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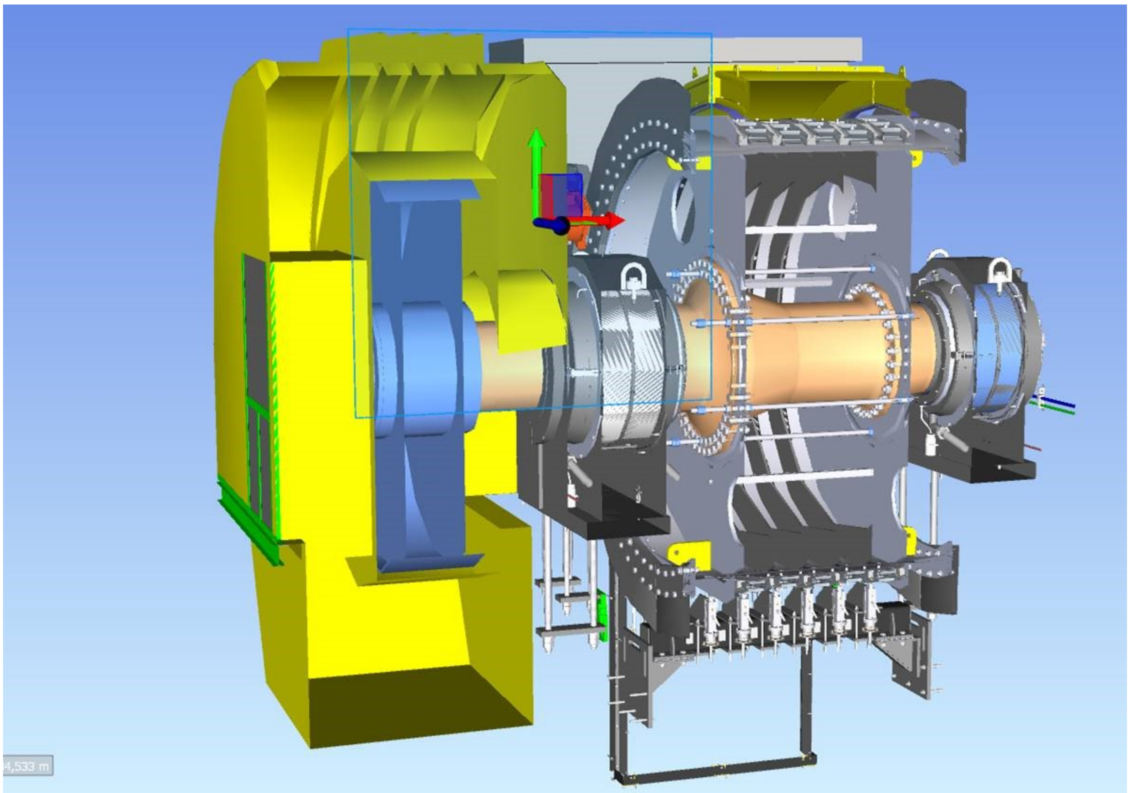

A Life Cycle Assessment of ABB Process Industries' mine hoist system

Master's thesis in Industrial Ecology

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DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
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Report No. E2021:126

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Cover: Computer aided visualization of the mine hoist system. Reproduced by permission from ABB

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Abstract

An extensive shift in how materials are being produced, used, and disposed of, and measures in how to use effectively and efficiently, is needed to handle future environmental challenges and comply with the Paris Agreement. This study investigates the environmental impacts of ABB Process Industries' mine hoist system by conducting an attributional LCA on a recently installed system currently used by LKAB in Kiruna. Mine hoist systems are industrial lifts used in underground mines for transporting mining ore, equipment, and humans. The information for the assessment is gathered from interviews and contacts with personnel at ABB and LKAB. The LCA-software openLCA is used in combination with the database Ecoinvent v.3.7.

Within the investigated mine hoist system, assumed to be used for 25 years in Kiruna in northern Sweden, the LCA results showed that the use phase was the most contributing life cycle phase. The electricity consumption over the life cycle showed the most contributing activity within all investigated environmental impact categories and contributed 72% of the climate change impact. The sensitivity analysis led to the understanding of critical aspects and how to proceed. Differences in electricity mix showed that it is possible to save up to 266 kilotonnes of CO2eq over the lifetime. Materials used in various applications for yearly maintenance over the entire lifetime showed a significant contribution. Each year, close to 30 tonnes of materials are replaced as maintenance materials, and over 25 years, more than one kilotonne of materials are used. A circular perspective and life cycle thinking, framed around waste and resource management with measures to use materials more effectively and efficiently and measures to extend the usage, could reduce the material flows with significant environmental savings.

The study helps ABB Process industries to understand the environmental impacts of their operations and provides suggestions for how to proceed in their environmental work. The results of this study, emphasizing the environmental impacts associated with energy consumption and material usage throughout the lifetime, shows how ABB could reduce the environmental impact associated with products offered by the hoist division. Other impacts that ABB and LKAB initially believed had more significant importance, such as transportations, end of life treatment, and lubrication oils usage showed little importance. The study found that ensuring that the energy comes from clean sources and further measures to reduce the material use, especially maintenance materials, are the two key takeaways and should be prioritized in order to reduce environmental impacts.

Keywords: Life Cycle Assessment, LCA, Circular economy, Sustainability, Elevator, Lift, Mining.

Acknowledgements

This master's thesis was written during the spring of 2021 at Chalmers University of Technology, the last assignment of a five-year engineering education leading to a master's degree in the field of Industrial Ecology. The thesis work has been carried out in cooperation with ABB Process Industries with the help of LKAB.

We want to express our gratitude to our supervisor and examiner at Chalmers University of Technology, Maria Ljunggren, for the proposal idea leading to this thesis and her assistance and guidance throughout the research project. We would further like to thank everyone at ABB and LKAB for making it possible to perform this thesis, especially Torbjörn Rohlin, Per Leine and Peter Ylivainio with all the time you have spent.

Our acknowledgements also goes to all remaining people at Chalmers, ABB and LKAB who have contributed with information and advices during the spring. Last but not least, we would also like to direct a thanks to ABB Process Industries for giving us the opportunity and believing in us to conduct this master's thesis.

Axel Hjelm, Fredrik Ström, Gothenburg, June 2021

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Abbreviations

GWP	Global warming potential
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LCI	Life cycle inventory
EPD	Environmental product declaration
EoL	End of life
AC	Alternating current
DC	Direct current
EAF	Electric arc furnace
MSWI	Municipal solid waste incinerator

1 Introduction

On behalf of ABB and their business area Process Industries, the students have been asked to study their division on mine hoist systems. Although earlier minor environmental assessments have been performed by Process Industries, they want more help with a more thorough assessment of their products' environmental impact.

Mine hoist systems are industrial lifts used in underground mines for transporting mining ore, equipment, and humans. They consist of mechanical and electrical components, which have been divided into seven different subcategories. The electrical components, including the motors, control and electrical system, are purchased from other ABB business areas and are not designed by Process Industries. However, the mechanical components such as hoist drums and skips are designed, produced, and handled by Process Industries Hoisting. They deliver products and solutions to customers worldwide. The products used in the final systems are purchased from other ABB divisions or subcontractors, where the majority are located in Europe.

Given how each project and process differ, all mine hoist systems are individually designed to suit their customers' needs. As a basis for comparison for the environmental assessment, a specific project with a recently renewed mine hoist system with available use data will be assessed. A specific system, the mine hoist system B2, one of 13 mine hoists used in LKAB:s mine in Kiruna, Sweden, has been decided to be the basis for this study.

ABBs' ambition is to gain more insight into how they can decrease the environmental impact of their systems while at the same time obtain an overall picture of the impacts of their products from cradle-to-grave. The energy consumption and the materials used are known to stand for a considerable part of the hoist systems' environmental impact. In mass, steel is the most used material, highly energy demanding to produce but long-lasting. ABB are interested in dimensioning and designing their products to last longer and become more efficient over time. However, this is a trade-off between material and durability, and ABB wants to learn more about the environmental impacts of different design choices. Furthermore, given how ABB historically has not been involved with end-of-life solutions for their products, they are also interested in investigating different strategies for re-circulating the materials after usage.

An additional reason for performing the study is the absence of research on equipment used in raw material extraction and the mining industry. The environmental impact of raw material extraction is an area in which there is much interest, including research. Further knowledge of the equipment used in the mining industry, such as hoist systems, could add more insight into the the environmental impact of the different parts of raw material extraction.

1.1 Aim

This thesis work aims to assess the environmental impact of ABB Process Industries mine hoist systems assumed to be used for 25 years and to create extended knowledge and understanding. This is achieved by conducting an attributional LCA on a recently renewed system currently used by LKAB in Kiruna. Considering ABBs interest in further understanding the environmental impact of their products, this thesis, with the results from the LCA, will provide ABB with improvement areas and suggestions of how their products could be designed, produced, used, and handled differently.

1.2 Limitations

The geographical boundary of the study consists of the manufacturing facilities for the production of components and the operating area of the system, Kiruna in northern Sweden. General data for transportation emissions will be used with European averages. The analysis is within the time horizon of the system's lifetime, assuming to last for the following 25 years. Improvement areas of motor design and changes will not play a significant part in the report. The suggestions for improvements within the areas of most environmental impact will not be of great technological detail. Smaller components with a weight below 0.5 kilograms and the usage of forklifts, cranes, and tools within the system's assembly, maintenance, and dismantling stages have been excluded from the inventory. Impacts from the mine not explicitly related to the mine hoist system are not considered in this study. Instead, the study focuses on identifying the most urgent areas of improvement and where their products have the most impact along the lifecycle.

1.3 Research questions

This thesis includes an attributional LCA, describing and mapping the impacts and physical flows from the mine hoist system, which will be used as the basis for further recommendations of how ABB could design their mine hoist products and strategies to reduce the environmental impact. Relevant theories will also be applied to answer how ABB strategically and technically could apply the recommendations provided by this report. The main objective is to analyze the environmental performance of the mine hoist system, and the research questions to be answered are the following:

- What is the environmental impact of an ABB mine hoist system cradle-to-grave?
- What are the environmental hotspots?
- How could ABB reduce the environmental impacts of mine hoist systems, especially considering circular economy opportunities?

With these research questions, answered primarily by drawing conclusions from the LCA, ABB's ambition to further understand the environmental impacts of their operations to further proceed in their environmental work could be obtained.

2
Literature review

2.1 Earlier studies

Although no earlier studies have been made on the environmental impacts of mine hoist systems, several studies have been found and read on ordinary residential elevators, similar in functions to mine hoist systems, the transportation of mass vertically. The Swedish firm Miljögiraff (2015) conducted and published a life cycle assessment for the elevator company Hydroware AB in 2015. The purpose of the study was to compare conventional traction elevators with hydraulic elevators. Whereas less energy is used to power traction elevators with their heavy counterweights, the results of the LCA showed that more energy is used to manufacture a cable lift counterweight than is required to run a hydraulic lift for 25 years. Including all factors, the hydraulic lifts showed to be environmentally preferable over traction elevators. The functional unit in the study, the reference flow to which all other flows are modeled and related to, was "elevation service in a building with four floors with in average 7,5% of the nominal rated load in 80 years".

Furthermore, a bachelor thesis work evaluating residential elevators for Vinga Hiss AB (Selander, 2016) and a Finnish study evaluating residential elevators for KONE Corporation by Salmelin, Vatanen, and Tonteri (2002) have been used for inspiration and methodological choices. The functional unit by Selander was "elevator transportation for 25 years", and by Salmelin, Vatanen and Tonteri the functional unit was "a distance of 1 km traveled by elevator". Selander's purpose was to evaluate potential environmental benefits with modernization versus new installation of elevators, with the results that modernization showed significant environmental benefits. The purpose of the study by Salmelin, Vatanen, and Tonteri was to identify the environmental characteristics of elevators and provide basic information for environmental product declaration and support for further building LCAs. Their results showed that most of the environmental impacts occurred during the use phase, where approximately 80% of the CO_2 emissions were generated during the use stage, assuming Belgian electricity mix. The results from Miljögriaffs study with the Swedish electricity mix stated that the usage phase for the hydraulic elevator accounted for more than half (58%) of the total environmental burden and further raises the issue of how the elevators are being used. Whereas the standby-mode stood for 68% of the total energy used, both the energy consumption when the elevators were driven and the energy, when they are in standby, is relevant to look at.

Although the purpose of these studies has somewhat differed, several relevant issues and questions have been raised for the study on the mine hoist system. Regarding the functional unit, all of the studies mention transportation, the primary function of an elevator. It is mentioned as "transportation", "elevation service with four floors" or "a distance of 1 km traveled". Miljögiraff (2015) and Selander (2016) also mentions the temporal aspect, in terms of 80 and 25 years, and although specifically not mentioned in the study by Salmelin, Vatanen, and Tonteri (2002), the results are also calculated for 25 years, with a frequency of 150 000 travels per year, with an average traveling height of 9 meters. Miljögiraff (2015) is the only study that includes the weight in the functional unit. In contrast, the others have considered this as a fixed variable and that the consumption within the use-phase uses average data. Another issue raised in the studies is the difference in the energy consumption for elevators in the use phase, with the difference in consumption for standby and transportation mentioned by both Miljögiraff (2015) and Selander (2016). Given the high environmental burden from usage provided by all studies, the electricity mix plays a significant role, as explained in the sensitivity analysis on different energy mixes by Miljögiraff (2015) and Salmelin Vatanen and Tonteri (2002).

A similar master thesis was also written in cooperation with ABB, which studied the environmental impacts of an ABB synchronous medium-voltage motor and drive system during their life cycle (Westberg, 2021). Although the study focused solely on the motor and drive system and not the surrounding equipment, it provided insight into the use phase's contribution. The study results were that the use phase of the motor and drive was the most significant contributor, with almost 99 % of total climate impact.

2.2 Circular economy

The concept of circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems (Ellen Macarthur Foundation, n.d.). It is framed around waste and resource management and tries to find new ways to prevent the current linear "take-make-dispose" practice, by, among others, promoting the notion of waste and resource cycling (Blosma and Brennan, 2017).

The concept is highly related to the concepts of life cycle assessments and life cycle thinking. The notion of circular economy and the idea of a more resource-efficient economy align with the LCA framework of studying products and processes from cradle-to-grave. Life cycle assessment is an efficient tool for promoting a circular economy, where it could identify and evaluate the environmental impacts from various impact categories throughout the lifetime. The systems perspective on materials resources in the circular economy encourages companies to evaluate their operations and their supply chains, think about how they extract, produce and use materials, how they could be more efficient, and where the need for raw materials can be designed out of the business model altogether (Benton et al., 2014). These strategies create further knowledge and control of the supply chains, reduce the exposure of resource risks, avoid reputational threats, and eliminate waste.

Böckin et al. (2020) have developed a life cycle-based typology for resource efficiency measures and guidance towards a circular economy. As shown in figure 2.1, the typology shows how circular measures for a product can be undertaken in various life cycle phases, from cradle to grave. With reduced material and energy usage in the extraction and production phase, more efficient and effective usage of products, extended usage within the use phase, and better recovery of the material after usage, resource efficiency, and circularity are improved, with reduced environmental impact.

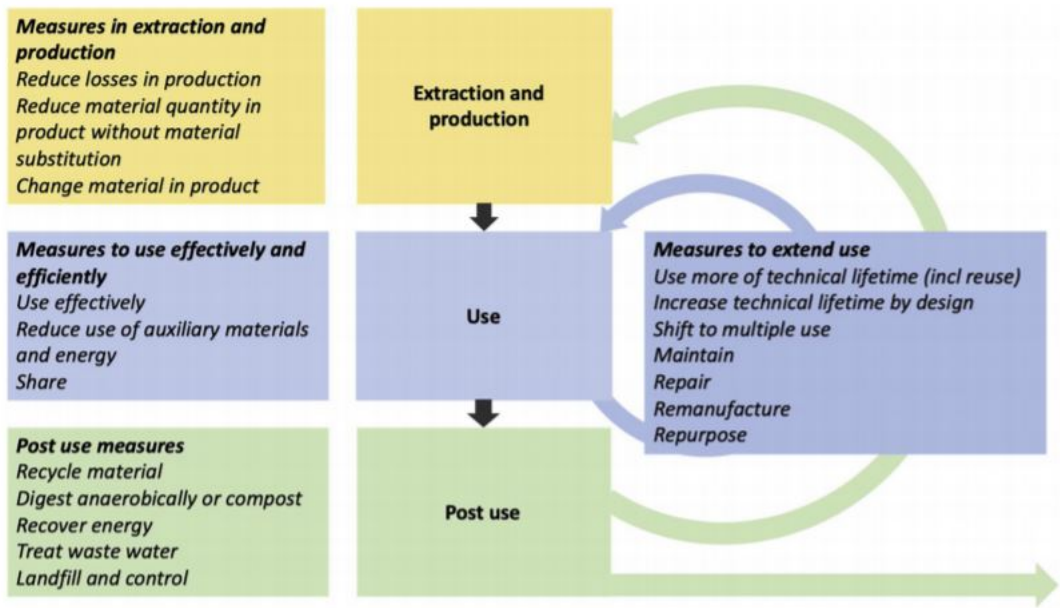

Figure 2.1: Life-cycle based typology of physical RE measures. (Böckin et al., 2020). Reproduced according to CC BY 4.0

The concept of circular economy has also in recent years gotten more political attention. The European Commission launched its first Circular Economy Action Plan in 2015, with a new and updated version published in 2020 with proposed policies and key focus areas. In Sweden, the government recently published its first Action Plan for how Sweden should transition to a circular economy (Government offices of Sweden, 2021). The action plan contains approximately a hundred measures in areas such as industrial conversion, material supply, technology development, and waste management. Through the decision, the government lays the foundation for a long-term and sustainable transformation of society through presenting current policy instruments and measures that the government has decided or intends to decide. The action plan presents current policy instruments and measures that the government has decided or intends to decide. Some measures describe key ongoing processes within the EU or globally where Sweden pursues or intends to pursue, certain issues of interest in the transition to a circular economy.

The Swedish consultancy firm Material Economics has published several reports on how a circular economy could play a significant role in the Nordic region's environmental challenges. The report" Circular Nordics" from 2019 explains how a circular economy could reduce emissions from material production and consumption through material recirculation, product material efficiency, and circular business models (see Figure 2.2). They conclude that the circular economy can reduce Nordic territorial emissions by 10-20 million tonnes CO_2eq. and states that the implementation is critical for reaching the Paris Agreement. On a larger scale, also including imported goods, this concept has the ability to face a series of environmental challenges.

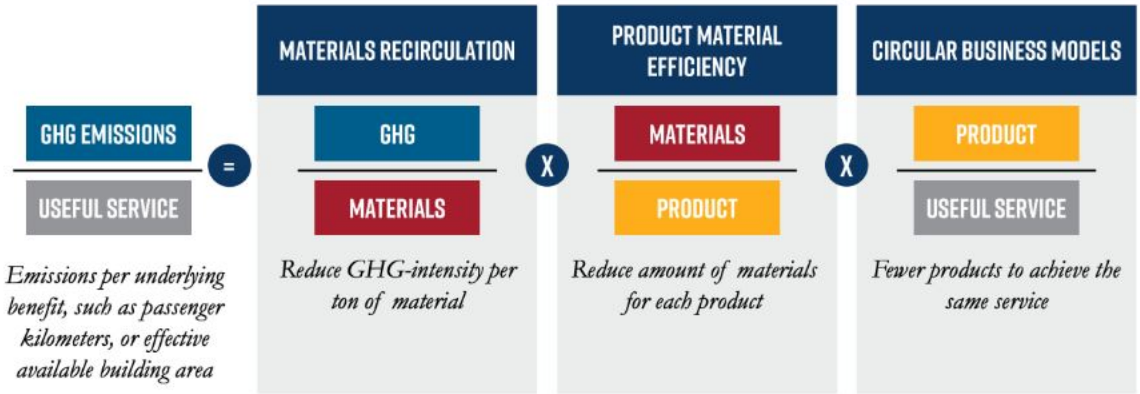

Figure 2.2: Circular Economy reduces emissions from material production and consumption. Reproduced by permission from Material Economics (2019)

In another report from Material Economics," Retaining value in the Swedish materials system" from 2018, regarding the circular economy and its role for the Swedish industry, they explain how the circular economy concept could help retain economic value in the Swedish materials system. Their results show how every year, 55 billion SEK worth of materials reach end of use in the Swedish economy, most of which could be recycled and made into new, secondary materials. Their findings further show how significantly increasing the proportion of material value preserved, 11 billion SEK worth of material could be recovered each year, just for the value chains of steel, plastics, and aluminum. More circular material systems are also central to achieving climate goals. With the current uses of steel, aluminum, and plastic, the carbon emissions in 2040 will rise to 13 Mt CO2, which is more than 20% of Sweden's total emissions in 2015. In a circular scenario, this could decrease to 9 Mt, a reduction of 30%.

Overall, the literature review for earlier studies shows that the use phase is the most contributing lifecycle phase for residential elevators and the synchronous medium-voltage motor. The majority of the total environmental burden arises from the electricity used during usage. The review of the circular economy guides how to reduce the environmental impact in various ways throughout the different life cycle phases. From cradle to grave, various measures are provided regarding how to reduce the environmental impact, helpful when providing ABB recommendations of how they could design their mine hoist products, and strategies to reduce the environmental impact.

3
Technical description of the mine hoist system

Understanding the system and every part of the ore elevating process is fundamental to perform the LCA. The most important is to understand the function of the system, which is to transport ore from the mining level up to ground level, a total of 802 meters vertically. From the function of the system, a functional unit can be decided.

The system is a so-called friction hoist, ropes connected between two transporting skips and not fixed to the hoist. As seen in figure 3.1, the ropes are hanging on the upper part of the pulley. Through friction, the torque from the motor is then transporting the ore upwards. The skips are traveling in the opposite direction, so when one skip is filled with ore and traveling upwards, the other skip is empty and traveling downwards. Because of the size of the system, different components have been divided into subcategories in order to simplify and furthermore have the opportunity to allocate and account for the subsystems in later discussions and analyses. This information that is presented in this chapter is mainly gathered from interviews and email contacts from relevant personnel on ABB and LKAB.

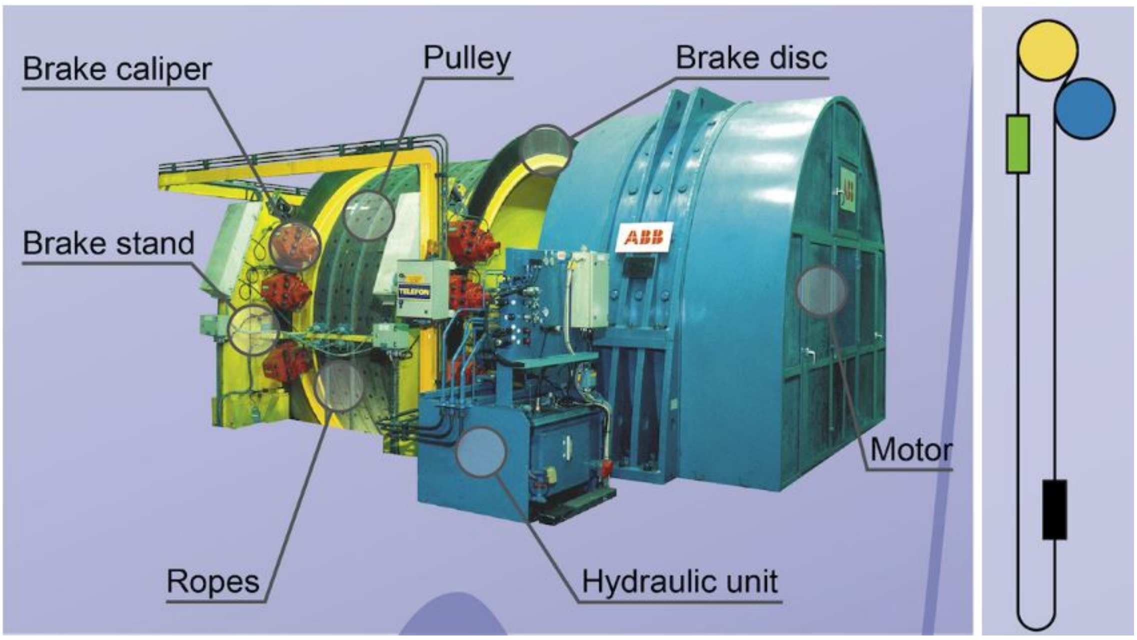

Figure 3.1: A friction hoist machinery. Reproduced by permission from ABB

3.1 Loading/dumping equipment

This subsystem accounts for the measuring pocket, including weight modules, the hydraulic units for the loading and dumping, as well as the motors provided to support these.

