it is possible to understand how big effect this has on the results of the study. If these differences are proven very large this suggests that it might be necessary to revise the LCA study with e.g. other data, different product system etc.

The role of the life cycle interpretation phase gives a good example of the iterative nature of ISO framework on LCA. It allows the LCA expert to identify uncertainties in the assessment and if these are judged as too high it might be necessary to go back in the process. This suggests that the life cycle interpretation aids in improving the LCA study and thereby allowing for more informed decisions taken from its results. Even so, it is common among companies to choose not to perform life cycle interpretations phase when working with LCA studies (Heijungs & Guinée, 2012).

3.5 Environmental Product Declaration (EPD)

With increased interest of increased product sustainability from both the private and public many companies faces the dilemma of how to inform their stakeholders about their environmental efforts in relation to their product(s). There is a wide range of possible strategies for a company to choose between, when wanting to communicate possible product sustainability claims, including various labels, certifications, declarations etc (Stevensson & Ingwersen, 2012). According to Erlandsson & Tillman (2009) many companies are currently realizing the need to meet increased consumer requirements on product sustainability by adopting standards and labeling schemes that are well recognized by the consumers.

The ISO 14020 series provides frameworks that a company can use to work with environmental product claims. There are three types of voluntary environmental product claims and each is covered by an ISO-standard; Type I (ISO 14024), Type II (ISO 14021), and Type III (ISO 14025). Out of these three types of environmental product claims the Type III ones are closely related to LCA as it is based on its methodology (Stevenson & Ingwersen, 2012). Therefore, Type III (also called Environmental Product Declaration or EPD) will be most relevant to consider for the purpose of this paper.

Type III environmental claims, or also referred to as environmental product declarations (EPDs), goes beyond what a company does by using either a Type I or Type II environmental claims. An EPD is a document that presents the environmental performance of a product, based on information retrieved from an LCA study that strictly follows the LCA methodology found in the ISO 14040 and 14044 standards (ISO, 2006c). Joakim Thornéus, Project Leader at the Swedish Environmental Management Council (SEMCo), states that the ISO 14025 standard provides a company with rules and guidelines on how to create an EPD for a product and what the EPD should contain. Furthermore, the ISO 14025 states that the quantified data that is used as the source of information in an EPD must come from an LCA study that follows the ISO 14040 standard on LCA (Thornéus, 2012). Most often an EPD takes the form of a document consisting of several pages of information regarding a specific product. The format of an EPD varies with the intended audience but generally it is arguable that it caters to a more complex consumer that requires environmental information of great detail (Stevenson & Ingwersen, 2012). Swedish industry was the initiators of EPD's in the middle of the 1990s when companies such as Vattenfall and ABB wanted to create a way to communicate complex LCA based environmental information to its stakeholders (customers) in a way that allowed these to more easily understand the environmental performance of specific products. The first EPD was created in 1998 and the number has experienced a rapid increase over the last five years. Initially EPDs aimed to serve as a B2B marketing tool but today there are also EPDs for B2C products (Thornéus, 2012).

According to Joakim Thornéus (2012), Project Leader at SEMCo, perhaps the most important aim of an EPD is to: *"allow for fair comparison of different LCA studies…allowing companies to cooperate with their competitors when setting the 'rules' of the game when forming product category rules for a certain product group…to provide a fair system of comparison"*. ISO 14025 states that an EPD needs to follow a set of rules found in the product category rules (PCRs). PCRs are basically a set of requirements, rules, and guidelines that a company needs to follow when creating an EPD for one of its products (ISO 2006c). LCA studies can differ much depending on how the study has been generated and presented and this can make it difficult to compare similar products based on their environmental performance. PCRs provide companies with guidance on how to form their LCA studies that should form the base for an EPD; e.g. how to determine functional unit, recommended data sources, allocation rules. The aim of the PCR is to ensure that companies are performing their LCA studies in a consistent manner which in turn will allow for the creation of EPD's that can be compared fairly within the same product category (Stevenson & Ingwersen, 2012). The process of creating a new set of PCR for a product category is fivefold. Firstly the interested party needs to appoint a PCR moderator with sufficient knowledge about EPDs and LCA. This person will be in close cooperation with an EPD programme operator. Secondly, one needs to consider if there are already a PCR existing for the product category under which ones product might fall. Some PCRs cover a wide range of product that can be argued to perform the same function. Thirdly, one needs to ensure the cooperation with other parties of interest. This can include competitors, branch organizations etc. Basically everyone that has an interest should be considered to be included in the process of creating the PCR. This will ensure that the future rules on how to form an EPD will gain higher acceptance in the market. Fourthly, there is a need to form a core group of people that will constitute a PCR consultation group that will represent the product group in question. This group will be formed by a sample that represents the whole population of interested parties to ensure an open climate. The group is decided by the PCR moderator and the Swedish Environmental Management Council (SEMCo). Finally, a decision is taken to start the work of creating a new PCR document which is circulated between all interested parties (Stevenson & Ingwersen, 2012). Basically, the whole process is rather complex and time demanding as it is crucial that all interested parties are allowed to provide their input into the creation of a new PCR. The work is sent around so that all parties can provide their opinions. The time it takes to form a new PCR is highly dependent on the communication skills between the interested parties.

However, a company is free to instead first form an EPD, based on an ISO compliant LCA study, and then ensure that PCR for the product group is created within one year's time. This can be a preferable option for a company that is lying ahead in terms of environmental work based on LCA as an environmental tool (Thornéus, 2012). Worth mentioning is that an EPD provides a company with some degree of flexibility as they are open to provide additional information that goes beyond the LCA study that provides the basis for the EPD. Broadly speaking there are three types of additional information that can accompany an EPD. Firstly, a company can provide information about other certified environmental management systems in place (e.g. ISO 14001). Secondly, a company can also inform about other environmental activities that are carried out in their operations. Lastly, it is possible to complement an EPD with information regarding e.g. geographical aspects, hazards and risks, materials content, biodiversity impacts etc, in relation to the product in question (Skaar & Magerholm, 2011). All information in an EPD relates to environmental aspects (ISO, 2006c). The idea of allowing for additional information is to allow companies to show stakeholders (customers) other environmental activities that have been done in previous efforts, but are not based on LCA methods.

4 Sandvik Group

Sandvik is an engineering company that operates in a high-technology market offering advanced products within materials technology. The Sandvik group is divided into five business areas; Sandvik Construction, Sandvik Machining Solutions, Sandvik Materials Technology, Sandvik Mining & Sandvik Venture. Each business area operates separately with responsibility for its own research and development, production, and sales of their products. The Sandvik group operates in more than 130 countries and offers a wide range of products, including; tools for metal cutting, equipment and tools for the mining and construction industries, stainless materials, special alloys, metallic and ceramic resistance material, and whole process systems (Sandvik Mining, 2012a). In 2011, the Sandvik Group reached sales over 94 billion SEK with over 50,000 employees (Sandvik, 2011b).

Figure 10 - Sandvik Group
Source: Author

Sandvik's Business Idea is defined as: *"… to develop, manufacture and market highly processed products, which contribute to improve the productivity of our customers. Operations are primarily concentrated on areas where Sandvik is – or has the potential to become – a world leader"* (Sandvik Group, 2012). According to Sandvik there are three ways that increased customer productivity can be achieved; through cost saving, through process efficiency, or through reliability. Founded in 1862 by Göran Fredrik Göransson, Sandvik has a long and successful history where corporate strategies focusing on high quality, close customer relationships, investments in R&D and exports have always been central for the company's way of doing business (The Sandvik Journey – Sandvik Anniversery Book, 2012).

Being a global company it is necessary for Sandvik to ensure that all business areas within the Sandvik Group follow a common way of working. The Power of Sandvik is a platform that provides all of Sandvik's employees with a set of rules and policies that provide guidance how to act in various situations. Part of the platform is Sandvik's Code of Conduct which is based on a set of guidelines from the Organization for Economic Co-operation and Development (OECD) that relates to business ethics, human rights, labor rights, and environmental concern. In the Power of Sandvik the Sandvik Group has set their vision, their strategy to reach this vision, their mission, the objectives that provides quantified and specific information on what results that Sandvik shall achieve, their company values, as well as policies to provide instructions and policies on how to act in specific areas (The Power of Sandvik, 2012).

Sandvik's Vision is defined as: *"Industries worldwide need to constantly improve their productivity. Sandvik makes this possible. We are dedicated to help our customers fulfill – and even exceed – their targets"* (Sandvik, 2012a). Sandvik wants their customers to see them as their productivity partners rather than their suppliers. A number of strategies support Sandvik's vision. Global Leadership reminds that Sandvik is a global company that allows for economics of scale. However, Sandvik´s local presence is the basic building blocks of this global company. It is important to always utilize the common strengths between the Sandvik Group's operating areas and markets. Benchmarking gives accurate performance measurements of Sandvik´s operations to ensure them to remain 'world class'. Additionally, the most important operations (in terms of quality, availability, and cost-efficiency) shall be kept within the Sandvik Group whereas other operations, less strategically important, can be outsourced. **Targeted R&D** refers to the importance of investing in R&D to ensure maximum customer value through new product and services, materials and process development, machine and tools design, and systems development. Sandvik spends more on R&D than their competitors and this allows Sandvik to offer their customers more efficient products and services, compared to their competitors (Sandvik, 2012a). Currently, Sandvik has more than 2,400 employees within R&D and owns over 5,000 active patents. Sandvik sees new products as a pre-requisite for continual growth of profits (Sandvik, 2012b). **Niche Focus** describes Sandvik's ambition to focus on market segments where they are (or have the potential to become) a world leader. These market areas shall also have good growth potential. Sandvik also strives to have a diversified customer base that makes Sandvik less sensitive to business fluctuations. **Customer Partnership** refers to Sandvik´s close cooperation with its customers and how Sandvik sees strong customer relations crucial for its success. Sandvik shall always offer their customers added value where their customers should view them as a company that offers benefits, and not just a product. **Powerful Brands** is a strategy concerning the Sandvik brand and how it is the brand for all companies within the Sandvik Group. Additionally, the Sandvik brand is further supported through a number of other Sandvik Group brands. For marketing reasons it is crucial that competing brands establish their own product marketing in order to ensure the value of Sandvik´s corporate brand (Sandvik, 2012a).

Sandvik's mission is defined as: *"Sandvik shall be the obvious first choice and provide the best possible value for our stakeholders – customers, shareholders and employees. At the same time we must act as a good corporate citizen characterized by sustainable leader ship in all out actions and business decisions"* (Sandvik, 2012a). Based on the mission, Sandvik has a number of objectives that describes what they shall strive to accomplish. **Customer-Driven Objectives** includes to be perceived as the market´s first and best choice for customers which should mean to also have the market´s biggest sales share. **Financial objectives** are set on a very ambitious level based off the ambitions to target market segments with high growth potential and the ambition to always have the highest sales share of these markets. **Social Objectives** refers to good working conditions, which allow Sandvik´s employees to be stimulated, develop personally and professionally. Sandvik aims to reduce occupational injuries, illnesses and incidents while also improving the health and well-being among its employees. Equality in factors such as sex, age, religion, race etc is of high importance and Sandvik works for constant increase in the quality of opportunity in at their workplaces. A number of social targets are in place to ensure continual improvement. **Environmental Objectives** describes how environmental concern shall be a natural environment in all of Sandvik´s operations and Sandvik shall, as a minimum, always comply with local environmental regulations. Sandvik are working actively for; more efficient energy- and input materials use, reduced air- and water emissions, increased materials- and by-product recovery, reduced environmental impact from hazardous chemicals, and increased number of products supported by sustainability principles. A number of environmental targets are set to ensure Sandvik´s continual improvement, including; energy- and water reduction in relation to sales, replacement of hazardous chemicals, compliance of all major production, service, and distribution units according to ISO 14001 within two years of establishment (Sandvik, 2012a).

As previously mentioned Sandvik aims to achieve a common culture within the company and this is supported through three **core values** that provide the entire company with a set of principles to guide decisions and behavior. These three core values are; **Open Mind**, **Team Spirit**, and **Fair Play** (The Sandvik Way, 2008). Open Mind highlights that Sandvik must maintain an open mind towards the world in which they operate in order to remain innovative. Innovation fuels Sandvik´s strategy to increase the value for its customers and Sandvik shall always be positive towards change as this gives the possibility to find improvements by being innovative. Open Mind promotes a corporate culture of innovation and continual improvement, a positive view of market change, understanding of diverse perspectives at different markets, and a focus on Sandvik´s stakeholders. Team Spirit points to that Sandvik must work as one team, always in close cooperation with the stakeholders. Every member of the 'team' shall care for the other team members and share information, knowledge and experiences with these. The corporate value promotes diversity of perspectives and the freedom to act. Fair Play is about taking responsibility when conducting business. Ethical responsibility, honesty, integrity, trustworthiness, and transparent stakeholder relations are important factors on that Sandvik´s operations are based on. These ethical standards are ensured through Sandvik´s Code of Conduct (Sandvik Mining, 2012a). The Sandvik Code of Conduct, part of the platform The Power of Sandvik, contains detailed policies and rules which set the foundation of Sandvik´s management systems and continual improvement of financial, environmental, and social performance of the company (Sandvik, 2004).

