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The Carbon Footprint of Kevitsa Mine and The Impact of An Electric Trolley Line

Jesse Riikonen

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Kevitsan kaivoksen hiilijalanjälki ja sähköisen trolley-linjan vaikutus
The Carbon Footprint of Kevitsa Mine and the Impact of An Electric Trolley Line

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Boliden on konserni, joka tuottaa ja kierrättää metalleja ja on asettanut tavoitteekseen vähentää hiilidioksidipäästöjään 40 prosentilla vuodesta 2012 vuoteen 2030 mennessä. Kevitsan kaivos on osa Boliden-konsernia, joka rakentaa parhaillaan kaivokselle sähköistä trolley-linjaa sähköenergiaa hyödyntäville kiviautoille. Louhittu kivi ja malmi kuljetetaan jatkossa sähköenergiaa käyttävien kiviautojen avulla ylös avolouhoksesta, edistettäen yhtiön päästötavoitteiden saavuttamista sekä yhä kestävämpien metallirikasteiden tuotantoa.

Opinnäytetyön tavoitteena oli koota tieto kaivoksen hiilidioksidipäästöistä vuoden 2021 osalta ja luoda selkeä kuva päästöjen muodostumisesta sekä jakautumisesta kaivoksen eri toimintojen välillä. Lisäksi tavoitteena oli luoda laskentamalli sähköisen trolley-linjan vaikutuksesta kaivoksen hiilidioksidi-päästöihin.

Kaivoksen kokonaishiilidioksidipäästöt vuonna 2021 olivat noin 114 550 tCO_2, sisältäen suorat sekä epäsuorat päästöt (scope 1, 2 & 3). Suurin osa päästöistä muodostui ostetun sähköenergian kulutuksesta (52 554 tCO_2) ja lähes yhtä suuri osa on peräisin fossiilisen polttoaineen kulutuksesta (47 200 tCO_2). Laskennan perusteella sähköisen trolley-linjan päästökertoimeksi saatiin noin 0,06 gCO_2/tm. Vastaava päästökerroin laskettiin myös polttomoottorikäyttöiselle kiviautolle (0,41 gCO_2/tm). Trolley-linjan todettiin vähentävän kaivoksen kokonaispäästöjä jopa 13 prosentilla, mutta kiviauton polttoaineenkulutus tulisi kuitenkin todentaa ennen kerrointen käyttöä päästölaskennassa.

Kaivoksella toimivien urakoitsijoiden päästöraportoinnin siirtämistä scope 3:sta scope 1:een voisi harkita, sillä urakoitsijat toimivat kaivoksen kannalta oleellisten toimintojen parissa, esimerkkinä näistä patokorotukset. Lisäksi kiviautojen todellista polttoaineen kulutusta olisi hyvä mitata vastaavalla trolley-linjalla, jotta päästölaskennasta saataisiin mahdollisimman paikkansapitävä.

Tulevaisuutta ajatellen olisi hyvä tutkia trolley-linjan vaikutusta pidemmällä aikavälillä, ottaen huomioon kaivoksen pitkän ajan tuotantosuunnitelmat. Lisäksi päästötavoitteiden saavuttamiseksi voisi olla hyvä tutkia trolley-linjan mahdollista soveltamista myös sivukivialueelle.

Avainsanat: kaivos, päästöt, hiilidioksidijalanjälki, vähentäminen

ABSTRACT

Tampereen ammattikorkeakoulu
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The Carbon Footprint of Kevitsa Mine and The Impact of An Electric Trolley Line
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Boliden is a company producing and recycling metals and has set the target of reducing 40 percent of its CO_2 emissions from 2012 to 2030. Boliden Kevitsa mine is building an electric trolley line for converted mine trucks to transport mined rock by using electricity in order to contribute to the company emissions reduction targets and to produce more sustainable metal concentrates.

The aim of this thesis was to collect the data of the CO_2 emissions of the mine in 2021, declaring a better view on sources contributing to the total emissions and to establish a calculation model to estimate the impact of the electric trolley line regarding the total CO_2 emissions of the mine.