The measuring pocket is the largest component in this system. It is a large steel container placed on weight measuring pads, which directs, weights and measures the right amount of ore and furthermore fills the skips. This is to optimize the process so that the skips are not overloaded or underloaded.

After the ore is dumped into the measuring pockets, it fills the skip through the bottom of the measuring pocket container with the help of hydraulics and its associated hydraulic unit. In the measuring pocket, sliding plates protect the measuring pocket from the ore, called skid plates. These plates are frequently worn down and therefore interchangeable. The weight modules are six smaller cells, each with a rated load of 500 kN, placed in a triangular shape to evenly distribute the load.

The hydraulic units are systems both on the upper and lower level. On the lower level, it opens the hatches of the measuring pockets and allows for the ore to be loaded into the skips. On the ground level, it operates similarly when opening the hatches of the skips allowing it to be dumped. All in all, there are five different hydraulic units in the entire system of witch 3 included in the loading/dumping equipment. One that distributes the ore in the measuring pocket, one connected to the measuring pocket that is opening a hatch on the measuring pocket so that ore falls into the skips, one to open a hatch on the skip so that the skip gets emptied.
When the skip is transported to its highest position, the hydraulic-powered contraption with the associated hydraulic unit opens the hatches at the bottom of the skip so that the ore is emptied and removed. These hydraulic units are provided with motors that pressurizes the oil. There are 6 different motor pumps, three on the lower level and three on the upper level. Also, one small motor for cooling the hydraulic unit for the dumping is included in the system.

Figure 3.2: Parts of the measuring pocket. Reproduced by permission from ABB

Figure 3.3: Parts of the measuring pocket. Reproduced by permission from ABB

3.2 Shaft equipment

This subsystem accounts for the skips, the sheave, the skip guiding equipment, and the guide rope weights including rope attachments. The main ropes, both the upper, which carries the load, and the lower that operates as a counterbalance, and the guide ropes are accounted for as maintenance material and further explained in chapter 3.7.

The two skips, traveling in the opposite direction of each other, are the containers that hold the ore while it is vertically transported via ropes. They are designed according to the narrow shape of the shaft and are thus elongated in shape to accommodate larger amounts without taking up much space. Each skip can transport 24 tonnes with each lift, and the size of it could be seen in figure 3.2.

Figure 3.4: The skip. Reproduced by permission from ABB

Connected with the skips are the main ropes (also referred to as upper ropes). These are the ropes the skips are hanging from, running around the pulley (also known as hoist drum). Between the ropes, there is a rope attachment equalizing the tension through hydraulics so that all ropes carry the same weight. There is also a component holding on to the ropes called rope locks, allowing the ropes to rotate called rope swivel. These are installed so that there will not be excessive rotational tension in the ropes.

The second set of ropes is the balancing ropes/under ropes that equalize the force on both sides of the pulley. Because of the weight of the ropes, this matter. Otherwise, the excessive force on the hoist drum would vary depending on where the skips are in the shaft. The third set of ropes are the guide ropes. They have the function of reducing the pendulum of the skips and reducing the movement of the skips in the horizontal plane. With skips traveling in the opposite direction and a narrow shaft, there is posing a risk of collision. Therefore the guiding ropes hang from the top of the shaft down beneath the lowest point of the shaft. At the bottom, big weights are mounted to put tension on the ropes. Also, guide rope runners are mounted on the skips to hold the guiding ropes, and there are a variety of different parts named skip guiding equipment that secure the skips when loading and unloading their load.

Also, although not included in all mine hoist systems, this particular mine hoist is mounted with a deflection sheave, seen as the blue wheel in the top right corner in figure 3.1. This deflection sheave is mounted to narrow the ropes and allows the pulley not to be placed directly over the shaft.

3.3 Hoist equipment

This subsystem accounts for the power transmission from the electrical motor to the ropes. In this subsystem, the motor shaft, the pulley (also known as the hoist drum), the bearings including sleeves and housing, hydraulic units and motors for lubrication, and the foundations for the hoist equipment.

The main component of this system is the pulley which the ropes are placed around. The pulley is 3.25 meters in diameter and has interchangeable friction inlays between the ropes and the pulley to increase the friction, durability, and ability for maintenance. The inlays are further mentioned in chapter 3.7. These friction inlays are turned with a specific tool, which removes the outer material and provides fresh grooves for a continued coefficient of friction, and also so that the hoist is even and balanced. Once the material has been turned and worn away, they are finally exchanged, and new inlays are mounted.

A motor axis directly transmits the motor's torque through the pulley, referred to as the motor shaft (see figure 3.3). This axis must be placed with roller bearings on each side of the pulley to eliminate rolling friction for the pulley and handle the vertical force that the weight of the components connected to the ropes are causing. To eliminate the play between the axis and the inner ring of the bearing, the bearing is mounted on conical adapter sleeves. The roller bearings are placed inside bearing houses that transmit this vertical force into the foundations.
The foundation details are the components that secure the bearing houses, brakes, and motor to the floor. These are metal plates under the concrete floor and bolts that go through the "floor" to attach the components above.

Figure 3.5: Motor shaft. Reproduced by permission from ABB

3.4 Brake system

This subsystem accounts for the brake system, designed to slow and halt the motion of the hoist drum. In this subsystem, brake stands, brake calipers, hydraulic blocks and units, and smaller electric motors for the various systems, and additional cooling are included.

The brake system is crucial to the safety of the system because it is the only thing that can break the momentum of the skips. When loading and unloading the iron ore from the skips, the balance between the skips is changing, and the brakes are preventing the pulley from rotating and therefore preventing the skips from moving vertically.

The brake system works by having 12 brake calipers connected to four brake stands that make them stationary (see figure 3.4). They are mounted around the brake discs that are attached directly to the pulley. Inside, springs are pushing on brake pads, pressuring the brake disc (that is attached to the pulley), which force causes the braking force through friction. To release the brakes, a hydraulic piston compresses the springs and therefore loosens the pressure between the disc and the brake pad. The hydraulic system requires one hydraulic unit, two hydraulic unit motors, and pumps, two cooling motors, and two hydraulic blocks that divide the hydraulic fluid to the brake calipers.

Figure 3.6: Brake stand with associated brake calipers. Reproduced by permission from ABB

3.5 Control and electrical equipment

This subsystem accounts for the main electrical components throughout the system, which distributes the currents and transforms and alters the currents to match the application's requirements. In this subsystem, the transformer, the low voltage switchgear, electric cabinets, frequency converters, the smaller electrical motors, and all electric cables are included.

The electrical equipment in the hoist system is composed of several components. There are 64 electrical cabinets with various components, frequency converters controlling the smaller motors in the system, two identical transformers that alter the voltage to the electrical components, and kilometers of wiring needed to send signals or provide the components with electrical power and switchgears. There is also a control desk where the operators can monitor and control the system from. However, the desk is used by several mine hoists in the facility and is therefore considered outside the scope of this study.

All electronics current throughout the system, except the main motor, are low voltage with alternating current (AC). What provides this current is the transformer that lowers the voltage from high current to the voltage used. That current is fed into the different applications. Switchgears are an essential technology for safe energy distribution and motor control. Their function is to distribute the electric currents and to control the electric system. In other words, it could be explained as a distribution center for the electronics currents. It also provides a safety aspect to which can be compared to a fuse, where for each input and output line, the switchgear has a switch or sometimes disconnector, which could close or open the electric current.

The low voltage switchgear included in this system is a bundle of components that control the demanding electrical components such as electrical motors and heating elements. It controls it by either providing the electricity or cutting it off. The electrical cabinets have somewhat the same function but are not handling the same currents as the switchgear is doing. The frequency converters are connected to one electrical motor each and control that motor's speed and power output. There are 18 different smaller motors in the entire system with various purposes and sizes. The smallest with a power output of 170 watts and the biggest with 37 kilowatts. These provide power for various cooling and hydraulic applications.

3.6 Drive system

This subsystem accounts for the drive system and the power supply for the hoist system. Which includes the main motor, the industrial DC drive, one transformer, and protective fencing.

The main motor is a DC motor of 4300 kW, bolted onto the shaft as mentioned in chapter 3.3. The main motor has been in usage since the 70s, where the magnetic rotor and steel housing of the motor is still in usage after 50 years. It has been maintained with services throughout the years and a rather extensive renovation in the 90s. The motor, with a rated speed of 100 rpm, does not have internal bearings and instead is supported by the bearings of the hoist. What is interchanged is the copper linings, which recently were exchanged with the recent construction.

The motor is feed power from a transformer used to alter the voltage to the motor's optimal. To control the motor, an industrial DC drive is needed, used to supply and control the power. The amount of current used causes heat in the motor, which is handled by fans with two motors that are blowing air through the motor. Within this subsystem, a small amount of protective fencing surrounding the motor is also included.

3.7 Maintenance

This subsystem accounts for the amount of material exchanged, refilled, and added throughout the lifetime of the use phase. Whereas the mechanical and electrical components installed are used for the entire lifetime, other components have a shorter lifetime and are replaced at various intervals. In this subsystem, the different types of ropes, guide rope equipment, lubricating oil, friction inlays, brake pads, air filters, and skid plates. Also, although not exchanged throughout the lifetime, the corrosion protective compound and the turning tool for the friction inlays are included in this subsystem.

The air quality is vital for the main motor, so the air is pushed through a “wall” of filters to remove any unwanted particles. These filters are also consumables and are replaced when needed. The ropes are changed due to wear, where the weight-bearing main ropes are the most replaced ones. The corrosion preventive compound, more specifically powder coating, is used for protecting the different metals. The oil in the hydraulic units is changed or refilled due to the fluids getting degraded and contaminated. These items, with new sliding plates and friction inlays, are exchanged at various intervals by LKAB.

3.8 Lifetime of system

The system under study has been assumed to be in usage for 25 years. This assumption is based on initial interviews with ABB personnel, where they stated how the mechanical and electrical components used in the system are designed to last for 25 years. Given how the system was recently renewed between 2019 and 2020, and previous similar modernizations have lasted for approximately 25 years, this was considered suitable as chosen lifetime of the system. Also, considering how both Miljögiraff (2015) and Selander (2016) used similar assumptions with the service life of 20 years and 25 years of lifetime, the chosen lifetime seems reasonable.

However, some components deviate from the mentioned lifetime. As mentioned in chapter 3.6, the main motor has been in usage since the 70s, where the magnetic rotor and steel housing of the motor is still in usage. It has been maintained with services throughout the years and a rather extensive renovation in the 90s, approximately 25 years before the recent modernization. Therefore, its remaining service life is assumed to be similar to the lifetime of the remaining mine hoist system, 25 years.

For this life cycle assessment, the motor is assumed to be disposed of after this use cycle and has been used for 75 years in total. Hence, the total weight of the motor is divided by three, where one-third is allocated to this usage in the impact assessment. Also, as mentioned in chapter 3.7, the maintenance materials need to be changed because of physical wear and therefore have a shorter lifetime and are replaced at various intervals. These components have different lifetimes and are expressed as kilogram products per year in Table 5.6 in the inventory analysis.

4

Methods

4.1 Life Cycle Assessment Framework

The methodology of life cycle assessment (LCA) is a framework for analyzing and understanding the environmental impact of products and services throughout their lifetimes. The entire industrial system involved in the production, usage, and end of life management, including all raw materials used to manufacture a product, all transport, energy usage, and waste management, with all accounted emissions are followed from “cradle”, the extraction of raw materials to its “grave”, the disposal. There are two different common approaches of life cycle assessments, accounting LCAs (aLCA), and consequential or change-oriented LCAs (cLCA). (Baumann and Tillman, 2004).

Whereas both aLCA and cLCA are used for different types of comparison, there are differences in methodology between the two. The goal of aLCAs is to answer questions such as “what is the environmental impact associated with this product?”, whereas cLCAs answer questions such as “what will be the environmental consequences of a certain action?”, or “what would happen if. . . ?”. In other words, attributional LCAs strive for completeness, while the consequential LCAs compare the consequences of alternative courses of action through modeling the effect of change (Baumann and Tillman, 2004).

LCA is a standardized framework according to the International Organization for Standardization with the standard ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework. According to the ISO-standard (2006), LCA can assist in:

- Identifying opportunities to improve the environmental performance of products at various points in their life cycle,
- Informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign),
- The selection of relevant indicators of environmental performance, including measurement techniques,
- Marketing (e.g. implementing an eco labelling scheme, making an environmental claim, or producing an environmental product declaration).

According to the ISO standard, the procedure of an LCA is divided into four different phases, explained in the following subchapters.

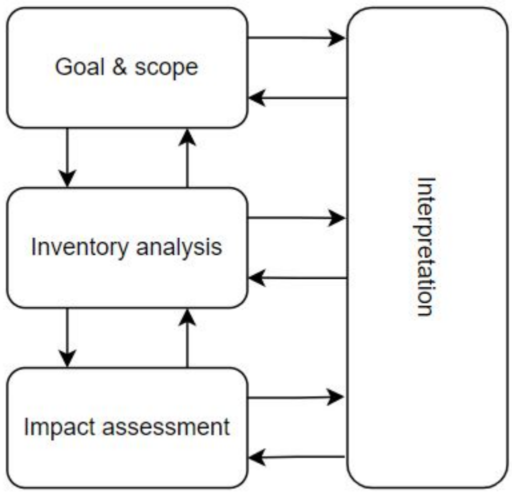

Figure 4.1: The LCA framework. Adopted from Baumann & Tillman (2004)

4.1.1 Goal and scope definition

The first phase deals with clarifying the purpose of the study. It is a crucial phase in LCA studies, given how this affects the choice of methodology with all its choices and specification (Baumann & Tillman, 2004). Although LCA is an iterative process, in the sense that certain information and choices are not apparent from the start and may need to be addressed or changed in later stages, the more defined goals, scopes, and choices, the more advantageous.

The ISO-standard (2006) has clarified what must be included in the study's initial phase. The goal of an LCA, the context in which the study is done, should involve the intended application, the reasons for why the study is carried out, the intended audience of the study, and state whether the results are intended to be used in comparative assertions intended to be disclosed to the public. The scope, the choices regarding the methodology to use in the modeling should, according to the ISO-standard (2006), be sufficiently well defined to ensure that the detail, breadth, and depth of the LCA study are compatible and sufficient to address the stated goal. Furthermore, the scope should include:

- The product system to be studied;
- The functions of the product system or, in the case of comparative studies, the systems;
- The functional unit;
- The system boundary;
- Allocation procedures;

- Impact categories selected and methodology of impact assessment, and subsequent interpretation to be used;
- Data requirements;
- Assumptions;
- Limitations;
- Initial data quality requirements;
- Type of critical review, if any;
- Type and format of the report required for the study.

When defining which options to model, the functional unit of the study is defined. Given how a system may have several functions, this unit defines the quantification of the function of the product or system (ISO, 2006) and answers the amount of input and output needed to fulfill the function. I.e., the functional unit corresponds to a reference flow to which all other flows in the systems are modeled and related (Baumann and Tillman, 2004), and is why it needs to be quantitative. The unit serves as a basis for comparisons between different products and services and represents the function in a reasonably fair matter.

4.1.2 Inventory analysis (LCI)

The second phase means to build a systems model according to the requirements previously set in the goal and scope definition. The systems model describes the technical system from cradle-to-grave and results in a mass and energy balance for the environmentally relevant flows for the system (Baumann & Tillman, 2004). The inventory analysis involves constructing the flow model where all activities are presented, data collection where all inputs and outputs for each activity are listed, and calculations for the data where the resource usage and pollutant emissions are related to the functional unit.

The different life cycle stages are divided between the foreground and background system. The foreground system includes the processes that are under the control of the decision-makers, and the background system includes the processes that indirectly influence the system (Life Cycle Initiative, 2021). Given how this product system is composed of various subsystems, all of which are composed of numerous components manufactured in different facilities and countries, specific energy consumptions and emissions from specific factories are too time-consuming to gather for each component. Masses of each component and their material composition are modeled in openLCA with relevant processes using the national averages of inputs and outputs. The manufacturing data for the components are made with data from EcoInvent, Inventory data by previous LCA studies, and other inventory databases such as the CPM database.

The choices of processing methods for materials are based on the most common methods. E.g., all aluminum in the different components is modeled by section bar extrusion, the copper wires are wire-drawn, most of the plastic is injection molded.

These choices are further explained in chapter 5.2. Whereas a significant few components count for a large proportion of the total weight, the inventory of material and its manufacturing have been investigated more thoroughly. The EOL modeling is modeled with cut-off allocation principles and uses Swedish emissions data for the various waste and recycling methods for the different materials while also studying the recycling standards from ABB and LKAB guidelines. The components are produced by various subcontractors, and all the processes used cannot be studied in detail. Hence, the processes used for modeling are generalized data from EcoInvent, most compatible with the actual manufacturing process.

4.1.3 Life cycle impact assessment (LCIA)

The third phase aims at describing the impacts of the environmental consequences quantified in the inventory analysis and could be seen as a “translation” of the environmental loads from the activities in the inventory results (Baumann & Tillman, 2004). The purpose of the translation is to make the results more relevant, comprehensible, and more communicable, and the information from the LCI is aggregated into fewer parameters. This is done through a variety of steps, explained by the ISO-standard (2006).

First of all, the impact categories, category indicators, and characterization models, the general categories of environmental impacts which were decided upon in the goal and scope definition, must be clearly defined. After that, the inventory parameters are sorted, grouped, and assigned to their respective type of environmental impact, the step known as Classification. Once the environmental loads have been categorized and assigned, they are calculated based on the category indicator results, known as Characterization. It is a quantitative process in which the environmental loads are calculated per category using equivalency factors aggregated within the impact categories. The ISO standards (2006) also raise the issue with the subjective regarding the choice, modeling, and evaluation of impact categories. Therefore, transparency is critical to the impact assessment and should be based on a thorough scientific analysis. Once the environmental loads have been quantified, they are presented as LCIA results (or LCIA profile) and could be further aggregated into formalized and quantitative weighting procedures. Although the classification and characterization steps are compulsory according to the ISO standards, the further aggregation steps are optional elements.

The LCIA profile could be further translated with Normalization, where the characterization results are related to a reference value, Grouping, where they are sorted and ranked into one or more sets, or Weighting, where the characterization results are aggregated across impact categories, and the relative importance of an environmental impact is weighed against another. Different weighting factors, such as monetarization, authorized targets, or panels, are quite controversial given the ethical and ideological values involved in the weighting elements (Baumann & Tillman, 2004).

4.1.4 Interpretation

The last step, but also pervaded throughout the LCA, is the interpretation. It could be explained as "the process of assessing results in order to draw conclusions" (Baumann & Tillman, 2004), where all the results from the LCI and LCIA are presented, and the conclusions are made. The phase involves identifying significant issues, such as important environmental findings and evaluations to establish confidence in the results. The findings are often presented in diagrams and graphs, which leads to conclusions and recommendations to decision-makers. It is vital that the findings should be understandable, complete, and aligned with the goal and scope of the study.

4.2 Modelling and data collection

Softwares for both the modeling aspects and inventory databases are often used in life cycle assessments. In this project, openLCA (2021b) is used as LCA software with the external database ecoinvent v.3.7 (2021C). This section presents the theory and implementation of the software and database used.

4.2.1 Data collection

The most time-consuming aspect of this study was the data collection of all inventory for the system. The LCI of the mine hoist system, the description of the technical system from cradle-to-grave, including all environmentally relevant flows for the system, is gathered from various sources. Interviews and contact with different ABB personnel, literature, and database sources have allowed for the construction of the flowchart where all activities are presented (see chapter 5.1.2.4), and the inventory of the data collection where all inputs and outputs for each activity is listed are presented in chapter 5.1.

ABB personnel provided initial order lists, including weights and origin, which further was investigated by the students. From the original order lists, the products were divided into subcategories in order to simplify and furthermore have the opportunity to evaluate their functions. Contacts were made through digital meetings, phone calls, and emails with different ABB business areas, LKAB, and a variety of subcontractors for the system under study.

4.2.2 OpenLCA

Software tools are highly helpful when conducting LCAs, especially when in contact with inventory and impact assessment databases (Baumann & Tillman, 2004). They provide structure to the analysis, provide graphical understanding when visualizing the results and model graphs, and further simplifies the calculations. There are various different LCA software available on the market, such as SimaPro, GaBi, and Umberto, although all of these are licensed software with fees for use. In this project, the software openLCA is used, which benefits from being open-sourced and free, making it versatile, fully transparent, and easily accessible. The software could identify environmental hotspots throughout the life cycle by process, flow, or impact categories and visualize the results in various ways. Also, it complies with ISO14040 (openLCA, 2021a).

In openLCA, the modeling is done by creating processes (e.g., transportation, production, or usage), linking them with flows in the form of in-and outputs defined by its reference flow property, such as area, mass, volume. It defines in which unit the flows are reported and allows for up-and downscaling of the process when linked with others. Flows are all products, materials, or energy in- and outputs in the system under study, and openLCA distinguishes three different types of flows:

- Elementary flow - material or energy entering or leaving the system directly.
- Product flow - material or energy exchanged between processes.
- Waste flow- material or energy leaving the system.

The overall purpose of the modeling is to create a linkage, or network, of processes to follow and track the flows and processes cradle to grave. Other than processes and flows, openLCA also covers the database elements on product systems- and projects level, structured in a hierarchical order. A network of processes and flows in a product system could be further expanded and evaluated on a larger hierarchy on a Project level if, e.g., one wishes to study and compare two alternatives on a highly detailed level.

4.2.3 EcoInvent

Given how openLCA does not have built-in LCA databases, external sources must be incorporated to contribute with data for inventory and impact assessment methods. In openLCA, there are almost 100 000 different data sets available (openLCA, 2021b), and in this project, the database ecoinvent 3.7 is used. This specific database contains large amounts of life cycle data for processes and materials, with approximately 18,000 LCI datasets in various areas, ecoinvent is one of the most comprehensive inventory databases available (Ecoinvent, 2021a). Each dataset represents one activity, e.g., cast iron production, a transforming activity that produces cast iron. Ecoinvent contains two different basic types of activities; transforming activity and market activity (Ecoinvent, 2021c).

Transforming activities are the most common type of activity in the database. It is the activity that transforms inputs into different outputs. E.g. how pig iron, iron scrap and other input materials, in combination with electricity, coal and natural gas is processed into a product of cast iron with emissions to air and water. The explanation of a transforming activity is seen in Figure 4.2.

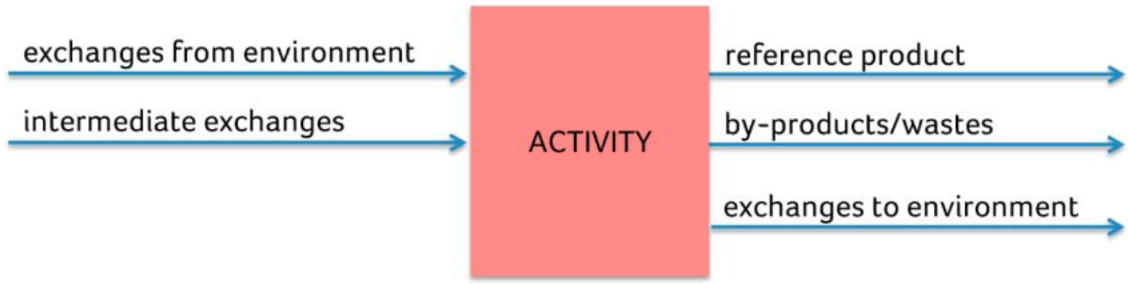

Figure 4.2: Explanation of a transforming activity in Ecoinvent. Reproduced by permission from Ecoinvent (2021c)

Market activities, on the other hand, do not transform the input but instead use the output of one or several transformation activities as inputs to a given activity that uses that exchange as an input. E.g., a market for cast iron, how manufactured cast iron is provided, including the manufacturing stage and transportation. These activities provide an average consumption mix for a given product and could be altered for a given region, with the marginal consumption mix in system models that use marginal suppliers. A market for any given product or process groups all activities producing the same reference product and includes transport and losses. The transport included in the market is default transport distances, which could be adjusted with correct transportation data regarding distances and emissions. The explanation of market activity is seen in Figure 4.3.