4.1 Sandvik Group EHS Policy

The Sandvik Group issued a new EHS policy in January 2013 that provides the basis for a strategy towards environmental, health, and safety that all of Sandvik's employees, contracted workers, and visitors shall consider. The EHS policy covers internal activities, as well as Sandvik's products and services that are provided at the market place. To influence their suppliers to strive towards the same standards that the Sandvik Group sets with its EHS policy the Sandvik Group implements their Code of Conduct on these. In Sandvik's EHS policy one can read that: "*…Sandvik commits to minimize the environmental impacts from its activities. We will strive for high efficiency in the use of energy and natural resources. We will also promote systems for reuse, recycling and recovery of materials and work to prevent pollution and other environmental harm… will strive to provide healthy and safe workplaces. We will continue to reduce injuries and illness and involve our employees in health and well-being activities… will continue to take a systematic approach to comply with or exceed applicable environmental, health and safety legal and other requirements… Environment, health and safety issues will be fully integrated into Sandvik's operations and we will achieve continual improvement through management by objectives and implementation of preventative actions. We will achieve this Policy by developing a strong environmental, health and safety culture and establishing best practice standards across the company"* (Sandvik EHS Policy, 2013).

4.2 Sandvik Mining

Sandvik Mining is one of the Sandvik Group´s five business areas and a global supplier of equipment and tools, services, and technical solutions for the mining industry. In 2011 Sandvik Mining's sales was approximately 32,200 million SEK and the company employed around 13,200 employees with operations in more than 130 countries globally. The product portfolio of Sandvik Mining has a wide range and the products are categorized into a number of product areas; Crushing & Screening, Customer Services, Drilling, Loading & Hauling, Mechanical Cutting, Mining Systems, and Rock Tools (Sandvik Mining, 2012)..

4.3 Sandvik Mining's supply chain

Figure 11 below shows a very simplified illustration of Sandvik Mining's supply chain. Naturally, in reality, this product system will look more complex containing factors that are not covered by the model. Even so, the model provides a basic understanding of how the life cycle of a Sandvik Mining product looks like.

The initial step will depend on which out of Sandvik Mining's product groups one considers. As the majority of the product groups include machinery used in the mining industry it is not difficult to imagine the materials that constitutes these. Equipment for mining operations is mainly constructed with various components from steel materials, such as steel frames/structures, axles etc. Additionally, the products are equipped with electronics, software, hydraulic systems, tires etc (Wester, 2012). Sandvik Mining's products are very diverse, ranging from rather simple drilling tools to very complex mining equipment consisting of several tens of thousands of components (Rosen, 2013).

Natural resources are extracted from the earth and provide the **raw materials** that Sandvik Mining's suppliers use for their manufacturing which are turned in to components purchased by Sandvik Mining. Some components that Sandvik Mining purchases might have a longer supply chain with more supplier steps included. Sandvik Mining machine and **assemble** the majority of components. Some components are purchased as 'white boxes' where Sandvik Mining creates a design for a module consisting of several components which is produced externally. Furthermore, some components are purchased as 'black boxes' where an external producer provides both the design and production of such component modules. The finished product assembled by Sandvik Mining is sold to customers that operate (**use**) the machine in various mining sites. When the product reach the end of its use Sandvik Mining's customers need to take **end-of-life** actions to ensure that the decommissioned machine is treated properly according to local legislation (Wester, 2013).

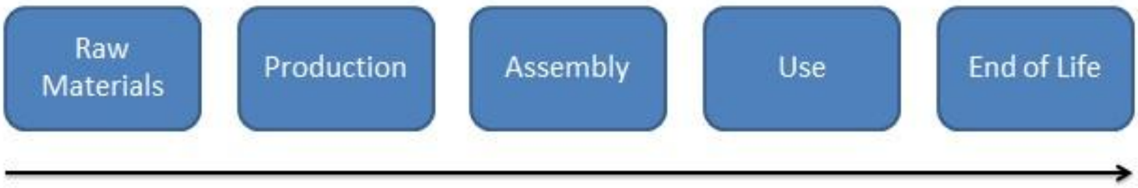


Figure 11 - Simplified life cycle for a typical Sandvik Mining product
Source: Author

It is important to point out the close cooperation that Sandvik Mining maintains with their customers. The relationship goes beyond simply selling a product and often includes detailed investigations in connection to aftermarket products. This type of project relies on the communication between Sandvik Mining and the customers to create a fully working solution for an entire mining site rather than a single product sale. Moreover, the end-of-life activities will depend on a number of factors. Some of Sandvik Mining's products have a system in place for recycling of used materials where Sandvik Mining purchases some parts of machines back from its customers. Another factor to consider is geographical differences in relation to end-of-life management where some market's legislation is much stricter than at others (Wester, 2013).

4.4 EHS at Sandvik Mining

Considering the EHS policy that the Sandvik Group has adopted to guide the way of doing business it is of importance for this paper to understand how this policy is reflected in the operations of Sandvik Mining. As Sandvik Mining, and their Global Product EHS department in particular, will serve as a case study on which the research of this paper is centered it is crucial to understand how their day-to-day activities are affected by this EHS policy.

The EHS policy for the overall Sandvik Group is rather wide in what it aims to accomplish. These accomplishments are then pursued by the use of set strategies and objectives for every individual business area. In the Sandvik Group EHS policy document one can read that: *"Environment, health and safety issues are integral parts of Sandvik's total operations and the company achieves continual improvement in these areas through management by objectives. Sandvik believes that the greatest effect is achieved through preventive actions."* (Sandvik Group EHS Policy). The idea is to create a strong EHS culture and in Sandvik Mining this translates into working towards achieving 'zero harm' to all employees, the environment in which Sandvik operates in, their customers, and their suppliers (Gandal, 2012). This EHS culture is ensured by the previous described objectives and core values that are valid for the entire Sandvik Group.

Sandvik Mining adopts this EHS policy on to their market and has realized a number of global trends within the mining sector that needs to be the focus of their EHS activities. The current trend of a growing population and increasing levels of urbanization increases the market demand of metal and minerals. However, as the supply of natural resources are diminishing this will mean that mining companies needs to target mining sites with lower ore grades or perhaps mining sites where they need to drill deeper to reach the minerals and are otherwise lying on remote locations, difficult to gain access to. This will in turn place Sandvik Mining in a situation where there is a growing customer demand for more advanced and effective mining products and services (Sandvik, 2012b). Simultaneously the more complex mining solutions will require more energy for mining operations. This has been clearly represented by an increase of customer requirements regarding energy efficiency on Sandvik Mining's products. Additionally, lately there has been a trend where customers to Sandvik Mining have asked for products that can deliver better environmental performance than earlier versions. Environmental considerations have traditionally not been of vital importance to Sandvik Mining's customers and more focus has lied on the efficiency, safety, and cost of the equipment (Rosén, 2013).

Derived from the EHS policy it is useful to consider Sandvik Mining's EHS activities as divided between two different strategies on how to approach it; operational EHS and product EHS. These will be further explained in the coming two subchapters but focus will lie on product EHS.

4.4.1 Operational EHS

Operational EHS at Sandvik Mining is governed globally by the EHS Director and Sandvik Mining's sites globally have designated environmental coordinators and environmental managers that are reporting their environmental work to the Global EHS Director. Operational EHS have its main focus on Sandvik Mining's own activities including its production sites where their products are assembled and sales areas where Sandvik employees sometimes work at customer sites. Furthermore, some EHS activities are targeted on other parts of Sandvik Mining's supply chain e.g. concerning product transports to customers or environmental demands placed on suppliers. The environmental management system ISO 14001 is used as a tool to ensure that all Sandvik Mining sites are operating according to a recognized framework for environmental work as well as to ensure harmonization within the organization. It is the aim of Sandvik Mining to have all its sites ISO 14001 certified (Rosen, 2013).

4.4.2 Product EHS

Sandvik Mining is, together with Sandvik Construction, the only business area within the Sandvik Group that have a separate EHS organization devoted to their products. Product EHS is a sub-department under the Global EHS Director and operates globally over Sandvik Mining's product areas. As the name suggest, Product EHS, aims to go beyond more traditional operational EHS practices that have already been in place at Sandvik Mining for some time. Operational EHS relates to the manufacturing (internal practices of Sandvik Mining i.e. EHS management according to ISO 14001 and OHSAS 18001) and Product EHS relates to all aspects of the product that takes place in the design and outside of Sandvik Mining's factories. This includes product specific factors such as; design, installation, use, maintenance, repairs, and disposal. The R&D (designers) of Sandvik Mining has the biggest opportunity to influence these factors relating to the product lifetime after it has been produced and sold by Sandvik Mining. Therefore, each R&D department also has a set of product EHS engineers and advisors within the specific product line (Sandvik, 2012c). The level of complexity of Sandvik Mining's products as compared to the products produced by other business areas within the Sandvik Group has given a situation where Product EHS is a necessary business function to deliver products that meets the increasing requirements that comes from various legislation, directives, standards and guidelines. Safety has always had a central role within the mining industry and has made Sandvik Mining get ahead with their product EHS work as compared to other business areas within the Sandvik Group (Rosén, 2013). Product EHS works with a vision of zero harm that aims to ensure that Sandvik Mining's products, services, and technical solutions are 'state of the art'. This shall ensure that these have a safe design, are of high quality, have long life times, are energy efficient, are environmentally sound, and as far as possible recyclable (Sandvik, 2012c).

4.5 New Product Development Process

Sandvik Mining uses a New Product Development (NPD) model when initiating innovation projects and/or when developing new products or upgrading existing ones. The NPD model is a stage gate model (Sandvik Mining, 2012a). Stage-gate models are widely used by companies over the world primary to simplify the often complicated process of product innovation. The stage-gate model consists of a series of stages in which key activities are performed. Complementing these stages is a number of gates in which the innovation process is evaluated on a regular basis. Typically, initial stages focus on opportunity identification and idea generation. Later stages often move into concept development, testing, and market launching. The stages are most often cross-functional, meaning that each activity is done parallel with others which allows the project to proceed in a faster manner. The gates provide decision points where a project team needs to evaluate whether to carry on with the project or not. These decision makers often consist of senior managers that at the gates will consider the business rationale of the project. The gates are generally containing three main elements; criteria, outputs, and deliverables (Frihammar et al, 2010).

Arguably, the NPD model also falls into the category of project models named V-models. These have the overall aim to provide a simpler way to approach a project that many times can become rather complex. Project management models require high levels of collaboration between business units and the idea of a v-model is to give a project a structure that ensures constant supervision of its progress. As the name, V-model, suggest the project is structured in various project steps that should be performed during the process. By dividing the project into smaller project steps a company will experience it easier to evaluate each step individually which can provide a better pinpointing of potential problems that might occur throughout the project as a whole (Forsberg & Mooz, 1998 & Johansson, 1999).

It is important to remember that a model will never be able to fully represent reality. The main aim of the NPD model used by R&D is to achieve harmonization between the stakeholders involved. The development of a new product at Sandvik Mining is a very complicated process where each project can take anything from 6 months up to two years of time. Planning is of course key in order to ensure that the project delivers results that are of satisfaction. Sandvik Mining's follows a product life cycle standard and this process goes from the initial stage of a design idea to a ready product. Sandvik Mining is running 50 to 100 NPD projects simultaneously which ranges from the development of completely new products to upgrading existing product lines (Rosén, 2013).

One can consider each NPD project to follow a life cycle thinking that goes from an idea to a ready product. Each project consists of four major phases that is governed by the management of the project. These four phases are; initiation, planning, execution, and closing.

At the project initiation a first assessment is made regarding the business opportunity of the expected outcome of the product that is being considered in the project. The project needs to be justified by showing potential to accomplish profits through e.g. increased sales or new technical knowledge. Secondly, the planning phase of the project is carried out where the full project is outlined and planned in order to ensure that the project can be carried out and completed. Thirdly, the actual execution of the project is carried out through; design, implementation, integration, verification, and validation. Finially, the project is closed and the project (finished product) is handed over to the receiver. The project must at this point be well documented to ensure that the gained knowledge stays within Sandvik Mining (Sandvik Mining, 2012a).

Each project phase is initiated and closed with a project gate where project management takes an informed decision based on detailed assessments on whether to continue the project, change it, or terminate it. The decision is based on weighing the recorded performance of the project against the project's business opportunity, status and progress. Gate 0 is the starting point of every project where the actual decision to initiate a project is taken. Gate 1 decides to start the planning of the project. Gate 2 decides to establish the project and start its execution. Gate 3 makes an assessment mid-execution to decide whether it should be continued to its finish. At this point the organization structure to produce the product will be in place and many 'big' decision are required e.g. to order the necessary parts etc. Gate 4 decides on handing the now finished project to its receiver (either internal or external customers). Gate 5 finally decides on closing the project (Sandvik Mining, 2012a).

4.5.1 Project organization

Any NPD project will require a well formed organization structure that divides the many responsibilities and tasks that the project will require. As each NPD project can be argued to be unique (depending on what its purpose is) this organization structure might come to look different from project to project. The main goal of forming is of course to ensure the success of each project. However, there are some guidelines on how Sandvik Mining works with forming their organization for a NPD project. Figure 12 depicts a basic scheme of the project organization and roles, which will be further explained below.

