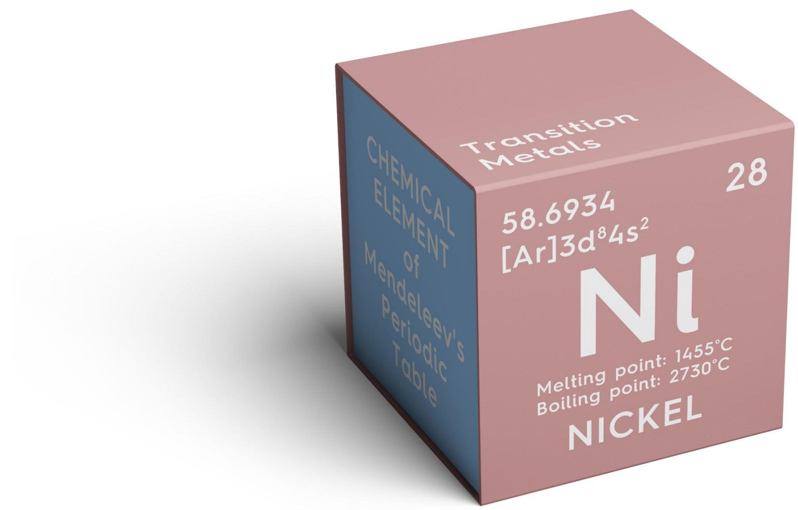
PROSPECTIVE LIFE CYCLE ASSESSMENT STUDY OF RÖNNBÄCKEN NICKEL CONCENTRATE PRODUCTION

Prepared for Nickel Mountain AB
10th of February 2022



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External Reviewers: N/A

1. Our Statement

Information contained in this report has been compiled and computed from sources believed to be credible. Application of the data is strictly at the discretion and the responsibility of the reader. Minviro is not liable for any loss or damage arising from the use of the information in this document.

Life cycle assessment is an environmental accounting tool with an inherent level of uncertainty, and it should not be seen as having the same level of precision as financial accounting. Life cycle assessment requires a very large amount of data, particularly to calculate all the inputs and outputs for every step.

Databases are often used since it is impractical to collect all the necessary data from the original sources (e.g. it is impossible to collect data from all the specific power plants from which electricity is sourced).

The report does not claim to be exhaustive, nor does it claim to cover all relevant products. While steps have been taken to ensure accuracy, the listing or featuring of a particular product or company does not constitute an endorsement by Minviro.

Nickel Mountain AB commissioned Minviro Ltd. as life cycle assessment practitioner in September 2021 to produce a life cycle assessment for the production of nickel concentrate produced at the Rönnbäcken project

The life cycle assessment was conducted using the best available data taken from Nickel Mountain AB's 2022 preliminary economic assessment. The intended application of this life cycle assessment is to assist in project development and improvement. The results will be used for long term strategic planning.

Table 1. Document Details

Document Details	
Document Title	Prospective Life Cycle Assessment of Rönnbäcken Nickel Concentrate Production
Date	10th of February 2022
Version	Final
Authors	Tijsseling, L.T, Whattoff, P.W.
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Table 2. Revision Details

Document Revision Details				
Version	**Revision**	**Authors**	**Reviewers**	**Comments**
Version 1.0	1	Tijsseling, L.T, Whattoff, P.W.	Lindsay, J.J.	N/A
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Final	N/A	Tijsseling, L.T, Whattoff, P.W.	N/A	N/A

2. Executive Summary

Minviro was appointed by Nickel Mountain AB to conduct a cradle-to-gate life cycle assessment on the production of nickel concentrate at the Rönnbäcken project in Sweden for reference year 2022. The project consists of ore extraction through open pit mining and concentration of the ore into a nickel concentrate using flotation. For both of those stages, technological and economic data was developed as part of an updated preliminary economic assessment. The Rönnbäcken project will co-produce cobalt that will report into the nickel concentrate, and a magnetite concentrate. The environmental impacts of producing nickel concentrate are reduced due to the production of these co-products. Tailings produced at the project are likely to be able to naturally sequester CO_2 from the atmosphere, however at this time no testwork has been carried out to quantify the CO_2 sequestration potential. A proxy calculation was completed assuming particle size, mineralogy, annual tailings production and effects of the regional climate.

The results of the life cycle assessment of production of 1 kg of nickel in concentrate and 1 kg of iron in magnetite concentrate can be found in Table 3. This table shows the results for the global warming potential impact category only. Additionally, an alternative project scenario with an electrified haulage fleet is evaluated. The global warming potential of that scenario is also presented in Table 3.

Table 3. Results Summary of Life Cycle Assessment Study

Scenario	Product	Raw Value	Units
Base Case	Nickel in Concentrate	10.0	kg CO_2 eq.
Electrified Mine Fleet Case	Nickel in Concentrate	7.5	kg CO_2 eq.
Base Case	Fe in Concentrate	6.9E-2	kg CO_2 eq.
Electrified Mine Fleet Case	Fe in Concentrate	5.7E-2	kg CO_2 eq.

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List of Acronyms

Acronym	Meaning
CO_2	Carbon dioxide
DQR	Data quality rating
eq.	Equivalent
GWP	Global warming potential
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
IPCC	Intergovernmental Panel on Climate Change
kg	Kilograms
L	Litres
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
m^2	Metres squared
m^3	Metres cubed
MJ	Megajoules
mol H^+	Moles of protons equivalent (units of acidification potential)
NaOH	Sodium hydroxide (caustic)
Na_2CO_3	Sodium carbonate (soda ash)
N	Nitrogen
Ni	Nickel
NO_x	Nitrogen oxides (NO, NO_2)
PEA	Preliminary economic assessment
PFS	Pre-feasibility study
P	Phosphorous
SC	Spodumene concentrate (% Li_2O)
SO_x	Sulfur oxides (SO, SO_2, SO_3)
t	Metric tonne(s)

3. Introduction

Nickel Mountain AB has retained Minviro to model the environmental performance of manufacturing their nickel concentrate product at the Rönnbäcken project using life cycle assessment (LCA). The results will be used to improve production processes, communicate to customers, and for long-term strategic planning. This chapter is a summary of the methodology applied by Minviro in the LCA.

3.1. Project Description

The Rönnbäcken project is the largest underdeveloped nickel resource in Europe, located in the northwest part of Sweden. The project consists of three nickel sulfide deposits, which are processed using conventional flotation methods to produce a nickel-cobalt concentrate and a magnetite concentrate. In 2011 a preliminary economic assessment was carried out, which has been updated throughout 2022. An overview of the relevant project characteristics is shown in Table 4.

Table 4. Rönnbäcken Production Overview

Production Parameter	Value	Units
Resource Type	Ultramafic-hosted disseminated nickel sulfide	N/A
Resource Grade	0.177	% Ni
Location	Sweden	N/A
Life of Project	20	years
Nickel in Concentrate	441,473	tonnes (life of mine)
Cobalt in Concentrate	12,743	tonnes (life of mine)
Fe in Concentrate	29,078,435	tonnes (life of mine)

3.2. Scope of Assessment

The goal of this LCA is to determine the major project and process parameters contributing to the life cycle impact of the production of nickel concentrate at the Rönnbäcken. Additionally, the difference in global warming potential impact is evaluated for different project scenarios to explore mitigation opportunities for the carbon footprint of the products. LCA is a tool to assess the environmental impacts associated with all stages of a product, process or activity.[1] Importantly, LCA makes it possible to evaluate indirect impacts that occur in the development of a product or process system over its entire life cycle, providing information that otherwise may not be considered. A wide range of environmental impacts can be captured both scientifically and quantitatively. The holistic approach generates results on how decisions made at one stage of the life cycle might have consequences elsewhere, ensuring that a balance of potential trade-offs can be made and avoiding shifting of the environmental burden.[2,3] It must be noted that LCA is a suitable tool for determining impacts on a global scale, however the methodology is less suitable for determining local impacts.

3.3. Life Cycle Assessment Methodology

This LCA study was conducted according to the requirements of the ISO-14040:2006 and ISO-14044:2006 standards.[4] LCA has four fundamental steps: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation, as presented below.