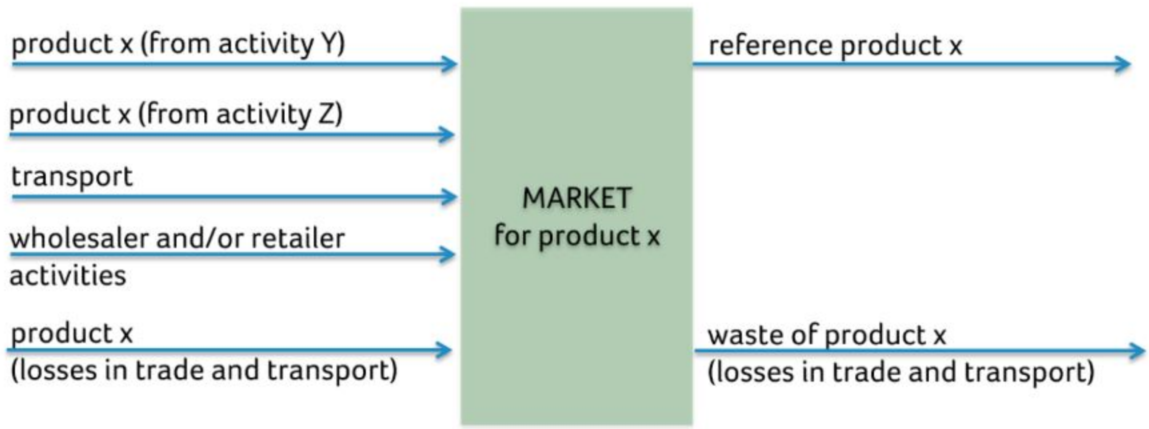

Figure 4.3: Explanation of a market activity in Ecoinvent. Reproduced by permission from Ecoinvent (2021b)

Regardless of which sort of activity, each dataset also includes the following information (Ecoinvent, 2021b):

- Activity information: All general information and documentation of the dataset, including at least one reference product (such as "cast iron" for the cast iron production)

- Exchanges: Contains the intermediate exchanges with the technosphere (e.g. the input of "electricity" or "diesel") and the elementary exchanges with the biosphere (e.g. emissions to air or land occupation)
- Exchange properties: All exchanges, both the intermediate and elementary exchanges, with a mass can have a number of properties. E.g. all products in the database have at least the following properties; wet mass, dry mass, water in wet mass, water content, fossil and carbon content, and non-fossil content.
- Cumulative LCIA results: With a variety of different LCIA methods, different impact categories, and indicators, one could do direct LCIA calculations of processes, product systems or projects.

4.2.4 End-of-life modeling and allocation principles

Allocation problems occur when different products or functions share the same process and environmental loads and where problems arise regarding how to assign the environmental loads. The ISO-standard (2006) explains allocation as ”partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems”. Furthermore, they state, ”consideration should be given to the need for allocation procedures when dealing with systems involving multiple products and recycling systems.”. Baumann and Tillman (2004) provide three basic cases for when allocation problems primarily are accounted for, multi-output and multi-input processes that are not addressed in this product system, and open-loop recycling. Open-loop recycling is where materials in a product system are partly or wholly recycled into other products while undergoing changes to their inherent properties (Hohenthal et al., 2019). Complexities then arise regarding how to allocate the specific inputs and outputs associated with the processes for extraction and processing of raw materials and the impacts associated with the recycling processes and final disposal of products when these are to be shared by several product systems.

There are several methodological approaches for allocating in open-loop recycling, which has been a debated issue within the LCA community. The different methodologies are based on various arguments about fairness regarding which products or processes are most responsible or the accountability regarding which process contributes most. Koffler and Florin (2013) explain two common approaches of allocating open-loop recycling for metals, the avoided burden approach, also known as End-of-Life (EoL) recycling, or the recycled content approach, also known as the cut-off method. The first approach, the EoL recycling, includes and allocates all impacts associated with recycling, e.g., collecting, sorting, remelting, and casting, to the first life cycle and then allocating as much of the primary material burden to the subsequent life cycles. The second approach, the cut-off method, draws the system boundary at the point of scrap generation and allocates all burdens of primary material production to the first life cycle. Baumann and Tillman (2004), who provide several methods for allocating open-loop recycling, also mention the closed-loop recycling approach as an applicable approach for metals where the quality losses may be controlled. Although the different approaches deal with the same issues, the numbers and the outcome could differ significantly between different approaches (GABI, 2014).

The methodological choices for EOL allocation are chosen and argued for based on the following information. The cut-off approach is found suitable by Ekvall et al. (2020) for attributional LCAs aiming to identify the share of the global activities and the environmental burdens that belong to a specific system. The approach is also recommended for materials with high recycled content (GABI, 2014), all of which is applicable for the studied product system where the data is just given for the amount of products and not always their origin. Lastly, it is the original methodological choice for Ecoinvent and found suitable when most of the chosen processes were initially modeled accordingly. Altogether, for the system under study, which consists primarily of metals with a higher recycling rate, it is found suitable to use the approach where primary production of materials is always allocated to the primary user of the material, and that considers the environmental loads or gains of recycling only within the product system under study. In this case, the average secondary materials used for the products bear only the impacts of the recycling processes. The benefits are given in the upstream modeling of input raw materials when a certain share (x) of input for a specific material is assumed to consist of secondary input. The remainder (1 - x) comes from primary material extraction (Nordenlöf et al., 2019).

4.2.5 Sensitivity analysis

Sensitivity analyses are performed to evaluate how different input parameters or assumptions change the outcomes. According to Baumann and Tillman (2004), these analyses allow for identifying critical parameters for the totals results. Therefore, a sensitivity analysis is conducted on critical contributors throughout the life cycle of the mine hoist system.

Other than the scenario under study, used for 25 years in Kiruna in northern Sweden, four other scenarios were investigated. These scenarios were applied to determine the difference in environmental impact using different lifetimes, energy mixes, types of steel and added materials in maintenance. The four additional scenarios are:

Scenario 2: 40 years of usage in Sweden
In order to evaluate how extended usage of the primarily installed mechanical and electrical components would affect the outcome. This scenario investigates a more efficient use of the materials. However, it does not change the amounts of yearly added maintenance materials, the allocation of the total weight of the main motor to this use cycle, or the energy mix.

Scenario 3: 25 years of usage in Australia
In order to evaluate and illustrate the environmental impacts originating from electricity production, the provider of energy was changed to an average Australian mix.

This country was chosen due to its carbon-intensive energy mix and the fact that they have a developed mining industry. Also, a similar LCA study for ABB investigating a medium-voltage motor and drive system investigated usage in Australia (Westberg, 2021), enabling comparisons for environmental impacts.

Scenario 4: 25 years of usage in Sweden. A halved amount of ropes and skid plates throughout the use phase
In order to evaluate and illustrate the environmental impacts originating from the amount of mass flows from the most significant maintenance contributors. Throughout the lifetime of 25 years, these two products contribute to the majority of the mass in the mine hoist system. This scenario investigates a more efficient use of the materials, and the assumption is that they would last twice as long, but the material composition is still unchanged.

Scenario 5: 25 years of usage in Sweden. Substitution to secondary steel throughout the system.
In order to evaluate the environmental impacts originating from the amount of steel in the system, all steel was substituted for secondary steel. More than 90% of the total mass in the system originates from different types of steel, varying from high alloy Nihard-steel in the skid plates to cast iron and structural steel in the mechanical components. Given the increased interest in fossil-free steel, comparisons with less carbon-intensive steel were of interest. However, the actual emissions from these products cradle-to-gate are still uncertain. The production of hydrogen, which is the dominant technology when producing fossil-free steel, is highly energy-intensive (Gullers & Gummeson, 2020) but can still reduce environmental impacts. Hence, all steel in the system was substituted with the steel in Ecoinvent with the lowest CO2e emissions, secondary low-alloyed steel produced in an electric arc furnace (EAF). Although this is not a realistic material substitution, it provides an overview of the environmental savings with less carbon-intensive steel. Including average market transportation, the emissions of the modeled steel were 0.56 kg CO2e per kg compared to the other steels that emitted from 1.04 to 2.66 kg CO2e per kg. Therefore, this scenario investigates the possibilities of less carbon-intensive steel and the environmental savings that could occur.

5

Life cycle assessment

5.1 Goal and scope definition

In this section, the goal and scope definition of the study is presented.

5.1.1 Goal and context

The goal is to investigate the environmental impact of a specific mine hoist system, the B2 system in Kiruna, and provide ABB with improvement areas and suggestions of how their products could be designed, produced, used, and handled differently to reduce the environmental impact. This thesis describe and map the environmental, physical flows from the mine hoist system. Theories within the concept of circular economy will also be applied to answer how ABB strategically and technically could apply the recommendations provided by this report.

5.1.2 Scope and modelling requirements

5.1.2.1 Functional unit

Given how the system's function is to transport goods from the underground mines to ground level, the functional unit is "1 tonne of goods * vertical kilometer transported". This provides a reference to the function of the studied system, in which both the inputs in the form of material and outputs in the form of environmental impacts can be related.

5.1.2.2 Impact categories

Although there is a wide selection of impact categories to chose from, the impact categories taken into account in this study are based on the Midpoint impact categories according to the ReCiPe 2016 v1.1. Midpoint impact assessment method. It uses a default list where the elementary flows could be assessed regarding its contribution to certain impact categories, translating the environmental loads from the environmental mechanisms, i.e., the midpoints, and if desirable, to the Endpoint area and its three areas of protection. (See figure 5.1).

The characterization factors that enable comparisons between different elementary flows, indicating the environmental impact per unit of stressor (e.g., per kg of resource used or emission released) could be presented on point a midpoint level, the point after which the environmental mechanism is identical for all environmental flows assigned to that impact category (Huijbregts et al., 2016), or endpoint level, corresponding to three areas of protection, i.e., human health, ecosystem quality, and resource scarcity.

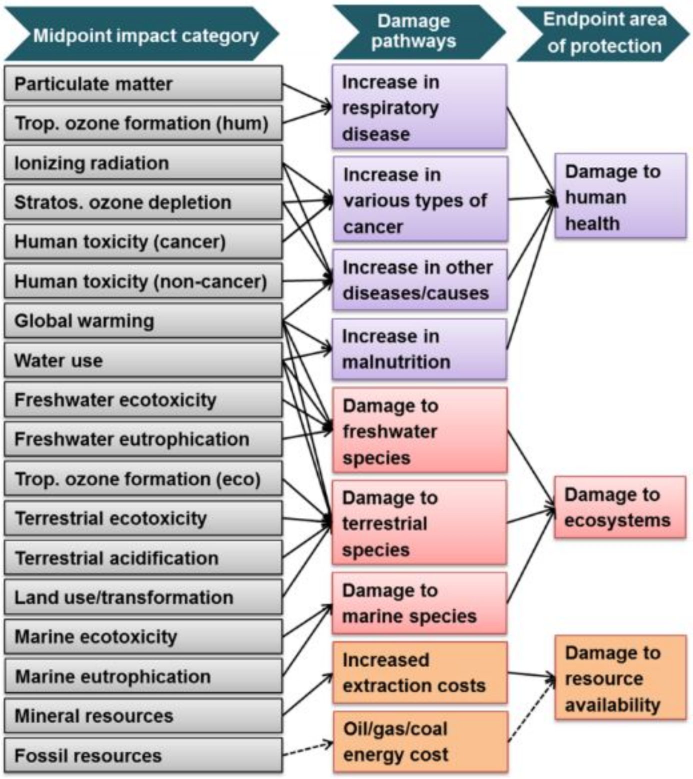

Figure 5.1: Impact categories covered in the ReCiPe2016 methodology (Huijbregts et al., 2016)

The impact categories chosen for this study are listed in Table 5.1, presented on midpoint level with the derivation of characterization factors with regard to the hierarchist perspective of value choice in the ReCiPe model (Huijbregts et al., 2016). This is based on scientific consensus with regard to the time frame of 100 years and plausibility of impact mechanisms.

Table 5.1: Impact categories chosen for the impact assessment

Impact category	**Characterization factor (midpoint)**	**Unit**
Climate change	Global warming potential: GWP	kg CO2 to air
Human toxicity: non-cancer	Human toxicity potential: HTPnc	kg 1,4 DCB to urban air
Terrestrial ecotoxicity potential	Terrestrial ecotoxicity potential TETP	kg 1,4- DCB to industrial soil
Land use	Agricultural land occupation potential: LOp	$m^2 \cdot yr$ annual crop land
Mineral resource scarcity	Surplus ore potential	kg Cu
Fossil resource scarcity	Fossil fuel potential: FFP	kg oil
Ionizing radiation	Ionizing radiation potential	kBq Co-60 eq

The remaining impact categories according to ReCipe2016 method of fine particulate matter formation, freshwater ecotoxicity, freshwater eutrophication, human carcinogenic toxicity, marine ecotoxicity, marine eutrophication, ozone formation for both human health and terrestrial ecosystems, stratospheric ozone depletion, terrestrial acidification, terrestrial ecotoxicity, and water consumption are all excluded in this study.

The reason for excluding them is lack of relevance, given how no contributing flows provided any significant impact and the readability of the study, using a limited number of indicators. This decision was made after the initial results from the impact assessment were obtained, and normalization of the results showed that the chosen categories listed in table 5.1 stood for 99.8% of the overall results. Given how the LCA methodology is an iterative process, the final choice of selection could be based on the impact assessment results. This process of using normalization for identifying and selecting impact categories is not conventional, mainly due to two factors.

The process of relating the characterization results to a reference value is normally performed to interpret and communicate results in the impact assessment. With normalization, the magnitude of the environmental impacts caused by the study, i.e., the characterization results, are related to a reference value to evaluate and compare the actual magnitude for each impact category. Secondly, the estimates of the normalization factors and the bases of the comparisons are subjectively made. Uncertainties such as biases, unreliability from the LCIA model, the geographical area of the reference system are not consistent with the area of the studied system, varying amounts of considered substances, and the age of reference year must be acknowledged. According to Aymard and Genoulaz (2018), the analyst must understand the chosen LCIA method and its associated normalization factors, and they must be able to evaluate its uncertainties and gaps.

The reference values for the normalization are from Sleeswijk et al. (2008), based on world emission data for the year 2000, further based on 860 environmental interventions collected for European and global systems. The authors present calculations of normalization scores for impact categories on the midpoint level, the scores used by the midpoint hierarchist ReCIPe model (Huijbregts et al., 2016). These factors, as all normalization data, come with uncertainties. The authors primarily state uncertainties with toxic substances. However, in this study, the normalization factors have only been used to select impact categories for presentation and further analysis, and not actually the interpretation of them. Also, this allowed for both completeness, practicality, and environmental relevance of the categories, all of which should be considered according to Baumann and Tillman (2004). The chosen categories cover the environmental problem of relevance from the perspectives of resource use, human health, and ecological consequences, it does not contain too many categories, and most importantly, they are environmentally relevant to the system under study.

5.1.2.3 System boundaries and type of LCA

The system boundary, the criteria of which process is part of the product system, is divided into a foreground and background system. The inventory for the foreground system consists of the manufacturing stages of the components and the usage over 25 years in Sweden, including exhaustion and wearing of materials. The inventory for the background system is the stages of raw material acquisition, material manufacturing, electricity production, transportation, and waste management. These are modeled with Ecoinvent data using European averages and “market” activities that provide an average consumption mix for the materials and processes.

This study is an attributional LCA (i.e., accounting type), given how the goal is to gain more insight into what point of influence ABB has to decrease the environmental impact of their products. The goal of attributional LCAs is to answer questions such as “what is the environmental impact associated with this product?” which is the ambition of ABB.

Inventory that throughout the technical description and inventory analysis that was decided to be excluded were:

- Pressure sensors
- Differential pressure sensors
- Signs
- Valve blocks
- Profibus connector and cables
- Rotary actuator fail-safes
- Junction boxes
- Transmitters and receivers
- Different types of switchers
- Plugs and sockets

These items could not be analyzed within the scope of the study. Although these items exist in several different subsystems, some of which may involve scarce metals, the proportion of the environmental impact is assumed to be negligible when the weight is below 0.5 kg. Similar logic has been made when excluding the usage of forklifts, cranes, and tools within the system's assembly, maintenance, and dismantling stages from the inventory. Over a period of 25 years, they are assumed to be insignificant compared to other environmental impacts.

5.1.2.4 Flowchart of the system

A flow chart providing a general overview of the system is presented in Figure 5.2. The subsystems, and the illustration of foreground and background system as mentioned in the previous chapter, are shown in the figure.

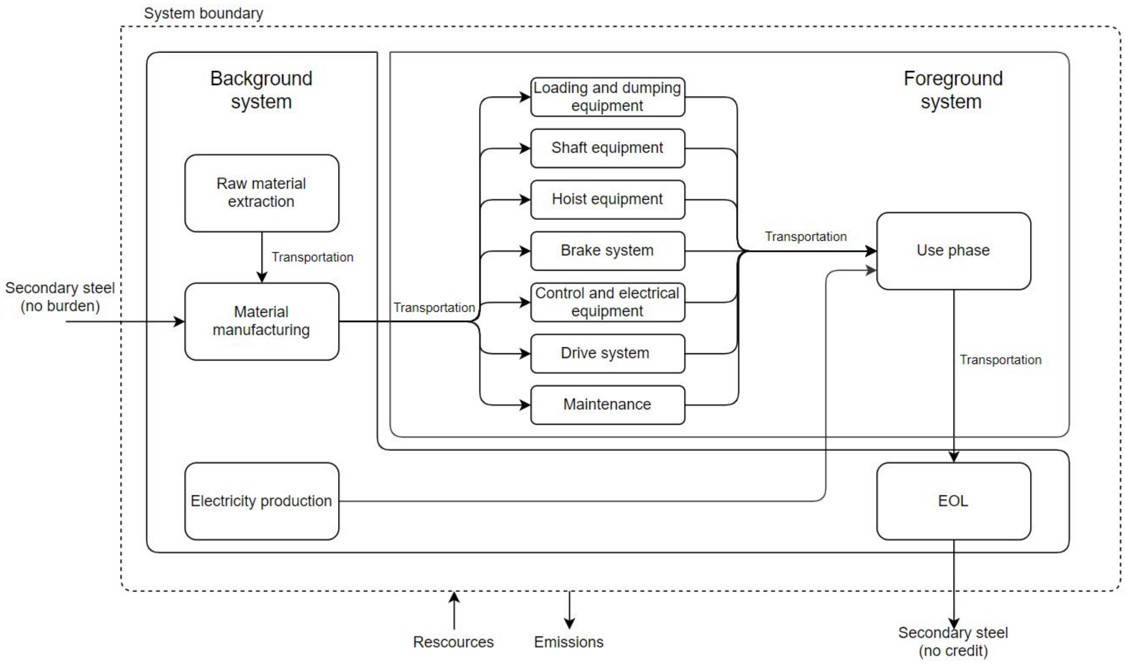

Figure 5.2: Simplified flow chart

5.2 Life cycle inventory analysis

In this chapter, the data collection received from the different ABB business areas, LKAB, and various subcontractors are presented. Throughout the following subchapters, explanations are provided on how the data have been obtained and how it has been interpreted. This is the data that has been used for the modeling in openLCA. The inventory analysis has been focused on the foreground system, consisting of the materials, manufacturing stages of the components, and usage, including exhaustion and the wearing of materials.

Interviews and contact with different ABB personnel, literature, and database sources have allowed for constructing the material list, as seen in Table 5.2. To understand the weight distribution between the different subsystems, Figure 5.3 illustrates the proportion. Further explanations in this chapter provide information regarding the processes, transportation, and EOL management. In Appendix A, a more elaborated tabular form of each subsystem with its weight, material composition, and transportation distances is presented.

Table 5.2: Material list of the system over 25 years of use

Material	**Weight(kg)**
Steel ropes	4.95E+5
Structural steel	2.03E+5
Ni-Hard	1.53E+5
Cast iron	7.95E+4
Low alloy steel	6.00E+4
Polyester resin unsaturated	3.60E+4
Lubricant oil	1.99E+4
Powder coating, steel	1.96E+4
Engineering steel	1.45E+4
Ferrit	1.09E+4
Polystyrene extruded	4.79E+3
Copper (cathode)	3.38E+3
Cable, unspecified	3.07E+3
Aluminium (cast alloy)	2.58E+3
Glass fiber	2.18E+3
Aluminium alloy AlMg3	1.73E+3
Epoxy resin (liquid)	1.69E+3
Glass fibre reinforced plastic, injection moulded	1.58E+3
Steel, chromium steel 18/8	9.74E+2
Fiber polyester	8.98E+2
Residual wood	8.00E+2
Polyethylene, high density, granulate	3.56E+2
Polymer foaming	2.99E+2
Phenolic resin	2.40E+2
Brass	1.44E+2
Tin	1.09E+2
Other	4.36E+2

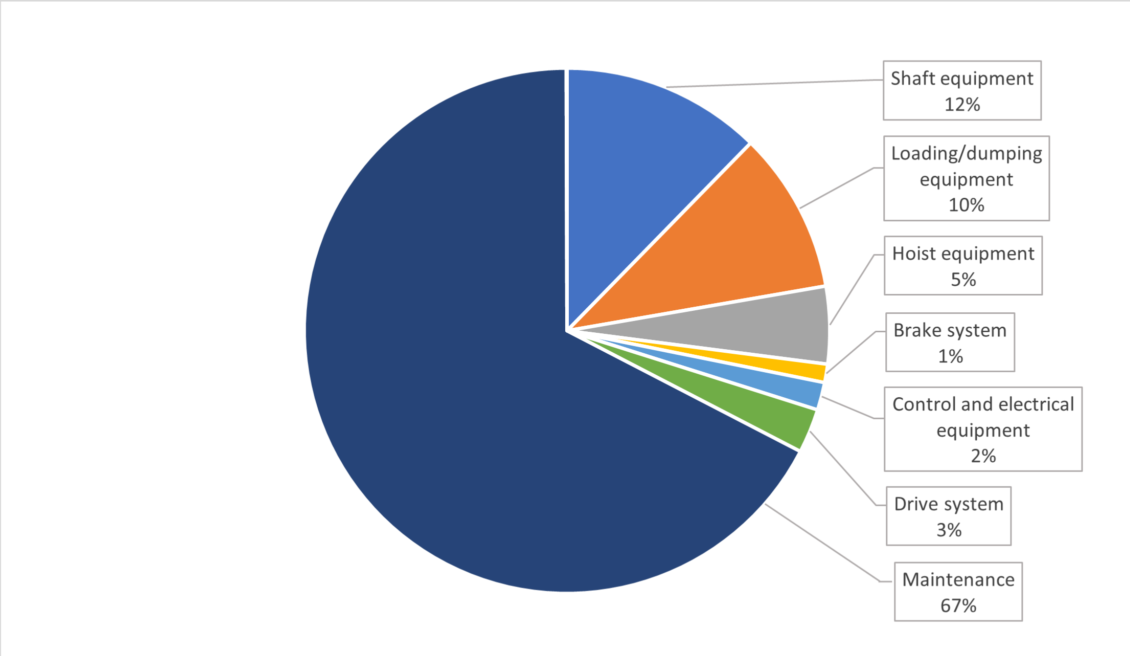

Figure 5.3: Distribution of weight between the subsystems

5.2.1 Transportation

The majority of components in this study are manufactured within Europe and further transported to Kiruna using lorries and ferries. The transportation distances from the manufacturing facilities to Kiruna are assumed to use the shortest route and are measured using digital maps. The transportation by lorries is modeled with the Ecoinvent process "transport, freight, lorry 16-32 metric ton, EURO5". The emission standard EURO5 is found plausible as an average in Europe, and the load factor of 16-32 metric tonnes is assumed as the average. The ferries, from Germany and Eastern Europe to Sweden, are modeled with "Transport, freight, sea, ferry" and the distance is measured in the same way as for lorries. The parts that do not originate from Europe are assumed to be transported via container ship to Rotterdam, modeled using "Transport, freight, sea, container ship". The rest of the distance is calculated in the same way as the other components manufactured in Europe. The Ecoinvent processes are modeled with the unit tonne*kilometer, which calculates average load factors and their environmental load with given lorry size and emission standard.

Regarding the transportation from cradle-to-gate for the different raw materials, the averages from Ecoinvents "market" activities are used, which provide an average consumption mix for the materials and processes. They provide average emissions for all materials, suitable when each raw material and its specific production route cannot be investigated. Similarly, average data in the form of tonne * kilometer is provided for sea, road, and air travels and is modeled with global averages given how each origin cannot be traced. Further information regarding material composition, processing methods, origins, transportation distances, wearing of specific materials, and energy consumption are explained in the following subchapters for the different components.

5.2.2 Steel

The mechanical components for the mine hoist system, such as the loading equipment, skips, motor, shaft, and pulley, weigh between 15 and 100 tonnes individually and therefore are investigated more thoroughly. The type of steel delivered to the Czech manufacturing facilities could be determined by examining material certificates. In the documents, several hundred pages long, it was obtained that the larger mechanical components were built in one of two types of steel; structural steel or engineering steel. Inventory data for the resource and energy inputs for these steel types were gathered with specific inventory data from World Steel Association (2021), see Appendix D. All steel types were further processed with different treatment methods. The structural steel was treated as either normalized or hot rolled, whereas the engineering steel was assumed to be normalized.