The total CO_2 emissions of Kevitsa mine in 2021 resulted in approximately 114 550 tCO_2 including direct and indirect emissions (scope 1, 2 & 3). The main source of emissions was purchased electric energy 52 554 tCO_2 with an almost similar amount of emissions produced by fuel combustion on site, approximately 47 200 tCO_2. The results also showed that the electric trolley line emission factor is approximately 0,06 gCO_2/tm. Similar emission factor was calculated for normal mine trucks (0,41 gCO_2/tm). The impact of trolley line is potentially 13 % in overall emission reduction, but the measured fuel consumption data is required before implementation to emissions calculations.

The emissions from contractors operating on site could be included in scope 1 rather than scope 3, as their operations are closely related to essential mine operations such as dam raising. Further measurements regarding the fuel consumption of mine trucks should be conducted to improve the emission reduction calculations of the trolley line.

As a recommendation for future research, it would be beneficial to study the emission reduction of the trolley line taking into account the production plan. Also studying the optional implementation of the trolley line concept in waste rock deposition could provide an opportunity for further decrease in CO_2 emissions in Boliden Kevitsa.

Key words: mining, emissions, carbon footprint, reduction

CONTENTS

GLOSSARY or ABBREVIATIONS AND TERMS (choose one or other)

CO_2	Carbon dioxide
tCO_2	tons of carbon dioxide
CO_2 eq	CO_2 equivalent
GHG	Greenhouse gas
GRI	Global Reporting Initiative
ISO	International Standardization Organisation
LFO	Light fuel oil
NME	Near mine exploration
WRA	Waste rock area
WR	West ramp in the pit
ROMpad	Run of mine ore reserve
UNW	Unusable waste rock
USW	Usable waste rock
EHSQ	Environment, Health & Safety, Quality
IEA	International Energy Agency

1 INTRODUCTION

Human activities have resulted in increasing greenhouse gas emissions (GHG) over the past 300 years. Since the last measurements published in 5th assessment report of Intergovernmental Panel on Climate Change in 2011, the increases in annual average concentrations have been evident. It is very likely, that these activities play a major role as a contributing actor towards global warming, climate change and temperature increase & acidification of oceans (IPCC, 2021.)

Energy and industrial business areas were the major sources of global greenhouse gas emissions in 2019, contribution being approximately 58 % of the total GHG emissions. Yet, the forementioned business areas have managed to decrease their emissions consecutively for over 10 years in around 20 countries. Most of these decreases reflect the improvements in production, energy efficiency and implementing new innovations (IPCC, 2022.)

Boliden Kevitsa Mining Oy is part of Boliden Group, focusing on mining and producing metal concentrates for the industry, mainly copper and nickel. Boliden Group has set ambitious targets to reduce their CO_2 emissions by 40 % from 2012 to 2030. In addition, Boliden is aiming at carbon neutrality by 2050. As part of emission mitigation, Boliden Kevitsa is converting thirteen mine trucks into electric mine trucks and establishing an electric trolley line that provides the needed electricity for mine trucks that are transporting the mined rocks from the pit.

The aim of the thesis is to collect the CO_2 emission data from year 2021, distinguish the current composition of sources of CO_2 emissions in Kevitsa and establish a calculation model to estimate the impact of electric trolley line regarding the total CO_2 emissions of the mine.

2 THEORETICAL BACKGROUND

2.1 Carbon footprint

Carbon footprint is often referred to when evaluating the environmental status and contribution towards climate change of a certain process, business, or industry. It may consider all greenhouse gases emitted that include non-carbon compounds (CO_2 eq), or just the actual tons of CO_2 emitted in fuel combustion and energy production. It may also consider the whole cradle to grave emissions or just the on-site emissions. Which leads to a conclusion that definition and scoping is crucial when determining the carbon footprint for certain product or process. In order to simplify the meaning and accuracy of carbon footprint, it is suggested that carbon footprint would consider the actual amount of CO_2 emissions that are generated directly by the activity or in the value chain (Wiedmann & Minx, 2007.)