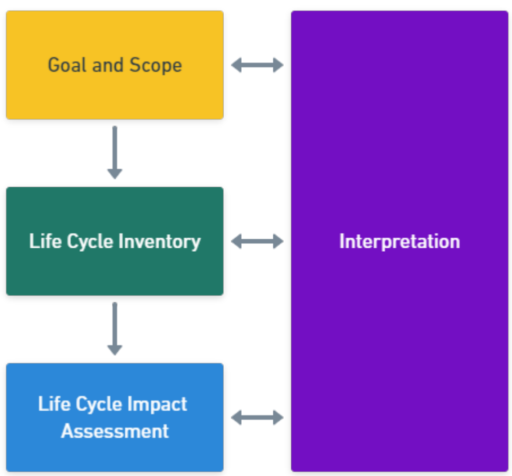

Figure 1. General Phases of a Life Cycle Assessment as Described by ISO 14040, Extracted from ISO 14040 (2006)

The life cycle impact assessment (LCIA) was carried out with a combination of data provided by Nickel Mountain AB and Ecoinvent databases of characterization factors. Ecoinvent version 3.7.1 provides a well-documented process for products supporting the understanding of their environmental impacts.[5] The Ecoinvent database comprises inventory data for most economic activities. The consistency and cohesion of this background life cycle inventory (LCI) dataset increases the credibility and acceptance of the

LCA. The baselines of this database are LCI datasets that consider human activities and their interactions with the environment.

3.3.1. Goal and Scope

This study assesses the life cycle impact of the production of 1 kg of nickel in concentrate produced from low grade sulfide ore extracted at Rönnbäcken in Sweden. The total production chain includes mining of the ore and concentrating of that ore into a nickel and cobalt concentrate using flotation. This LCA is a cradle-to-gate study, meaning the product life cycle impact is assessed from the point of resource extraction to the end-gate. The end-gate has been set so the concentrate is ready for shipment after the concentrator. The use of the product in, for example, cathode manufacturing and end-of-life is outside the scope of this LCA study. To understand the full life cycle impact of the nickel concentrate product from cradle-to-grave or cradle-to-cradle requires the extension of the system boundary into the use-phase and the end-of-life phases.

In 2011, data on the mining and concentrating was developed as part of a preliminary economic assessment, which was updated in 2022. The data generated during these studies provides estimates on the technical parameters for ore extraction and concentration of nickel into the concentrate. The primary objective for carrying out this study is to quantify the environmental impacts of the proposed production routes and to identify the environmental hotspots for the production of nickel concentrate. The second objective of this study is to assist in project development and improvement, with a third motivation being to assist with strategic planning through a scenario analysis.

This study has been conducted according to the requirements of the ISO-14040:2006 and ISO-14044:2006. It is recognised that the data provided by this LCA study may be used by others for comparative assertions in separate future studies. These comparisons should be made on a product system basis only and carried out in accordance with ISO 14040 and 14044 standards.

3.3.2. Functional Unit

LCA uses a functional unit as a reference to evaluate the components within a single system or among multiple systems on a common basis. The **functional unit** is the quantitative reference used for all inventory calculations and impact evaluations. The primary **functional unit** for this study is defined as: **one kilogram of nickel in concentrate, produced from sulfide ore from the Rönnbäcken deposit.**

A second functional unit is included to provide impact evaluations of the iron ore product: **one kilogram of iron in concentrate, produced from sulfide ore from the Rönnbäcken deposit.**

3.3.3. System Boundary

This LCA models production of nickel in nickel concentrate from primary nickel sulfide resources. The life cycle impacts of two stages of the project are modelled: mining of the ore and concentrating of the ore into a cobalt containing nickel concentrate. The system boundary for the LCA study covering these stages is presented in Figure 3.

The first stage in the project is extraction of the nickel-bearing ore. It is assumed that 30 million tonnes of ore will need to be extracted per year, assuming a conservative stripping ratio of 1.0. That means that per tonne of ore, one tonne of waste rock will need to be removed, which per year means 30 million tonnes of waste rock. Ore and waste rock are liberated using bulk explosives, after which conventional diesel fueled haulage equipment is used to transport the ore to the concentrator. A small amount of electricity is consumed in the mining stage. Additionally, minor consumables such as drill bits, primers are detonating cords used.

The second stage, the concentrator, is designed to process 30 million tonnes of ore per year. It is assumed that autogenous milling followed by two secondary pebble mills is used, meaning that there is no requirement for grinding media. Using a conventional flotation process, nickel and cobalt are separated from the ore, which together are the final product of the process. Magnetite present in the ore is pelletised, which is considered to be a co-product of the process.

For both the mining and the concentrating stages, it is assumed that the electricity is sourced from the Swedish grid. It is assumed diesel as a fuel has a calorific value of 38.6 MJ per litre.

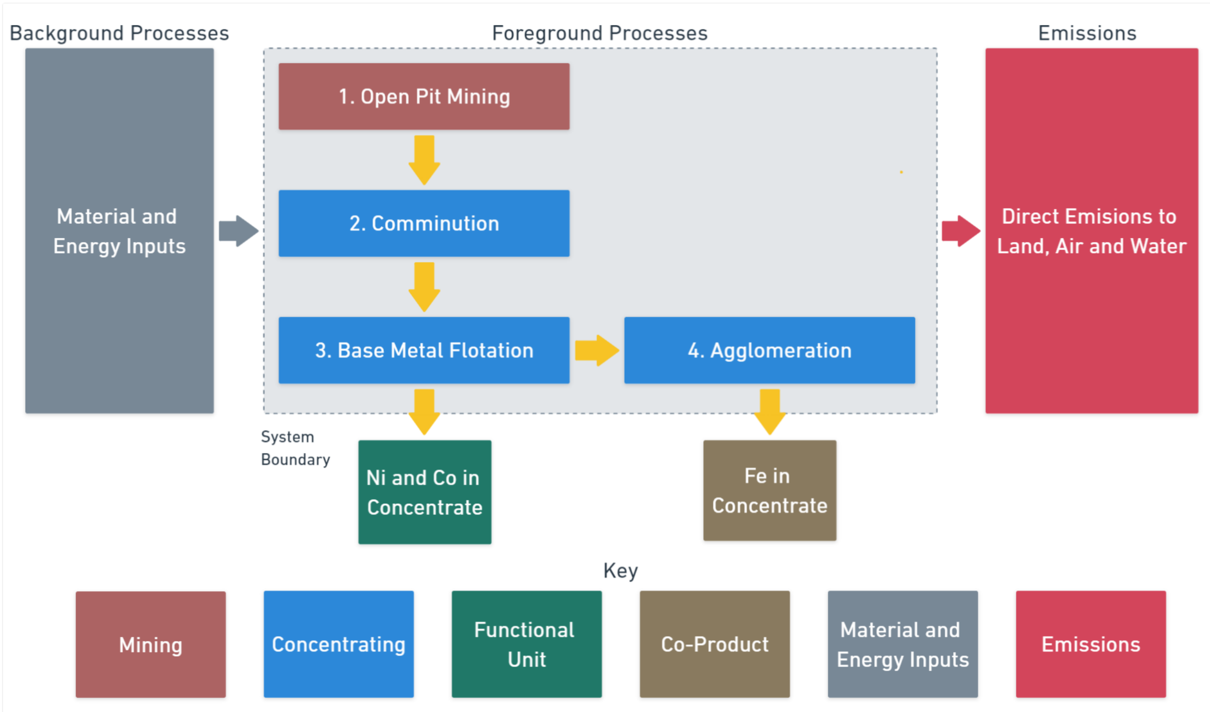

Figure 2. System Boundary Applied to the Life Cycle Assessment Study

3.3.4. Multi-Output Allocation

In LCA it is critical to ensure that environmental impacts are divided among the different products of a process operation in a way that is scientifically valid and best practice. Following the guidance provided in ISO-14044:2006 standards, it is recommended to avoid allocation as much as possible.[1]

Avoiding allocation can be achieved by allocating impacts to specific process streams that produce only one product, or by using a method known as system expansion. It is recommended to allocate the impacts following the physical relationships between the products before any alternative allocation methodologies are used. Two common alternative allocation methodologies include mass-based and economic allocation, in which the relative mass or economic value of the different products is used to allocate the impacts among them.

In this study, both mass based allocation and economic allocation were used. Table 5 shows the production volume, product pricing and economic contribution of the nickel, cobalt and iron ore products. Allocation is avoided by ensuring that inventory items related to the production of one product are excluded for the other products. For example, the energy and material requirements for agglomerating the iron ore are not allocated to the nickel and cobalt products. Vice versa, the flows related to the concentrating of nickel and cobalt are not allocated to the iron ore product.

Mass based allocation is used to discount the impact of the nickel product for the co-production of the cobalt product. As the production volume of the cobalt co-product is much lower than the production volume of nickel in concentrate, this is acceptable following LCA guidelines.

For the iron ore concentrate, the production volume is around 70 times higher than the nickel concentrate production. However, the relative economic contribution is 17.5%. Therefore it would not be appropriate to divide the environmental impacts equally between the nickel, cobalt and iron ore products on a mass basis. This means that economic allocation is used, by accounting for both the production volume and the relative economic contribution of the nickel, cobalt and iron ore products.