Normalization is the subsequent annealing process where the materials are heated above their recrystallization temperature and later cooled down slowly at room temperature. This slow cooling process that alters the steel's microstructure increases the ductility and reduces the hardness of the material. Normalization is often performed on steel alloys after forming and hardening to reduce the brittleness caused, making the steel more formable, machinable, and reducing residual stresses in the material that could lead to unexpected failures. In Ecoinvent, there was no process of normalization included. However, a suitable generic cradle-to-gate process of "sheet rolling" was found similar. This process, used for un- and low-alloyed steels, included similar steps as normalized structural steel, with the process steps continuous pickling line, cold rolling, annealing, tempering, inspecting, and finishing. Normalization, sometimes referred to as an annealing process, differs slightly from conventional annealing in how it is cooled by placing it in a room-temperature environment rather than cooled at a controlled rate in a furnace (Metal supermarkets, 2019). This difference in energy input is negligible, though, and hence the available data set of "sheet rolling" was found suitable for normalized structural steel modeled.

Hot rolling consists of mostly similar steps to normalization. It consists of heating the steel past the crystallization point, rolling it in mills, shaping and forming it to desired needs, and further cooled at room temperature. The difference lies in how it is being rolled or formed and whether it is rolled above or below the material's recrystallization temperature. When hot rolled, it becomes more malleable and can be properly formed and shaped (NMC, 2018). It also allows for the ability to produce larger quantities of steel. The steel is then cooled at room temperature, which "normalizes" it, eliminating the worry for stresses in the material arising when quenching or work-hardening. The processing steps between normalized or hot-rolled steel are mostly similar, but given how the differences in the forming and heat treatment have an impact on the end-product, it was still decided to use different processes.

In Ecoinvent, the process of "hot rolling steel" was available, including the process steps of scarfing, grinding, heating, descaling, rolling, and finishing.

All structural steel components have a mixed composure of the hot-rolled and normalized treatment. This is because the different parts of the components require different amounts of toughness, ductility, and hardness regarding their purpose. Furthermore, all structural steel and engineering steel components are processed in three different steel mills, all located in the Czech Republic.

The inventory for the ropes was gathered from World Steel Association (2021) similarly as for the structural and engineering steel, as seen in Appendix D, where resource and energy inputs were provided, which allowed for the ropes to be modeled more thoroughly. The skid plates were also modeled specifically, further explained in chapter 5.2.9.3. The remaining steel in the system has been modeled using available Ecoinvent processes for steel. The generic process "Metalworking average" in ecoinvent is used when no other modeled process is similar or suitable to the actual process. The process includes energy and auxiliary inputs, the manufacturing, the machines used, and the average waste of the steel that is not used in the product.

5.2.3 Shaft equipment

The components accounted for in this subsystem are the skips, the skip guiding equipment, the guide ropes weight including rope attachment, and the sheaves.

5.2.3.1 Skip and guiding equipment

The skips, the containers that hold the ore, and the guiding equipment, are according to the ABB personnel, approximately 30% normalized structural steel, whereas the rest is hot rolled structural steel. Both the normalized and hot-rolled steel are modeled with similar assumptions of steel manufacturing as the Ecoinvent flow “metal working, average for metal product manufacturing”, which includes average energy inputs and material losses for the processing by machines as well as the factory infrastructure and operation. Additional welding is modeled with Ecoinvents arc welding flow, assuming 100 meters per skip. The links and logic in openLCA are illustrated in Figure 5.4 and are performed similarly for all structural steel components.

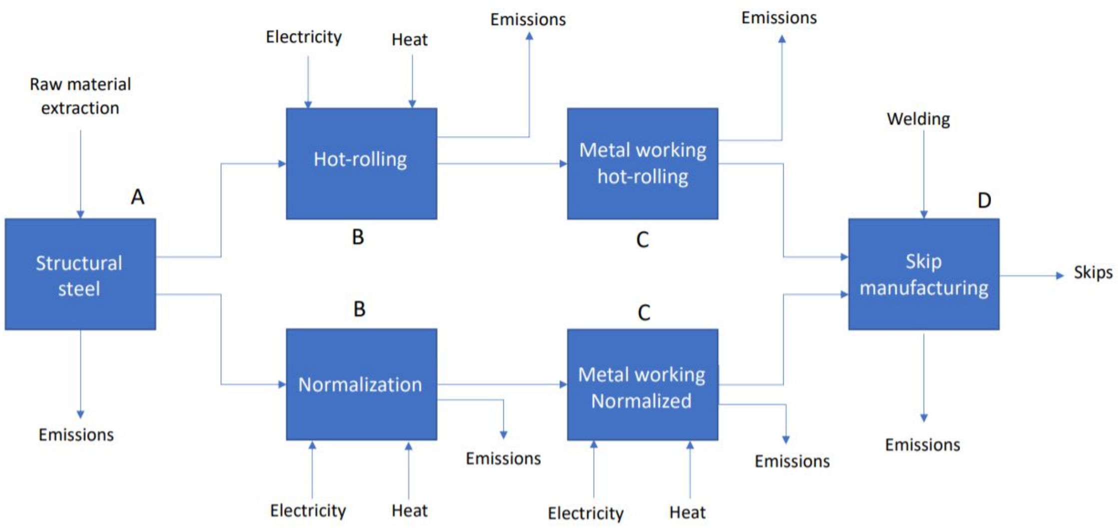

Figure 5.4: Modelling of the skips

The skip guiding equipment is also structural steel with the same mixed composure of the hot-rolled and normalized treatment and hence is modeled with the same logic as the skips.

5.2.3.2 Sheave

Similarly to the main motor, the sheave has been in place since the 70s, and its weight is 3.2 tonnes, assumed to be without the friction inlay. For this lifecycle of 25 years, one-third of this weight is allocated, 1.1 tonnes. The material is assumed to be hot rolled, low alloy steel. The environmental loads related to manufacturing and transportation have been excluded, given how its origin from the 70s could not be obtained.

5.2.3.3 Guide rope weights

The guide rope weights are big cast-iron weights that provide tension and stability to the guide ropes. The weight of these weights sums up to 76 tonnes. Unfortunately, the production site could not be obtained, and therefore, the market process for cast iron has been used.

5.2.4 Loading and dumping equipment

The components accounted for in this subsystem are the measuring pocket, the weight modules, and the hydraulic units.

5.2.4.1 Measuring pocket

The measuring pocket, the “fillers of the skips”, are according to a supply chain manager on ABB, the same steel proportion as the skips with 30% normalized structural steel and 70% hot-rolled structural steel, and is hence modeled with similar logic.

Additional welding is modeled with Ecoinvents arc welding flow, assuming 500 meters of welding. The product is manufactured in Latvia.

5.2.4.2 Weight modules

The weight modules are six smaller cells, each with a rated load of 500 kN, placed in a triangular shape to distribute the load evenly. They weigh 260 kg, produced in Sweden, and are built of yellow chromate steel. They are modeled with Ecoinvent "steel, chromium steel 18/8, hot rolled" and further Ecoinvents "metal working, average for metal product manufacturing" flow for manufacturing.

5.2.4.3 Hydraulic units

There are five different hydraulic units in the system, as mentioned in the technical description. Three of these are located in the subsystem of the loading and dumping equipment, and two are associated with the measuring pocket, i.e., the loading and one for the dumping at ground level. Furthermore, there are hydraulic units for the brake system and lubrication. Four of them are provided by the same supplier, and another supplier provides the hydraulic brake unit. Therefore the information regarding the material composition differs slightly.

The first four comprise 84% low alloy steel, 15% steel chromium steel 18/8, and 1% copper (cathode). The total weight of the four hydraulic units is 4.7 tonnes. The remaining one, the hydraulic brake unit, comprises 500 kg low alloy steel, 150kg cast iron, 20kg aluminum (cast alloy), and 30kg copper (cathode). Two hydraulic blocks are connected with the hydraulic brake unit. They are composed of 300kg low alloy steel and 30 kg of copper (cathode). The manufacturing process for these components are unknown, so the general process "metalworking, average for steel manufacturing" is used for all the hydraulic units.

5.2.5 Hoist equipment

The components accounted for in this subsystem are the engine shaft, the pulley, the bearing houses, the bearings, and the foundation details,

5.2.5.1 Motor shaft

In contrast to all the structural steel used in the system, this is the only component that uses engineering steel, a tougher material that can better absorb the energy and without fracturing. This was also assumed to be normalized. The engine shaft is turned into its final shape, modeled with the Ecoinvent product flow of "steel removed by turning", where the process accounts for the energy use per kg of removed material. The amount of removed steel is assumed to be 23% as that is the general value in Ecoinvent.

5.2.5.2 Pulley

The pulley, or hoist drum, has a different steel composure. It has slightly less content of hot-rolled steel and is instead constructed with 50% normalized structural steel and 50% hot-rolled structural steel. Other than this change of steel composure, it is modeled with similar logic as the skips. Furthermore, 50 meters of welding is assumed, using the Ecoinvents arc welding flow.

5.2.5.3 Bearing houses

The bearing houses, specially designed to fit the specific bearings, protect and secure the bearings to their fixed position. The bearing house placed between the pulley and motor weighs 8.2 tonnes, and the bearing house placed on the other side of the hoist 5.6 tonnes. Although these pieces are large metal pieces, with far thicker metal sheets than the ones in the other components, they are still hot-rolled with similar techniques. It then uses hot rolling steel, assuming pure hot-rolled structural steel, with an included general metal working process as in previous components.

5.2.5.4 Bearings and adapter sleeves

The bearings used in the system are two specific bearings, where the weights were found from the manufacturer's product catalog, 1.1 tonnes respectively 1.7 tonnes. Data regarding the processes and the material composition is based on an LCA study on a similar bearing but with a slightly other weight of 1.2 tonnes, including the transporting box (Berg & Häggström, 2002). From the study, each part's material was obtained and the processes and scraps from production. The inner and outer rings, guide rings, and rollers are built in steel, assumed to be formed by turning. The material in the bearing cage is brass and assumed to be formed by turning.

In the study, the added total weight of the steel in the bearing was 1.1 tonnes, and the brass was 55kg, the steel removed by turning was 680kg and the brass removed was 150kg (Berg & Häggström, 2002). This data was later scaled to the specific bearings with a total of 2.8 tonnes of bearings.

The total steel used for the two bearings was 2.5 tonnes, and the total brass used in the bearings was 130 kg. The amount of scrap that was removed was 1.6 tonnes steel respectively 350 kg brass. One noticeable fact is that according to the study, the material losses throughout the process were quite significant. Material losses of 63% and 273% are, by far, more than the turning averages in Ecoinvent, 23%, which is recommended to use for both steel and brass.

The steel is modeled with low alloy steel, which is hot rolled and turned. Here, the total amount of 4.1 tonnes hot-rolled steel is accounted for in input. 1.6 tonnes is used as mass for the turning process, using the Ecoinvent product flow of "steel removed by turning", where the process accounts for the energy use per kg of removed material. The amount of steel removed is later added to the bearing production, where all removed material is assumed to have been treated. Similarly to steel, the brass input is 480 kg, assumed to be cast using the Ecoinvent process "casting, brass". Then, 350 kg is used as mass input for the turning process, using the Ecoinvent product flow of "brass removed by turning", based on similar assumptions. The bearing adapter sleeves are assumed to be low-alloy steel which furthermore is turned with Ecoinvents turning flow. This follows earlier logic and the assumptions are that the material losses from turning are 23%. Hence 0.23 kg of the turning flow is added to the process per kg of steel material.

5.2.5.5 Foundation details

The foundation details weights add up to 4.7 tonnes and are also structural steel, similar to the mechanical components. These are assumed to be manufactured through hot rolling, assuming pure hot-rolled structural steel, with the following metal working process, similar to the shaft, loading, and dumping equipment.

5.2.6 Brake equipment

The components accounted for in this subsystem are the brake calipers and the brake stands.

5.2.6.1 Brake calipers

These products on 3.3 tonnes are composed of 780kg of low alloy steel and 2.5 tonnes of cast iron which is modeled with Ecoinvents cast-iron flow. Since the casting processes are included in that product flow of Ecoinvent, no additional process flows are added.

5.2.6.2 Brake stands

The four brake stands weigh 2 tonnes each, 8 tonnes in total. These are manufactured through hot rolling, assuming pure hot-rolled structural steel, with the following metal working process as the foundation details produced at the same facility.

5.2.7 Control and electrical equipment

The components accounted for in this subsystem are the electric cabinets, the transformer, the frequency converters, the industrial DC drive, low voltage switchgear, and the smaller electric motors.

5.2.7.1 Electric cabinets

The electric low voltage distribution of the system is carried out using distribution boards throughout the mine shaft. The electric system contains 65 distribution boards, further addressed as electric cabinets. It was obtained from interviews that there are 65 cabinets in the mine hoist system, seven large, ten medium, and 48 small cabinets, weighing a total of 5 tonnes. Given how the exact material composition could not be obtained, the material composition has been estimated with an average cabinet of 77 kg, used as a reference. The average cabinet on which the material composition is based is a specific model from the ABB product catalog of low voltage distribution systems (ABB, n.d.A)

Based on a specific model, the NC850-G-SE-Z6 cabinet, it is obtained that the cabinet has a net weight of 61 kg of steel, made of galvanized steel sheets. Additional accessories such as anchoring, foundation plates, and locks are estimated to weigh 4 kg with similar steel material. All steel is assumed to be hot rolled, low-alloyed steel using the Ecoinvent process. The galvanization, the process of applying a protective zinc coating, is modeled with Ecoinvents zinc coating process. In Ecoinvent, the data of coating is given per square meter of coated product which could be converted to the required area of coating per treated mass. The data given per tonne of coated product had to be transformed by dividing it by the mean surface area of 60 m^2. Hence, for each kilogram of coated product, 0.06 m^2 of coating is needed, assuming a coating layer between 65 and 130 μm thick.

The cable connectors are estimated to weigh 1 kg, assuming four CIZ 300 connectors with 0.5kg aluminum, 0.25kg brass (assumed 70% Cu and 30% Zn), and 0.25kg steel according to similar material compositions in similar connectors (ABB, 2018). Based on pictures of the cabinets, it is assumed there are three larger fuse switch disconnectors, one ZLBM3-3P-Z-V, and two ZLBM00-1P-Z-M8, weighing approximately 10kg according to the product catalog. The material composition for the fuse switch disconnectors is further based on an EPD for smaller low voltage circuit breakers, whose function is similar to the fuse switch disconnector.

Based on the model F 200 4P (ABB, 2006), the estimation is that the fuse switches consist of 51% plastic (assumes high-density polyethylene), 30% hot-rolled low-alloyed steel, and 19% wire drawn copper. The remaining 1kg is assumed to be electrical cables, using existing Ecoinvent data for this process. These cabinets are built in the Czech Republic, and the environmental load for resource use and manufacturing have been modeled with the Ecoinvents flow “metal working, average for metal product”, which includes average energy inputs and material losses for the processing by machines as well as the factory infrastructure and operation.

5.2.7.2 Transformer

It was initially obtained that the transformers for the system were two identical 9.4 tonnes pieces from Germany. In the mine hoist system, one of these is included in the control and electrical equipment subsystem, and the other is included in the subchapter, drive system. From the drawings and technical information, it was obtained that the core was 5.5 tonnes and that the conductors were built in aluminum, weighing 1.1 tonnes. The transformers are assumed to be ferrit core transformers, one of the most commonly used types (Custom Coils, 2018) and furthermore used by Ecoinvent in their material composition for smaller transformers. The MnZn ferrite used by Ecoinvent is further assumed to be forged into the desired shape using Ecoinvents process of steel forging. The aluminum is assumed to be a cast alloy aluminum, which is processed with section bar extrusion.

Although much technical information was available for the transformer, information other than the weight of the core, conductors, and the total weight was harder to find. Based on drawings, the dimensions of the protective cover and beams were calculated, and the total weight of these was calculated with respective density. Assuming approximately 15 meters of steel beams weighing 25 kg per meter (Eref, n.d), and approximately 22 m2 of protective steel cover, weighing 30 kg per m2 (BE group, n.d), the weight is one ton, assuming hot rolled low-alloyed steel.

The remaining weight of the transformer is assumed to be 1.8 tonnes cast resin with high glass fiber content. Although the exact material composition has not been obtained, the assumption is that it is glass fiber reinforced epoxy resin. The technical description explained that the plastic contained high glass fiber content. Further product descriptions from Hitachi ABB Power Grids (n.d.) explain how the windings contain an even distribution of glass fiber rovings and epoxy resin. Although the proportion of glass fiber in the resin is not given, a similar Ecoinvent process of glass fiber reinforced polyester resin gives a mass proportion of approximately 60% glass fiber and 40% resin. It is further mentioned in the production description of ABBs transformers how they are hermetically cast in epoxy without the use of a mold. This process is, however, not available in Ecoinvent, and the process of injection molding was found as the most suitable approximation.

Inputs and outputs during production are further based on scaled energy- and waste data from the available Ecoinvent data, the production of a 3 tonnes inverter which manufacturing process was assumed to be mostly similar to a transformer. The Ecoinvent data that included the electricity used for manufacturing and industrial waste outputs for plastic was scaled with the fraction 3.13 for the 9.4 tonnes transformer.

5.2.7.3 Frequency converter

The frequency converters used in the mine hoist system, also known as low voltage AC drives, consist of three different units, two smaller ACS880-01 and one larger ACS880-11. The weights of the units with their respective size of frame were obtained from the product catalogs (ABB, 2020), the weights from a technical data sheet (ABB, 2020b), and the material compositions using ABBs recycling instruction of the products (ABB, 2017) and (ABB, 2019).

There was a slight difference between the product weight and the material composition in the recycling instruction. This was dealt with by scaling the materials used to ensure that the share of material was correct for the inputs of materials. The choke is modeled with Ecoinvents ring core choke type inductors. The metal parts for both the housing and internal metals are modeled with hot-rolled, low-alloyed steel, where the housing is galvanized. Similar to the electric cabinets, the Ecoinvent data of coating is given per tonne of coated product, and that 0.06 m2 of coating is needed per kilogram of material. The aluminum is an Al-Mg Si alloy, which was estimated with Ecoinvents AlMg3 alloy and section bar extrusion. The plastic was assumed to have the same composure as the smaller transformers, with 70% epoxy resin and 30% polycarbonate, which further is injection molded. The copper cathode is wire drawn, the ferrit is MnZn ferrit similar to the transformer, and the rubber is assumed to be synthetic rubber, a specific Ecoinvent flow that is commonly used as seals. These products are built in Finland, and the environmental load for resource use and manufacturing have been modeled with the Ecoinvents flow “metal working, average for metal product”.

5.2.7.4 Low voltage switchgear

The electronic distribution and control system consists of a larger cabinet that connects all ingoing and outgoing connections. Compared to the other electrical components in this system, such as the industrial DC drive or the frequency converters, this product is not of a model which could be ordered off the shelf. Each switchgear is individually designed and produced for its specific purpose, and hence the material composition has not been obtained. The weight of the switchgear was obtained though, a weight of 1.3 tonnes.

As explained in chapter 3.5, the function is rather similar to the DC drive to control and distribute electric currents. Where the DC drive directs the current to a specific object, and the switchgear distributes it to several, their internal construction is still mostly similar with the copper phase plates, power contacts, smaller modules, and circuit breakers. According to ABB brochures regarding switchgear systems, the cabinets also seem to be similar to those of DC drives, see Figures 5.5 and 5.6, and it was found reasonable to model these to products with similar material composition. They are manufactured in Sweden.

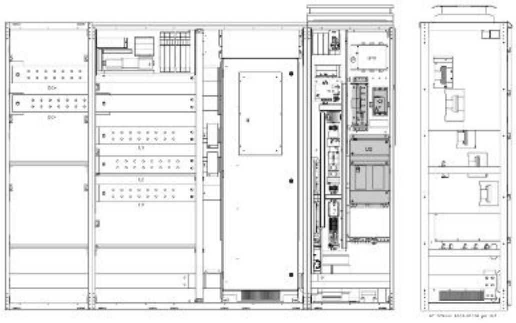

Figure 5.5: Internal view DCS800 (ABB, n.d.B)

Figure 5.6: Internal view low voltage switchgears (ABB, n.d.C)

5.2.7.5 Electric motors

Throughout the system, there are 17 smaller electric motors with different applications. Fifteen of these are for the hydraulic units, providing power for pumping and cooling, and two motors are providing the power for the fans. These motors are designed similarly but with different weights, sizes, and power outputs, and vary from 0.17 to 37 kW, still defined as smaller electric motors. These are comparably lightweight, but because of the content of scarce metals, a more detailed level of inventory was searched upon. The material composition for these motors have hence been gathered from a study by Torrent, Martinez, and Andrada (2012), where the authors performed an LCA with included material inventory for three different electric motors, 1.1kW, 11kW, and 110kW, with the material composition as seen in Table 5.3:

Table 5.3: Material inventory electric motors for a given industrial application. (Torrent, Martinez & Andrada, 2012)

	1.1 kW	11 kW	110 kW
Electrical steel (kg/kW)	5.40E+0	3.60E+0	3.10E+0
Other steel (kg/kW)	1.50E+0	9.50E-1	6.70E-1
Cast iron (kg/kW)	2.50E+0	1.30E+0	3.00E+0
Aluminium (kg/kW)	1.70E+0	9.00E-1	1.80E-1
Copper (kg/kW)	1.24E+0	6.40E-1	5.40E-1

These weights with the given reference values could later be applied and transformed to the power outputs of the motors in the hoist system. In order to get the most accurate assumptions, interpolation was done, using the formula:

$$f(c) \approx f(a) + f(b) - \frac{f(a)}{(b-a)\cdot(c-a)}$$

The formula calculates the data points between the given data points. There are electrical motors whose output was below 1.1 kW. However, due to the comparably low weight, the calculation was based on the assumption that those motors had the same weight of material/kW quota as the 1.1 kw motor. The calculations provide an interpolated value of the material used for the different electrical motors. In Table 5.4, the amounts of materials used in the motors are listed.

Table 5.4: Weight of the electrical motors

Material	**Weight (kg)**
Electrical steel	4.80E+2
Other steel	1.25E+2
Cast iron	2.14E+2
Aluminium	1.15E+2
Copper	8.93E+1
Total	1.02E+3

Electrical steel, which also could be referred to as silicon (Si) steel (McHenry and Laughlin, 2014), are not available in the Ecoinvent database. These alloys of iron and silicon, which are common within electrical applications (motors, transformers,etc.) are instead modeled with low alloyed, hot-rolled steel. The cast iron is modeled with a process that includes melting, refining process, and casting. The aluminum is assumed to be a cast alloy aluminum, which is processed with section bar extrusion, and the copper cathode is wire drawn.

5.2.8 Drive system

5.2.8.1 Industrial DC drive

The DC drives, also known as enclosed converters, are used for the supply of power and control of DC machines. In this mine hoist system, two drives named DSC800-

A02-4800-06 are used, 1.2 tonnes each. From the product catalog (ABB, 2016) and from conversations with personnel from ABBs DC drive systems, it was obtained that the drives were two separate cabinet installed drives, using a specific D7 frame with a 310 kg drive module included in the 1.2 tonnes drives, and that they are manufactured in Poland. From the recycling instructions (ABB, 2018a) for the DCS 800 drives, the material composition for D7 frames could be obtained.

All steel in the drives is assumed to be hot-rolled, low-alloyed, where the external sheets were zinc galvanized. All plastics are assumed to be injection molded, glass-fiber reinforced polyamide. The aluminum alloy is an AlMg3 aluminum alloy, section bar extruded. The copper in the busbars is assumed to be a hot-rolled copper cathode, which furthermore is galvanized. The semiconductors are assumed to consist of 50% plastic, 25% copper, 15% Aluminium alloy, and 10% tin. The fuse switches are similar to the electric cabinets based on the existing EPDs for the model F 200 4P (ABB, 2006), with 51% plastic, 30% steel, and 19% copper. The copper from the fuses and semiconductors are assumed to be wire drawn. The resistors, capacitors, and printed circuit boards, all of which are comparatively small, are modeled with the Ecoinvent flows “resistor, metal film type”, “capacitor, tantalum” and “integrated circuit, logic type”.

Similar to the transformer, the DC drives energy inputs and wastes are also modeled with available Ecoinvent data for the production of a 3 tonnes inverter. Given how the inverter is mostly similar to a converter, whereas it converts (AC) to (DC) rather than vice versa, the data is found plausible for converters and are scaled-down by 20% to the 2.4 tonnes DC drives.

5.2.8.2 Main motor

As mentioned in chapter 3.6, the main motor is a DC motor of 53 tonnes with a rated output of 4.3 MW, attached to the pulley via the engine shaft and bolted onto the motor foundations. The motor has been in usage since the 70s, where the magnetic rotor and steel housing of the motor is still in usage after 50 years. It has been maintained throughout the years and with two more extensive renovations, one recently and one in the 90s. In both the 90s and within the recent renovation, new copper linings weighing 1.5 tonnes was exchanged. The motor with a rated speed of 100 rpm does not have internal bearings but is supported by the bearings of the hoist. Additional maintenance during these use phases has been assumed to now include any larger flows of new material.