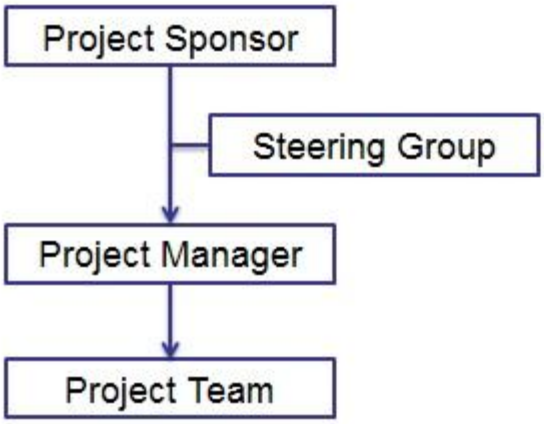


Figure 12 – Organization and roles of a NPD project
Source: Sandvik Mining (2012a

The highest degree of responsibility is given to a project sponsor, or also called management team or steering group, which has the ultimate responsibility to steer the project from a business perspective aligning it to existing business strategies and directives. This project sponsor is often made up by the different product line managers that are found around the world at Sandvik Mining's facilities. Other members of the steering group might come from other business functions whose participation is necessary for the success of the project e.g. HR, IT, Finance, Sourcing, Supply, Production, R&D, Marketing. The steering group is formed based on the judgment from the project sponsor that needs to decide how to form the team according to the requirements of the NPD project. As the steering group often includes people with rather high company positions and with many other responsibilities it is necessary to appoint a project manager for the NPD project. The project manager is delegated the responsibility to manage the project towards its goal and deliver results in line with the scope of the project. Additionally, the project manager manages the project planning and progress by steering and leading the project team. The project manager works somewhat more 'hands-on' with the NPD project but of course needs to regularly report 'up' to the project sponsor and the steering group. With the ultimate responsibility the project sponsor and the steering group takes decisions at the different gates of the model whether to proceed with the project. Each gates decision is of course done through careful assessment of the many factors relevant for the project e.g. economic, technical, EHS etc. The next level of the project organization consists of the project team. The project team is formed by a range of employees that are considered as experts from their field with knowledge that is relevant for the project. The project team often consists of engineers and designers, employees with the skills to carrying out the actual design work that is to be accomplished in the project. The team is in charge of all implementation of the project which was planned by the higher levels of the project organization. This includes e.g. work processes, rules, documentation, guidelines, and training.

A NPD project is of course including all factors that are relevant for Sandvik Mining in the product that is being developed. However, for the purposes of this paper it is necessary to only focus on how Sandvik Mining is working with product EHS in the NPD model.

4.5.2 Product EHS in the product development process

Over the last 20 years there has been an increased focus on not only safety, but also health and environmental matters that all falls under Sandvik Mining's EHS work. Product EHS cannot be seen as being new phenomena in Sandvik Mining and the company has gained much business throughout its existence by delivering products and services that offer high degrees of safety to its customers. Another trend that should be considered is that over the last 10 years or so Sandvik Mining's customers have increasingly asked for products that can deliver high environmental performance. The environmental of EHS has moved from being something that is handled by meeting legislative requirements to more ambitious targets that are demanded from Sandvik Mining's customers. Still, safety remains to be the most important factor within product EHS and the efforts are focused on this (Rosen, 2013).

Figure 13 shows how Sandvik Mining works with EHS in their new product development model. The different model steps will be further described in the coming sections of the paper. One can see that a bigger yellow arrow encircles the smaller arrows that depict the different task that are carried out throughout a NPD project. This yellow color defines these tasks as the responsibility of the project team where the actual 'work' to design a new product is made. Figure 13 includes only the activities related to product EHS as this is the most relevant to consider for the purpose of this paper. Each arrow is further described in the coming sections, where each arrow is given a headline. The work process follows a v-model that allows Sandvik Mining to work with a project in a systematic manner and verify the project throughout its process. The work process follows this V-shape starting with **requirements** and ends up in **safety file** (Sandvik Mining, 2012a).

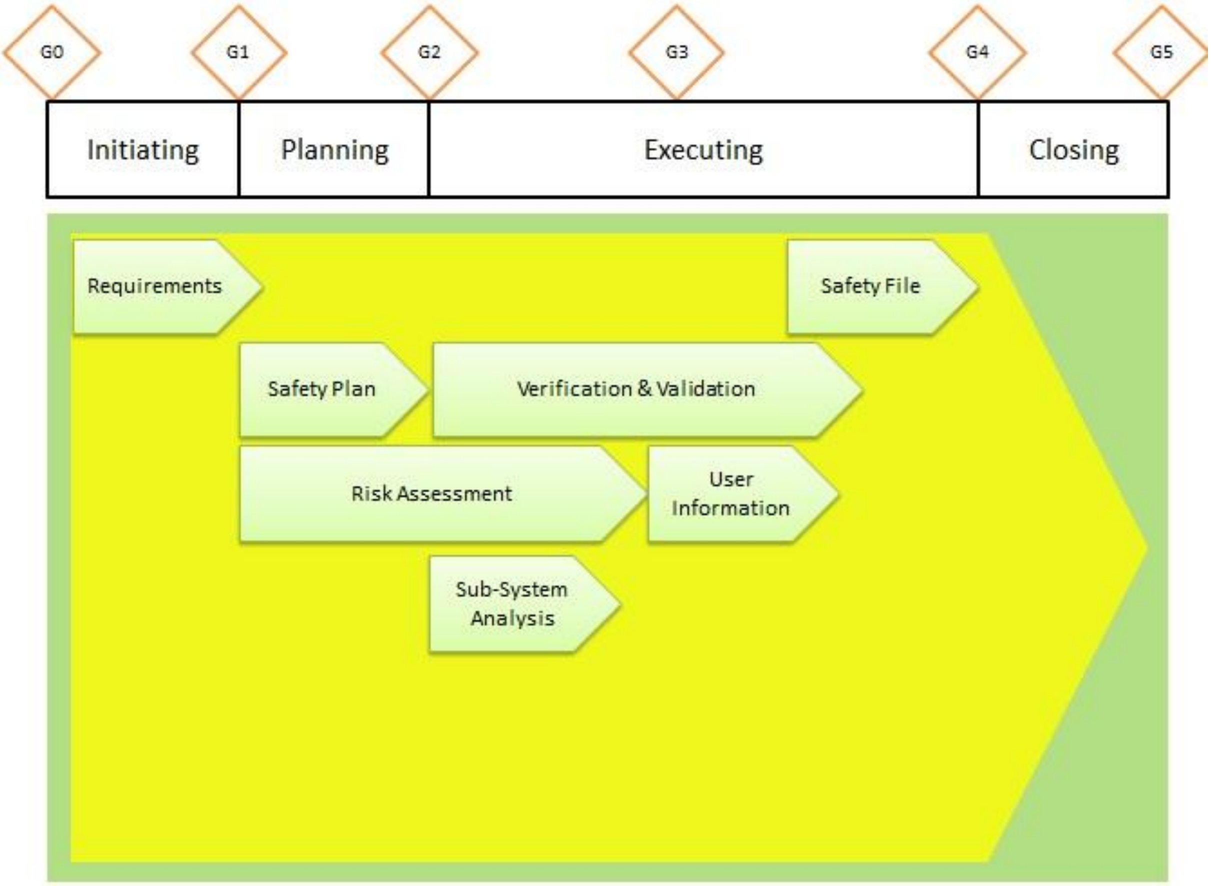


Figure 13 - New Product Development model with product EHS activities
Source: Sandvik Mining (2012a)

Requirements

This phase of the project aims to ensure that all products developed, using the NPD model, must fulfill the legal and regulatory requirements that exist in the markets that the product will be sold to. Examples of regulations that relates to Sandvik Mining's product are e.g. the European Commission's Directive 2006/42/EC on safety of machinery (European Commission, 2006a). Furthermore, the European Commission's regulation on chemicals REACH and its directive on restrictions of hazardous substances in electrical and electronic equipment 2011/65/EU (RoHS recast) some requirements on Sandvik Mining's new products (European Commission, 2006b; European Commission, 2011). These three regulations are perhaps the most relevant to consider regarding environmental requirements in an NPD project. However, there are also other regulatory documents and standards. Depending on which market the new product is intended for, the project needs to consider various local requirements (Wester, 2013). Additionally, customer requirements needs to be taken into consideration at this point of the project as many customers have demands that goes beyond a level that is acceptable from a legislative perspective (Rosén, 2013).

Safety Plan

The second phase of the work process for product EHS in the NPD project model handles the creation of a safety plan to be used throughout the execution of the project. The safety plan describes which safety related development activities that will be performed during the project. The aim of this safety plan is to ensure that the final product will meet the requirements that have been identified in the earlier phase including; compliance with legal requirements and directives, compliance with various standards deemed relevant for the project, as well as meet the customer demand on product EHS (Sandvik Mining, 2012a).

Risk Assessment

In every new product development project (or upgrade) a thorough risk assessment must be done which consist of three steps; life cycle hazard identification, likelihood and severity analysis, and risk reduction (Sandvik Mining, 2012a).

A hazard is defined as anything with the potential to harm health, life, or property and the aims of the risks assessments are to identify and control all hazards that related to the products, throughout their life cycles. As the risk assessment is done at an early stage of the NPD project it is necessary to base it on data from sources that are easily accessible e.g. expert inputs, reusing data from similar products, previous experience from similar product developments, concept descriptions and ideas, or even brainstorming sessions. The method is in accordance with the ISO 12100:2010 standard (Sandvik Mining, 2012a). All identified EHS hazards and potential impacts are then evaluated in relation to their likelihood of occurrence and their severity, using a quantitative risk matrix that provides an approach to understand how rank the identified risks according to their urgency of risk reduction (Sandvik Mining, 2012a).

The most effective way to control the identified risks is to eliminate these. Every risk assessment follows a set hierarchy of control of dealing with the risks that are identified. The **first** level is the hierarchy is to re-design the product eliminating the risk. The **second** level aims to minimize the identified risk. The **third** level aims to isolate the identified risks, the **fourth** to establish administrative procedures including; warning devices, training, preventative maintenance, emergency procedures etc. And the lowest level ensures that welfare facilities are sufficiently available within the proximity of the machine used as aid in a potential accident caused by the identified risks (Sandvik Mining, 2012a).

Sub-System Analysis

Various sub-system analysis allows Sandvik Mining to analyze certain components and system in greater detail. Furthermore, this allows realizing risks that require design changes in an earlier stage of the NPD project which otherwise can be difficult to handle at later stages of the process (Rosén, 2013).

Verification and Validation

This phase of the NPD project aims to ensure compliance with the requirements that was identified and added to the safety plan. In order to verify that the product meets the requirements a wide range of calculations, reviews, audits, simulations, and tests are needed. **Testing** is often required to prove that all requirements of the product can be met. **Calculations and simulations** are used when actual testing of the product might not be possible. **Design reviews** involve a set of experienced employees representing different departments of Sandvik Mining. These multidisciplinary reviews ensure that the product and its components, manuals, and instructions fulfill the requirements (Rosén, 2013).

User Information

This phase aims to describe and promote correct use of the product. All relevant information is compiled into a package containing e.g. operator's manuals, safety signs and labels explanation, material safety data sheets, training materials (Sandvik Mining, 2012a).

Safety File

When the process described above is completed the generated information is documented. The documentation may consist of; drawings, calculations, risk assessments, verification and validation reports, notes from design reviews, compliance declarations. Depending on which geographical market that the safety file is prepared for it will face a variation of requirements of what content that it needs to consist of. For example within Europe the European machinery directive requires that Sandvik Mining provide their customers with a declaration of conformity (Sandvik Mining, 2012a).

4.6 Previous use of LCA at Sandvik Mining

Sandvik Mining wishes to establish a process regarding how to approach LCA. This section will account for some of the LCA knowledge that product EHS at Sandvik Mining has gained previously.

In 2008, a LCA study for a Sandvik Mining DX780 drill rig in Tampere, Finland was done. The LCA study applied the ISO 14040 framework. Sandvik Mining viewed the study as very positive, providing much knowledge that was previously not known to the organization (Luukko, 2012). Figure 14 summarizes the findings of the LCA study. The use of diesel while operating the machine was identified as the greatest environmental impact caused throughout its life cycle. The study shows that over 95% of the total energy use throughout the life cycle of the drill rig takes place in the use phase. This is represented by the red area (Rouhiainen, 2008).