2.2 Mining industry carbon footprint

In 2019, the total GHG emissions to air produced in Finland was approximately 57 million tCO_2 eq, from which 431 000 tons (0,75 %) was generated in mining industry (Statistics Finland, 2021.)

2.3 Scoping

Scoping is a tool that ensures the outcome of the work is according to the aims and objectives of the work by setting the boundaries for what is included and excluded. It also helps in identification of the most important emission sources that should be included in the work and assessed in detail. (European commission, 2001.)

Boliden Kevitsa Mining Oy is reporting the CO_2 emissions of the mine in accordance with the Global Reporting Initiative (GRI) standard 305, which follows the scope classification defined by International Organization of Standardization (ISO) in publication "ISO 14064 - International Standard for GHG Emissions Inventories and Verification":

- Direct emissions (scope 1) generated on site including central heating plant and Boliden-owned operations.
- Indirect emissions (scope 2) which originate from the purchased electric energy.
- Indirect emissions (scope 3) which are formed in the value chain.

The detailed description of the scopes is presented in figure 1 (Global Reporting initiative, 2016).

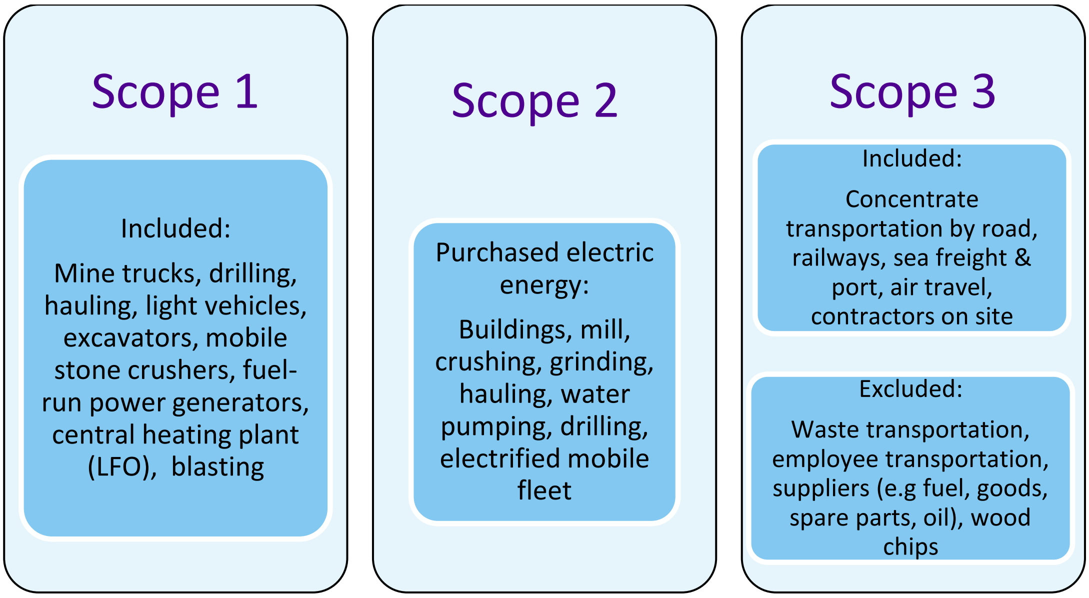


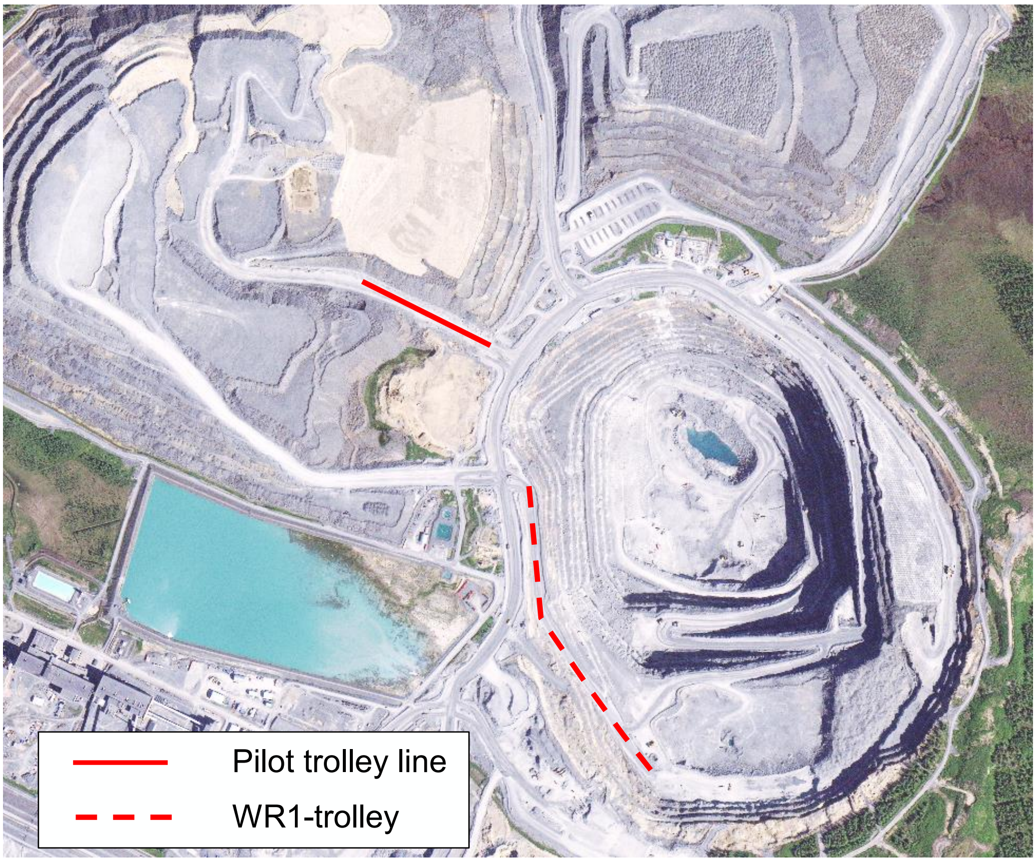
FIGURE 1. Description of CO_2 emission scopes for reporting in Kevitsa mine.

These boundaries are already established by the mining company and will be utilized in this study (Boliden, 2022). Light fuel oil (LFO) is used in mine trucks, drilling machinery, excavators, mobile stone crushers, power generators, heating plant (when the demand is low) and is the