Each lifecycle phase of the motor is, as mentioned in chapter 3.8, assumed to be 25 years. The motor has recently been thoroughly renovated a second time in its 50 years of usage and has now initiated its third cycle. For this life cycle assessment, the motor is assumed to be disposed of after this use cycle and has been used for 75 years. Hence, the total weight of the motor is divided by three, where one-third is allocated to this usage, excluding the 1,5 tonne weight of the initial copper linings, which were allocated to the first use cycle. The previous copper linings used in the second use cycle are allocated to the previous use phase, and the latest refurbishment is included in this phase.

The material content could not be obtained for the motor and was estimated according to existing EPDs from ABBs motors ranging from 1.6 MW - 31 MW. In Appendix C, an overview of the material composition from five different EPDs could be seen, which percentage averages were calculated according to the total weight of the motor. The results are seen in table 5.5. Excluding the copper, all flows are divided by three and accounted for in this cycle. Assuming the remaining copper excluding the initial linings has not been replaced, it is the initial weight excluding the copper linings divided by three accounted for in this study.

These assumptions are found accurate enough, acknowledging varieties in material composition and the fact that the investigated motor seems to be significantly heavier than the other references. Based on an average mass per output, the main motor weighs 2.65 times more than the ABB references, which might be the case for an older motor. Also, the fact that the use phase on average accounts for 98-99% of the environmental impact made by electric motors (Orlova et al., 2016; Westberg, 2021) allowed for this simplification, as long as the total material flows are accounted for.

Table 5.5: Material composition of the main motor

Material	**Main Motor based on percentage**	**Allocated to the this study**
Electro steel	2.25E+4	7.43E+3
Normal rolled steel	2.19E+4	7.23E+3
Special steel	2.47E+3	8.16E+2
Cast iron	9.28E+2	3.06E+2
Aluminium	3.32E+3	1.10E+2
Copper	4.46E+3	9.76E+2 + 1.50E+3
Insulation	9.84E+2	3.25E+2
Wooden boxes and planks	2.43E+3	8.01E+2
Impregnation resin	2.10E+2	6.93E+1
Paint	5.91E+1	1.95E+1
		Total: 1,81E+4 kg

The environmental loads related to manufacturing have been excluded, given how the percentage of emissions accounted to the manufacturing were less than 1% for all EPDs. When allocating just a third of these to this cycle, it is assumed to be negligible. Similar assumptions have been made for transportation. The mass flows allocated to this cycle are hence shown in table 5.5. All steel is assumed to be hot rolled, low-alloyed steel using the Ecoinvent process. The aluminum is assumed to be a cast alloy aluminum, processed with section bar extrusion and the copper is wire drawn. The insulation is assumed to be 50% glass fiber reinforced polyester resin plastic and 50% epoxy resin insulator (Westberg, 2021). The packaging wood is dry residual wood, assuming firm wood with a density of 800kg/ m^3, and the paint is assumed to be acrylic paint. Also accounted to the motor is an additional 280 kg of hot-rolled, low-alloyed steel used for protective fencing.

5.2.9 Maintenance

The components accounted for in this subsystem are the materials that are replaced at a higher interval throughout the lifetime. These include ropes, skip equipment, skid plates, corrosion preventive compounds, filters, oils, friction pads, brake pads, and electrical fuses. All these components have different lifetimes, but these are expressed as kilogram products per year for simplicity in the modeling, see Table 5.6.

Table 5.6: Yearly added maintenance materials

Material	**Yearly added materials (kg/year)**
Main ropes	1.10E+4
Skid plates	6.13E+3
Guide ropes	4.62E+3
Balancing ropes	4.16E+3
Friction inlays	1.44E+3
Oils	7.53E+2
Guide rope runners	6.89E+2
Filter	2.39E+2
Brake caliper renovation	1.84E+2
Rope swivel	6.60E+1
Hydraulic rope equalizer	5.62E+1
Corrosion preventive compound	5.15E+1
Rope lock	4.60E+1
Electric fuses	4.50E+1
Brake pads	2.40E+1
	Total: 2.95E+4 kg

5.2.9.1 Ropes

The three types of ropes used are the main ropes, balancing ropes, and guide ropes. Specific LCI data was gathered from World Steel Association (2021), known as “EU steel wire rod, cradle to gate”, which included inputs for the energy and raw material, with 0.23 kg of scrap input per kg produced wire rod. Like the structural and engineering steel and the allocation principles explained in chapter 4.2.4, the data provided did not consider a burden for scrap input or a credit for the EoL recycling. This means it could be implemented with Ecoinvents steel scrap flow just carrying the environmental burden for recycling processes and not the burden for the secondary materials raw material acquisition. Appendix D, shows how the data was presented with inputs and outputs.

Suitable processes for the wire ropes manufacturing were not available in the Ecoinvent database. In general, they are first drawn through hot metal through shafts and later wound on a special winding. However, in this study, they are modeled with Ecoinvents “wire drawing, steel” process. The wire-rods are furthermore manufactured in a Belgian factory and transported to Sweden with lorries. The different ropes are changed at different intervals, but each year there is an average new amount of 11 tonnes, 4.2 tonnes and 4.6 tonnes per year for the main-, balancing- and guide ropes. Although there are minor differences in diameter for the different ropes, they are assumed to be manufactured similarly, and only the weight differs.

5.2.9.2 Skip equipment

The skip equipment changed during the system’s lifetime is the rope swivel, the hydraulic rope equalizer, the rope lock, and the guide rope equipment. These components are assumed to be made out of hot rolled low alloy steel, and the weights add up to 860 kg per year (majority comes from guide rope runners). The providers of these components are located in Sweden and USA, and the guide ropes runners manufacture was not found, so the market process in the ecoinvent database was used.

5.2.9.3 Skid plates

The skid plates are located in various parts of the system, and its function is to protect the permanent mechanical parts from wear caused by the ore that is transported over these plates. The steel used in these is special steel, regarding how it has to endure much wear. Therefore, it is constructed using a unique material called Ni-Hard, specifically designed to resist much wear and abuse. The skid plates are interchangeable and are changed regularly, which adds up to a significant amount over the lifetime. Therefore, the level of detail in modeling is of importance. The annual amount that is changed is 6.1 tonnes, calculated given the sizes of the skid plates, the interval of changing, and the density of Ni-Hard that is $7.7 tonnes/m^3$. The specific material is an alloy with 4% nickel and 2% chromium, commonly used for this application where high hardness and resistance to abrasion are required. The material has been modeled by altering the Ecoinvent process "iron-nickel-chromium alloy" to the required nickel and chromium composition according to the nominal composition for Ni-Hard steel type 1 and 2 assumed (Nickel Institute, n.d.). The skid plates have been assumed to be hot-rolled, and the transportation is modeled using European market activities.

5.2.9.4 Corrosion prevention compounds

Given how the materials are exposed to harsh conditions in the mines, where rust and other corrosion forms can lead to rapid wear and safety issues, all exposed steel materials built in either structural-or engineering steel, low-alloy steel or cast iron must be processed with corrosion prevention methods. There are various ways and measures to treat the metals. The steel sheets in the electric cabinets, the industrial DC drives, and switchgears are galvanized. However, the treatment method was not obtained for the mechanical components and assumed to be coated using powder coating.

Powder coating is one of the easiest and cheapest ways to prevent corrosion (Eon-Coat, 2019), where it is heated and applied to the metal surface to create a thin protective film. The powder coating process for steel in Ecoinvent is a coating process found suitable for all other exposed mechanical components. Given their size, other treatment methods such as galvanization were not found suitable. One supplier provided their compound, TECTYL 506, a wax base, corrosion preventive compound similar to the powder coating based on polymer resin based in combination with pigments, curative, flow modifiers, leveling agents, and several other additives (AMF, 2019). Furthermore, the cost-effectiveness and flexibility of powder coating, where it could be applied to different sorts of metals and sizes, is why it is assumed to be the corrosion prevention process for all exposed structural-or engineering steels, low-alloy steels or casts irons in the shaft, excluding the steel ropes. This treatment is assumed to have been done in their respective manufacturing stages.

Given how the Ecoinvent process was calculated per square meter and the dimensions for all components were unknown and only given in mass, some assumptions had to be made. Whereas ecoinvents zinc coating process used for the galvanization of steel sheets also calculated using coating area rather than mass, it provides information for converting the flows per m^2 to flows per kg of coated product. For each kilogram of zinc coated product, 0.06 m^2 of coating is needed, assuming a coating layer between 65 and 130 μm thick. For the powder coating, which according to Ecoinvent generally has a coating thickness of 80 μm similar conversion is assumed, that 0.06 m^2 of coating is needed per kilogram of treated material. Given how there is 285 tonnes of initial material, and 30 additional tonnes of maintenance material throughout the lifetime that needs corrosion prevention, almost 19 000 m^2 of coating is needed.

5.2.9.5 Filters

For the air filters, the supplier and the module size were provided by LKAB, 592x592x520 mm, as well as its interval of change. From the suppliers' website, the weight of the specific filter (Camfil 2021), as well as a provided EPD for the product was provided (Camfil, 2020). According to these, the frame weighed 0.9 kg, where 80% of the weight consisted of the plastic frame, 15% for the filter media, and 5% for the glue. Furthermore, with substances listed in the EPD, the flow" polystyrene, extruded" was chosen for the frame," fibre, polyester" for the filter media and" polymer foaming" for the glue was chosen in Ecoinvent. The energy consumption in manufacturing was 0.17 kWh per filter with Swedish energy mix, and the distance from the factory to the mine, 1300 kilometers, was added. With these flows, the environmental impact regarding GWP obtained was very similar to the EPD, with a small deviation.

For the hydraulic filters, only the supplier of the filters and their intervals of change was obtained. Similar hydraulic filters with relatively high flow rates (50 liters/minute) weighed approximately one kg each (Parker, 2013). Although not composed exactly like the air filters, they were modeled similarly as the air filters. Given how the interval of change in hydraulic filters was 18 times smaller than for the air filters, the small weight, and their similarity in function and material, this assumption is found plausible. All in all, 266 new filters are added yearly.

5.2.9.6 Oils

The ecoinvent flow "Lubricant oil" is used for both hydraulic fluids (for brakes, hydraulic units, and hydraulic rope equalizer) as well as lubricants for bearings. The total amount of oil that is changed per year is 750 liters. The transportation is modeled using European market activities.

5.2.9.7 Friction pads

This system is composed of two identical sets of friction pads. The first one is mounted on the pulley, where the lines are resting on the upper part of the pulley through friction. The second one is on the deflection sheave, which redirects the ropes and pushes them inwards. The supplier of the pads is a German manufacturer known for producing friction materials for hoist and lifting systems in mining systems. They provide a specific type of material called Becorit. With various types of friction materials, LKAB provided the specific type in which the density could be obtained. The overall weight could further be calculated from the volume when the length and inner and outer radius of the pulley was obtained from the pulley's technical drawings. With 1.7 m3 in volume and 1.2 tonnes/m3 in density for the friction material, each friction pad set weighs 2.2 tonnes. The deflection sheave, with similar diameter and length, hence uses identical pads and is exchanged on the same interval as the drive sheaves.

The material, according to the supplier, is a specific synthetic material and belongs to the chemical group of thermosetting plastics. The chemical property further allows for a high coefficient of friction, even when spills of oil and liquids occur. Although the exact material composition for the friction pads could not be obtained, the Ecoinvent flow "unsaturated polyester resin" was chosen, a synthetic resin that belongs to the chemical group of thermosetting plastics. These are further assumed to be injection molded, where the pad, which looks like a large cylinder, is composed of smaller pieces inserted onto the sheaves and pulley. The material also has good machinability and is turned to the rope groves with a specific turning tool. Once the groves are too deep, the entire pads are exchanged at similar intervals for both pads.

5.2.9.8 Brake pads

Although LKAB provided the frequency of replacement of the brake pads, neither the material composition nor the weight was obtained by the subcontractor and hence had to be estimated. Given how the model of the brake unit was provided, technical data from the manufacturer provided information that the pads were organic. Also, the area of the pads and data of wear was provided.

Although the material composition for organic pads could be very varied, a specific study provided a general chemical composition for organic brake pads (Bretotean-Pinca et.al, 2019). In their study, the pads were composed of aluminum, graphite, silicon carbide, titan oxide, phenolic resin, and coconut fiber. Although coconut fibers could not be found in Ecoinvent, jute fibers were chosen as a substitute, which is mentioned to have the potential application to be a filler in non-asbestos organic friction composites (Matejka, Fu Kukutschová, 2013). Furthermore, zirconia oxide and hexametyl tetramine, which were listed in the study by Bretotean-Pinca et al., were excluded in the modeling since they were not included in the Ecoinvent database. Instead, they were replaced with an increased share of the other materials.

Although the type of brake pads and the exact mixture of raw materials were not obtained, the two studies' level of detail is plausible. Furthermore, given how the filters are collecting the dust from wear and brake emissions in the mines, the emissions to air are not accounted for. Only the environmental load for resource use and manufacturing using the Ecoinvents flow "metal working, average for metal product" is accounted for, including average energy inputs and material losses for the processing by machines and the factory infrastructure and operation. The weight of the industrial brake pads is 6 kg per pad and 4 pads are changed per year which equals 24 kg/year.

5.2.9.9 Brake caliper renovation

The brake equipment needs regular maintenance when oil leaks appear or when something breaks. This is dealt with by replacing parts of the brake calipers or by replacing the entire brake caliper. These renovations add up to 180 kg low alloy steel per year.

5.2.9.10 Electric fuses

The thyristor, which in the recycling instructions is referred to as semiconductor, and the thyristor fuse, referred to simply as fuses, are both changed on average yearly. These were modeled in the DC drive according to material composition in the recyclings instructions (ABB, 2018b). From that, the fuses that weighs 20 kg each were assumed to be 51% plastic, 30% steel, and 19% copper, and the semiconductors that weighs 25 kg each are assumed to consist of 50% plastic, 25% copper, 15% aluminium alloy and 10% tin. They are assumed to be manufactured in Poland, where the DC drives are manufactured.

5.2.10 Electricity consumption

The electricity consumption is used mainly by the main motor, and only a fraction is used in other applications. Initial facts that were obtained were the energy use per ton ore and the ton ore per hour. The total electricity consumption was calculated over the lifetime of the system, assumed to be 25 years. The energy per year amounted to 11 GWh. Due to the installed system's geographical location, the "electricity, high voltage, production mix- SE" process in the ecoinvent database was chosen.

5.2.11 Turning tool

The turning tool is used to even out the friction pads. This tool weighs 480 kg, delivered to LKAB by ABB. It is manufactured in Sweden and is assumed to be made out of low alloyed, hot-rolled steel.

5.2.12 End of life

All transportation from the hoist system to the waste facilities is based on various market activities, including average Swedish distances for waste management. The amount of mass for end-of-life treatments includes both the initial mechanical and electrical components and all disposed of maintenance material throughout the lifetime. Seeing that LKAB has structured and developed methods for EOL management and recycling according to their published guides (LKAB, 2019), it is assumed that all materials have a 100% EOL recycling rate from LKAB after usage in this scenario. Since recycling plastics is assumed to be incinerated in the Ecoinvent database, this assumption is found plausible. The different EOL processes chosen for the EOL treatment are shown in Table 5.6.

Table 5.7: End-of-life inventory data

Material	Application	Mass (kg)	End of life process
Steel (including) brass and tenn	Mechanical components	1.02E+6	market for iron scrap, sorted, pressed | iron scrap
Polypropylene	Friction inlays (thermoplastics)	3.60E+4	sorted, pressed market for waste polypropylene | waste polypropylene
Lubricant oil	Hydraulics	1.99E+4	market for waste mineral oil | waste mineral oil
Other plastics	Electronics	9.05E+3	market for waste plastic, industrial electronics | waste plastic, industrial electronics
Aluminium	Transformers, electronics, main motor	4.10E+3	market for aluminium scrap, post-consumer, prepared for melting | aluminium scrap, post-consumer, prepared for melting
Copper	Electronics, main motor, DC drive	3.13E+3	market for metal part of electronics scrap, in copper, anode | metal part of electronics scrap, in copper, anode
Electric wiring	Cables	3.00E+3	market for used cable | used cable
Mineral wool	Glass fibre	2.18E+3	market for waste mineral wool | waste mineral wool
Wiring boards	Electronics	1.27E+3	market for used printed wiring boards | used printed wiring boards
Wood	Packaging	8.00E+2	market for waste wood, untreated | waste wood, untreated

The European market activity for the steel process creates the output flow "iron scrap, sorted, pressed", which is used as input of secondary material for further steel production. The cutoff is hence at this level, where further processes should be allocated to the following use phases, similarly to how the iron scrap is inserted into the steel production initially in the manufacturing stage of this use cycle. With diesel and electricity as energy inputs in the steel process, environmental impacts do occur. However, it is in the primary steel production where the impacts are more considerable. Throughout the life cycle of the processes, more than one kilotonne of steel is sent to recycling. Although brass and tin are not originally recycled this way, they are still included due to their small weight and no suitable treatment processes.

The EOL process for the friction pads was modeled with polypropylene, a thermoplastic polymer found suitable for the Becorit, a specific synthetic material belonging to the chemical group of thermosetting plastics. With transportation distances and disposal mix country-specific for Sweden, the market activity assumes municipal solid waste incineration (MSWI).

Treatment processes for lubricant oil are either treated through incineration as hazardous waste with or without energy recovery or used in clinker production. The European market activity assumes that the waste mineral oil is treated in the same place as it is produced and uses average distances.

The aluminum scrap is modeled with a European market activity for aluminum scrap, post-consumer, which transports and prepares the scrap for melting. The cutoff is similar to iron scrap, given how it prepares the scrap for secondary production but does not fully produce the aluminum in the following steps. The next process is “treatment of aluminum scrap, post-consumer, prepared for recycling, at refiner”, which furthermore casts and produces secondary aluminum that is hence not included within the system boundaries.

For copper, the waste flow “metal part of electronics scrap, in copper, anode” was chosen, where its provider “treatment of electronics scrap, metals recovery in copper smelter” have similar logic to the other metals and with the same cutoff. However, this market activity did not include transportation data, which were added using similar Swedish market activities.

The remaining plastic, cables, glass fiber, waste from electronics, and the packaging material were modeled similarly with the waste treatment, and material recovery flows according to table 5.7, where the environmental inputs and outputs related to each process were added. In openLCA, the EOL was modeled with an output flow in for the mine hoist system with the EOL process as the provider.

5.3 Life cycle impact assessment

The results from the life cycle impact assessment, the environmental impacts quantified, and a “translation” of the environmental loads from the activities in the inventory analysis are presented for the investigated mine hoist system and is furthermore compared, discussed, and interpreted when comparing it to various scenarios. The study, which assesses a mine hoist system used for 25 years in northern Sweden, is compared to four other scenarios, as explained in chapter 4.2.5 and shown in the following sensitivity analysis chapter in chapter 5.3.1.

The quantitative data of the environmental impacts for the system under study are shown in Table 5.7 according to the functional unit “1 tonne of goods * vertical kilometer transported”. The contributions from the different impact categories are shown in Figure 5.7, illustrating the substantial contribution from the electricity production for the use phase. Other than the electricity production, the ropes and skid plates are the two succeeding environmental contributors for most of the impact categories. This mainly has to do with its mass, given how they are exchanged throughout the lifetime and are the largest mass flows contributing close to 60% of the total mass throughout the life cycle.

Table 5.8: Results of LCIA. Environmental impact per functional unit

Impact category	Unit	Swedish energy mix 25 years
Climate change	kg CO_2-eq to air	1.67E-1
Human toxicity: non-cancer	kg 1,4 DCB to urban air	1.57E-1
Terrestrial ecotoxicity potential	kg 1,4- DCB to industrial soil	7.54E-1
Land use	$m^2 \cdot yr$ annual land crop	4.38E-2
Mineral resource scarcity	kg Cu-eq	2.63E-3
Fossil resource scarcity	kg oil-eq	2.91E-2
Ionizing radiation	kBq Co-60-eq	1.05E+0

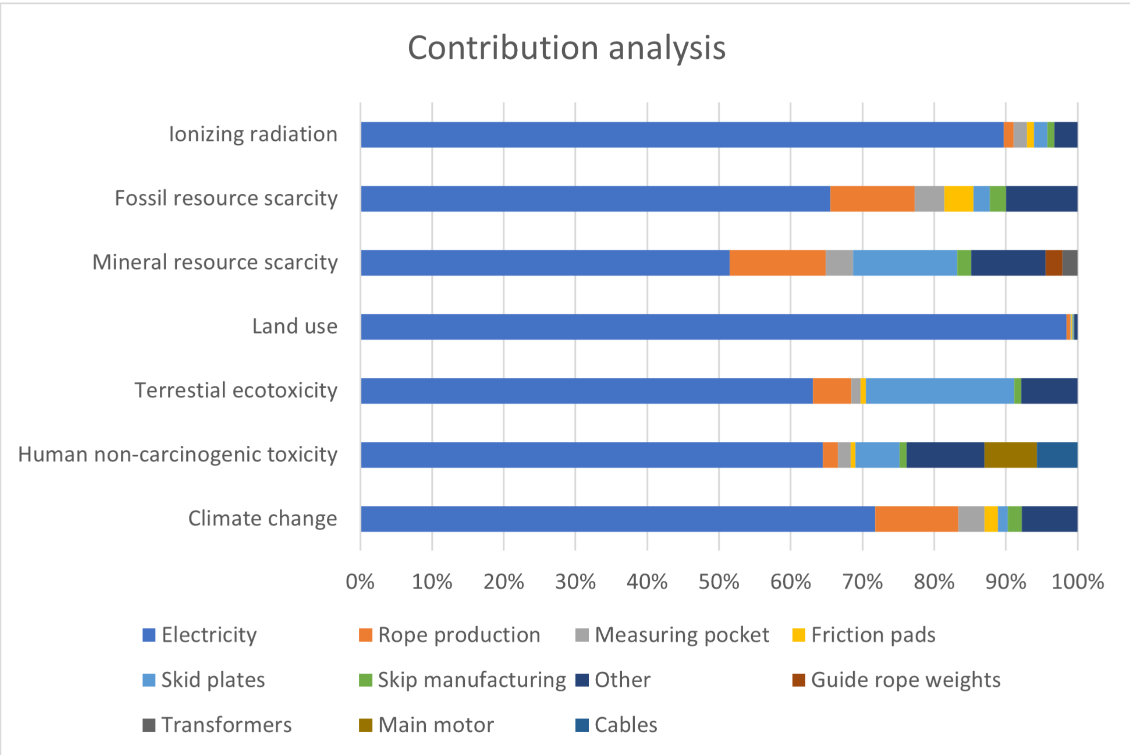

Figure 5.7: Contribution analysis mine hoist system

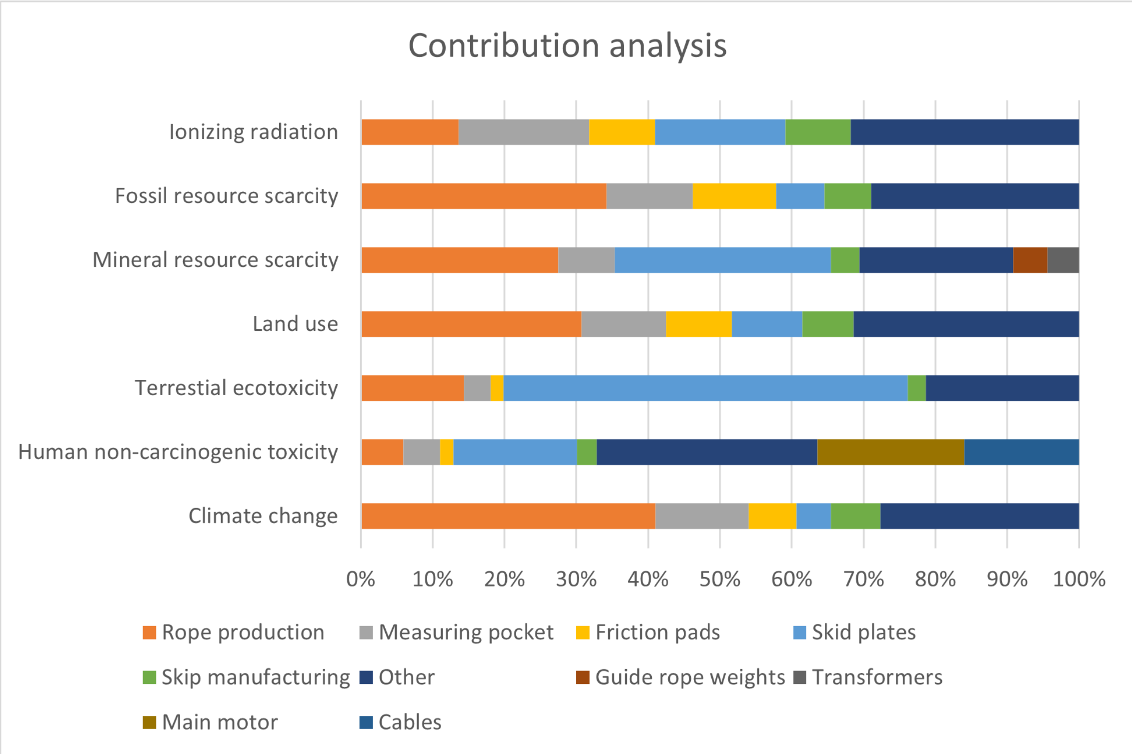

Figure 5.8: Contribution analysis mine hoist system excluding electricity

5.3.1 Sensitivity analysis

The seven different impact categories, divided between the five scenarios as explained in chapter 4.2.5 illustrates the critical contributors throughout the life cycle of the mine hoist system. The contribution of the different inputs and the variation that arose between the different scenarios is presented in further detail in Appendix B.