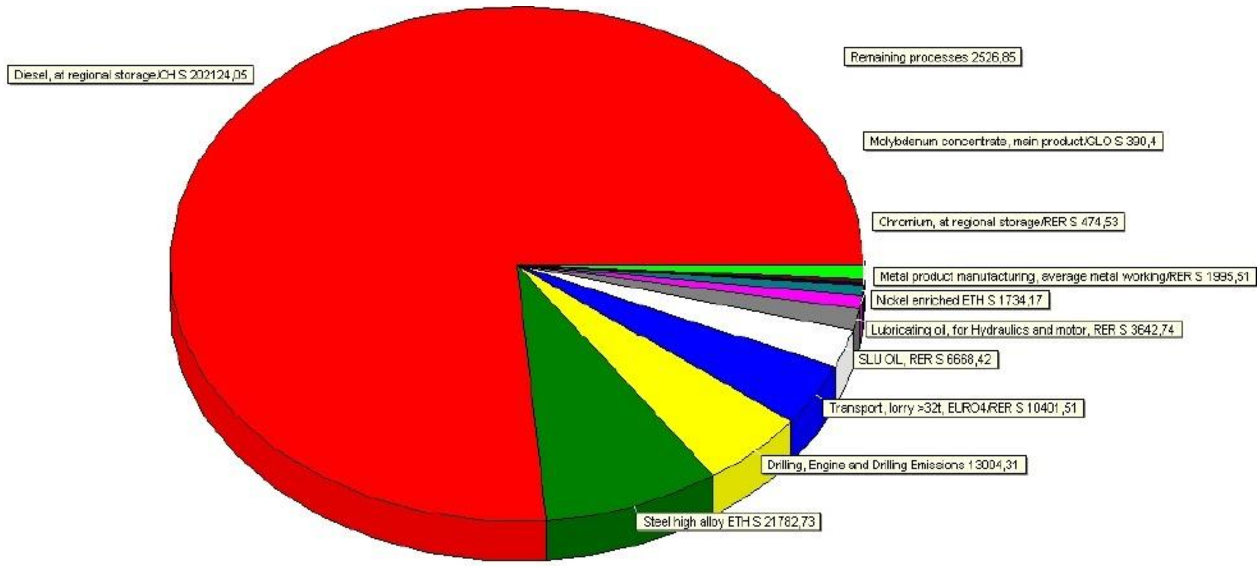


Figure 14 - Environmental impacts of Sandvik Mining DX780 Drill Rig
Source: Rouhiainen (2008)

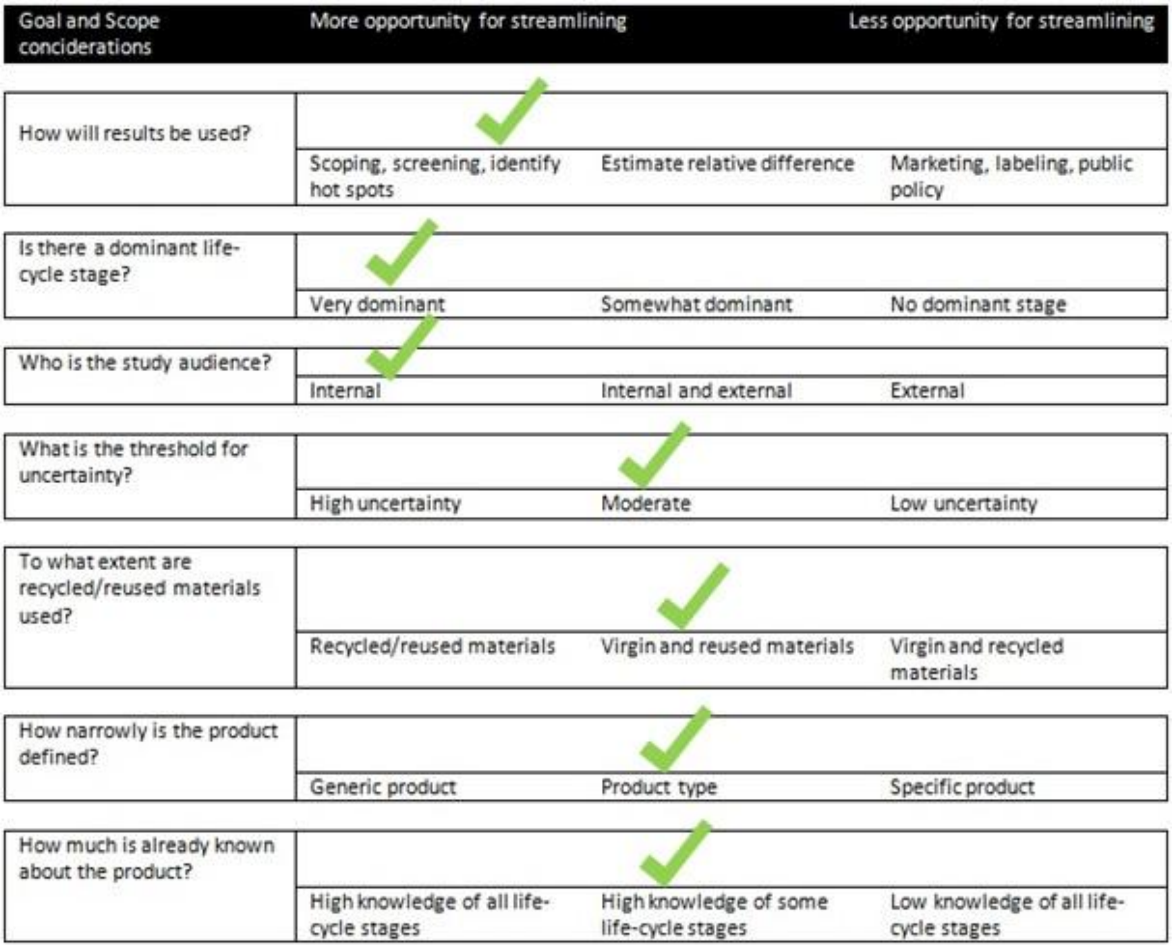
It did not come as a surprise to Sandvik Mining that the fuel consumption of the product caused the highest environmental impact. However, the LCA study allowed Sandvik Mining to get a quantitative expression of the product's environmental performance which could allow for future improvements (Wester, 2013).

5 Analysis

Sandvik Mining has been used as a case study for this paper. The observations from case study were compared with theoretical framework on LCA and SLCA. This comparative analysis method allowed the paper to identify correlations between theory and practice. The analysis is broadly speaking twofold. The first part aims to answer the question: **'could streamlined LCA be used the purposes of Sandvik Mining?'**. The second part of the analysis, based on the first part, aims to answer the question: **'How should Sandvik incorporate SLCA into its new product development model?'**.

5.1 Streamlining potential at Sandvik Mining

Considering the research by Curran & Todd (1999) it is possible to assess the potential of streamlining activities that could be considered by Sandvik Mining. Their research, summarizing the main factors for streamlining LCA, is displayed in Figure 15 below. Through the case study it was possible to map Sandvik Mining in Figure 15. The rational for choosing the specific positions will follow.



Goal and Scope conciderations	More opportunity for streamlining		Less opportunity for streamlining
How will results be used?	✓ Scoping, screening, identify hot spots	Estimate relative difference	Marketing, labeling, public policy
Is there a dominant life-cycle stage?	✓ Very dominant	Somewhat dominant	No dominant stage
Who is the study audience?	✓ Internal	Internal and external	External
What is the threshold for uncertainty?	High uncertainty	✓ Moderate	Low uncertainty
To what extent are recycled/reused materials used?	Recycled/reused materials	✓ Virgin and reused materials	Virgin and recycled materials
How narrowly is the product defined?	Generic product	✓ Product type	Specific product
How much is already known about the product?	High knowledge of all life-cycle stages	✓ High knowledge of some life-cycle stages	Low knowledge of all life-cycle stages

Figure 15 - Goal & Scope considerations for Sandvik Mining
Source: Curran & Todd (1999)

5.1.1 Depth and detail – how will results be used?

"How do you intend to use the information derived in the study?" (Curran & Todd, 1999)

As previously argued the purpose of every LCA study must guide the LCA expert towards where to streamline. The first consideration should lie in understanding the depth and detail that is required from the LCA study in order to ensure that the information it provides can be used in the way that the company intends. If a company wants to use LCA as a method to screen/scope various ideas, in terms of environmental performance, this most often require less precision of the assessment. The intended use of the LCA information can also be to highlight environmental 'hot-spots' and thereby awareness of where to improve. These types of activities allow for higher levels of streamlining. In situations where a company that has the intention of using the LCA information internally more streamlining can be used in constrast to situations where a company wants to use their product's environmental performance as an external tool, stating an environmental preferability, less streamlining activities can be justified. Such a comparative LCA study would have to be very precise and follow strict LCA methods in order to ensure a fair comparison between products (Curran & Todd, 1999).

As an initial attempt to incorporate SLCA into the current NPD model Sandvik Mining is first and foremost looking for a structured way to harmonize methods for environmental efforts. The level of knowledge about Sandvik Mining's products is high and there is already awareness of environmental 'hot-spots', however there is a lack of a structured process. The idea of Sandvik Mining is also to establish a database of environmental information that allows for the measurement of future product EHS actions. Additionally, Sandvik Mining sees the potential to use LCA information externally at some point in the future. The reasons for this might come from e.g. stricter legislation or changing customer requirements asking for transparancy (Wester, 2013).

Following the line of argumentation above, Sandvik Mining can therefore be argued to have a rather high potential to use SLCA. For the initial purposes of Sandvik Mining using SLCA, and a rather high degree of streamlining can be justified. However, with time the LCA knowledge will increase within the organization and an acceptance of this suggested work 'routine' should be established. This will allow Sandvik Mining to evolve their SLCA studies to be more complete and thereby deliver more precise information. In turn the amount of streamlining actions will decrease as the changing purpose of using LCA will demand more reliable information. Sandvik Mining's desire of an initial use of LCA information for strictly internal purposes suggests that a rather simple SLCA model will suffice initially..

5.1.2 Breadth and completeness – is there a dominant life-cycle stage?

"Is there a dominant stage in the life cycle of the product being studied?" (Curran & Todd, 1999)

The second consideration deals with the occurrence of one life-cycle stage that can be argued to dominate the whole product system. The argument can be made that removal of non dominant life-cycle stages will not affect the conclusions of the LCA study. Typically, this type of streamlining potential is found when assessing durable products. Durable products generally have higher input- and output flows in the use and end-of-life stages in the product life-cycle. However, it is important to remember that an LCA study that aims to be comparative will not have the same potential for streamlining as the elimination of life-cycle stages could hide important product differences found when studying two different product systems (Curran & Todd, 1999).

Much is already known about where products' 'hot-spots' are found at Sandvik Mining. For example it is known that the highest environmental impacts (especially in terms of energy) are caused during the use of a product (Rosén, 2013). Looking at a specific mining equipment, for example a loader it is not hard to understand that the biggest environmental impact will occur while it is used at various mining sites around the world. The function of Sandvik Mining's products is to operate in the most productive manner, running as much and often as possible. The LCA study of Rouhiainen (2008) confirmed this, finding that 95 percent of the total energy use is diesel consumption in the use phase. Furthermore, it can be assumed that the absolute majority of the product's environmental impact is caused during this life-cycle stage, as there is also a need to continuously replace wear and spare parts, fluids and maintain the equipment (Wester, 2013)..

Sandvik Mining's products are durable with long life-times ensuring buyers with reliable operations. Some product categories will of course have longer life-times than others. A mining vehicle e.g. a drill rig is a durable product and the cost for purchasing varies depending on model and requirements. . However, over the long run the main cost for a customer is keeping the equipment in production e.g. power-supply, maintenance, repairs. Among the variable costs the dominant factor is known to be of the fuel that the machine runs on (Wester, 2013).

The analysis suggests that there is much potential for streamlining activities due to the use phase being the dominant life cycle stage and it is well known within the company and product EHS that the use-phase in the life-cycle of their products causes the absolute majority of environmental impact. Further, there is no intention to use acomparative LCA in the initial incorporation of LCA into the existing NPD model. Sandvik Mining is placed at the very left in this consideration.

5.1.3 Transparency – who is the study audience?

"What audience or context are the study results going to be released or applied to?" (Curran & Todd, 1999)

The third consideration relates to what the intended use of the information generated by the LCA study is. The possible level of streamlining activities correlates with the required precision of the LCA study's results. An LCA study that has an internal information purpose will not require as high degree of transparency and reliability as an LCA study that aims to inform externally. It is important that a company can ensure reliability in the LCA results that forms the base of this information. If the goal is to claim environmental superiority over competitor's products an EPD might be necessary. It is possible however to still use LCA results externally for informatory purposes without going as far as using an EPD. The key here is to realize that any claim needs to be made from reliable information to avoid potential greenwashing scenarios that might end up hurting the company. SLCA can still be used to communicate environmental improvments to customers etc. and if the results are used for internal purposes e.g. informative, knowledge enhancing, identification of 'hot-spots' more opportunities for streamlining can be justified (Curran & Todd, 1999).

The ambition of Sandvik Mining is currently to study LCA to potentially incorporating SLCA into its existing NPD model. This will allow for a structured process to work with the environmental aspects of product EHS when developing or upgrading a product. Many things have already been done in relation to environmental efforts and the SLCA can allow Sandvik Mining to harmonize the method for these efforts.

Initially the audience of the LCA study will be primarily internal but as the knowledge and experience of using LCA within product EHS increases the ambition is to expand the use of the results this generates. Sandvik Mining sees the potential of using information derived from LCA to inform customers of their products' environmental performance. However, information claiming environmental preferability (e.g. an EPD) is not seen as possible or relevant to accomplish in the near future. If the SLCA generated information is used for informative and not comparative purposes and the information is deemed as correct, Sandvik Mining sees no problem in using it both internally and externally (Wester, 2013). Following the line of argumentation above Sandvik Mining can be placed to the far left in the third consideration as suggested by Curran & Todd (1999).

5.1.4 Data quality objectives – what is the threshold for uncertainty?

"What is your threshold for uncertainty?" (Curran & Todd, 1999)

Any streamlining activity will present uncertainty to an LCA study. This section concerns the level of uncertainty that can be tolerated while still satisfy the intended use. Depending on how the LCA study will be used, the LCA expert must decide the quality of the data requirements to be used, in terms of; availability, precision, bias, comparability, compatibility, completeness, representativeness etc. The ideal LCA study will only use data specific to product system but naturally this is not reasonable to expect. Streamlining occurs when the LCA expert makes compromises in the quality of data. If the intended use of the LCA study still can be ensured, these activities can be justified (Curran & Todd, 1999).