major fuel type used in Kevitsa. Diesel oil is used mainly in light vehicles and trucks that are registered for public roads. Electric energy is used in the mill process as ore is crushed, grinded and milled. Electricity is also needed in water pumping, office building, drilling and mine trucks in the future. Contractors are hired for example in dam raising operations and waste rock handling.

2.4 Mine truck electrification

Boliden Kevitsa Mining Oy has decided on investing in modifying 13 Komatsu 830E-5 mine trucks into electric mine trucks and building an electric trolley line to 1A ramp in waste rock area (WRA) and to West Ramp (WR) ascending from the pit to ground surface. The trolley line in 1A was used as a testing line for the project, from which the contractor responsible on building the trolley line gathered data used in this thesis. The length of the trolley line in 1A was approximately 500 meters. According to the current UNW disposal plan, the trolley line in 1A will be dismantled and relocated to either 1B-ramp or as part of the WR trolley line. The locations of the trolley lines are presented in picture 1 (Partamies, 2022).

The electric trolley line in WR is planned to be built in two parts. The building process of the first 500 meters in WR will commence during the year 2022. The second part of the building project is planned to initiate in 2023 and is 500 meters to 800 meters in length, depending on the mining process in the pit. The aim of the project is to establish approximately 1300 meters long electric trolley line in WR (Partamies, 2022).



PICTURE 1. The location of pilot trolley line in WRA and actual trolley line (to be built) in the pit (Boliden, 2021. Authorized use).