Table 5. Rönnbäcken Product Allocation Parameters

Product	Production (tonnes per year)	Product Pricing (USD per t)	Economic Contribution
Nickel in Concentrate	22,074	22,000	78.0%
Cobalt in Concentrate	637	44,000	4.5%
Fe in Concentrate	1,453,922	75	17.5%

3.3.5. Life Cycle Inventory

3.3.5.1. Nickel and Iron Concentrate Production Route

This study was desk-based, meaning that all data was either provided by Nickel Mountain AB, collected from public sources, or assembled from public and private databases. Background data was used from Ecoinvent 3.7.1. All primary data was obtained from the

2011 and 2022 PEA studies, carried out by an independent subcontractor of Nickel Mountain AB.

An LCI summary is included in Appendix A. An analysis of all material and energy flows within the system boundary was made. All major material and energy flows related to the extraction and concentrating of sulfide ore to produce nickel concentrate have been included in the LCI and included in the life cycle impact assessment. This includes materials consumed, energy consumed and major outflows.

3.3.5.2. Carbon Dioxide Sequestration Potential

At this time no test work has been carried out to understand the natural carbon sequestration potential of process tailings of the Rönnbäcken project, and thus this has been estimated for this study by an external expert.

3.3.5.3. Impact Mitigation Scenarios

To understand decarbonisation opportunities available to lower the impacts of producing nickel concentrate at the Rönnbäcken project, a scenario assuming the utilisation of an electrified haulage fleet was simulated. This was conducted using internal proxy calculations available at Minviro.

3.3.6. Cut-Off Criteria

Cut-off criteria are used in LCA to decide which inputs should be included in the assessment based on mass, energy, or environmental significance. In this study, cut-off criteria were applied to the flows entering the mining stage. Minor consumables such as explosive caps, detonation cords, drill bits and primers were excluded. It is expected that the relative contribution to the global warming potential of those items is minimum.

All flows provided by Nickel Mountain AB were considered in the LCA study. It is possible that cut-off effects have been applied to the background flows from Ecoinvent 3.7.1 due to missing flows in the background dataset. Life cycle inventory related to the manufacturing of equipment, maintenance, packaging, and infrastructure have been excluded in this LCA. The reason for excluding these flows is that they are often very small compared to flows of reagents or energy consumed in the process over decades of operation. These flows are also often challenging to model.

3.3.7. Life Cycle Impact Assessment

The LCIA category selected for this study is global warming potential (GWP). It is expected that this impact category is the most relevant for Nickel Mountain at this stage of development. The LCIA results are relative expressions and do not predict impacts on category endpoints, and the exceeding of thresholds, safety margins, or risks.

3.3.7.1. Global Warming Potential

Baseline model of 100 years based on IPCC 2013

Climate change can be defined as the change in global temperature caused by the greenhouse effect of "greenhouse gases" released by human activity. There is now scientific consensus that the increase in these emissions is having a noticeable effect on climate. Climate change is one of the major environmental effects of economic activity, and one of the most difficult to control because of its global scale.[6] The environmental profiles characterization model is based on factors developed by the UN's Intergovernmental Panel on Climate Change. Factors are expressed as global warming potential over the time horizon of different years, the most common historically being 100 years, measured in the reference unit, **kg CO_2 eq.**

The Greenhouse Gas Protocol identifies three "scopes" of GHG emissions which have been included in this study, however it should be noted that scopes of emissions are not a framework inherent to LCA. The GHG Protocol defines scopes of emissions as:

Scope 1: Direct GHG emissions (e.g. furnace off-gas, combustion of fuels).
Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat, or steam (e.g. emissions embodied in grid power or embodied in steam at an industrial park).
Scope 3: Other indirect emissions such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. transmission and distribution losses) not covered in scope 2, outsourced activities, and waste disposal. Scope 3 emissions can be

either "upstream" or "downstream". In a cradle-to-gate LCA, "upstream" scope 3 must be included.

3.3.8. Interpretation

Results of the LCA were interpreted with reference to the goal and scope, comparing the impacts associated with the identified process routes, geographic regions, and technology implemented. Contribution analysis, sensitivity analysis, and uncertainty analysis were carried out to support the interpretation of the LCA.

3.3.9. Data Quality Review

The key data criteria used to evaluate the quality of the LCI used for this LCA study were:

- Technological, time, and geographical representativeness: data is representative if it matches geographical, temporal, and technological aspects of the goal and scope of the study. By utilising representative data for all foreground processes, the study can be made as representative as possible. When primary data are not available, best-available proxy data is used, ideally from databases or academic LCA literature.
- Completeness: a dataset is judged based on the completeness of inputs and outputs per unit processes and the completeness of the unit processes. The goal is to capture all relevant data in terms of unit processes.
- Precision: measured primary data is considered to be of the highest precision, followed by calculated data, data from the literature, and estimated data. This study is carried out using PEA data. It must be noted that measured data can be precise but inaccurate. Accuracy can be obtained by cross-validation of measured data.
- Methodological appropriateness and consistency: data is considered appropriate and consistent if the differences between data reflect actual differences between distinct product systems, and are not due to inconsistencies in data collection or modelling.

Table 6 presents the grading system of data quality indicators.[12] An evaluation of the data quality for this LCA study on nickel concentrate can be found in later chapters of this report.

Table 6. Grading Guidelines for Data Quality Assessment as Environmental Footprint 2.0 Pedigree Matrix

Data Quality Indicator	Very Poor	Poor	Fair	Good	Very Good
Technological Representativeness	Old to dissimilar technology used	Technology dissimilar to what is used	Generic technology average	From technology specific to the application	All technology aspects of data have been modelled
Time Representativeness	The dataset is older than 8 years	The dataset is less than 8 years old	The dataset is less than 6 years old	The dataset is less than 4 years old	The dataset is less than 2 years old
Geographical Representatives	Data represented is from a distinctly dissimilar region of project location	Similar regions are represented in data	Global average is represented in data	Country of interest is represented in the data	Region of interest is fully represented in data
Completeness	Unknown coverage	Data is from small parts of the target region	Data is less than 50% from the target region	Data is more than 50% from the target region	Data is representative of the entire target region
Precision	Rough estimate with known deficits	Estimates based on calculations not checked by the reviewer	Estimates based on expert judgement	Estimates based on measured and prior values	Measured and verified values with <7% uncertainty
Methodological Appropriateness and Consistency	Attribution process-based approach and following none of the three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Attribution process-based approach and following one out of three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Attribution process based approach and following two out of three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Attribution process based approach and following three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Full compliance with all requirements of the PEF guide

3.3.10. Critical Review

At this time, no critical review of the LCA study has been conducted.

4. Results

4.1. Nickel

4.1.1. Global Warming Potential - Total

The total global warming potential for one kilogram of nickel in concentrate is 10.0 kg CO_2 eq. per kg of nickel in concentrate according to the LCA model produced by Minviro. The total global warming potential is presented broken down by area of the LCA in Figure 3.

The mining stage contributes 3.8 kg CO_2 eq. per kg nickel in concentrate. The concentrating stage contributes 6.4 kg CO_2 eq. per kg nickel in concentrate. The CO_2 sequestration potential of the tailings reduces the global warming potential by 0.2 kg CO_2 eq. per kg nickel in concentrate.