Naturally there are numerous ways to retrieve the data used in an LCA study. Process- and facility specific data allows an LCA study to deliver information of very high certainty. However, such specific data might not be available and other types of data must be used e.g. composite data, aggregated data, industry-average data, or generic data. (Curran & Todd, 1999).

The product areas and connected product development centers within Sandvik Mining have product EHS engineers and advisors that often are part of a NPD project team. They are responsible to look after the EHS factors for every project. The responsibility for each of the different product groups are divided over the organization and the different production facilities.Each product area typically has one main assembly site (Rosén, 2013). The availability of data that can be used in an LCA study will differ depending on which assembly sites are considered. Some sites might have the opportunity to record process- and facility specific data whereas others might not. The data from the assembly sites are representative for the manufacturing phase of the life cycle. One aim of incorporating SLCA into the NPD model is to provide a possibility for different product areas to set their own data requirements for each environmental assessment. Additionally, Sandvik Mining has access to a license of GaBi LCA software that comes with a wide LCI dataset. This data is mostly focused on the raw material used by the suppliers to Sandvik Mining (Wester, 2013).

Much data already exists within Sandvik Mining such as in a platform named Reliability Workbench (or MLOC) that aims to provide customers with information regarding variable costs connected to maintenance and repairs. Customers are reporting their 'wear-and-tear' of Sandvik Mining's products into a database. Derived from this database it is then possible for Sandvik Mining to inform their customers on e.g. how many units of spare parts a certain machine requires per ton of loaded minerals. This type of data could be translated into useful LCA data to understand some of the environmental impact caused in the use phase of the product life-cycle (Rosén, 2013).

The observations that have been made in the case study of Sandvik Mining show that an incorporation of LCA into their NPD project model requires some degree of flexibility. The intended outcome of the use of LCA is primarily to create a common method to work with environmental assessments within product EHS. The information derived from the LCA study will firstly be used internally to increase knowledge and capability. Coming intensions aims a little higher where at the establishment of the updated NPD model will allow for an LCA database that can be used for measurement of future environmental improvements. Initially it seems that Sandvik Mining has access to data that is reliable enough for the intended use of the LCA studies. The data quality requirements will be set differently depending on which production facility that performs the NPD project. Furthermore, the data quality requirements will increase over time as the organization's capability and knowledge increases and the intended use of the LCA studies become more externally focused. Sandvik Mining is therefore placed in the middle regarding the forth consideration. Some degree of streamlining activities could be justified when deciding the data quality requirements.

5.1.5 Allocation conventions – to what extent are recycled/reused materials used?

"What is the role of recycling for one or more products being studied?" (Curran, 1999)

Depending on what product system that is assessed in the LCA study the amount of recycled materials that is found in the system will affect the opportunity to justify streamlining. If the product that is studied is produced using virgin materials this will require a more complete LCA study including upstream activities in the product system. A comparative LCA study assessing one product made from virgin materials against a second product made from recycled materials should not be limited to exclude upstream activities as these the advantages of the recycling system would be hidden to the LCA expert. A product system that includes the use of recycled or reused materials will typically have less environmental impact (Curran & Todd, 1999).

Sandvik Mining's products consist of many different components that are both purchased complete from suppliers and/or machined internally. The products consist to a large majority of steel constructions. Production of steel typically has recycling systems in place where much recyclable metal is put back into the production. However, the producers are most often required to add virgin materials as the steel-quality cannot be ensured through the use of strictly recycled materials. Still, a Sandvik Mining product will to a great extent consist of steel suggesting that recycling systems will affect its environmental impact (Rosén, 2013).

Considering downstream activities of Sandvik Mining product's life cycle the end-of-life management can differ much between geographical markets and product. Some countries have strict legislation requiring a mining company to scrap their equipment when it reaches the end of its life. Other countries have no such legislation in (Wester, 2013). This is also a matter of cost. Where it is more cost effective to sell the equipment as scrap, a larger amount of the material will be recycled. One example is the manganese steel used in Sandvik Mining's crushers that is bought back from customers and competitors to be recycled in the internal Sandvik Mining production (Rosén, 2013).

The aim of incorporating a standardized method for using SLCA in the NPD project model will create some difficulties within this consideration. The wide stream of components that a Sandvik Mining product consists of will make it complex to assess all upstream and downstream activities in the life cycle of the product. Additionally, certain product types will have some flows of reused materials within their product systems. Sandvik Mining is placed in the middle of this fifth consideration. Some degree of streamlining can still be justified by using e.g. various cut off criteria.

5.1.6 Product specificity – how narrowly is the product defined?

"How narrowly is the product or process under study defined?" (Curran & Todd, 1999)

The sixth consideration for an LCA expert to make before forming an LCA study relates to how detailed the assessed product system should be. An LCA study aiming to assess a generic product category can justify more streamlining activities than an LCA study that aims to assess a specific product. A specific product requires a very narrowly scoped study and detailed data of that particular product system. The assessment of a generic product type instead rallows for a more loosely defined product system and thereby also less specific data (Curran & Todd, 1999).

As previously stated, Sandvik Mining has a wide range of products within each of its many product areas. The product areas can be argued to represent the function that the products in them deliver to Sandvik Mining's customers e.g. load and haul, crush and screen, breaking and demolition, drilling (Wester, 2013). Typically, a product series is renewed every three years using the NPD model and roughly 10 to 20 percent of all NPD projects include the creation of entirely new products (Rosén, 2013).

For this sixth consideration Sandvik Mining is placed at the middle defining product according to type. This is motivated by Sandvik Mining's stated purpose of incorporating SLCA into its NPD model. A generic product category LCA study would allow for more opportunities of streamlining however this would not provide sufficiently detailed LCA information. In contrast, an LCA study assessing a specific product would require resources and data that cannot be justified by Sandvik Mining. Results would be more reliable but developed at a pace too slow to keep up with the development of the machines. A product specific LCA study would take too long to perform and would of course only be relevant for one particular product. At the initial introduction of SLCA into the NPD model this would be far too ambitious to consider.

From the observations made in the case study of Sandvik Mining it seems most fitting to aim for an SLCA that allows for an assessment of the various product types that Sandvik Mining have. This allows Sandvik Mining to utilize data that is readily available to them. Additionally, it would allow Sandvik Mining to establish a database of environmental assessments making it possible to measure future improvements in environmental performance due to a NPD project. Sandvik Mining should define its products according to their function such as; load and haul, crush and screen, breaking and demolition, drilling etc. This offers a different approach than the single-case LCA studies that have been done previously such as the one made on a drill-rig in Tampere, Finland. This approach will allow Sandvik Mining to streamline their LCA studies while still meeting their intended use. It will provide a method that gives a quantitative expression of a certain product-type's environmental performance and the possibility to measure future improvements of the same.

5.1.7 Level of knowledge and information – how much is already known about the product?

"What is your level of knowledge about the product/processes being studied?" (Curran & Todd, 1999).

The seventh and final consideration that an LCA expert should make relates to the level of knowledge and information about the product that exists within the organization prior to the assessment. The continuum on which one needs to position one's own situation has two extremes. With high knowledge of the entire life-cycle there are more opportunities of streamlining activities. In contrast, low knowledge of the product's life cycle will make it harder to justify streamlining activities. The more knowledge and information that already is available to the LCA expert, the easier it will be for him/her to have confidence in that these streamlining activities will still generate the desired results of the LCA study (Curran & Todd, 1999).

Sandvik Mining has in place an organization with long experience from producing and selling products and services to the mining industry. This long experience and strong focus on R&D has given high knowledge of its own products (Wester, 2013). Sandvik Mining's organization works with product activities occurring in the design of a product as well as activities outside of Sandvik Mining's factories (Rosén, 2013).

The observations in this case study showed that the knowledge of the product life cycles is high. However, not all life cycles are relevant to consider in their work and the focus lies on improving products in their design phase so they have less impact during the use. Additionally, there is a high knowledge about the actual use of their products. Other life-cycle stages such as raw material extraction are less known, however the expertise exists in other Sandvik business areas.

Previous LCA studies have shown that some life-cycle stages are responsible for the majority of environmental impact. These studies confirmed the knowledge that already existed in the company. With good understanding of how their product's life cycles look Sandvik Mining has a very high degree of knowledge and information in place already. This suggests that there is much potential for justifying streamlining activities. However, since this paper has a clear focus on Sandvik Mining's product EHS organization some of this knowledge and information is not relevant to consider here. Instead, Sandvik Mining is placed at the middle of this consideration's continuum.

5.2 Incorporation of SLCA in the NPD model

This following section aims to answer the question: **'how should Sandvik incorporate SLCA into its new product development model?'** Case study observations from Sandvik Mining are analyzed through the theoretical framework on LCA and SLCA. This results in an upgraded version of Sandvik Mining's new product development model as shown in Figure 16. The additions to the model suggest how SLCA can be incorporated as an environmental tool, complementing the NPD model's current product EHS activities. The suggested project phases are further developed in the coming sections with a sub-heading devoted to each addition.

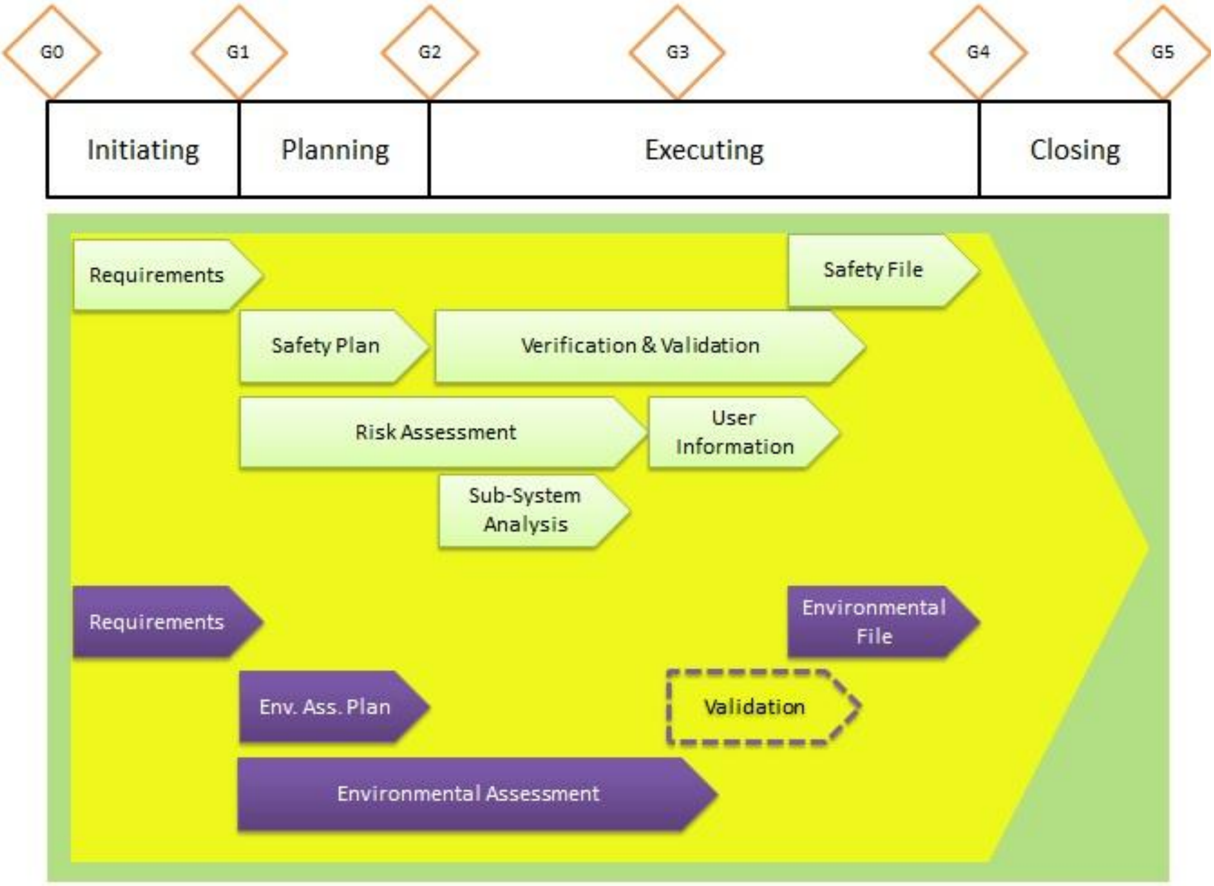


Figure 16 - NPD model with recommended additions
Source: Sandvik Mining (2012a) and additions by the author

5.2.1 LCA Requirements

Identification of requirements will be an important part when doing a SLCA. REACH and the new directive on restrictions of hazardous substances in electrical and electronic equipment 2011/65/EU (RoHS recast) is arguably the most relevant environmental. Documentation will be of key importance in this process step and it should clearly be documented what are the requirements of the SLCA study, why these have been used and how they are affecting the forming of the SLCA study.