3 METHODS

3.1 Data acquisition

This work uses the CO_2-emission data from the year 2021 as a reference for emission reduction calculations and fuel consumption distribution. The data has been collected by the mining company. In addition, this work is highly dependent on data regarding the demo trolley line test drives and mine truck fuel consumption along the yet to be built electric trolley line in the pit. The source of data for this work is presented in table 1.

TABLE 1. The source and type of emission data required by this work.

Data	Source	Description
Fossil fuels	Boliden env. department, supplier	Based on fuel consumption
Electric energy	Boliden Group	Based on consumption
Heat	Boliden env. department	Based on fuel consumption
Explosives	Operator, Boliden mining department	Based on explosives consumption
Scope 3	Contractor	
Trolley line test drives	Boliden maintenance department and 3rd party operators	Based on electric energy consumption during test drives
Fuel consumption distribution	Boliden economic department	Derived from fuel refilling data (liters)
Electric energy distribution	Boliden maintenance department	Based on consumption
Annual production	Boliden mining department	Total tons of rock mined in 2021

The light fuel oil and diesel oil is distributed for Boliden's own mobile fleet and contractors at the fuel station on site. The fuel supplier reports the amount of fuel consumption on-site to the mine's environmental department on a monthly basis. The mining company has collected and reported the fuel consumption and energy usage since June 2016. The data from 2021 is used for the study of the current carbon footprint and emission source composition. Currently the diesel consumption distribution is assumed to divide 50% for the mine department and 50% for the mill department. The CO_2 emission coefficient for fuels is provided by Statistics Finland (2021). The primary fuel used in the heating plant is wood chips although, some light fuel oil is used instead during the summer season when the demand for heating is significantly lower. The plant is operated by an external company, which reports the fuel consumption and generated heat energy on a monthly basis. The information regarding light fuel oil and diesel oil energy content and CO_2-emission factor is provided by Statistics Finland (2021). Explosive emulsion used in Kevitsa is Kemiitti 850, and the information regarding emulsion usage and the CO_2 emission factor, considering the detonation emissions, is provided by the explosives supplier.

The amount of purchased electric energy is reported monthly by the Boliden Group. Boliden Group also provides the IEA CO_2 emission factor for each year. Electric energy consumption in the current CO_2 emission reporting is allocated entirely to the mill department. The average yearly distribution of electricity can be interpreted from the electricity monitoring system established for the maintenance department of the mine.

CO_2 emissions generated from the concentrate transportation by road, railroads and sea freight / ports are reported by the contractors on quarterly basis. Important detail to notice is that the quarterly reporting considers timeframe from December to November instead of normal calendar year. Contractors operating on site in Kevitsa report their fuel consumption to the mining company on monthly basis.

3.2 Demo line test

The demo trolley line was built in the WRA at ramp 1A. Two mine trucks were modified into electric mine trucks, which were used in the test drives. The maximum capacity for these trucks was approximately 214 tons of rock. During the tests, the cumulative mileage, net electric energy consumption and time elapsed was recorded. This thesis is applying the data recorded during the test drives on 1.-5.11.2021.

3.3 Trolley line emission calculations

The test drives on the electric trolley line in Kevitsa were conducted during the autumn 2021. The power consumption and time elapsed were observed for the distance travelled along the trolley line. The data is provided by the company that is responsible in constructing the trolley line. The formula for calculating the electric mine truck CO_2 emission factor (gCO_2 per ton of rock) is presented in formula 1.

$$C_{el} = \left(\frac{E_{el} * d_2}{d_1 * m_{rock}}\right) * c, \tag{1}$$

Where C_{el} is the CO_2 emission factor for ton of rock transported using electric mine truck, E_{el} is the electric energy consumption (kWh) during the test drives along the demo trolley line, d_1 is the length of the test drive in demo trolley line in meters, d_2 is the length of the actual trolley line in the pit in meters, m_{rock} is the mass of the transported rock on a mine truck in kg and c is the CO_2-emission factor for purchased electric energy (gCO_2 per kWh).