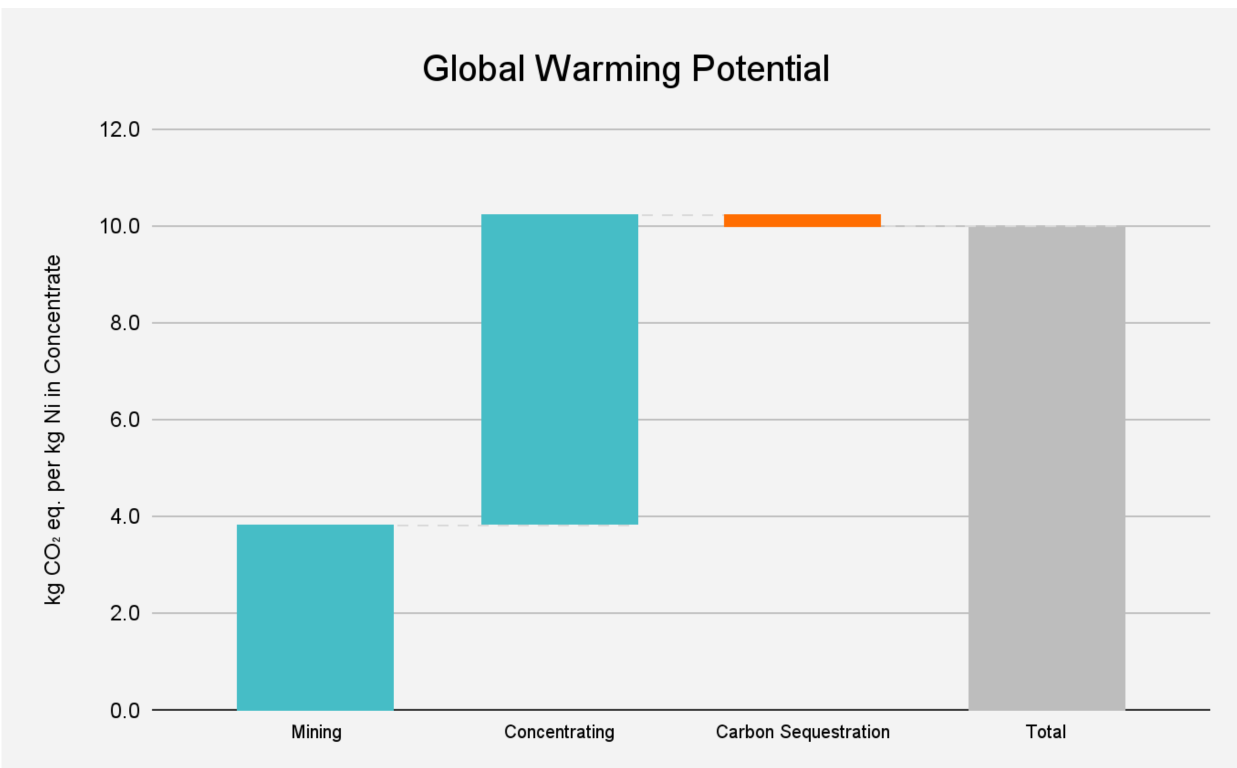

Figure 3. Total Global Warming Potential for Nickel in Concentrate

4.1.2. Global Warming Potential - Contribution Analysis

Contribution analysis of the global warming potential is presented in Figure 4 and Table 7. The top three most significant contributors towards the global warming potential impact in the production of nickel at the Rönnbäcken project are:

- 2.7 kg CO_2 eq. per kg nickel associated with the combustion of diesel, used by the haulage fleet in the mining stage;
- 2.4 kg CO_2 eq. per kg nickel associated with the consumption of dispersants in the concentrating stage;
- 1.6 kg CO_2 eq. per kg nickel associated with the use of collectors in the concentrating stage;
- 0.2 kg CO_2 eq. per kg nickel deducted from the global warming potential due to the calculated carbon sequestration potential of the process tailings.

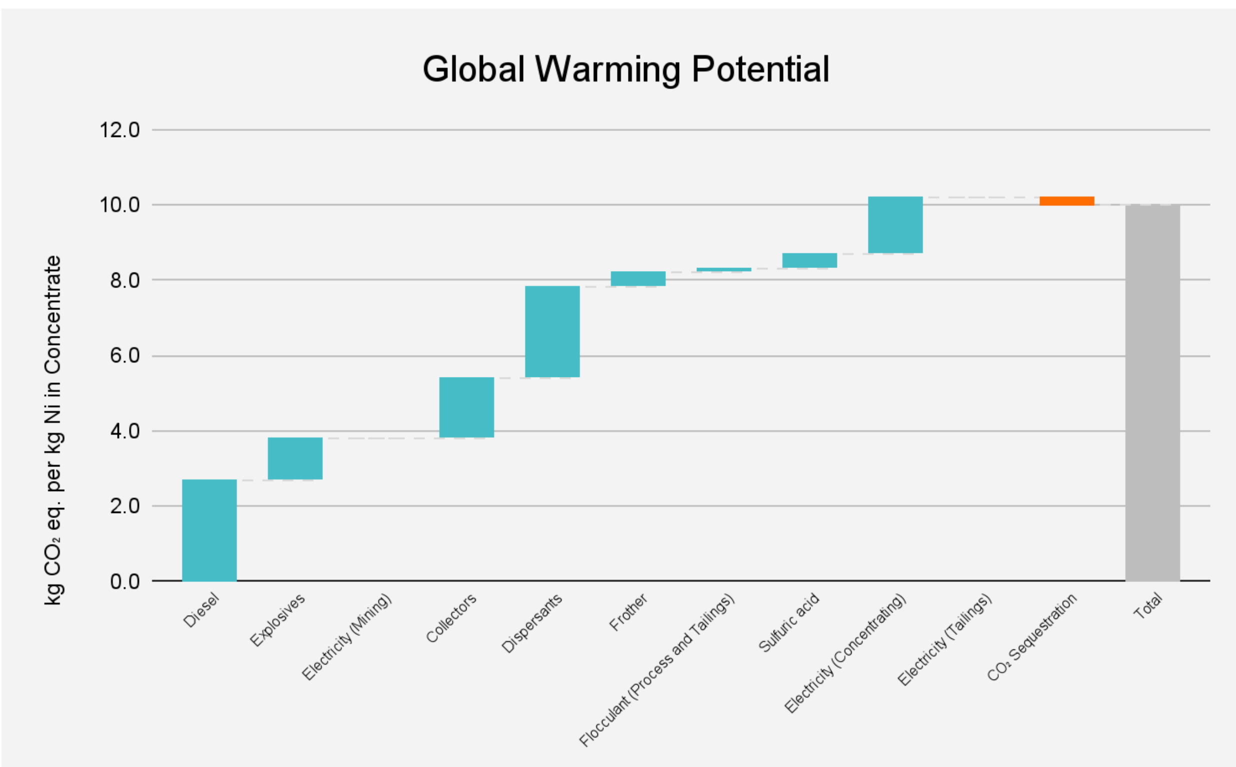

Figure 4. Global Warming Potential Contribution Analysis for Nickel in Concentrate

Table 7. Global Warming Potential Contribution Analysis for Nickel in Concentrate

Stage	Inventory Item	Raw Value	Units
Mining	Diesel (Mining)	2.7	kg CO_2 eq. per kg Ni
	Emulsion	1.4	kg CO_2 eq. per kg Ni
	Electricity (Mining)	< 0.1	kg CO_2 eq. per kg Ni
Concentrating	Collectors	1.6	kg CO_2 eq. per kg Ni
	Dispersants	2.4	kg CO_2 eq. per kg Ni
	Frother	0.4	kg CO_2 eq. per kg Ni
	Flocculant (Process and Tailings)	0.1	kg CO_2 eq. per kg Ni
	Sulfuric Acid	0.4	kg CO_2 eq. per kg Ni
	Electricity (Concentrating)	1.5	kg CO_2 eq. per kg Ni
Carbon Sequestration	CO_2 sequestration potential	0.2	kg CO_2 eq. per kg Ni
Total		**10.0**	kg CO_2 eq. per kg Ni

4.1.3. Global Warming Potential - Total Breakdown by Scope

The global warming potential broken down by scopes (1, 2 and 3) is presented in Figure 5 and Table 8.

The single contributor towards scope 1 emissions is the use of diesel by the haulage fleet in the mining stage, which is reduced by the CO_2 sequestration potential of the process tailings.

The top contributor of scope 2 emissions is the use of electricity in the concentrating stage, with a minor amount of scope 2 emissions coming from the use of electricity in the mining stage.

The top contributors of scope 3 emissions are the use of reagents in the concentrating process, predominantly the use of collectors and dispersants. The embodied impact of explosives used in the mining process is the major contributor to scope 3 emissions for that stage.