According to Da Silva (2012) is crucial that a company, that wants to incorporate LCA into its innovation processes, does not disregard their already existing mission, vision, and strategies. Among other things, Sandvik Mining's EHS policy aims for increased energy efficiency of products and promotion of reuse, recycling, and recovery or materials. Moreover, it states that Sandvik Mining should comply with or exceed EHS legislation (Sandvik EHS Policy, 2013). This suggests that it is important to include these already identified focus areas prior to forming the SLCA study in the NPD model. Weitz et al. (1996) suggests one streamlining activity in the use of so called 'showstoppers' or 'knockout criteria'. These will usually be formed on past experience and knowledge within the company. If the set criteria are encountered at later stages in the NPD model, when performing the SLCA assessment, this signals the LCA expert of the need for instant decision making regarding the potentially necessary revision of the assessment. The initial incorporation of SLCA into the

NPD model will most likely not require the formation of this type of 'showstoppers' that goes beyond the legislative requirements that are already considered today.

Da Silva (2012) argues that a company at this stage of an innovation project will already have ideas on how a product can become more sustainable and the challenge is to filter these ideas down to a few worth pursuing. By including a LCA expert into the innovation team it is possible to achieve an initial screening of these ideas from an LCA perspective. Companies will often have some type of checklist based on legislative requirements, company strategies and goals, and certain customer requirements. Environmental requirements from customers are today not that common, besides energy- and water efficiency that are frequently asked for by Sandvik Mining's customers. Legislative requirements refer mainly to the ban of certain substances and there are no requirements directly related to LCA (Rosén, 2013). All of these requirements will act as an initial filtering in the NPD model. Most of the discussed environmental requirements are already part of the NPD model and there are no specific requirements relating to LCA. It is however important that every NPD model consults ISOs frameworks on LCA to ensure harmonization between the environmental assessments and their methods.

5.2.2 Environmental Assessment Plan

The second phase in the NPD model currently includes the creation of a safety plan describing how risk assessments, risk mitigation, and verification & validation will be done throughout the project. The aim of the safety plan is to ensure that the final product will meet the requirements identified in the initial phase of the NPD model (Sandvik Mining, 2012a). This phase should be complemented with an environmental assessment plan describing how the later environmental assessment will be done. The main aim of the environmental assessment plan should be to define the goal and scope of the planned SLCA done in the next stage of the NPD model.

Goal

According to Heijungs & Guinée (2012) a number of questions needs to be answered when setting the goal of the LCA study. **Firstly**, it must be clearly defined what the intended use of the assessment is. Sandvik Mining wants to use the incorporated SLCA to identify environmental hot-spots in their products life-cycles. The quantitative method that SLCA provides will allow them to measure the environmental improvements in new products (Wester, 2013). **Secondly**, it must be defined who the intended audience of the study is (Heijungs & Guinée, 2012). Initially the intended audience of the SLCA will be primarily internal (Wester, 2013). **Thirdly**, the defined goal of the assessment must clearly state the reason for why the assessment is done (Heijungs & Guinée, 2012). Sauer (2012) argues for four major categories of LCA studies and it is important that the environmental assessment plan clearly states under which it falls. The SLCA incorporated in the NPD model will initially be an assessment studying a **single system** with **internal use of results.**

Scope

When streamlining an LCA study Curran & Todd (1999) argues that there are two major ways that this can be accomplished. The LCA expert can chose to either streamline in the methodology of the LCA or within the LCA process. Streamlining activities related to the scoping of a LCA study commonly refers to the choice of narrowing this down. A number of definitions needs to be in place; **product system, functional unit, system boundaries, impact categories, cut-off criteria, data requirements and sources, limitations, and critical review**.

5.2.2.1.1 Product system

Any LCA or SLCA study needs to define the product system that is chosen to analys in the assessment (Curran & Todd, 1999). ISO 14040 defines a product system as: *"collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product."* (ISO, 2006a). As previously argued, a LCA study can quickly become very complex when aiming to understand every single factor and actions that takes place from the initial raw material extraction to a final product ready to be used. It is necessary for a LCA expert to limit the product system that will be studied by the LCA (or SLCA) to make the environmental assessment manageable. These limitations can be viewed as streamlining activities. Christiansen (1997) and Graedel (1998) suggest a streamlining activity in that processes that are seen of low importance for the product system as a whole can be left out. Moreover, the number of life-cycle stages that are included in the product system can be limited if it can be argued that the disregarded stages environmental impact is difficult to change. Weitz et al. (1996) strengthens this argument by suggesting that upstream- and/or downstream components in a product system can be left out in an SLCA if these are of little relevance of the results.

Product EHS already have a great level of knowledge regarding the life-cycle stages that are causing most environmental impact and this has been confirmed by previous LCA studies. Additionally, product EHS focus on the life cycle stages use and end-of-life of Sandvik Mining's products (Wester, 2013). Therefore it is suggested that Sandvik Mining should define its product system in their SLCA studies to include these two life-cycle stages; use and end-of-life.

5.2.2.1.2 Functional unit

The functional unit provides a quantification of the function of the assessed product. It provides a reference against which the inputs and outputs of the product system can be related. If the goal of the SLCA is to compare the product against another the functional unit must allow the assessment to fairly compare the products, taking their differences into account (Sauer, 2012). As it was found in the previous section of the analysis the most fitting SLCA should narrow down its scope towards the type of product that it assessed. This will allow Sandvik Mining to use data that is readily available within the organization and establish a database of previous environmental assessments that can be used as a baseline, or comparison, when new products are made. This suggests that the functional unit needs to be defined in the environmental assessment plan in a way that ensures that SLCAs can be fairly compared in the future. By setting the functional unit according to the function of the product type this can be accomplished; e.g. load and haul, crush and screen, breaking and demolition, drilling. For a loader this could for example be defined as 'x tonnes of material loaded and hauled x kilometers per hour, for 25 years of time.

5.2.2.1.3 Boundaries

ISO 14040 argues that the assessed product system must have clearly stated boundaries. Geographical boundaries need to account for specific setting of e.g. technology, energy mix, transport capabilities, distances, and raw materials sourcing (ISO, 2006b). The SLCA must be careful when setting the geographical boundaries of the studied product system. Experience at Sandvik Mining suggests that the geographical differences can be large. The decision to exclude some life-cycle stages and focus on the use- and end-of-life phase will make it complicated to account for the geographical differences within the mining industry. Therefore it will be important for the SLCA studies to use some form of averaged data to set their geographical boundaries. Otherwise it might be difficult to compare different SLCAs with each other. Time boundaries are also important to consider, especially for products with a long life, when defining the boundaries of the assessed product system. Technology, recycling systems and energy mixes are examples of factors that change over time risking some environmental impacts to be hidden or overestimated by the environmental assessment (Sauer, 2012). The environmental assessment plan should choose a technology- and energy mix that is representative for the region in which the product is operating. The same goes for the chosen recycling system to be included into the defined product system. GaBi offers the opportunity for Sandvik Mining to use a technology- and energy mixed based on aggregated data allowing their SLCA to e.g. express the energy mix that is used in production in Northen Europe, or Sweden.

5.2.2.1.4 Impact categories

An important part of scoping the environmental assessment will be for the LCA expert to define the impact categories. The amount of data that the assessment will require correlates with the number of impact categories that are chosen. It is therefore necessary to define the impact categories to meet the stated goal of the environmental assessment (ISO, 2006b). Christiansen (1997) and Graedel (1998) suggest that a LCA expert can choose to streamline an environmental assessment by focusing on one or a few environmental impacts. From Sandvik Mining's EHS policy one can derive that energy- and resource efficiency is of importance (Sandvik EHS Policy, 2013). Sandvik Mining's customers have started to ask for product information regarding energy efficiency and water use, which can be explained by increased mining operations at remote locations (Rosén, 2013). Being an initial effort to incorporate SLCA into the NPD model it can be argued that the number of impact categories that the environmental assessment aims to focus on should be kept rather few. The information that is generated by the SLCA should aim to meet Sandvik Mining's environmental strategy and deliver the information that is asked for by its customers. Additionally, it is known to Sandvik Mining that its products cause the biggest environmental impact during their operation due to either power- or fuel consumption. Therefore it is suggested that the impact categories to be included into the SLCA should be; global warming, terrestrial toxicity, resource depletion, and water use.

5.2.2.1.5 Cut-off criteria

As described in the theoretical framework cut-off criteria aim to make a LCA study manageable by excluding some components of the defined product system (ISO 2006b). Christiansen (1997) and Graedel (1998) argue that it is possible to disregard processes that are considered to be of low importance to the product system as a whole. This will reduce the amount of data required to form the LCI of the study. Setting threshold weights, masses, volumes etc will accomplish this. Weitz et al. (1996) argue that mass is perhaps most useful to disregard where raw materials representing a small fraction of total mass can be excluded from the study. However, all these streamlining activities assume that they are not endangering the quality of the study's results. The use of cut-off criteria can cause a LCA study to provide results that are not representative for a product's total environmental impact. Sandvik Mining's machines consist mainly by its steel construction and in terms of mass and volume this will be a very dominant input (Rosén, 2013). Sandvik Mining's customers are mainly interested in environmental information relating to energy efficiency and water consumption as this is clearly related to their flexible costs and local regulations (Wester, 2013). This suggests that Sandvik Mining should not use cut-off criteria that disregard inputs and outputs with low representation of total mass or volume as this could not give a reliable understanding of the product's environmental impact.

5.2.2.1.6 Data requirements and sources

The goal and scope of an environmental assessment will decide the data quality that is required from it. The more narrow the scope of an LCA study is the higher data quality will be required (ISO, 2006b). In theory a 'complete' LCA study should only include process- and facility specific data retrieved directly from the studied product system (Curran, 2012). The reality is however that data is often hard for a company to attain making it necessary to utilize alternative data sources. Christiansen (1997), Graedel (1998) and Weitz et al. (1996) suggest a number of streamlining activities that allows a company to attain data in an easier manner.

Christiansen (1997) and Graedel (1998) suggest that a company can use indirect data instead of direct data (process specific) in situations where direct data is impossible, or too costly, to attain. Sandvik Mining has much of the necessary data available within the organization e.g. through the platform MLOC (Rosén, 2013). This data is readily available and can provide much of the data required to form the life cycle inventory for the use phase of a product. Other inputs and outputs in the defined product system might not have direct data readily available and it should be considered by the LCA expert if it is possible to easily attain. If it is not, other indirect data should be used instead. Sandvik Mining has databases available through the software GaBi (Wester, 2013)

Christiansen (1997) and Graedel (1998) also argue that data from old environmental assessments can be used in a SLCA. A company can create a database of their previous assessments from which data can be reused. This approach is suitable for a company which products are not the subject to big changes when upgraded. Sandvik Mining's products must be argued to be rather stable in terms of development (Rosén, 2013). NPD projects are mostly upgrading existing product models and completely products are often similar to their predecessors. Additionally, one of the aims of incorporating SLCA into the NPD model is to ensure that Sandvik Mining achieves documentation of their environmental work (Wester, 2013). This suggests that this streamlining activity is highly relevant for Sandvik Mining to use when their LCA work has been established within the organization. The reuse of data will make it easier for Sandvik Mining to compare their environmental assessments.

5.2.2.1.7 Limitations

It will be important for the environmental assessment plan to also address the limitations of the set goal and scope for the coming environmental assessment. As Curran & Todd (1999) argue all streamlining activities taken in an environmental assessment will give some uncertainty to its results. It was found in the initial part of the analysis that the uncertainty level that is acceptable to Sandvik Mining allows for SLCA. The incorporation of SLCA into the NPD model, as an initial effort to work with LCA, will use the information internally (Wester, 2013) and possibly also externally in the future. According to Douglas Helman a LCA study that does not include all of a product's life cycle stages must be careful to not claim to be a 'full' LCA. However, companies can chose to exclude life cycle stages if this can still ensure the intended use of the study (Helman, 2012).

Transparency will be important to ensure all relevant members of the NPD project can easily understand and follow how the SLCA has been done and why. It is crucial for Sandvik Mining to account for the limitations in their environmental assessment, including the various streamlining activities. It should be clearly stated that; some life cycle stags are disregarded, some data is indirect, not all impact categories are considered etc. Furthermore, the use of SLCA information (both internally and externally) must not claim to come from a 'full' LCA study. Instead, it should be clear that it comes from an environmental assessment built on the LCA method.

5.2.2.1.8 Critical review

A company that intends to use the results of a LCA study externally should consider including a critical review of their environmental assessment. This is especially true for a comparative LCA study with external use of the results, claiming environmental preferability over other products (ISO, 2006b). Many companies use EPDs to claim this preferability, forming their environmental assessments according to the set PCR for that particular product category (Stevenson & Ingwersen, 2012). An EPD requires third party verification (ISO, 2006c). Sandvik Mining's intended use of their SLCA generated information will initially be for internal purposes. The aim is to also include external information uses when the method of using SLCA in the NPD model has been established within the organization. However, Sandvik Mining does not aim to conduct comparative SLCA studies to claim environmental preferability (Wester, 2013). In this initial effort of using SLCA it does not seem necessary for Sandvik Mining to include any critical third party reviews of their environmental assessments. For their intended use of the information generated by the SLCAs it should be sufficient to rely of the life cycle interpretation activities already conducted by the LCA expert.

5.2.3 Environmental Assessment

When the scope and goal of the SLCA has been defined the LCA expert and the other members of the project team should at this point have a clear understanding of 'what' will be done in the environmental assessment, and 'how' this should be done. This suggested new phase of the NPD model, named environmental assessment and will include two major tasks for the LCA expert; an inventory analysis (LCI) and an impact assessment (LCIA).