Scenario 1: 25 years of usage in Sweden
Scenario 2: 40 years of usage in Sweden
Scenario 3: 25 years of usage in Australia
Scenario 4: 25 years of usage in Sweden. A halved amount of ropes and skid plates throughout the use phase
Scenario 5: 25 years of usage in Sweden. Substitution to secondary steel throughout the system

5.3.1.1 Climate change

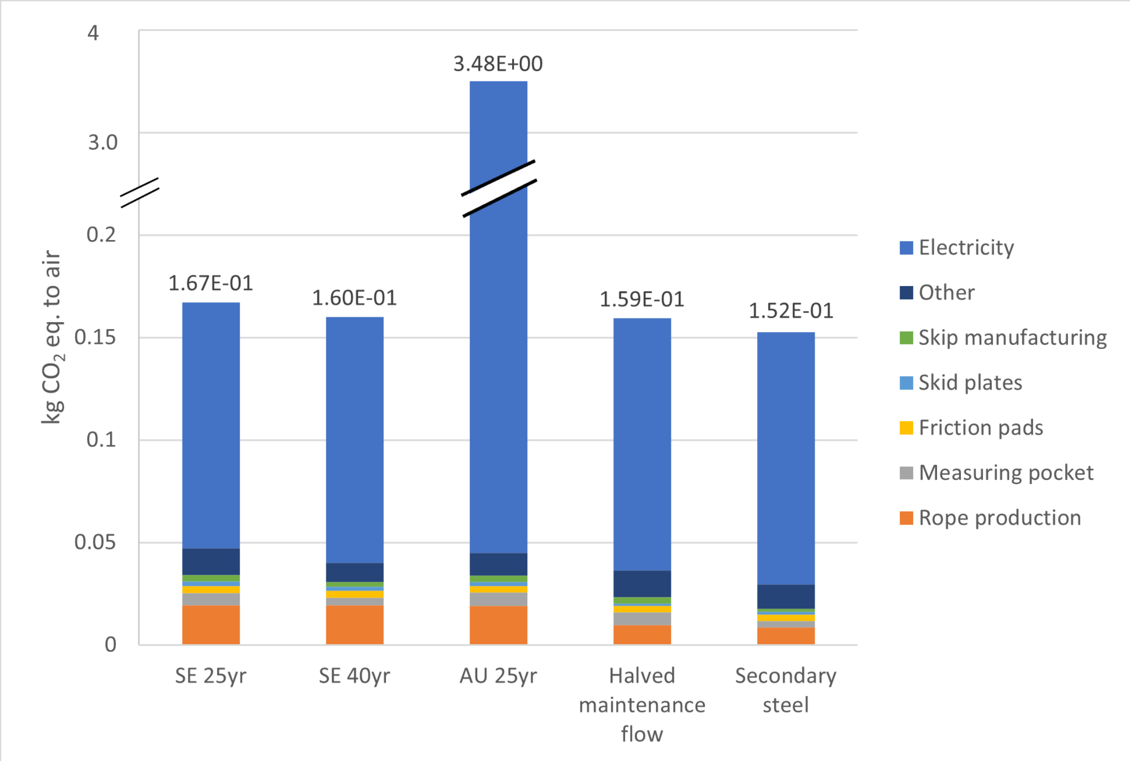

Figure 5.9: Sensitivity analysis climate change

The results speak clearly for the influence on the choice of the energy mix and the ropes' weight and exchange rate over the lifetime. Furthermore, the overall impact from the use phase is the most significant lifecycle stage. The various choices of scenarios showed no significant changes in the quotas between contributing product stages, except for the third scenario, where the contribution from electricity increased to almost 99%.

In the initial scenario with a Swedish energy mix and a usage over 25 years, the global warming potential is 0.17 kg CO_2eq. per functional unit. An increased lifetime as in the second scenario, with 15 years of increased usage, showed reduced GHG emissions by 4.3%. Given how the electricity and the rope production represent 72% and 12% of the proportion, extended usage of the mechanical and electrical components showed a reduction per functional unit. However, with an extended supply of electricity consumption and maintenance materials, this reduction is relatively small.

The third scenario with a changed electricity mix showed a more considerable difference with 5.6 kg CO_2eq. per functional unit. Australia gets 25% of its electricity from low-carbon sources, meaning nuclear or renewables, compared to 98% in Sweden (Our World In Data, 2021). Needless to say, the global warming potential increased significantly with a more carbon-intensive energy mix. The Australian energy mix emits 0.97 kg CO_2eq. per kWh according to Ecoinvent, rather than the

Swedish energy mix that emits 0.026 kg CO_2eq. per kWh. This increase, by a factor of 37, responds to an overall increased GWP with a factor of 20. In the scenario with the Australian energy mix, electricity represented almost 99% of the global warming potential rather than 72% from the initial scenario.

The results from the fourth scenario with a reduced material quantity showed the potential of a reduced amount of maintenance materials, which led to a reduction of GHG emissions by 4.6%. Due to the extensive materials flows from the ropes and skid plates, to double the lifetime and half the material flows showed greater carbon savings than to extend the usage on the mechanical and electrical components as in scenario two. However, as a preventive method, the fifth scenario seemed most promising when it showed a reduction of 8.7% in GHG emissions. Given how more than 90% of the total mass in the system originates from different types of steel, substitutions to less carbon-intensive steel could have significant changes on the overall emissions.

Another realization is that global warming potential was the only impact category that showed any noticeable contribution from the end-of-life treatment. However, it only contributed approximately 1% in all scenarios other than in the third scenario, where it was reduced to 0.05%. From the end-of-life treatment, it is primarily the incineration of plastic that emits carbon dioxide. Also, the transportation showed smaller contributions which in the other categories were neglectable. Regarding transportation, the main contribution came from the ropes, which due to their weight and long distance of transportation, contributed to approximately 2% of the overall impact.

5.3.1.2 Human toxicity

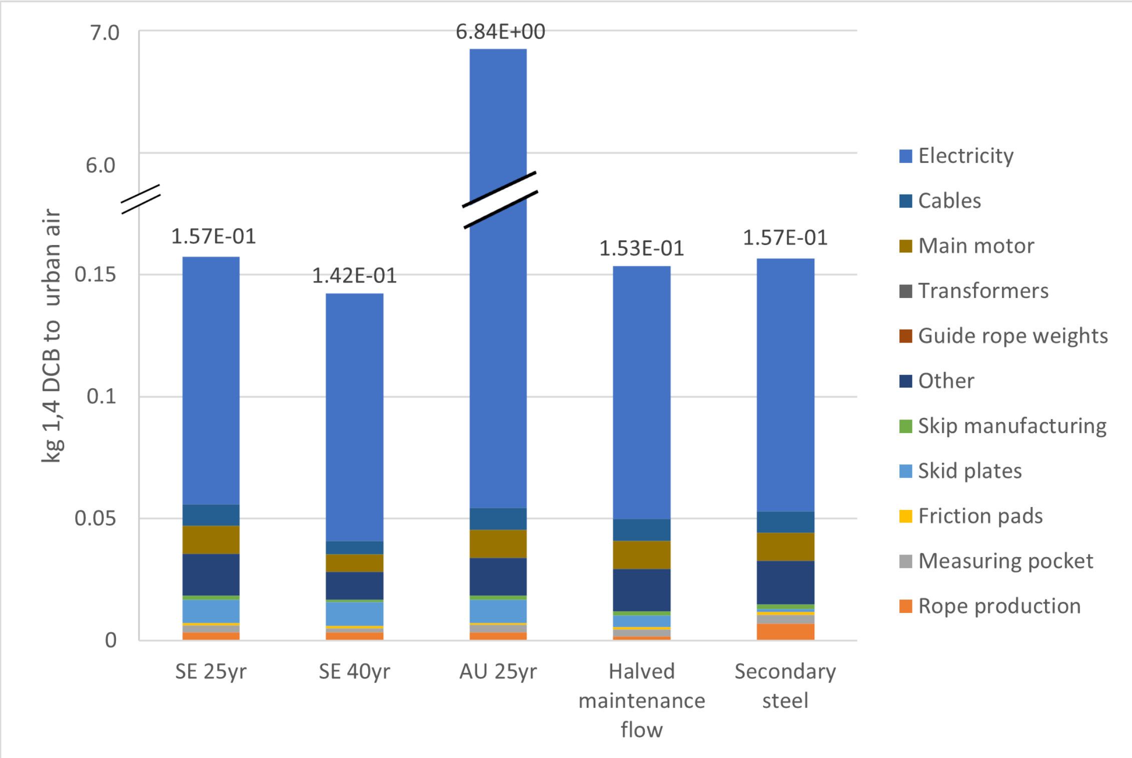

Figure 5.10: Sensitivity analysis human non-carcinogenic toxicity

Within this impact category, the differences are primarily seen through the various contributions from electricity production in scenarios three. The scenarios with Swedish electricity production all show mostly similar results. The main contributor of the toxicity comes from the heat generation of wood chips, where the treatment of wood ash mixture leads to 64 kg 1,4-DCB per kg waste. The second scenario does, however, show some variations with a 9,5% reduction, where the extended usage of the main motor leads to smaller contributions from the copper. The different production methods and contributing waste streams from copper contribute to this impact category. E.g., the treatment of sulfidic tailings, a common waste from copper mine operation, contributes to an equivalent of 1,7 kg 1,4-DCB per kg of sulfidic tailings.

From the third scenario, increased by a factor of 27, it is almost exclusively the lignite and coal that contributes to the toxicity. The great amount of waste from these processes leads to significant impacts. The treatment of spoil from lignite mining contributes to the equivalent of 0,14 kg 1,4-DCB per kg of spoiled lignite, and the treatment of spoil from hard coal mining contributes to an equivalent 0,16 kg 1,4-DCB per kg of spoiled coal. However, due to the sheer amount of spoiled coal and lignite, the contribution becomes proportionately larger.

5.3.1.3 Terrestial ecotoxicity

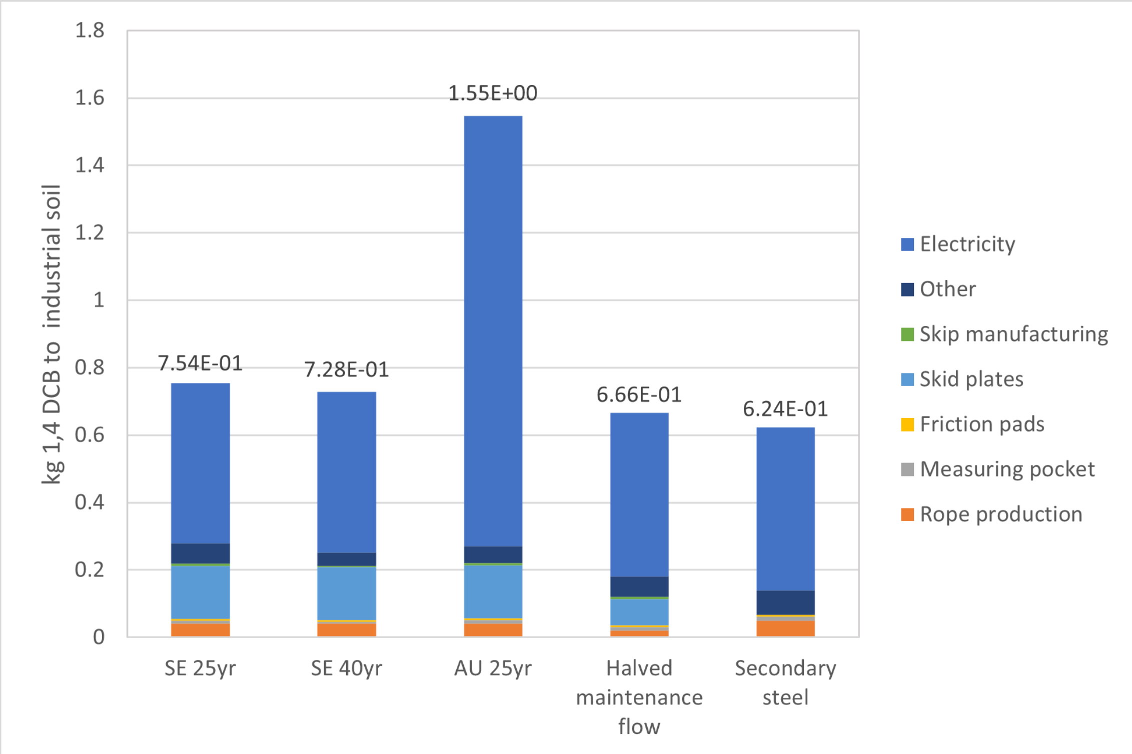

Figure 5.11: Sensitivity analysis terrestial ecotoxicity

Although the results seem similar to human non-carcinogenic toxicity, the contributors are varying. The electricity is for all scenarios most contributing. From the scenarios using Swedish electricity, the impact from nuclear sources is more evident, followed by the heat generation of wood chips. The skid plates with high nickel content furthermore contributed significantly, with 21% of the initial scenario. The smelting and refining of 1 kg nickel concentrate are equivalent to 9.5 tonnes 1,4-DCB.

Provided that the impacts from materials other than skid plates had small contributions, the difference when extending the lifetime in scenario two showed a slight difference. However, in scenario four, when the weight of skid plates was halved, it showed an overall 12% reduction. Similarly, in scenario five, when they were substituted to secondary steel, which contained a much lower content of nickel, the impact was reduced by 17%. For terrestrial ecotoxicity, the fifth scenario may therefore be somewhat misleading. The scenario is more applicable for global warming and illustrating the savings of less carbon-intensive steel. However, it still shows the opportunities for reducing the terrestrial ecotoxicity impact when reducing the amounts of nickel in the skid plates.

For the third scenario using Australian energy, it is primarily the use of lignite that contributes 80% of the overall impact. The use of approximately 1,2 kg of lignite per kWh contributes to proportionately 0,37 kg 1,4-DCB.

5.3.1.4 Land use

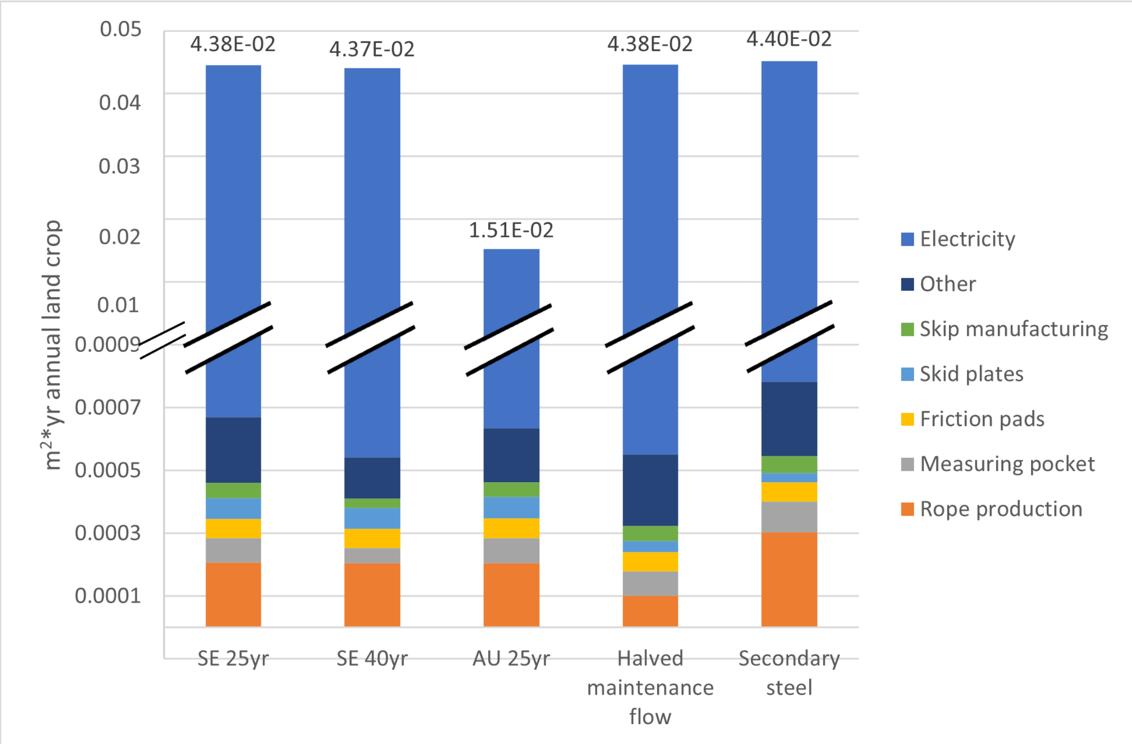

Figure 5.12: Sensitivity analysis land use

Similarly to the other categories, electricity is the superior contributor with 96-99% of the overall impact in the different scenarios. The reason for the electricity production contribution varies between the three different providers. For the Swedish scenarios, it is bioenergy, the energy made from biomass in wood chips, that contributes to 87% of the land usage. In the Australian scenario, coal usage is the primary contributor, which contributes to 42% of the overall usage, followed by wood chips contributing 33%, and lignite that contributes 15%.

5.3.1.5 Mineral resource scarcity

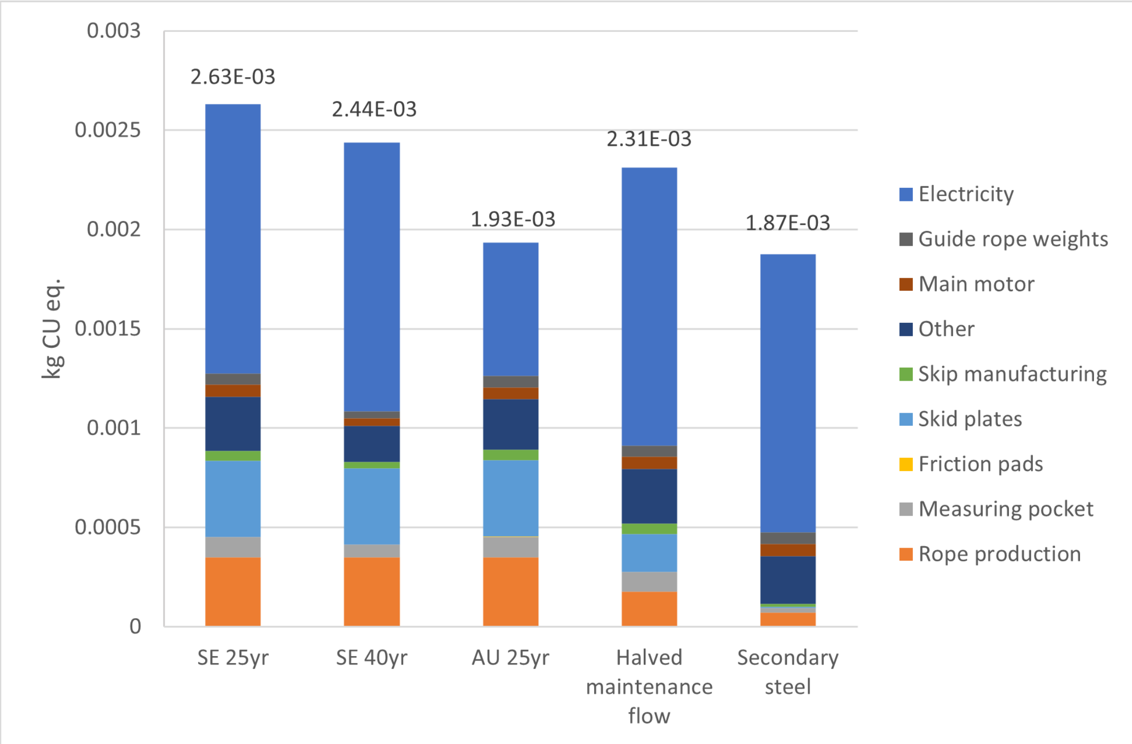

Figure 5.13: Sensitivity analysis mineral resource scarcity

Within this impact category, the contribution from electricity is in comparison lower than the other categories. Instead, the materials primarily in the ropes and skid plates show higher proportions. However, energy production is still the main contributor, where upstream processes for extracting uranium, lignite, and coal in the different scenarios contribute to the impact category.

Regarding the materials, the minerals used in all steel throughout the systems show corresponding high contributions. Here, the skid plates show the highest contribution, and especially in comparison to their weight. Although the material flows of ropes are more than three times as high, the contribution from the skid plates is still higher. This has to do with the high contribution from nickel, which the skid plates have a much higher concentration of. In the impact category, 1 kilogram nickel is equivalent to 4.9 kilogram copper equivalent. This means that the 1 kg of produced skid plates is equivalent to 0,2 kilogram copper equivalent, whereas the ropes only 0,050 copper equivalent per kilogram produced.

5.3.1.6 Fossil resource scarcity

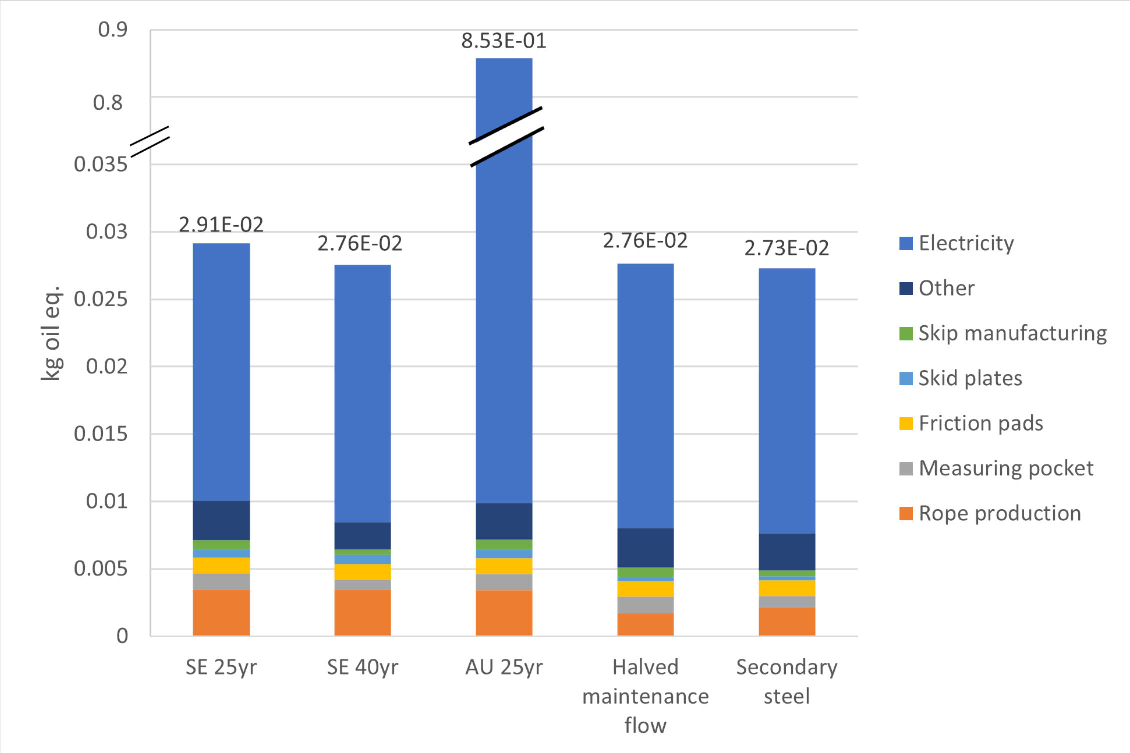

Figure 5.14: Sensitivity analysis fossil resource scarcity

The bars of fossil resource scarcity is mostly consistent with the appearance of the bar of climate change, not that surprising given how fossil resources are the main contributors to climate change. The third scenario with the Australian, more carbon-intensive energy mix shows, as expected, a much higher contribution with 29 times higher impact per functional unit. In the Australian scenario, the lignite, hard coal, and natural gas used for electricity production contributes to 97% of the overall contribution. In the other scenarios, the import of electricity to Sweden was the contributing factor.