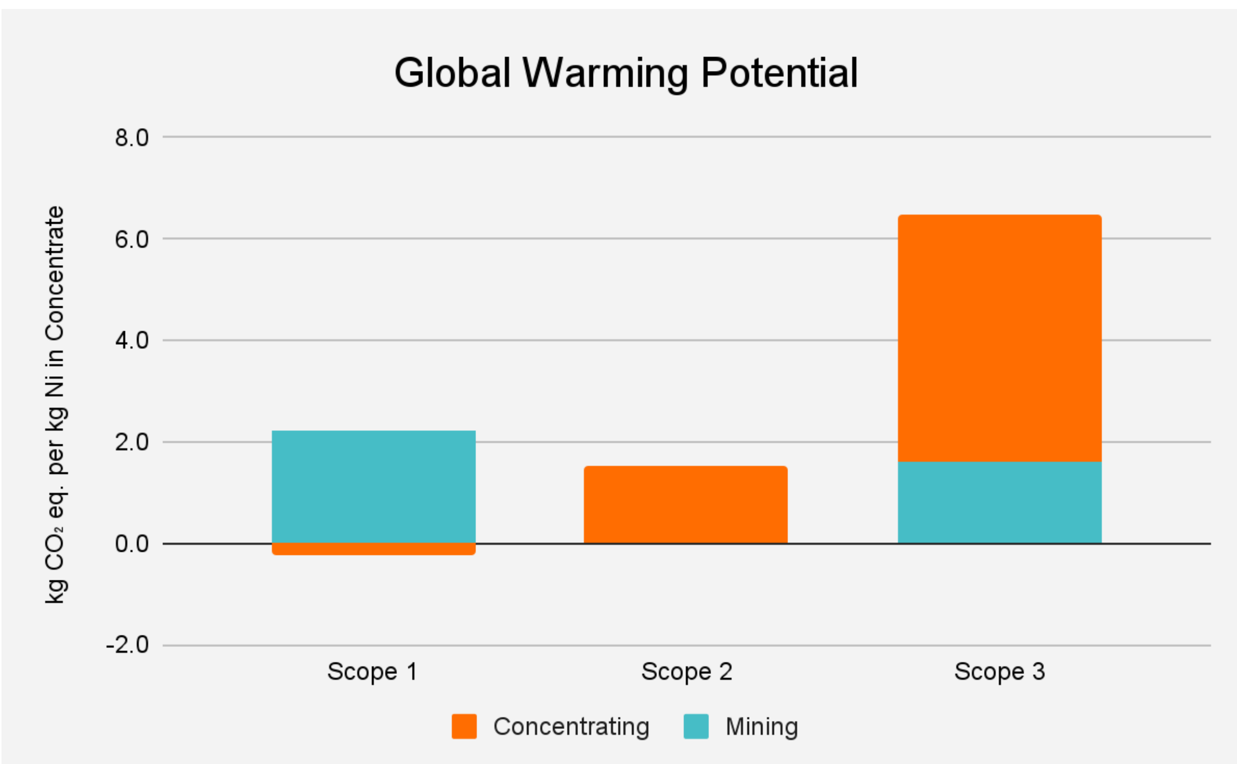

Figure 5. Global Warming Potential Contribution Analysis by Scope of Emissions for Nickel in Concentrate

Table 8. Global Warming Potential Contribution Analysis by Scope of Emissions for Nickel in Concentrate

Stage	Scope 1	Scope 2	Scope 3	Units
Mining	2.2	< 0.1	1.6	kg CO_2 eq. per kg Ni
Concentrating		1.5	4.9	kg CO_2 eq. per kg Ni
Carbon Sequestration	0.2			kg CO_2 eq. per kg Ni
Total	2.0	1.5	6.5	kg CO_2 eq. per kg Ni

4.2. Magnetite

4.2.1. Global Warming Potential - Total

The total global warming potential for one kilogram of iron in concentrate is 6.6E-2 kg CO_2 eq. per kg iron in concentrate according to the LCA model produced by Minviro. The total global warming potential is presented broken down by area of the LCA in Figure 6.

The mining stage contributes 1.3E-2 kg CO_2 eq. per kg iron in concentrate. The concentrating stage contributes 2.1E-2 kg CO_2 eq. per kg iron in concentrate. Processing of the magnetite ore contributes 3.6E-2 kg CO_2 eq. per kg iron in concentrate. Carbon sequestration potential allocated to the iron in magnetite concentrate is 6.5E-4 kg CO_2 eq. per kg iron in concentrate.

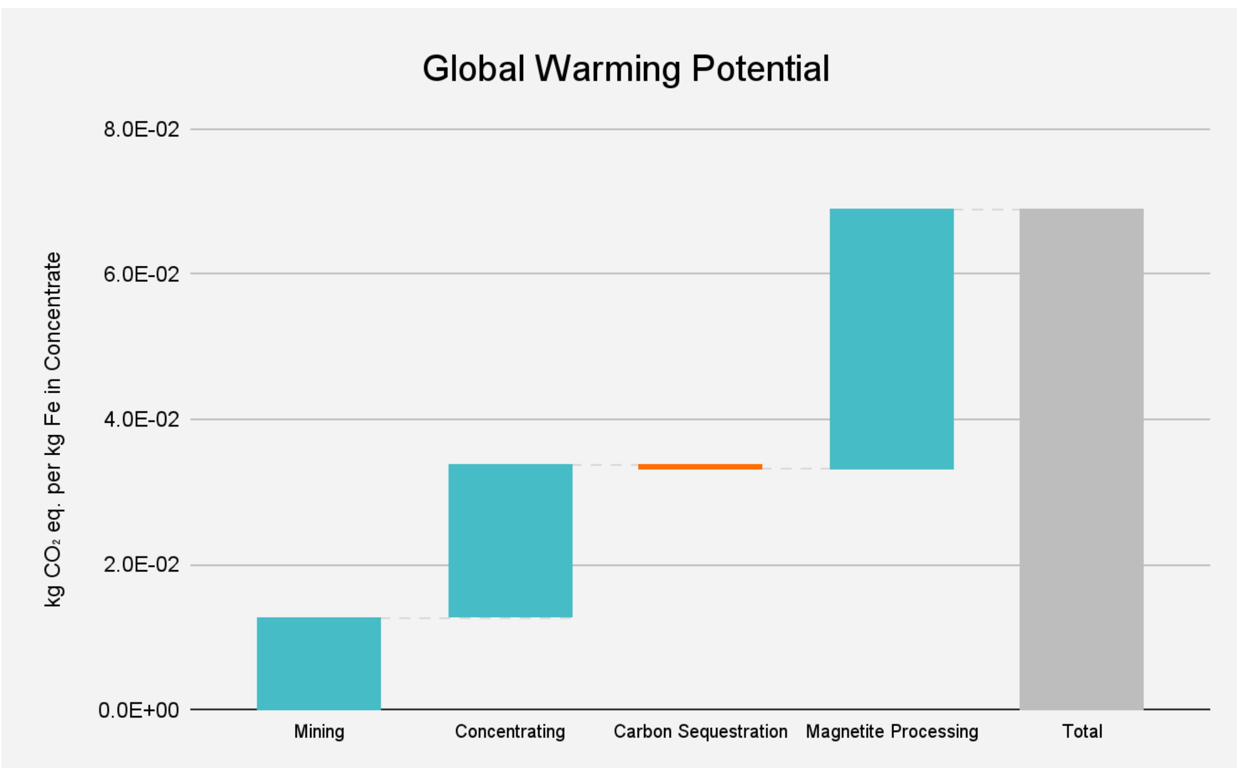

Figure 6. Total Global Warming Potential for Iron in Magnetite Concentrate

4.2.2. Global Warming Potential - Contribution Analysis

Contribution analysis of the global warming potential of producing one kilogram of iron in concentrate is presented in Figure 7 and Table 9. The top three most significant contributors to global warming potential in the production of magnetite concentrate at the Rönnbäcken project are:

- 1.3E-2 kg CO_2 eq. per kg iron in concentrate associated with the use of soda ash in magnetite processing;
- 9.6E-3 kg CO_2 eq. per kg iron in concentrate associated with the use of an amine collector in magnetite processing;
- 8.9E-3 kg CO_2 eq. per kg iron in concentrate associated with the use of diesel in the mining stage.

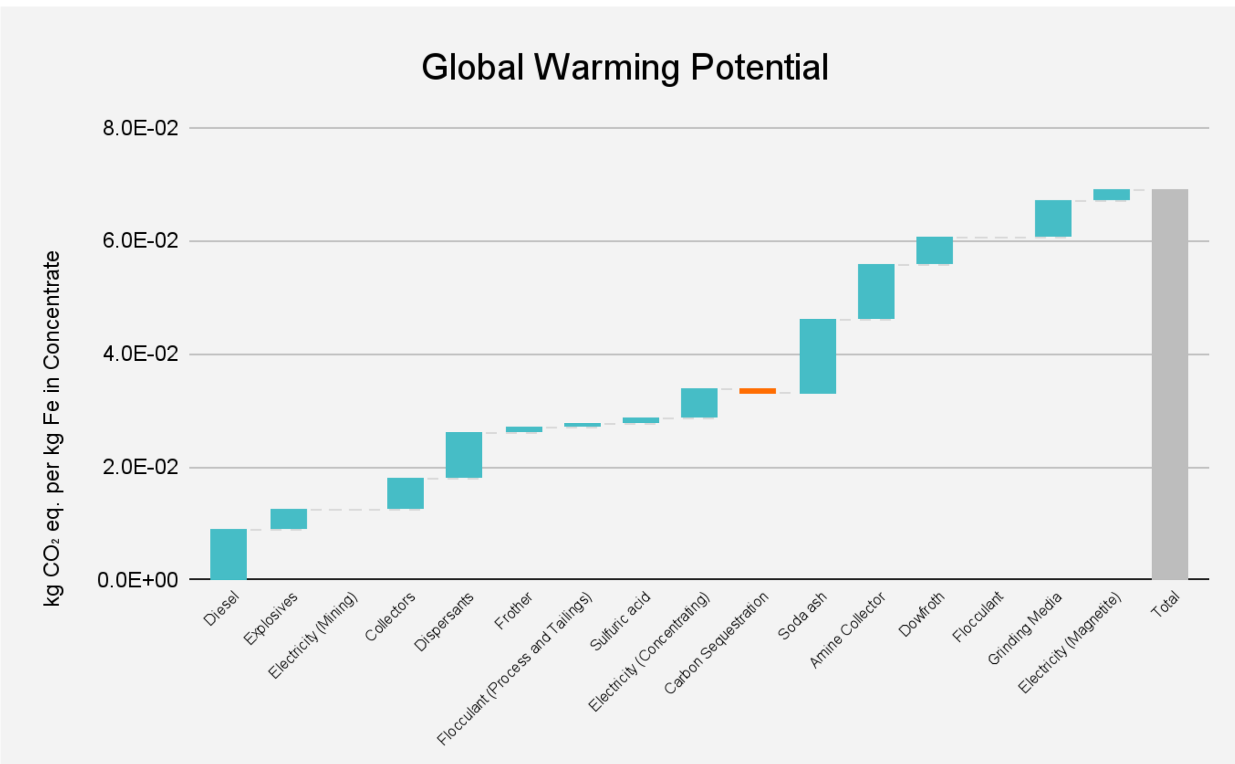

Figure 7. Global Warming Potential Contribution Analysis for Iron in Magnetite Concentrate