Curran (2012) states that the largest effort in creating the LCI lies in the collection of data used in the environmental assessment. However, as the goal and scope was defined in the previous phase the LCA expert can now form the data collection activities accordingly. This will shorten down the required time and effort required to collect sufficient amounts of data.

Sandvik Mining has access to a license for the LCA software tool GaBi (Wester, 2013) which at this point should be utilized to accomplish a structured method for the data collection. GaBi allows the user to construct the product system that the environmental assessment aims to understand and Sandvik Mining needs to construct the process flow which is their defined product system. Furtermore, GaBi also offers the user access to large datasets with LCI data that have been constructed by LCA experts (Helman, 2012). Figure 16 provides a very simplified example of how the product system in an SLCA might come to look like. Here the product system has been expanded to separate the actual use of a Sandvik Mining product from its maintenance. This is useful for Sandvik Mining to consider as a large part the resources that goes into a product are directly related maintenance activities. A mining vehicle is built to last and operate as much as possible, which in turn requires repairs and replacement of parts to ensure its operational efficiency (Rosén, 2013).

The LCI needs to include all inputs and outputs from the defined product system (ISO, 2006b). As an initial effort to incorporate LCA into the NPD model Sandvik Mining wants to use a SLCA to make their work with environmental assessments manageable (Wester, 2013). The previous defined impact categories that Sandvik Mining should initially consider (global warming, terrestrial toxicity, resource depletion, and water use) were justified due to their relevancy for Sandvik Mining's own strategies, defined hot spots, as well as increasing customer requirements. Naturally, this will limit the amount of input and output data that is needed in the LCI and Figure 17 present only the perhaps most obvious. A product system will in reality look much more complex (Helman, 2012) as each single input or output needs to be traced back to their point of origin.

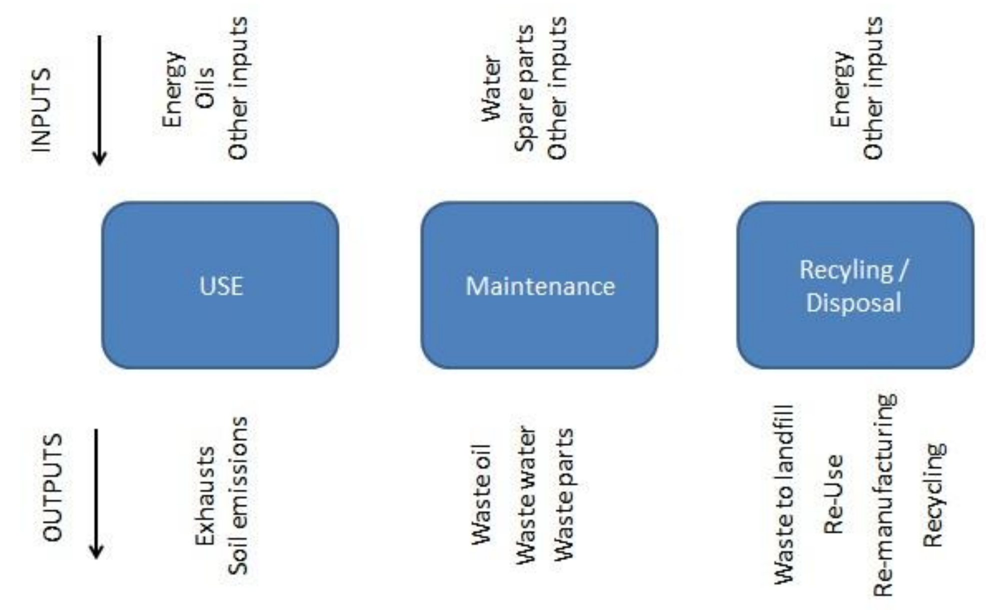


Figure 17 - Simplified product system to be considered by Sandvik Mining
Source: Author

The process model (product system) will look very different within GaBi but Figure 17 still provides an understanding of how the LCA expert at this point has defined the scope of his environmental assessment and now needs to collect the data that is required from it. Curran (2012) argues for two types of LCI data; primary or secondary. The environmental assessment plan has at this stage defined the data requirements for the LCI. It was recommended for Sandvik Mining to use primary data to the largest extent possible as it is considered more reliable including process- and facility specific information (Curran, 2012). Sandvik Mining should utilize primary data found through on-site measurements, interviews etc. Additionally, MLOC can offer useful data although it might require some restructuring to fit within the LCI.

Primary data is naturally always preferable to use (Curran, 2012) as it provides the most accurate information related to the studied product system. The reality is however that primary data can be difficult to attain (Helman, 2012; Curran, 2012). Therefore, it is suitable for Sandvik Mining to use secondary data sources where primary data cannot be accessed. With access to GaBi, Sandvik Mining should utilize the large LCI datasets that are available to all user of this LCA software. Additionally, GaBi allows the LCA expert to form own LCI datasets with e.g. primary data simplifying the process of data collection for future SLCAs. The LCI data offered in GaBi is data from industry that LCA experts are compiling to allow the user to include aggregated data instead of perhaps disregarding it from the environmental assessment (Helman, 2012). This complementation should of course be done within the previously defined scope and goal of the study. It is useful for a company to have data collection prepared that categorizes the required data according to its relevant impact category. The ISO 14044 framework provides an example such a data collection sheet in its annex (ISO, 2006b).

When the LCI is set, containing all data as required by the scope and the goal of the SLCA study, the LCA expert should move into the second phase of this environmental assessment; the LCIA. Margni & Curran (2012) states that the LCIA aim to give the LCA expert an increased understanding of how the data identified in the LCI relates to potential human health and environmental impacts. The **first** action from the LCA expert has already been completed when setting the scope and goal of the SLCA; to select the impact categories that will be considered by the assessment (ISO, 2006b). For Sandvik Mining it was found that the initial purposes of using SLCA in their NPD model should consider the impact categories: global warming, terrestrial toxicity, resource depletion, and water use. The **second** step in the LCIA (classification) assigns the LCI data to categories according to the impact to which they relate. Some LCI data can be assigned to several impact categories. **Thirdly** the LCA expert uses characterization in which every substance, now assigned to an impact category, is expressed as its potential impact for the entire impact category (ISO, 2006b). The LCA software GaBi will be of importance here as the use of such a tool is suggested by Curran & Todd (1999) to be one of the most common ways to streamline an LCA study. The initial scoping and goal setting of an environmental assessment will together with the actual collection of its required LCI data will most often be the most time-consuming and complicated part, for a company working with LCA (Helman, 2012). This is true also for Sandvik Mining as the actual environmental assessment can be performed rather quickly with the aid of GaBi.

5.2.4 Validation

The fourth suggested addition to the NPD model is to include a project phase aiming to validate that the environmental assessment generated results that are acceptable to the goal and scope of the study, defined earlier in the environmental assessment plan. The interpretation of the results from an LCA study can often be complicated, making it hard to be certain that one product is better than another. This is especially true for comparative LCA studies as these often have higher levels of uncertainty (Margni & Curran, 2012). However, an LCA study will still provide understanding of how various development decisions correlates with environmental impacts (Da Silva, 2012). ISO 14044 states that a life cycle interpretation aims to give the LCA expert further understanding of a LCA study. This is accomplished by: analysis of results, explainitation of limitations, giving recommendations and reaching conclusions based on the results from the study. This will in turn give a more understandable, complete, and consistent presentation of the study's results (ISO, 2006b). During the conducting of an environmental assessment the LCA expert needs to make many assumptions and compromises which in turn will lead to uncertainties within the study. The life cycle interpretation is basically a transparent way of being honest with the study's limitations (Helman, 2012). For Sandvik Mining's purposes it is argued that the validation phase is very dependent on the intended use of the results generated by their SLCAs. The initial purpose of using SLCA is to primarily use the information internally (Wester, 2013) suggests that interpretation beyond the common sense of the LCA expert is redundant at this moment. The trend of increasing customer requirements on environmental information (Rosén, 2013) can however lead to stricter interpretation practices in the future. If Sandvik Mining changes their intended use of SLCA information to external purposes e.g. claiming environmental preferability through an EPD, this suggested NPD phase should become a consistent part of the model. At this time however, the aim of this validation should be to ensure that the results generated by the environmental assessment is acceptable to the previously defined goal and scope of the study.

5.2.5 Environmental File

This suggested phase of the NPD model will be rather similar to the safety file currently in place. The main goal of the current safety file is to compile documentation of actions throughout the NPD project (Sandvik Mining, 2012a). Similarly this suggested phase, the environmental file, should consist of documentation regarding activities related to environmental efforts that has been done throughout the project. This includes; the environmental assessment plan, the results of the environmental assessment, and validation activities. The content of the safety file has in place a number of requirements depending on which market it is issued to e.g. Declaration of Conformity (Rosén, 2013). No such requirements are relevant for the environmental file as the choice to use SLCA as a method is a voluntarily effort by Sandvik Mining. GaBi allows the LCA expert to create reports directly in the software where it is possible to choose which information to extract from the environmental assessment and how this should be presented (Helman, 2013) and it is suggested that Sandvik Mining utilizes this function. The intended use of information will steer the level of content regarding validation activities. The initial internal use of information will not require large amounts of such information. If the intended use changes and is supposed to be used externally it can become necessary to include information regarding e.g. third-party verification processes.

6 Conclusions

6.1 Reflections on analysis

The analysis reaches two major findings; that SLCA can be justified by the goal and scope considerations suggested by Curran & Todd (1999) and a suggestion for how to incorporate SLCA into Sandvik Mining's new product development model.

Part of the purpose of this paper was to investigate how to incorporate SLCA into Sandvik Mining's already existing NPD model. This model is used by all product development centers that Sandvik Mining has in place over the world and provides harmonization. The SLCA model that is the result of this thesis could be argued to be valid for the whole population as long as the streamlining activities are adapted to suit each NPD project's needs. First of all the goal and scope considerations that justifies the suggested streamlining activities can look very different depending on which product development center that is considered. As the goal and scope of a SLCA study decides on its shaping (Curran, 2012) the updated NPD model will not look different due to these differences, but the content will change. The model needs to be general enough to fit the needs for all product development centers and provide the opportunity for modifying the content.

It is crucial to point out that the analysis only reflects the current situation for Sandvik Mining. Da Silva (2012) suggests a three step process for a company to incorporate of LCA into its innovation processes; **understand, improve,** and **succeed.** The analysis strengthens a perhaps already obvious fact, that Sandvik Mining is only initiating their work with LCA. It is clear that Sandvik Mining is currently located within the first step of **understanding** how to make LCA a resource efficient tool to evaluate the environmental performance of their products. At this point an LCA study can be used for an initial generation of- and simple assessment of innovation ideas. This initial incorporation of LCA into innovation allows a company to use LCA without that high requirement on reliability (Da Silva, 2012). The analysis confirms this argument as a number of streamlining activities are found and justified. However, as Sandvik Mining has a strategy to continue their incorporation of LCA into innovation it is important to realize that the analysis of this paper represents a snapshot of the current situation. In a long-term perspective Sandvik Mining aims to collect their SLCA work into a database which will allow them to create a baseline to which they can measure the sustainability improvements of new product developments in the future. This strategy will move them towards the second step of Da Silva's process. In an even longer perspective it might also become relevant for Sandvik to use their SLCA generated information for external and comparative purposes, moving them towards the third and final step of Da Silva's process. As Sandvik Mining continues their incorporation of LCA into their innovation processes this will restrict the number of streamlining activities that can be justified. But, it is also important to highlight some criticism to Da Silva's theory as it assumes that there is a market pull for this kind of information and the success lies within presenting external information rather than design changes. The intended purpose of LCA for Sandvik Mining must be to improve the EHS of the industry which is not considered to be efficient through the development of EPDs.

Curran & Todd (1999) suggest that all LCA studies can be placed at a point of a continuum where a 'full' LCA study is one end-point and a 'streamlined' LCA study is the other. Over time Sandvik Mining will move from the initial 'streamlined' LCA that is suggested from this paper's analysis towards a more complete LCA that minimizes its number of streamlining activities.

The analysis confirmed the argument of Curran & Todd (1996) that the majority of streamlining activites are closely related to the goal and scope of an LCA study. Perhaps not surprisingly, the forming of the environmental assessment in the **environmental assessment plan** and the actual process of performing this in the **environmental assessment** showed the most potential for streamlining. Again, it is important to state that the updated NPD model is a suggestion made from case study observations that were compared against a theoretical framework on SLCA and LCA. The suggested SLCA will of course be very sensitive to each NPD project's unique setings. This was shown during a presentation that the author gave to Sandvik Mining regarding the suggestion for an updated NPD model where a participant from a product development center in Finland made it clear that their ambitions of using environmental assessments would require a 'full' LCA. Their intended use of information from an environmental assessment was for external purposes. The recommendations on how to do a SLCA that is suggested from this paper's analysis assumes an internal use, however the suggested model would allow a full LCA to be done. Further, one must also state the question whether it is actually possible to improve the design of the equipment by using SLCA in the product development process. As stated earlier, data is a crucial part and the result of the SLCA will depend on the reliability of the used data.