Regarding the materials, some additional discoveries were made. Similar to climate change, transportation showed some contributions within this category, emerging from fossil transportation fuels. The contributions were actually higher than for the climate change category, where, e.g., the main contributor, the ropes, contributed 3.7% of the overall impact. Regarding the various steel materials, the fossil resource scarcity per kg of product showed variations. E.g., the skid plates, which have a larger weight over the lifecycle than the measuring pocket and skips, showed a lower impact per kilogram of material. This primarily had to do with the larger rates of secondary steel in those products with a smaller amount of fossil fuels used in production, which could be seen in scenario five, where the use of secondary steel in the system reduced the overall impact by 6.0%. Also, the friction pads showed the highest percentage contribution within this category, 4.4% in the initial scenario.

This came from the production of petroleum-based polyester resin.

5.3.1.7 Ionizing radiation

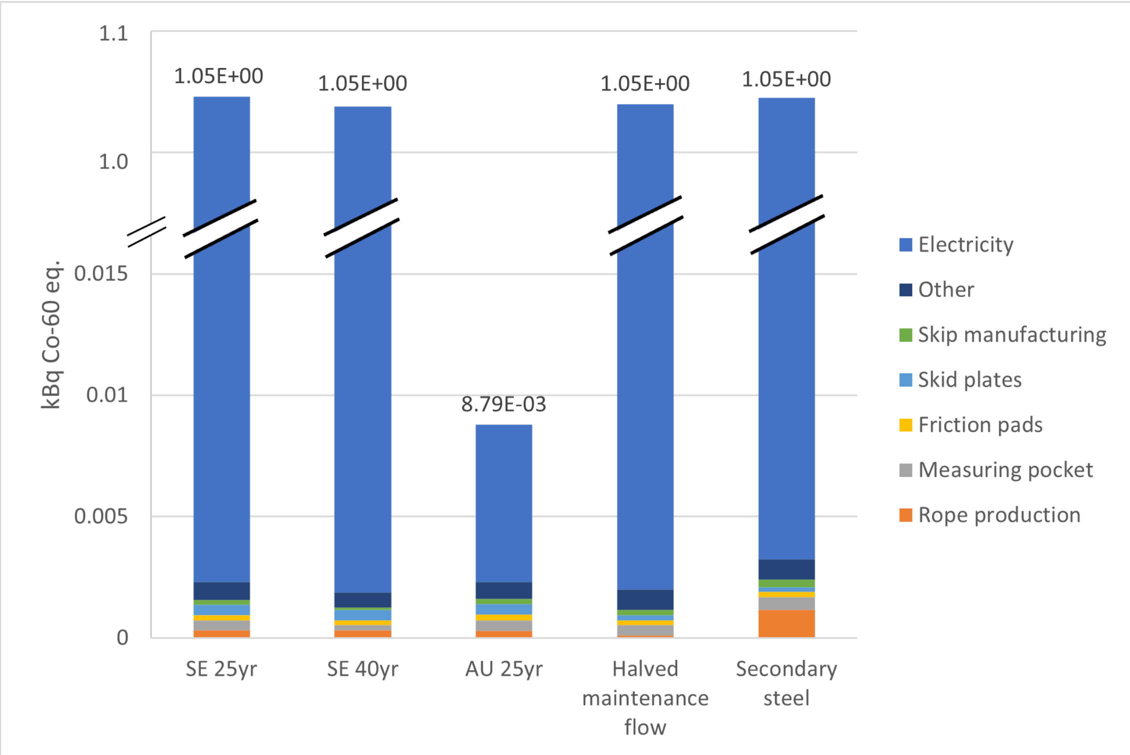

Figure 5.15: Sensitivity analysis ionizing radiation

The ionizing radiation is significantly lower in scenario 3, by a factor of 79, due to the lower amount of nuclear power usage.

The lignite, hard coal, and natural gas actually do contribute to ionizing radiation as well, but far lower. Where e.g., 1 kWh of electricity from lignite emits 0.00012 kBq Co-60 equivalent, 1kWh of electricity from nuclear power emits 0.061, more than 500 times as much. Resource materials used in the construction of wind turbines, such as coal and electricity inputs, had small contributions as well but were significantly smaller.

6

Results and discussion

This chapter answers the research questions as stated in the introduction, one at a time. The first two questions are the result of the Life Cycle Impact Assessment and further interpreted and summarized. The third and final question relates more to how ABB strategically and technically could apply the recommendations provided by this report. In combination, these answers provide ABB with improvement areas and suggestions of how their products could be designed, produced, used, and handled differently.

6.1 What is the environmental impact of an ABB mine hoist system cradle-to-grave?

From the impact assessment, with quantitative results of the environmental impacts per functional unit and elaborated sensitivity analysis used for interpretation, some overarching results could be obtained. As seen in Table 5.8, the results have shown the environmental impacts for the mine hoist system cradle-to-grave, with the raw materials extraction and production of materials, the energy consumption and maintenance materials added throughout the use phase, and end of life treatment.

The choice of the functional unit "1 tonne of goods * vertical kilometer transported", although highly applicable for the system's function and making comparisons to other systems, makes the results somewhat hard to define and interpret without references to other similar studies. Its function to transport mass over a distance could, e.g., be compared to lorries. Compared to a 16-32 metric ton, EURO5 lorry, which has been used for modeling in this study with the same reference flow, the mine hoist systems contribution to climate change is 13% higher per tonne*kilometer. However, this interpretation should be treated with caution when the usage of these two different systems is highly different.

The significant contribution from the use phase, primarily the electricity consumption, is also interesting evaluating in a larger perspective. As seen in the sensitivity analysis and the contribution analysis, the results showed how the 11 GWh of electricity used each year contributed 72% of the climate change impact over a lifetime. Once put in perspective to the total energy use for LKABs operations in Kiruna, the electricity consumption for the mine hoist systems shows significance. LKABs operations in Kiruna used more than 2200 GWh of energy in 2020, where the electricity consumption amounted to 1200 GWh (LKAB, 2021). Based on this, the evaluated b2 mine hoist system accounts for 0.94% of the total electricity consumption of the Kiruna mine. Considering the 12 other mine hoists, this amounts to more than 10% of LKABs electricity consumption. Even though not all mine hoist systems have the same configuration, and the conditions and the structure of mines differ, this comparison shows the electricity contribution from mine hoist systems and the relevance in reducing the costs and environmental impact of these.

This attributional life cycle assessment has provided ABB with data on the environmental impact associated with the mine hoist system, which has generated knowledge that could be used for further comparisons of the impacts of mine hoist systems. Also, the results provided could be used to increase the knowledge regarding the environmental impacts of raw material extraction when the research of impacts from mining equipment in hoist systems has been investigated.

6.2 What are the environmental hotspots?

Identification of the environmental hotspots answers primarily the areas that give rise to the largest environmental impact and provides insight into what areas improvements could be made. As seen in the contribution analysis, the electricity during the lifetime is by far the single largest environmental impact throughout all impact categories. The second-largest environmental impact is from the production of all steel parts used during the system's lifetime. The environmental impact is strongly related to the mass of the parts. This results in that the ropes and skid plates in the maintenance are the following main contributors, followed by the measuring pocket, the heaviest mechanical component.

Results of all the scenarios in the sensitivity analysis, and further investigations of the contributions, led to the understanding that the transportation of all materials is relatively small, contributing the most in the climate change and fossil resource scarcity categories, primarily for the ropes. These were surprising results given how ABB personnel thought that the emerging impacts from transports would be a highly contributing factor in initial discussions. Also, similar awareness was raised regarding the impacts from the end of life disposal. The contributions were only noticeable within the category of climate change, primarily from the incineration of the friction pads.

6.3 How could ABB reduce the environmental impacts of mine hoist systems, especially considering circular economy opportunities?

Beyond which areas to focus on, the question of how to change is equally important. The life cycle-based typology for resource efficiency measures by Böckin et al. (2020), as explained in the literature review, provides guidance and circular measures towards how to reduce the environmental impact in various ways throughout the different life cycle phases. Throughout the extraction and production of materials, usage, and post-usage, various measures are provided regarding how to reduce the environmental impact.

Given how the business area of Process Industries mine hoist systems do not have any production of their own, measures within extraction and production are more related to the design of products and demands on their suppliers. Changes of materials in the products as seen in scenario five, or to reduce the material quantity in products without material substitution as seen in scenario four, both showed the potential of significant environmental savings.

Within the use phase, the environmental impact could be reduced from two perspectives, with measures to use more effectively and efficiently and with measures to extend the usage. The most significant contributor of impacts emerging from the electricity consumption shows the potential of reducing the energy consumption or changing the provider, as seen in scenario three with the Australian energy mix. In this study, the efficiency of the motor has not been investigated. An updated motor might have the potential to reduce consumption even further. With the high consumption over a lifetime of 25 years, a small improvement in efficiency could have vast environmental savings. However, this could be expensive, and other focus areas may be preferable to act upon. As illustrated by the spikes in the third scenario through several categories, the provider of energy is essential. To reduce the environmental impact, especially within the impact of climate change, the choice of a clean energy provider is low-hanging fruit and a measure that has the highest impact on environmental savings.

Measures to extend the usage, either through increasing the lifetime by design, through increased maintenance, or reusing parts, also have the potential of reducing the impacts. However, as seen in the inventory, the maintenance materials, primarily the ropes and skid plates, contributed 67% of the total mass in the system and is where the main focus should lie. When just extending the system's lifetime, as in scenario two, the savings are relatively small without altering the amounts of maintenance materials. Scenario four, doubling the lifetime of all maintenance materials, showed relatively larger environmental savings. Either scenario is individually perhaps not plausible. However, the realization of the environmental savings through extended usage should be brought to forthcoming projects. E.g., it was realized that the friction inlays are replaced at similar intervals for both the hoist drum and deflection shave. Even if it is logistically preferable, it is environmentally preferable to use the products as long as possible before disposing of them.

In this study, the end-of-life has not been assessed through various scenarios. Average treatment methods used in Sweden have been assumed, and furthermore that all materials are either recycled or incinerated. The responsibility to ensure that the materials are disposed of properly lies within the user of the product, in this study LKAB. Furthermore, available local infrastructure such as modern waste incineration facilities is not always possible as in this study. To continue working with these measures, ensuring that materials are being kept in use and preventing the linear "take-make-dispose" practice is important.

Finally, and relevant throughout the entire life cycle, are changes towards a more circular business approach in general. If the mine hoist system is sold as a function or service rather than as a product, additional incentives for environmental improvements could be obtained both for ABB and their customers. When ABB has responsibility for the system throughout the life cycle, they could create further knowledge and control of the supply chains. Westberg (2020), who investigated the environmental impacts of an ABB synchronous medium voltage motor and drive, explained how customers, unfortunately, rarely are interested in paying the additional cost of environmentally improved products. However, through circular business models, it might be possible for ABB to enable the improvements and investments needed, where the customers are paying per function rather than as a product. Closer collaborations with all stakeholders and a circular approach of thinking could have the potential to reduce the environmental impact associated with the mine hoist system and create positive externalities along the value chain of mine hoist systems.

6.4 Discussion

Since this study is the first of its kind to evaluate the environmental impact within a narrow area of mine hoist systems, it fills a gap of uncertainties for both ABB and academic research on mining equipment. The accuracy of the overall work is challenging to evaluate. To gather knowledge and quickly familiarize oneself within new areas such as electronics, mechanics, and industrial-sized operations is a challenge for the practitioners as in all life cycle assessments. Remote working due to the pandemic also came with additional challenges when all communication was digital, and the mine hoist system could not be seen on site. However, with the circumstances and resources available, the authors are overall satisfied with the results and the completed work. There are, however, some topics to discuss regarding the results and methodology of the study.

6.4.1 Discussion of methodology

Regarding the life cycle methodology, the ISO standard and the four phases as described in chapter 4 have been followed. However, the procedures come with interpretations, and some comments could be made on the presented impact categories, the selection of functional unit, and the layout of the LCA model.
Although the methodological choice of selecting impact could be questioned, the authors want to emphasize that it does not alter the quantitative results, merely what categories are being selected as mentioned in chapter 5.1.2.2. However, any assortment of categories is subjectively based unless all of them are presented, which is problematic from other perspectives. Therefore, in this study, the authors chose to relate all results to specific reference values and choose the most relevant ones while still presenting climate change and resource scarcity categories, as desired initially in the study.

Furthermore, regarding the result and as a comment on mainly using generic data from Ecoinvent or the World Steel Association. With generic data, there are uncertainties when there is no available data for every material and process in every country. As in every life cycle assessment, the results should be seen as conclusions of significant issues within environmental findings and not necessarily be seen as exact values of the environmental data throughout the life cycle. Gathering an entire inventory of all environmental and physical flows in detail for all components in the system would be impossible to perform with the provided time span. Similar reasons go for the exclusion of inventory, as mentioned in chapter 5.1.2.3. Some components whose weight was realized to be insignificant after the material composition had been obtained would, in hindsight, been excluded with similar logic. However, with the efforts already made, they were chosen to be included, although it hardly mattered.

Regarding the functional unit, it does provide further comparisons with other systems and could easily be allocated to the impact of raw materials. However, the unit in tonne*kilometer is much harder to interpret. From the values, the percentage reduction looks insignificant, but it is important to realize that the masses transported and distances traveled over a day are huge. Over a 25-year lifetime, they are massive. This balancing, between a reference flow that easily could be interpreted and understood, or a flow that is more suitable for future comparisons fell on the latter.

The modeling of the system, which was built upon through the various subsystems, led to a grouping of the activities into products, rather than categories of life cycle phases, such as production, transport, usage, and end-of-life. The hotspot analysis was hence primarily made from the various products, although distinct conclusions regarding the phases could still be obtained with the massive and evident contribution from the electricity production throughout all impact categories. The results still showed the areas of most urgent improvement but could have explained with more detail of various life cycles if the logic during modeling would have been performed differently.

6.4.2 Discussion of results

Regarding the results, the conclusions are that the use phase with the electricity consumption and material contributions from maintenance contributed to the majority of impact associated throughout the lifetime. However, some additional comments could be made regarding how the data has been calculated and presented.

The software used, openLCA, whereas highly helpful and timesaving in modeling, does come with limitations. First of all, the impact assessment and further investigations of contributing activities does only show the emissions per equivalent unit of each characterization factor and not for all contributing emissions. In order to investigate the different contributors to climate change, e.g. nitrous dioxides and methane, the different contributing activities must individually be assessed, which is highly time-consuming. Further assessment of which environmental flows contribute to the various impact categories could provide additional insight into how to reduce the impact, but were outside the scope of this study.

Also, given how this system is primarily constructed of various types of steel, the ambition was to investigate these types and gather inventory with a higher level of data than using generic data from Ecoinvent. The differences in environmental impact for the different steel types have not been further investigated, and the impact associated with the various steel was proven to be mostly correlated with the amounts of secondary steel used. The inventory sources were also based on generic data, although more recent and geographically applicable life cycle inventory for specific steel types in Europe by World Steel Association. Further environmental studies which focus exclusively on the source, recycling rate, and inventory of the steel used could improve the assessment's level of detail. Due to the scope of the study, however, generic data had to be used.

The final results were highly comparable to similar studies, such as Westbergs (2021) life cycle assessment for ABB, where the study found the use phase of the motor and drive to be the biggest contributor, with almost 99% of total climate impact. The study also concluded that a Swedish electricity mix could lower climate impact by a factor of 25, similar to a factor of 21 in this study. Although this study has a broader scope with more components, the results were still highly similar. The earlier studies on residential elevators (Salmelin et al.,2002; Miljögiraff, 2015; Selander, 2016) also showed the high environmental burden from usage and the importance of the electricity mix, as confirmed in this study.

6.4.3 Recommendation for future studies

This study has provided ABB with suggestions for how to proceed in their environmental work and an insight that the environmental impacts primarily are associated with energy consumption and material wear throughout the lifetime. Some comments could be made on how to proceed with these findings and the recommendations for ABB.

The first recommendation is to investigate the electrical efficiency measures possible to implement in the motors and the costs vs. benefits for this. As seen in the contribution analysis and the sensitivity analysis, reduced electricity consumption has the opportunity to significantly reduce the environmental impact, especially in countries with a more carbon-intensive energy mix. However, as discussed with personnel in ABB and LKAB, these measures can be expensive with an extensive system transformation. Therefore, measures should be focused on is the environmental saving versus the monetary cost, leading to more efficient environmental work over the entire system.

The second recommendation is to investigate measures to reduce the maintenance materials. As seen in the inventory analysis, close to 30 tonnes of materials are added as maintenance materials each year, primarily as ropes and skid plates. Over 25 years, more than one kilotonne of materials is consumed. Future studies should investigate the ability to minimize the maintenance materials that are continually exchanged. The studies could investigate other materials that will prolong the lifetime or other designs that could extend the lifetimes or reduce the amount of materials.

The third and final recommendation is to investigate how circular business models most effectively could be implemented for ABB and their customers. As discussed with the third research question, a circular business approach could create economic and environmental incentives for ABB and its customers. With circular business models, it could be possible for ABB to enable the improvements and investments needed, where the customers are paying per function rather than as a product. However, the organizational and economic barriers to this are recommended to evaluate further. Circular business models such as providing a service rather than a product or measures for maintaining, repairing, and remanufacturing the products could furthermore reduce the environmental impact and cost for the systems. Further studies evaluating the stakeholder opinions, challenges, and opportunities for circular business models could provide ABB with further suggestions for proceeding in their environmental work.

7
Conclusion and recommendation

In this study, the environmental impact of ABB Process Industries mine hoist systems has been assessed. A deepened knowledge and understanding have been gathered through the identification of the most urgent areas of improvement and how to conduct those changes considering circular economy opportunities efficiently.

From the findings presented in this report, some conclusions can be drawn. The study has shown that the largest single contributor to all environmental impacts is electricity consumption. Differences in electricity mix have shown the possibilities to save up to 266 kilotonnes of CO2e, and circular measures such as more effective and extended usage of materials could reduce the material flows with several tens of thousand kilograms, with significant environmental savings.

The authors want to emphasize, though, in relation to the results provided, the importance of not focusing too narrowly on solely the energy contributions and ignoring the other contributions. The contributions from electricity and the differences to the third scenario illustrate the importance of choosing sustainable and renewable energy sources. However, if the electricity provided does come from clean sources, ambitious efforts to reduce the electricity consumption could be both problematic and expensive, where more reasonable measures would be to first investigate within what areas the maintenance materials could be reduced.

The recommendations of how to proceed, other than ensuring that the energy comes from clean sources, consist of further efforts to reduce the amount of materials, especially within the area of maintenance material. 67 percent of the overall weight throughout the lifecycle emerges from the maintenance subsystem, primarily from the ropes and skidplates. Investigations into whether an increased amount of materials used in maintenance products would improve their lifetime would be interesting. Other studies, such as if the materials could be substituted against an environmentally preferable option or if design changes could extend the lifetime, would also lead to increased insight into how to reduce the impacts. Further interest and lookout for decarbonization strategies in the steel production should also be followed, potentially reducing the climate impact as seen in the sensitivity analysis.

To conclude, this study has provided ABB Process industries with suggestions of how to proceed in their environmental work. With a newly emphasized understanding of the importance of impact associated with energy sources and the realization of the impact associated with material usage throughout the lifetime, this study could create new opportunities for ABB to reduce the environmental impact associated with products offered by the hoisting division.

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A

Appendix

Table A.1: LCI data for Loading/dumping equipment

	Total weight (kg)	Transport distance (lorry)	Transport distance (ferry)	Structural steel	Low alloy steel	Cast iron	Aluminium (cast alloy)	Copper (cathode)	Steel, chromium steel 18/8
Loading/dumping equipment									
Measuring pocket	1.03E+05	1.40E+03	2.77E+02	1.03E+05					
Weigh modules	2.64E+02	1.36E+03							2.64E+02
Hydraulic unit loading	1.73E+03	2.44E+03	2.00E+01		1.45E+03			1.73E+01	2.60E+02
Hydraulic unit loading motor (Pump2) 5.5kw	1.12E+02	2.82E+03	2.00E+01		6.44E+01	2.16E+01	1.48E+01	1.07E+01	
Hydraulic unit dumping	1.52E+03	2.44E+03	2.00E+01		1.28E+03			1.52E+01	2.28E+02
Hydraulic unit dumping motor (Pump 1) 37kw	2.74E+02	2.82E+03	2.00E+01		1.61E+02	6.46E+01	2.63E+01	2.27E+01	
Hydraulic unit dumping motor (Pump 2) 2,2kw	2.59E+01	2.82E+03	2.00E+01		1.46E+01	5.21E+00	3.54E+00	2.58E+00	
Hydraulic unit dumping motor (Pump 3 cirkulati	1.82E+01	2.82E+03	2.00E+01		1.02E+01	3.68E+00	2.50E+00	1.82E+00	
Motor for cooling of hydraulic unit dumping 0.3	4.60E+00	2.82E+03	2.00E+01		2.56E+00	9.30E-01	6.30E-01	4.60E-01	
Hydraulic cylinder	3.71E+02	2.87E+03	2.00E+01		3.71E+02				
Hydraulic unit guide and hatch	7.80E+02	2.44E+03	2.00E+01		6.55E+02			7.80E+00	1.17E+02
Hydraulic unit motor 7.5kw	6.86E+01	2.82E+03	2.00E+01		4.04E+01	1.29E+01	8.87E+00	6.39E+00	

Table A.2: LCI data for Shaft equipment

	Total weight (kg)	Transport distance (lorry)	Transport distance (ferry)	Structural steel	Low alloy steel	Cast iron
Shaft equipment						
Skip	5.22E+04	2.86E+03	2.00E+01	5.22E+04		
Guide ropes weights including rope attachment	7.62E+04					7.62E+04
Sheave	1.07E+03				1.07E+03	
Skip guiding equipment	5.92E+03	1.40E+03	2.77E+02	5.92E+03		

Table A.3: LCI data for Hoist equipment

	Total weight (kg)	Transport distance (lorry)	Transport distance (ferry)	Structural steel	Low alloy steel	Cast iron	Aluminium (cast alloy)	Copper (cathode)	Steel, chromium steel 18/8	Engineering steel	Brass
Hoist equipment											
Shaft, machined	1.45E+04	2.86E+03	2.00E+01							1.45E+04	
Pulley and brake disc	1.50E+04	2.86E+03	2.00E+01	1.50E+04							
Bearings	2.81E+03	1.58E+03			2.53E+03						1.28E+02
Bearing adapter sleeves	5.50E+02	1.58E+03			5.50E+02						
Bearing houses	1.38E+04	2.86E+03	2.00E+01	1.38E+04							
Hydraulic unit, lubrication	7.50E+02	2.44E+03	2.00E+01		5.89E+02			7.01E+00	1.05E+02		
Hydraulic unit motor, lubrication 0.55kw	2.04E+01	2.82E+03	2.00E+01		1.14E+01	4.14E+00	2.82E+00	2.04E+00			
Hydraulic unit motor, lubrication 0.17kw		2.82E+03	2.00E+01		1.17E+00	4.30E-01	2.90E-01	2.10E-01			
Foundation details	4.74E+03	1.21E+03		4.74E+03							

Table A.4: LCI data for Brake system

	Total weight (kg)	Transport distance (lorry)	Transport distance (ferry)	Structural steel	Low alloy steel	Cast iron	Aluminium (cast alloy)	Copper (cathode)	Transport distance (container chip)	polyethylene, high density, granulate
Brake system										
Brake Calipers	3.29E+03	2.03E+03			7.80E+02	2.51E+03				
Brake stands	8.00E+03	1.21E+03		8.00E+03						
Hydraulic block, brakes	3.34E+02	3.29E+03	2.00E+01		3.04E+02			3.00E+01	8.09E+03	8.00E+00
Hydraulic unit brake system	7.01E+02	3.16E+03	2.00E+01		5.01E+02	1.50E+02	2.00E+01	3.00E+01	6.99E+03	1.70E+01
Hydraulic unit motor, break system 5.5kw	1.12E+02	2.82E+03	2.00E+01		6.44E+01	2.16E+01	1.48E+01	1.07E+01		
Hydraulic unit motor, break system, cooling 0.55	6.80E+00	2.82E+03	2.00E+01		3.80E+00	1.38E+00	9.40E-01	6.80E-01		
Hydraulic unit motor, break system, cooling 0.18	2.10E+00	2.82E+03	2.00E+01		1.18E+00	4.30E-01	2.90E-01	2.10E-01		