Table 9. Global Warming Potential Contribution Analysis for Iron in Concentrate

Stage	Inventory Item	Raw Value	Units
Mining	Diesel (Mining)	8.9E-3	kg CO_2 eq. per kg Fe
	Emulsion	3.7E-3	kg CO_2 eq. per kg Fe
	Electricity (Mining)	8.9E-5	kg CO_2 eq. per kg Fe
Concentrating	Collectors	5.3E-3	kg CO_2 eq. per kg Fe
	Dispersants	8.0E-3	kg CO_2 eq. per kg Fe
	Frother	1.3E-3	kg CO_2 eq. per kg Fe
	Flocculant (Process and Tailings)	3.6E-4	kg CO_2 eq. per kg Fe
	Sulfuric Acid	1.2E-3	kg CO_2 eq. per kg Fe
	Electricity (Concentrating)	5.0E-3	kg CO_2 eq. per kg Fe
Carbon Sequestration	CO_2 sequestration potential	-6.5E-4	kg CO_2 eq. per kg Fe
Magnetite Processing	Soda ash	1.3E-2	kg CO_2 eq. per kg Fe
	Amine Collector	9.6E-3	kg CO_2 eq. per kg Fe
	Dowfroth	4.8E-3	kg CO_2 eq. per kg Fe
	Flocculant	1.0E-4	kg CO_2 eq. per kg Fe
	Grinding Media	6.4E-3	kg CO_2 eq. per kg Fe
	Electricity (Magnetite)	2.0E-3	kg CO_2 eq. per kg Fe
Total		**6.9E-2**	kg CO_2 eq. per kg Ni

5. Scenario Modelling

Figure 8 and Figure 9 present the results of both the base case and the scenario analysis. For the base case, the total global warming potential impact was calculated to be 10.0 kg CO_2 eq. per kg nickel in concentrate. Of that impact, 3.8 kg CO_2 eq. per kg nickel in concentrate came from the mining stage, 6.4 kg CO_2 eq. per kg nickel in concentrate from the concentrating stages and -0.2 kg CO_2 eq. per kg nickel in concentrate from the CO_2 sequestration potential.

For the electrified mining fleet scenario, a higher energy efficiency is assumed for an electrified fleet. This means that the total energy requirements is lower compared to energy obtained from combusting diesel. The additional electricity required for an electrified mining fleet is assumed to come from the Swedish grid. Overall, the total global warming potential reduces to 7.5 kg CO_2 eq. per kg nickel in concentrate. The impact of the concentrating stage and the CO_2 sequestration potential remain the same. The global warming potential of the mining stage reduces to 1.3 kg CO_2 eq. per kg nickel in concentrate.

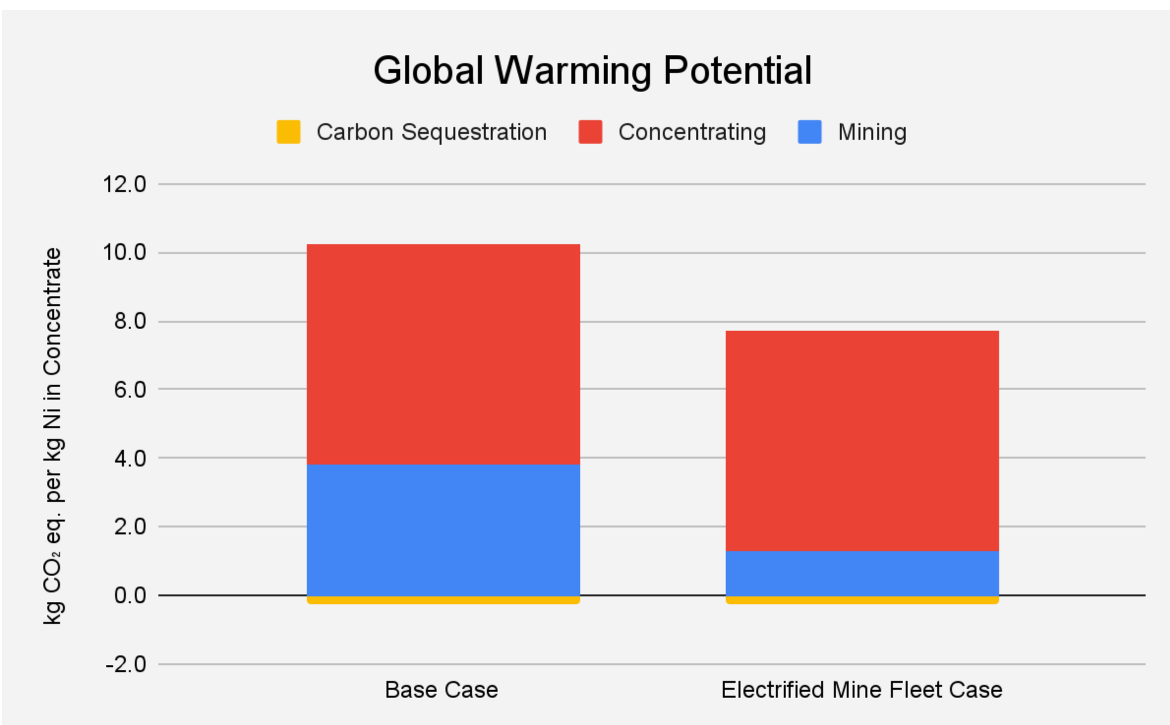

Figure 8. Global Warming Potential by Stage for the Base Case and the Electrified Mine Fleet Case

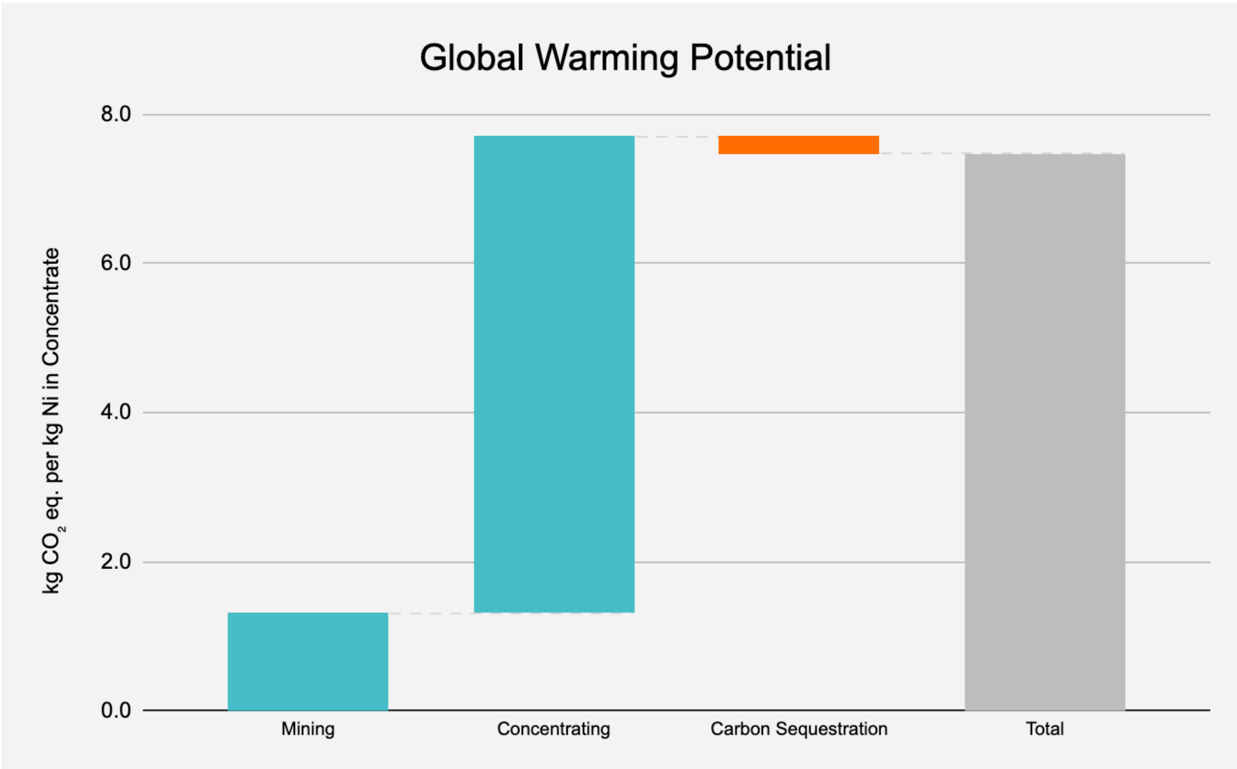

Figure 9. Total Global Warming Potential for Nickel in Concentrate For the Electrified Mine Fleet Case