A factor that was perhaps not given sufficient attention in the paper is time. The analysis was, as previously stated, based on the observation that Sandvik Mining is approaching the use of LCA with an interest of making this method manageable through streamlining. Streamlining activities will in the end mean less work for an LCA expert which in turn will translate into less time required to do an environmental assessment. This needs of course to be weighed against the goal and scope of the environmental assessment which still should deliver acceptable results (Sauer, 2012). Sandvik Mining needs to consider how much time that can be invested into the environmental assessment of each NPD. When their intended use of the information generated by the SLCA will become more ambitious to include more external uses this will require a less streamlined LCA study which in turn will require more time. However, there will also be a greater access to more reliable data as it has been continuously collected over time.

Curran & Todd (1999) suggest that a streamlining activity that not directly relate to the goal and scope of a LCA study lies in the usage of LCA software. The analysis identified the possibility for Sandvik Mining to use the LCA software GaBi for a few streamlining activities. For instance, some of the data that is required from the SLCA could be drawn from GaBi's databases and the actual environmental assessment (LCI, LCIA, life cycle interpretation) should be done using the software. However, the most resource intensive part of the SLCA will most likely occur during the collection of data. Furtermore, in order to work with GaBi it is necessary that this collected data is sufficient to meet the goal and scope of the SLCA study. Naturally Sandvik Mining should utilize their access to GaBi but the level of streamlining that it provides them with is rather low as it is today common practice to use LCA software for an environmental assessment (Helman, 2013).

Curran & Todd (1999) establish that all LCA studies are in fact streamlined. In the end an LCA study is an attempt to give an expression of a product environmental impact over its life cycle. The idea is not that complex but the method to arrive at its conclusion will require some simplifications of reality. LCA is like all other models never more than a model of a much more complicated reality. The analysis of this paper compared case study observations with theory on LCA and SLCA to arrive at a suggestion for a streamlined LCA study to be incorporated into Sandvik Mining's innovation process. A model that has been deliberitly simplified dervided from theory that assumes an already simplified reality, causing uncertainties worthy of discussion. SLCA is a common thing to do and there are plenty of companies that do it. In the end a SLCA is acceptable if it ensures that the outcome meet its defined goal and scope (Curran & Todd, 1999; Helman, 2013; Sauer, 2012). As established in the initial part of the analysis the current situation of Sandvik Mining will allow for the use of SLCA. In a discussion with Douglas Helman (2012) he stated that: *"Streamlining is widely used and can be an appropriate action for Sandvik Mining to concider… having some information is better than nothing… ISO allows a company to use streamlining activities as long as they are transparent about them and do not claim a 'full' LCA study if certain parts of the methology differs from their frameworks"* suggesting that Sandvik Mining can use SLCA in their innovation processes as long as they can ensure their intended results of the study. However, Helman (2012) also stated that: *"It is a very dangerous activity to initiate as it requires LCA knowledge to justify the streamlining activities… the risk is that Sandvik Mining disregards important aspects of their product's life cycles ending up with LCA results that might not be reliable…"*. This is however the perspective of an LCA expert. Again, the discussion will lie in the ever existing weighing between time and resources spent by R&D and the reliability of results that is required by the LCA expert. This paper has done this weighing and been able to identify opportunities for Sandvik Mining to use SLCA while satisfying both R&D and the LCA expert. The paper also translates these opportunities into a suggested incorporation of SLCA into Sandvik Mining's NPD model. The point remains though that the weight-relationship can look different depending on where the model is applied. Furtermore, future changes in Sandvik Mining's intended use of SLCA can also come to shift the centre of mass that this analysis has identified.

6.2 Reflections on research

Method

The choice of focusing research on a single case study was motivated from the rather specific research problem identified. The close cooperation with Sandvik Mining was initiated through Johanna Wester and the research problem used in this paper was to some extent already developed by them. Upon initial contact the research problem was then further defined and trimmed to also ensure the attention of a worthy research gap. The single case study was done mainly on-site at Sandvik Mining's offices in Sandviken, Sweden. This proved very rewarding as a single case study has its obvious strengths in attaining very specific observations in order to analyze Sandvik Mining in-depth which was possible through this rather intimate setup.However, for more in depth study and verification of the results of this thesis, it would have been userful to compare the outcome to the results of earlier LCA studies.

Furtermore, it proved useful to have close access to the Global Product EHS department's employees when discoveries within the literature review required a change of direction in the datacollection from Sandvik Mining. The opportunity to move between offices and ask questions and clarifications in person proved invaluable.

It is the author's opinion that the single case study was the most appropriate research method to ensure the arrival at a recommendation of an updated NPD model. The biggest strength of the method also proved to be its biggest weakness though. The paper was able to fulfill its purpose thanks to the observations made at Sandvik Mining. However, the rather specific nature of these observations also made it difficult to apply the findings to a company other than Sandvik Mining, and their product EHS organization. Initially it was the intention of the author to include several case studies retrieving observations from other companies working with LCA and SLCA. This method could have found common factors that could then be applied to Sandvik Mining (Lewis, Bryman & Liao Futing, 2004). However, it proved difficult both to get into contact with these companies as well as persons with knowledge about the specific topic. Additionally, it is in the author's opinion that the observations that could have been made at companies such as ABB, Vattenfall, Volvo etc would have proven hard to apply to Sandvik Mining but would have added value to the critical review of the result of the thesis.

The literature review followed a common approach. Initially more established LCA literature was reviewed e.g. ISO 14040 series filtering down to more specific litterture on e.g. EPDs and SLCA. It was found that litterature on SLCA was rather disseminated, often consisting of single research papers focusing on one particular streamlining action. The process of the literature review could have been done in a more systematic manner whereas now many resources that were studied fell out of the scope during later stages of the paper. In particular the acess to Mary Ann Curran's book; Life cycle assessment handbook - A guide for environmentally sustainable products proved extremely valuable for the research as it provided a great overview of current practices within SLCA.

The interviews conducted with experts within LCA, SLCA, and EPD gave valuable knowledge and direction to the research. In retroperspective these interviews would have been even more fulfilling if these had followed a more structured approach when conducted. The author realized at later stages of the research that the interviews could have replaced parts of the literature review and had they been transcribed and recorded more sufficiently than they were. Furtermore, the interviews did in some cases lead into continous e-mail correspondence from which the author could extract more information from.

The analysis of the case study that was used in the paper defines Sandvik Mining as the subject of study, which is analysed through the theoretical framework of LCA. The biggest strength of this approach was that it allowed the full focus that Sandvik Mining required. The greatest weakness of the method can be argued to be its qualitative nature where case study observations cannot be considered beyond a rather arbitrary approach (Thomas, 2011). An observation can either be argued to correlate with theory or not correlate with theory. This makes it very difficault to consider the identified streamlining activities in terms of one being more easily justifiable than another. Graedel (1998) has published an article that compares the reliability between an SLCA- and a 'full' LCA study using the same product system to compare the differences of the results given by the two environmental assessment methods. A similar approach would have been useful for this research as it could have provided an analysis with results expressed more exact in terms of their reliability. However, this approach would require that a SLCA- and a LCA is done on at least one NPD project which today has not happened. For the purposes of this paper the analysis was sufficient.

Theory

The theory that forms part of the framework of this paper consists of four major components; life cycle assessment, streamlined life cycle assessment, environmental product declarations, and life cycle assessment in product innovation.

Da Silva (2012) presents an up-to-date view on how a company can incorporate innovation into its innovation processes. This was seen as an optimal fit to the stated research problem and provided a good starting point for the theoretical framework. Da Silva's suggested process aims to provide guidance for a company and does not cover all aspects of LCA in innovation. This is clearly a weakness of the theory and it was therefore decided to not rely too heavily on it in the analysis of the paper. Da Silva's theory seems to assume that a company always experience a market pull for high environmental performance. The initial phases of the suggested innovation model was deemed as relevant for Sandvik Mining with strong correlations of the initial actions a company can take when incorporating LCA. The initial phases included various streamlining activities. Later phases had a clear focus on using LCA as a marketing tool which cannot be seen as relevant for Sandvik Mining at this time. These limitations of Da Silva's theory made it necessary to exclude parts deemed as unrelevant for the paper. Still, the three major steps of the LCA incorporation; understand, improve, succeed were however useful for the research as it reflected Sandvik Mining's situation well. An alternative approach to the incorporation of LCA into product innovation is suggested by Ulrich & Eppinger (2011) which argue that a company should use design for environment (DfE) strategies to achieve environmental sustainability. They suggest a model for a company to incorporate into their standardnized product development process, similar to what Da Silva does. However, Ulrich & Eppinger (2011) extends the use of LCA in their model and gives, what the author feels is a, more complete model. An alternative would therefore have been to instead use this model as the starting point of the theoretical framework.

EPD was relevant for the purpose of the paper. It is classified by the ISO 14025 framework as a Type III environmental claim. It was shown that Sandvik Mining's current use of the SLCA information is not aimed towards external purposes or for comparative claims. Therefore this theory did not determine the outcome of the analysis but can become relevant in the future. During the research an interesting alternative theory was discovered called stepwise EPD that allows a company to develop a simplified EPD using a SLCA with the requirement to strengthen this with a 'full' LCA at a later stage to receive also a 'full' EPD (Thornéus, 2012). This theory was disregarded due to the lack of relevancy to Sandvik Mining's situation.

The main part of the theoretical framework is focused on LCA theory and the underlying SLCA theory. The LCA theory was mainly derived from the ISO 14040 series as these are seen as the most accepted methodology both by academia and industry. It was necessary to establish a solid base of LCA theory prior to deciding on SLCA theory. Consulting the ISO 14040 series it became evident that the framework was far too encompassing to fully be used as a theoretical framework. Instead the author included the content necessary to provide the background for the included theory on SLCA. A question that reappeared throughout the research was; **how much can a company steamline a LCA study without endangering its results?** A number of streamlining activities are suggested by the paper's SLCA theory but few references can provide any understanding in how much liability these will present to the company that use them. There is no single right answer here and instead it seems necessary to accept Curran & Todd's (1999) argument that: *"all LCAs are streamlined to varying degrees… streamlining is an inherent part of any LCA. The key is to link the streamlining activities closely with the goal and scope definition process."*. Baitz et al. (2012) argues the development of LCA has changed over time from over last 20 years being a theoretical concept that industry could learn from and apply to its practices and now experiencing a vice versa situation. It is clear that LCA and SLCA will require knowledge and experience from a company such as Sandvik Mining. As these factors increase it will be easier to identify and justify streamlining within their LCA studies. The key is for Sandvik Mining to find a balance between theory and practice in every environmental assessment of every NPD project. The suggested NPD model will accomplish this by carefully defining the goal and scope of each SLCA study in relation to the time and resources that are acceptable.

6.3 Revisiting the research question

The purpose of this paper was to understand how Streamlined Life Cycle Assessment (SLCA) can be used by a global manufacturing company as an environmental tool. The paper also assessed the concept of SLCA to understand how an LCA study can be simplified and still provide results that are acceptable to the LCA expert. It was also the purpose of the paper to understand how LCA can be incorporated into a global manufacturing company's existing product development model.

The paper found that SLCA can be justified to be used by Sandvik Mining. The observations made at Sandvik Mining were analyzed against a theoretical framework to assess the streamlining potential as suggested by Curran & Todd (1999). A number of considerations relating to the goal and scope of a SLCA were applied to Sandvik Mining's current situation which showed that there is opportunity for streamlining activities within the company. The paper also suggested how Sandvik Mining should incorporate SLCA into its new product development through further analysis; weighing case study observations of Sandvik Mining against the theoretical framework of the paper. The analysis showed how Sandvik Mining can justify this streamlining and still ensure results acceptable to the goal and scope of their environmental assessments. The recommendations that came from the analysis remain very specific for this certain case of Sandvik Mining. It will be difficult for other organizations to adopt the findings of this paper directly into their operations. Even for Sandvik Mining the findings of this paper must be treated carefully due to internal differences in LCA and SLCA requirements. Even so, the paper was able to answer its research question with findings that satisfy its intended audience.

6.4 Recommended and future research

The path that has been the process of writing this thesis has been far from straightforward. This has left the author with a certain degree of curiosity regarding what could have been the outcome of the thesis if this path would have looked different to the one travelled. Perhaps the biggest headscratcher was to ensure that the findings of the thesis could have become the subject of more generalizability in the end. The findings of this thesis are very narrowly defined and it has been found that a number of factors can complicate their adoption even within Sandvik Mining. This will make it very difficult, if not impossible, to generalize the findings on another company than Sandvik Mining. It would therefore be interesting to continue this strain of research to instead give focus on a number of companies that are using LCA, and in particular SLCA, in their product innovation. The case studies would allow the research to identify common facilitating factors and barriers within the selected companies that could help to explain their success of using SLCA. Furtermore, the design for environment strategy as suggested by Ulrich & Eppinger (2011) would serve as an interesting lens through which to study sustainable innovation.

As one of the outcomes of this paper is a suggestion on how Sandvik Mining should incorporate SLCA into its innovation model (NPD). The feedback given from Sandvik Mining has been positive and there seems to be motivation to utilize the findings of this paper within the organization. It would be interesting to conduct continual research in order to understand how well the suggested NPD model would work at Sandvik Mining. As Sandvik Mining initiates their work of documenting their streamlined environmental assessments it could be very interesting to compare one of these against an environmental assessment done on the same product, but without the suggested streamlining activitites. Previous research from Huebschmann et al. (2011) accomplished this by comparing a LCA study against a SLCA study finding that the streamlining activities that were done in that case did not change the conclusions of the results. If this research method could be imitated on Sandvik Mining it could be possible to understand if the suggested SLCA provides reliable results.

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