Table A.5: LCI data for Control and electrical equipment

	Total weight (kg)	Transport distance (lorry)	Transport distance (ferry)	Low alloy steel	Aluminium (cast alloy)	Copper (cathode)	Aluminium alloy AlMg3	Ferrit	polyethylene, high density, granulate	Brass	Epoxy resin (liquid)	Polycarbonate	Glass fibre reinforced plastic, injection moulded	Glass fiber	Lubricant oil	Cable, unspecified	Inductor, ring core choke type	Integrated circuit, logic type	capacitor, tantalum-, for through-hole mounting	corrugated board box	resistor, metal film type, through-hole mounting	Tin
Control and electrical equipment																						
Electric cabinets	5.00E+03	2.99E+03	2.00E+01	4.43E+03	2.35E+01	1.24E+02			3.31E+02	1.62E+01						6.49E+01						
Switchgears	1.30E+03	1.31E+03		1.51E+02		2.25E+02	5.72E+02						2.99E+02		3.82E+02	5.42E-01	1.90E-01		4.87E+00	5.91E+00	2.92E+01	1.62E+01
Transformer	9.30E+03	2.51E+03	2.00E+01	1.02E+03	1.10E+03			5.48E+03			7.25E+02			1.09E+03								
Frequency converter	1.01E+02	1.10E+03		3.54E+01		6.40E-01	1.16E+01	7.20E-01			6.45E+00	2.76E+00					3.63E+01	8.50E+00				
Electric cables	3.00E+03															3.00E+03						

Table A.6: LCI data for Drive system

	Total weight (kg)	Transport distance (lorry)	Transport distance (ferry)	Low alloy steel	Aluminium (cast alloy)	Copper (cathode)	Aluminium alloy AlMg3	Ferrit	Epoxy resin (liquid)	Glass fibre reinforced plastic, injection moulded	Glass fiber	Lubricant oil	Cable, unspecified	capacitor, tantalum-, for through-hole mounting	corrugated board box	resistor, metal film type, through-hole mounting	Tin	Cast iron	Residual wood	Acrylic paint
Drive system																				
LC 2306 motor	1.79E+04			1.58E+04	1.10E+02	2.18E+03			2.32E+02	1.62E+02								3.06E+02	8.00E+02	1.96E+01
DC drive DSC 800-A02-4800-06	2.40E+03	2.82E+03	2.00E+01	2.79E+02		4.16E+02	1.06E+03			5.53E+02		7.05E+02	1.00E+00	9.00E+00	1.09E+01	5.40E+01	3.00E+01			
Transformer	9.30E+03	2.51E+03	2.00E+01	1.02E+03	1.10E+03			5.48E+03	7.25E+02		1.09E+03									
Motors, cooling fans 22kw 1,2 och 2,2	3.26E+02	2.82E+03	2.00E+01	1.96E+02	3.61E+01	2.77E+01												1.29E+02		

Table A.7: LCI data for Maintenance

	Total weight (kg)	Transport distance (lorry)	Low alloy steel	Transport distance (ferry)	Transport distance (container chip)	Steel wire rod	Ni-Hard	Polyester resin unsaturated	Lubricant oil	Powder coating, steel	Copper (cathode)	Aluminium alloy AlMg3	Glass fibre reinforced plastic, injection moulded	Tin	Polystyrene extruded	Fiber polyester	Polymer foaming	Aluminium (cast alloy)	Fiber jute	Grafite	Phenolic resin	Silicon carbide	Titanium oxide
Maintenance (weight per year)																							
Main ropes	1.10E+04	2.80E+03		2.00E+01		1.10E+04																	
Balancing ropes	4.16E+03	2.80E+03		2.00E+01		4.16E+03																	
Guide ropes	4.62E+03	2.80E+03		2.00E+01		4.62E+03																	
Hydraulic rope equalizer	5.62E+01	1.20E+03	5.62E+01																				
Rope lock	4.60E+01	1.20E+03	4.60E+01																				
Rope swivel	6.60E+01	2.96E+03	6.60E+01	2.00E+01	7.26E+03																		
Guide rope runners	6.89E+02		6.89E+02																				
Skid plates	6.13E+03						6.13E+03																
Yearly added corrosion preventive compound	5.15E+01									5.15E+01													
Filters	2.39E+02	1.30E+03													1.92E+02	3.59E+01	1.20E+01						
Oils (hydraulic, brake and lubrication)	7.53E+02								7.53E+02														
Friction inlays (Friktionsinlägg)	1.44E+03	2.52E+03		2.00E+01				1.44E+03															
Brake pads	2.40E+01	2.03E+03																4.80E+00	2.40E+00	1.20E+00	9.60E+00	3.00E+00	3.00E+00
Brake caliper renovation	1.84E+02	2.03E+03	1.84E+02																				
Electric fuses	4.50E+01	2.82E+03	6.00E+00	2.00E+01							1.00E+01	3.75E+00	2.26E+01	2.50E+00									

Table A.8: LCI data for turning tool and corrosion prevention compound

	Total weight (kg)	Transport distance (lorry)	Low alloy steel	Powder coating, steel
Other				
Turning tool	4.84E+02	1.20E+03	4.84E+02	
Corrosion prevention compounds	1.83E+04			1.83E+04
Energy demand (kWh) per year	1.13E+07			

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Appendix

Table B.1: Global warming. Contributions of inputs

	Global warming									
Total per item scenario	1.34E+07		2.05E+07		2.79E+08		1.28E+07		1.22E+07	
Total per f.u. scenario	1.67E-01		1.60E-01		3.48E+00		1.59E-01		1.52E-01	
	Scenatio 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	Mass	%	Mass	%	Mass	%	Mass	%	Mass
Electricity	7.18E-01	1.20E-01	7.50E-01	1.20E-01	9.87E-01	3.44E+00	7.71E-01	1.23E-01	8.06E-01	1.23E-01
Rope production	1.16E-01	1.93E-02	1.21E-01	1.93E-02	5.50E-03	1.92E-02	6.06E-02	9.66E-03	5.68E-02	8.66E-03
Measuring pocket	3.66E-02	6.11E-03	2.39E-02	3.82E-03	1.80E-03	6.27E-03	3.84E-02	6.12E-03	2.03E-02	3.10E-03
Friction pads	1.89E-02	3.16E-03	1.97E-02	3.15E-03	9.00E-04	3.14E-03	1.98E-02	3.16E-03	2.07E-02	3.16E-03
Skid plates	1.35E-02	2.26E-03	1.41E-02	2.25E-03	6.00E-04	2.09E-03	7.10E-03	1.13E-03	7.50E-03	1.14E-03
Skip manufacturing	1.93E-02	3.22E-03	1.26E-02	2.01E-03	9.00E-04	3.14E-03	2.02E-02	3.22E-03	1.11E-02	1.69E-03
Other	7.81E-02	1.30E-02	5.88E-02	9.40E-03	3.20E-03	1.12E-02	8.25E-02	1.31E-02	7.72E-02	1.18E-02

Table B.2: Human non-carciogenic toxixity. Contributions of inputs

	Human non-carcinogenic toxicity									
Total per item scenario	1.26E+07		1.83E+07		3.44E+08		1.23E+07		1.26E+07	
Total per f.u. scenario	1.57E-01		1.42E-01		4.29E+00		1.53E-01		1.57E-01	
	Scenatio 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	Mass	%	Mass	%	Mass	%	Mass	%	Mass
Electricity	6.45E-01	1.01E-01	7.13E-01	1.01E-01	9.87E-01	4.24E+00	6.75E-01	1.04E-01	6.61E-01	1.04E-01
Rope production	2.10E-02	3.30E-03	2.32E-02	3.30E-03	8.00E-04	3.43E-03	1.08E-02	1.66E-03	4.51E-02	7.07E-03
Measuring pocket	1.83E-02	2.88E-03	1.26E-02	1.79E-03	7.00E-04	3.00E-03	1.88E-02	2.88E-03	2.27E-02	3.56E-03
Friction pads	6.40E-03	1.01E-03	7.10E-03	1.01E-03	2.00E-04	8.58E-04	6.60E-03	1.01E-03	6.40E-03	1.00E-03
Skid plates	6.12E-02	9.62E-03	6.77E-02	9.63E-03	2.20E-03	9.44E-03	3.14E-02	4.82E-03	8.50E-03	1.33E-03
Skip manufacturing	9.70E-03	1.53E-03	6.70E-03	9.53E-04	4.00E-04	1.72E-03	1.00E-02	1.53E-03	1.20E-02	1.88E-03
Other	1.09E-01	1.72E-02	8.07E-02	1.15E-02	3.60E-03	1.54E-02	1.15E-01	1.76E-02	1.14E-01	1.79E-02
Guide rope weights		0.00E+00		0.00E+00		0.00E+00		0.00E+00		0.00E+00
Transformers		0.00E+00		0.00E+00		0.00E+00		0.00E+00		0.00E+00
Main motor	7.27E-02	1.14E-02	5.02E-02	7.14E-03	2.70E-03	1.16E-02	7.45E-02	1.14E-02	7.29E-02	1.14E-02
Cables	5.68E-02	8.93E-03	3.93E-02	5.59E-03	2.10E-03	9.01E-03	5.82E-02	8.93E-03	5.70E-02	8.93E-03

Table B.3: Terrestrial ecotoxicity. Contributions of inputs

	Terrestial ecotoxicity									
Total per item scenario	6.05E+07		9.34E+07		1.24E+08		5.34E+07		5.00E+07	
Total per f.u. scenario	7.54E-01		7.28E-01		1.55E+00		6.66E-01		6.24E-01	
	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	Mass	%	Mass	%	Mass	%	Mass	%	Mass
Electricity	6.31E-01	4.76E-01	6.54E-01	4.76E-01	8.25E-01	1.28E+00	7.28E-01	4.85E-01	7.77E-01	4.85E-01
Rope production	5.31E-02	4.01E-02	5.50E-02	4.00E-02	2.61E-02	4.04E-02	3.01E-02	2.00E-02	7.94E-02	4.95E-02
Measuring pocket	1.36E-02	1.03E-02	8.80E-03	6.41E-03	6.70E-03	1.04E-02	1.54E-02	1.03E-02	1.91E-02	1.19E-02
Friction pads	6.60E-03	4.98E-03	6.80E-03	4.95E-03	3.30E-03	5.10E-03	7.50E-03	4.99E-03	8.00E-03	4.99E-03
Skid plates	2.08E-01	1.57E-01	2.15E-01	1.57E-01	1.02E-01	1.57E-01	1.18E-01	7.83E-02		0.00E+00
Skip manufacturing	9.50E-03	7.17E-03	6.20E-03	4.51E-03	4.70E-03	7.27E-03	1.08E-02	7.19E-03		0.00E+00
Other	7.87E-02	5.94E-02	5.41E-02	3.94E-02	3.23E-02	4.99E-02	9.08E-02	6.04E-02	1.16E-01	7.24E-02

Table B.4: Land use. Contributions of inputs

	Land use									
Total per item scenario	3.52E+06		5.61E+06		1.21E+06		3.51E+06		3.53E+06	
Total per f.u. scenario	4.38E-02		4.37E-02		1.51E-02		4.38E-02		4.40E-02	
	Scenatio 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	Mass	%	Mass	%	Mass	%	Mass	%	Mass
Electricity	9.85E-01	4.32E-02	9.88E-01	4.32E-02	9.58E-01	1.45E-02	9.87E-01	4.32E-02	9.82E-01	4.32E-02
Rope production	4.70E-03	2.06E-04	4.70E-03	2.05E-04	1.36E-02	2.06E-04	2.30E-03	1.01E-04	6.90E-03	3.04E-04
Measuring pocket	1.80E-03	7.89E-05	1.10E-03	4.81E-05	5.30E-03	8.01E-05	1.80E-03	7.88E-05	2.20E-03	9.68E-05
Friction pads	1.40E-03	6.14E-05	1.40E-03	6.12E-05	4.10E-03	6.20E-05	1.40E-03	6.13E-05	1.40E-03	6.16E-05
Skid plates	1.50E-03	6.57E-05	1.50E-03	6.56E-05	4.50E-03	6.80E-05	8.00E-04	3.50E-05	7.00E-04	3.08E-05
Skip manufacturing	1.10E-03	4.82E-05	7.00E-04	3.06E-05	3.10E-03	4.68E-05	1.10E-03	4.81E-05	1.20E-03	5.28E-05
Other	4.80E-03	2.10E-04	3.00E-03	1.31E-04	1.14E-02	1.72E-04	-2.24E+0(	-9.79E-02	-3.49E+0(	-1.53E-01

Table B.5: Mineral resource scarcity. Contributions of inputs

	Mineral resource scarcity									
Total per item scenario	2.11E+05		3.13E+05		1.55E+05		1.85E+05		1.50E+05	
Total per f.u. scenario	2.63E-03		2.44E-03		1.93E-03		2.31E-03		1.87E-03	
	Scenatio 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	Mass	%	Mass	%	Mass	%	Mass	%	Mass
Electricity	5.15E-01	1.35E-03	5.56E-01	1.35E-03	3.47E-01	6.71E-04	6.06E-01	1.40E-03	7.47E-01	1.40E-03
Rope production	1.33E-01	3.51E-04	1.44E-01	3.50E-04	1.81E-01	3.51E-04	7.58E-02	1.75E-04	3.73E-02	6.99E-05
Measuring pocket	3.81E-02	1.00E-04	2.57E-02	6.27E-05	5.18E-02	1.00E-04	4.33E-02	1.00E-04	1.35E-02	2.53E-05
Friction pads		0.00E+00		0.00E+00	2.40E-03	4.64E-06		0.00E+00		0.00E+00
Skid plates	1.46E-01	3.84E-04	1.57E-01	3.84E-04	1.98E-01	3.84E-04	8.30E-02	1.92E-04	3.40E-03	6.37E-06
Skip manufacturing	1.94E-02	5.10E-05	1.31E-02	3.19E-05	2.64E-02	5.10E-05	2.21E-02	5.11E-05	7.10E-03	1.33E-05
Other	1.04E-01	2.72E-04	7.45E-02	1.82E-04	1.32E-01	2.55E-04	1.19E-01	2.76E-04	1.29E-01	2.41E-04
Main motor	2.32E-02	6.10E-05	1.57E-02	3.83E-05	3.16E-02	6.11E-05	2.64E-02	6.10E-05	3.26E-02	6.11E-05
Guide rope weights	2.15E-02	5.65E-05	1.45E-02	3.54E-05	2.92E-02	5.65E-05	2.44E-02	5.64E-05	3.01E-02	5.64E-05

Table B.6: Fossil resource scarcity. Contributions of inputs

	Fossil resource scarcity									
Total per item scenario	2.34E+06		3.54E+06		6.84E+07		2.22E+06		2.19E+06	
Total per f.u. scenario	2.91E-02		2.76E-02		8.53E-01		2.76E-02		2.73E-02	
	Scenatio 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	Mass	%	Mass	%	Mass	%	Mass	%	Mass
Electricity	6.55E-01	1.91E-02	6.92E-01	1.91E-02	9.88E-01	8.43E-01	7.09E-01	1.96E-02	7.19E-01	1.96E-02
Rope production	1.18E-01	3.44E-03	1.25E-01	3.44E-03	4.00E-03	3.41E-03	6.23E-02	1.72E-03	7.98E-02	2.18E-03
Measuring pocket	4.13E-02	1.20E-03	2.73E-02	7.53E-04	1.40E-03	1.19E-03	4.35E-02	1.20E-03	2.99E-02	8.16E-04
Friction pads	4.00E-02	1.17E-03	4.22E-02	1.16E-03	1.40E-03	1.19E-03	4.21E-02	1.16E-03	4.27E-02	1.16E-03
Skid plates	2.31E-02	6.73E-04	2.44E-02	6.73E-04	8.00E-04	6.83E-04	1.22E-02	3.37E-04	9.90E-03	2.70E-04
Skip manufacturing	2.25E-02	6.56E-04	1.49E-02	4.11E-04	8.00E-04	6.83E-04	2.37E-02	6.55E-04	1.69E-02	4.61E-04
Other	9.99E-02	2.91E-03	7.41E-02	2.04E-03	3.20E-03	2.73E-03	1.07E-01	2.95E-03	1.02E-01	2.78E-03

Table B.7: Ionizing radiation. Contributions of inputs

	Ionizing radiation									
Total per item scenario	8.41E+07		1.35E+08		7.05E+05		8.41E+07		8.42E+07	
Total per f.u. scenario	1.05E+00		1.05E+00		8.79E-03		1.05E+00		1.05E+00	
	Scenatio 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	Mass	%	Mass	%	Mass	%	Mass	%	Mass
Electricity	9.98E-01	1.05E+00	9.98E-01	1.05E+00	7.39E-01	6.49E-03	9.98E-01	1.05E+00	9.97E-01	1.05E+00
Rope production	3.00E-04	3.15E-04	3.00E-04	3.14E-04	3.39E-02	2.98E-04	1.00E-04	1.05E-04	1.10E-03	1.15E-03
Measuring pocket	4.00E-04	4.20E-04	2.00E-04	2.10E-04	4.74E-02	4.17E-04	4.00E-04	4.19E-04	5.00E-04	5.25E-04
Friction pads	2.00E-04	2.10E-04	2.00E-04	2.10E-04	2.91E-02	2.56E-04	2.00E-04	2.10E-04	2.00E-04	2.10E-04
Skid plates	4.00E-04	4.20E-04	4.00E-04	4.19E-04	4.74E-02	4.17E-04	2.00E-04	2.10E-04	2.00E-04	2.10E-04
Skip manufacturing	2.00E-04	2.10E-04	1.00E-04	1.05E-04	2.43E-02	2.14E-04	2.00E-04	2.10E-04	3.00E-04	3.15E-04
Other	7.00E-04	7.34E-04	6.00E-04	6.29E-04	7.91E-02	6.95E-04	8.00E-04	8.39E-04	8.00E-04	8.40E-04

C

Appendix

Table C.1: Material composition main motor

	AMS 800			AMT 1250			AMA 450		
Rated output (kW)	8.28E+03			6.50E+03			1.60E+03		
Total weight (kg)	2.78E+04			8.08E+04			5.55E+03		
Material	kg/product	Percentage	kg/kw	kg/product	Percentage	kg/kw	kg/product	Percentage	kg/kw
Electro steel	8.11E+03	2.92E-01	9.80E-01	5.06E+04	6.27E-01	7.79E+00	2.50E+03	4.50E-01	1.56E+00
Normal rolled steel	1.23E+04	4.44E-01	1.49E+00	1.80E+04	2.23E-01	2.77E+00			
Special steel	1.67E+03	6.00E-02	2.01E-01	2.43E+03	3.01E-02	3.74E-01	2.35E+03	4.23E-01	1.47E+00
Cast iron	4.60E+02	1.65E-02	5.60E-02	1.06E+03	1.32E-02	1.64E-01	5.00E+01	9.01E-03	3.00E-02
Aluminium	5.80E+01	2.09E-03	7.00E-03	5.70E+01	7.06E-04	9.00E-03	1.20E+02	2.16E-02	8.00E-02
Copper	2.90E+03	1.04E-01	3.50E-01	3.56E+03	4.41E-02	5.48E-01	3.44E+02	6.20E-02	2.10E-01
Insulation	4.21E+02	1.51E-02	5.10E-02	1.64E+03	2.02E-02	2.52E-01	9.00E+01	1.62E-02	6.00E-02
Wooden boces and planks	1.61E+03	5.79E-02	1.95E-01	3.35E+03	4.15E-02	5.15E-01	6.00E+01	1.08E-02	4.00E-02
Impregnation resin	2.07E+02	7.45E-03	2.50E-02	2.01E+01	2.49E-04	3.00E-03	2.00E+01	3.60E-03	1.00E-02
Paint	1.67E+01	6.01E-04	2.00E-03	1.40E+01	1.73E-04	2.00E-03	1.60E+01	2.88E-03	1.00E-02

	GBA 1120			GBA800		
Rated output (kW)	3.10E+04			8.28E+03		
Total weight (kg)	6.36E+04			2.79E+04		
Material	kg/product	Percentage	kg/kw	kg/product	Percentage	kg/kw
Electro steel	2.15E+04	3.38E-01	6.93E-01	8.19E+03	2.93E-01	9.89E-01
Normal rolled steel	2.64E+04	4.16E-01	8.59E-01	1.23E+04	4.39E-01	1.48E+00
Special steel	4.52E+03	7.12E-02	1.46E-01	1.63E+03	5.83E-02	1.97E-01
Cast iron	1.26E+03	1.98E-02	4.10E-02	6.67E+02	2.39E-02	8.10E-02
Aluminium	1.92E+02	3.02E-03	6.00E-03	5.80E+01	2.08E-03	7.00E-03
Copper	5.18E+03	8.15E-02	1.67E-01	2.90E+03	1.04E-01	3.51E-01
Insulation	1.09E+03	1.72E-02	3.50E-02	5.20E+02	1.86E-02	6.30E-02
Wooden boces and planks	3.04E+03	4.78E-02	9.80E-02	1.61E+03	5.76E-02	1.95E-01
Impregnation resin	2.81E+02	4.42E-03	9.00E-03	8.20E+01	2.94E-03	1.00E-02
Paint	6.30E+01	9.91E-04	2.00E-03	1.67E+01	5.98E-04	2.00E-03

Material	Average percentage	Average kg/kW
Electro steel	4.00E-01	2.40E+00
Normal rolled steel	3.89E-01	1.61E+00
Special steel	4.39E-02	1.84E-01
Cast iron	1.65E-02	7.44E-02
Aluminium	5.90E-03	2.18E-02
Copper	7.92E-02	3.25E-01
Insulation	1.75E-02	9.22E-02
Wooden boces and planks	4.31E-02	2.09E-01
Impregnation resin	3.73E-03	1.14E-02
Paint	1.05E-03	3.60E-03

Material	Main Motor based on percentage			Main motor based on kg/kW
Electro steel			2.25E+04	1.03E+04
Normal rolled steel			2.19E+04	6.94E+03
Special steel			2.47E+03	7.89E+02
Cast iron			9.28E+02	3.20E+02
Aluminium			3.32E+02	9.37E+01
Copper			4.46E+03	1.40E+03
Insulation			9.84E+02	3.96E+02
Wooden boces and planks			2.43E+03	8.97E+02
Impregnation resin			2.10E+02	4.90E+01
Paint			5.91E+01	1.55E+01
	Weight	5.63E+04	kg	
	Output	4.30E+03	kW	2.12E+04

D
Appendix

4 LCI Results: Cradle to Gate excluding Recycling for 1kg steel

The data does not consider a burden for scrap input or a credit for the EoL recycling.

Inputs (mass, kg)

	1kg of EU Wire rod
Bauxite	[redacted]
Crude oil (resource)	[redacted]
Dolomite	[redacted]
Hard coal (resource)	[redacted]
Lignite (resource)	[redacted]
Limestone (calcium carbonate)	[redacted]
Natural gas (resource)	[redacted]
Uranium (resource)	[redacted]

	1kg of EU Wire rod
Total freshwater consumption (including rainwater) 1 [kg]	[redacted]
Blue water consumption 2 [kg]	[redacted]

[1] The total fresh water consumption is the net amount of freshwater, lake water, river water and rain water that is consumed. It excludes sea water.

[2] Blue water is Ground water + surface water. This is what is used for water footprint calculation. Please note the blue water is from the water footprint network and is for information only.

Inputs (mass, kg)

	1kg of EU Wire rod
Chromium	[redacted]
Copper	[redacted]
Iron	[redacted]
Lead	[redacted]
Nickel	[redacted]
Tin	[redacted]
Titanium	[redacted]
Vanadium	[redacted]
Zinc	[redacted]

	1kg of EU Wire rod
Steel and iron scrap [kg]	[redacted]

Emissions to air (mass, g)

	1kg of EU Wire rod
Carbon dioxide	[redacted]
Carbon monoxide	[redacted]
Hydrogen chloride	[redacted]
Hydrogen sulphide	[redacted]
Nitrogen dioxide	[redacted]
Nitrogen oxides	[redacted]
Nitrous oxide (laughing gas)	[redacted]
Sulphur dioxide	[redacted]
Dioxins (unspec.)	[redacted]
NMVOC (unspecified)	[redacted]
Methane	[redacted]
Particles to air	[redacted]

Emissions to fresh water (mass, g)

	1kg of EU Wire rod
Biological oxygen demand (BOD)	[illegible]
Chemical oxygen demand (COD)	[illegible]
Nitrogenous Matter (unspecified, as N)	[illegible]
Solids (dissolved)	[illegible]
Iron	[illegible]
Phosphate	[illegible]
Phosphorus	[illegible]

Environmental Indicators – for information only

	1kg of EU Wire rod
CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2 eq.]	[illegible]
CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate eq.]	[illegible]
CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years) [kg CO2 eq.]	[illegible]
CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	[illegible]
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	[illegible]

Figure D.1: Provision of inventory by World Steel Association. The inventory data is not included in this version of the report and hence redacted due to confidentiality.

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