6. Data Quality Assessment

The foreground and background data of the LCI were judged on technological and time representativeness, geographical coverage, completeness, precision, and consistency. Foreground data used in this study was generated from data provided by Nickel Mountain AB. The background data used in this LCA was from Ecoinvent 3.7.1.[5] The Rönnbäcken project is in the PEA stage. The primary limitation to this study is the level of definition, which is considered to be the most uncertain of the distinct development stages of resource projects. This has been addressed by assigning a 35% uncertainty to the data.[13]

- Technological representativeness: the technology assumes recovery of nickel using conventional open pit mining and concentrating processes. All background data was sourced from Ecoinvent 3.7.1. **The technological representativeness is considered to be very good.**
- Time representativeness: data was updated for the PEA study in 2022. **The time representativeness is considered to be very good.** It must be noted that although the PEA was updated in 2022, data for the concentrate processing was generated over 8 years ago. It is assumed that the processing data is still valid for that flowsheet in current date and time.
- Geographical Coverage: **The geographical representativeness is considered to be fair.**
- Completeness: all elementary flows related to the production of nickel and magnetite concentrate were considered in this study. It must be noted that due to the level of development at which the Rönnbäcken project is at, some flows might be missing. Therefore, **the completeness was considered to be good.**
- Precision: the primary limitation of the data is the level of definition of the PEA study The precision of this data will increase throughout further development stages. **The precision of the data was considered to be fair.** All background data sources were sourced from EcoInvent 3.7.1 or LCA Commons, of which the precision was documented.
- Methodological appropriateness and consistency: the methodology used in this LCA study aligns with the methodology as used by the Nickel Institute in the industry

wide LCA study. However, as the use-phase and end of life-phase of the products are not included, it only covers a part of the product life cycle. **The methodological appropriateness was therefore considered to be fair.**

7. Sensitivity Analysis

Sensitivity analysis was carried out to explore the effects that variations in reagent, material, and energy consumption may have on the final product LCIA results. The analysis studies the effect of variation of the five most significant contributors to global warming potential in the LCA: diesel used in the mining stage, collectors, dispersants and electricity used in the concentrating process, and the carbon sequestration potential of the process tailings. Although the carbon sequestration potential is not one of the main drivers of the global warming potential impact, it is included as it is the only variable that reduces the global warming potential of the nickel product. The results are presented in Figure 10.

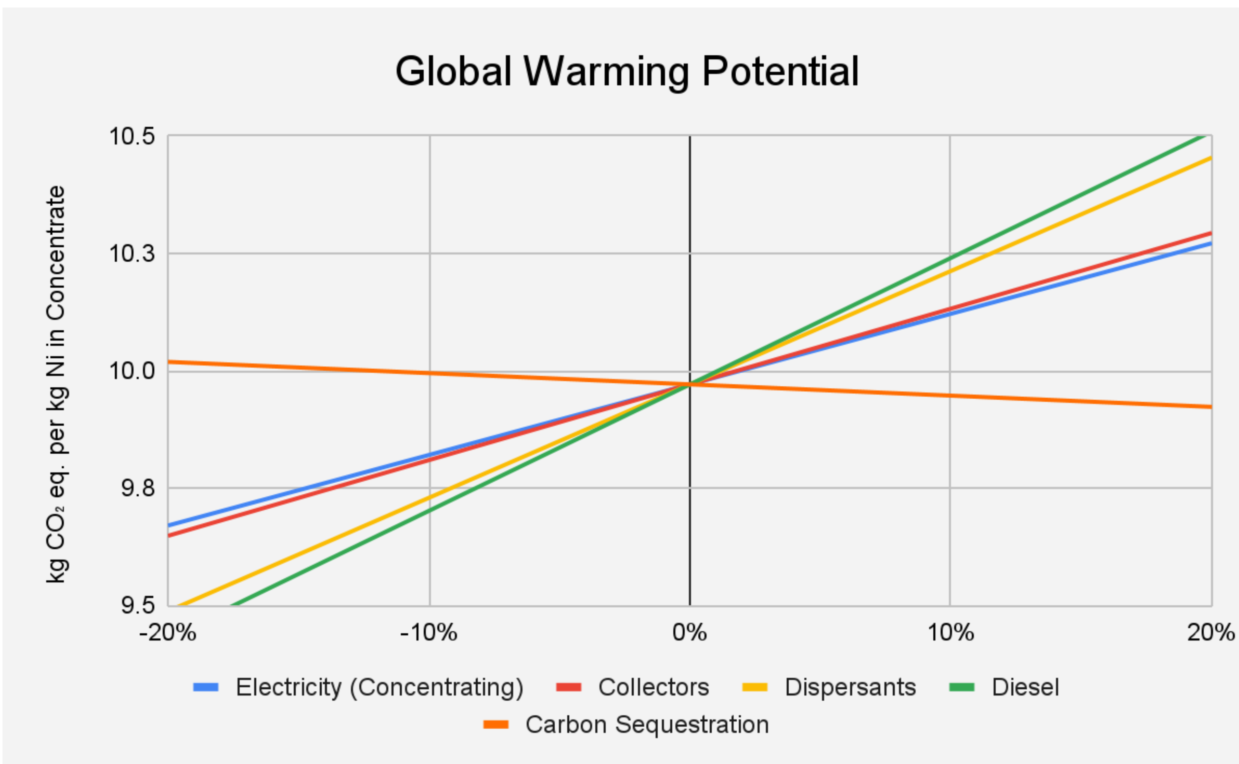

Figure 10. Sensitivity Analysis of Major Contributors to Global Warming Potential

This analysis shows that the LCA model for global warming potential is most sensitive to the contributions of dispersants used in the concentrating process and diesel used by the haulage fleet. The model is less sensitive to contributions from collectors and electricity used in the concentrator. The effect of carbon sequestration potential follows a reverse correlation, which means that if the carbon sequestration potential decreases the global warming potential of the nickel product increases.

If the consumption of diesel in the mining stage, the most significant contributor to GWP, increased or decreased by 20%, the total global warming potential would vary between 9.4 and 10.5 kg CO_2 eq. per kg nickel in concentrate. Meanwhile, if the consumption of electricity in the concentrator, the fourth most significant contributor, increased or decreased by 20%, the total global warming potential would vary between 9.7 and 10.3 kg CO_2 eq. per kg nickel in concentrate. For a variation of ±20% in the carbon sequestration potential of the tailings, the global warming potential could vary between 10.0 and 9.9 kg CO_2 eq. per kg nickel in concentrate.

This is a clear demonstration of the high sensitivity of the LCA model to a small number of major inputs to the process of manufacturing Nickel Mountain AB's nickel concentrate. These top contributors should be the main targets of environmental impact mitigation strategies.

8. Uncertainty Analysis

The uncertainty in the LCI and data quality has been explored in relation to the environmental impacts of the project using a Monte Carlo simulation, which assesses the range and likelihood of different impacts.

The Monte Carlo method, also known as a statistical simulation method, is a precise method of numerical calculation guided by probability statistical theory. The method uses random numbers to solve practical problems, whereby random variables are generated with a certain probability distribution and the numerical characteristics of the model are estimated with statistical methods. The Monte Carlo method randomly samples the values of uncertain variables and combines with the predetermined impact assessment method to simulate statistically significant environmental impact evaluation results. This can reflect the influence of uncertain factors more accurately. The use of Monte Carlo simulation in LCA can effectively present the uncertainty associated with the LCA and its inputs. The results of the Monte Carlo simulation assist with understanding the impact of risk and uncertainty in the prediction and forecasting of models.

In the Monte Carlo simulation conducted for the LCA, uncertainty was addressed by assuming an uncertainty of 35% for all items in the LCI. Emissions cannot be modelled unless the materialistic reason for the emission increases as well (e.g. direct emissions associated with the combustion of diesel). The Monte Carlo simulation does not consider the uncertainty of the background data, as it is assumed that the 35% uncertainty associated with the PEA of the project will include the uncertainty of the background data.[13] The Monte Carlo simulation was run through 1,000 iterations using a normal probability distribution modelling the associated uncertainty. As the project moves from PEA into later stages of development, the standard deviation will decrease. The results of the Monte Carlo simulation for the global warming potential are presented in Figure 11 and Table 10. Values generated in the simulation range from 4.3 to 15.6 kg CO_2 eq. per kg nickel in concentrate. The mean value of the simulation is 10.0 kg CO_2 eq. per kg nickel in concentrate, which is the same as the finding of the LCA. This is expected as an equal uncertainty was assigned for all energy and material inputs.

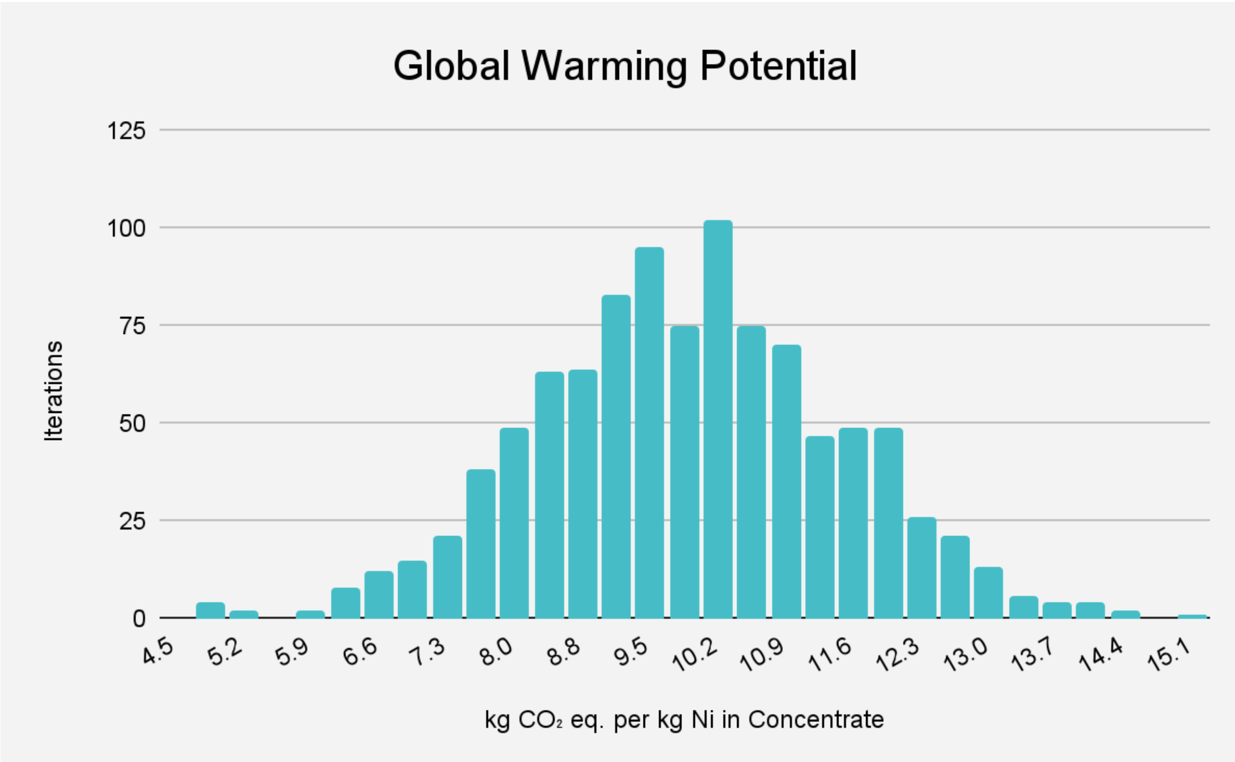

Figure 11. Monte Carlo Simulation for Global Warming Potential

Table 10. Statistics Describing Results of the Monte Carlo Simulation of Global Warming Potential

Parameter	**Global Warming Potential (kg CO_2 eq.)**
LCA Study Result	10.0
Mean	10.0
Minimum	5.0
Maximum	15.2
20^{th} Percentile Value (P20)	8.7
80^{th} Percentile Value (P80)	11.4
Standard Deviation	1.6

9. Conclusions and Recommendations

9.1. Conclusions

In this LCA study, the global warming potential impact of producing nickel concentrate at Nickel Mountain's Rönnbäcken project was investigated. Using process data from a 2022 PEA study as a baseline scenario, the global warming potential impact of the nickel concentrate product is 10.0 kg CO_2 eq. per kg nickel in concentrate. When pursuing full electrification of the mining fleet, the global warming potential of the nickel product decreases to 7.5 kg CO_2 eq. per kg nickel in concentrate.

The consumption of diesel by the haulage fleet in the base case scenario is one of the predominant causes for the global warming potential, due to direct emissions associated with combusting diesel. The embodied impact of consumables in the flotation process, namely dispersants and collectors, are also large drivers of the impact. Although electricity in Sweden has a low CO_2 intensity per kWh, the electricity used in the process still has a significant impact on the global warming potential. This comes from the relatively large electricity requirements in the process, around 50 kWh per kg nickel in concentrate.

The CO_2 sequestration potential of the tailings may reduce the global warming potential of the nickel product, which in this study was used to discount the global warming potential impact of the nickel product.

We have greatly enjoyed working with Nickel Mountain AB on this interesting project. We hope to continue our relationship with the goal of minimising the environmental impacts of producing nickel that is critical for the energy transition.

9.2. Recommendations

Minviro has several recommendations for Nickel Mountain AB to improve the quality of this LCA and to improve the environmental performance of the nickel concentrate of the Rönnbäcken project.

- The data used in this LCA has been based on results prepared for a 2022 PEA. It is recommended to update the LCA when better defined data becomes available, as the project progresses into further stages of development. This will decrease the uncertainty associated with the LCA work.

- Testwork on the flotation of the nickel product was carried out in the 2000s. It is possible that other processing methodologies could be more suitable for the nickel ore going forward. It is recommended to update the LCA work on any future data obtained from further experimental work.
- Carbon sequestration potential was calculated as part of this LCA, but was based on first principle calculations rather than accurate testwork. It is recommended to update the LCA once experimental testwork has been carried out on the tailings of the Rönnbäcken project.
- In this LCA study, only the global warming potential impact category was studied. For battery materials, other impact categories are also important, such as water scarcity footprint and land use impacts. It is recommended to include this in a future update.
- The LCA did not consider the transport of consumables to site or of constructing the required infrastructure. Minviro recommends to include this in a future LCA update. It is not likely that this will contribute significantly to the global warming potential, however proving this might be beneficial for Nickel Mountain AB.
- To reduce the global warming potential impact of the project, Minviro recommends finding suppliers with low CO_2 credential to reduce the global warming potential of the nickel product. From this study, it has been shown that finding low global warming potential collectors, dispersants and explosives could be considered beneficial for the low carbon footprint credential of the project. Also focussing on maximising the carbon sequestration potential of the tailings could lead to a reduction in the CO_2 footprint. Minviro recommends pursuing both strategies, enabling truly sustainable development.

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Appendix A - Life Cycle Inventory Summary

The full LCI used in this study is presented in Table 9.

Inventory Item	Raw Value	Unit	Reference Unit
Mining			
Diesel	60,000	liters	per day
Explosives	40,000	kg	per day
Electricity (Mining)	60,000	kWh	per day
Operational days	350	days	per year
Concentrating			
Ore	30	million tonnes ore	per year
Collector 1	98	grams	per tonne ore
Collector 2	147	grams	per tonne ore
Dispersant WG	0	grams	per tonne ore
Dispersant CMC	535	grams	per tonne ore
Dispersant P10	22	grams	per tonne ore
Complexant		grams	per tonne ore
Copper sulphate	0	grams	per tonne ore
Frother	75	grams	per tonne ore
Flocculant (Process and Tailings)	30	grams	per tonne ore
Sulfuric acid	1,770.00	grams	per tonne ore
Grinding Media	N/A	N/A	N/A
Electricity (Concentrating)	1,173	GWh	per year
Electricity (Tailings)	10	GWh	per year
Ni in Ni Concentrate	22,074	tonnes	per year
Co in Co Concentrate	637	tonnes	per year
CO_2 Sequestration Potential	6600	tonnes	per year
Magnetite Pelletising			
Ore	30	million tonnes ore	per year
Soda ash	500	grams	per tonne ore
Amine Collector	150	grams	per tonne ore
Dowfroth	50	grams	per tonne ore
Flocculant	1.5	grams	per tonne of ore
Electricity	152	Gwh	per year
Fe in Fe concentrate	1,453,922	tonnes	per year
Steel balls for magnetite regrind	3600	tonnes	per year