By excluding d_2 from formula 1, the CO_2 emission factor for gCO_2 per ton of rock per meter can be calculated. This can prove useful in a situation when the length of the final trolley line is not known. The formula is as follows:

$$C_{elm} = \left(\frac{E_{el}}{d_1 * m_{rock}}\right) * c, \tag{2}$$

In order to evaluate the impact of mine truck electrification on the mine CO_2-emissions, the fuel consumption of non-electrified mine truck needs to be measured on the length of the electric trolley line.

Such data was not available at the time of this thesis and the current input data is based on mere evaluations provided by the mobile fleet maintenance department. The formula for calculating the LFO operated mine truck CO_2 emission factor (gCO_2 per ton of rock) is presented in formula 3.

$$C_{LFO} = \frac{m_{fuel} * energy\,factor * emission\,factor * d_2 * 10^3}{d_1 * m_{rock}}, \tag{3}$$

where C_{LFO} is the CO_2 emission factor for ton of rock transported by using LFO, m_{fuel} is the LFO consumption in tons, $energy\,factor$ represents the LFO net calorific energy content (GJ per ton of fuel), $emission\,factor$ is the amount of CO_2 emissions emitted (tCO_2 per TJ), d_1 is the length of the test drive in demo trolley line in meters, d_2 is the length of the electric trolley line and m_{rock} is the mass of rock transported in tons.

Similar to formula 2, by excluding d_2 from the calculations a CO_2 emission factor for gCO_2 per ton of rock per meter can be calculated. The formula is as follows:

$$C_{LFOm} = \frac{m_{fuel} * energy\,factor * emission\,factor * 10^3}{d_1 * m_{rock}}, \tag{4}$$

As the LFO consumption has not been measured in parallel to the electric trolley line, the total fuel consumption during parallel ascend along the electric trolley line is estimated. As mine truck is ascending with 214 tons of rock, it is considered to travel with full throttle throughout the distance covered. The m_{fuel} is calculated with the following formula:

$$m_{fuel} = f_{max} * \left(\frac{d_1}{v}\right) * \rho, \tag{5}$$

where m_{fuel} is the total fuel consumption in kg, f_{max} is the estimated maximum LFO consumption of the mine truck with full throttle (liters per hour), d_1 is the distance of test drive in kilometers, v is the estimated average ascending speed in km per hour and ρ is the density of LFO (t/m^3).

In order to estimate the CO_2 emission reduction by utilizing the electric trolley line in transporting rock from the pit, following formula is used:

$$CO_2\ reduction = (C_{FLO} - C_{el}) * m_{total}, \tag{6}$$

where C_{FLO} is the CO_2 emission factor for FLO operated mine trucks, C_{el} is the CO_2 emission factor for electric mine trucks and m_{total} is the total amount of rock transported from the pit.

4 RESULTS

4.1 Direct emissions (scope 1)

The total direct CO_2 emissions in Kevitsa during 2021 was approximately 47 188,41 tons from which 94,72 % is generated from fuel oil consumption, 1,33 % from diesel oil consumption and 3,95 % from blasting. Emissions generated from LFO consumption was approximately 94,7 % and 1,3 % from diesel oil consumption. The scope 1 emission data is presented in table 2.

TABLE 2. Direct CO_2 emissions according to the mining company Scope 1 CO_2 emission reporting policy and the excluded contractor emissions.

Source	Consumption (t)	Emission (tCO_2)	Portion (%)
LFO	14475,08	44695,89	94,72 %
Diesel oil	227,05	628,74	1,33 %
Blasting	10 964	1863,78	3,95 %
Total		47188,41	100 %

A major part of the LFO consumption occurs in waste rock and ore transportation from the pit to waste rock area (UNW), mobile crushing area (UNW & USW) and ROMpad (ore). The emissions from Komatsu 830E-5, HD785-8E0 and CAT 793 haul trucks totalled in 87,05 % of all LFO consumption in Kevitsa. The second largest LFO consumption was in drilling machinery with 4,35 % of all LFO consumption. The emission distribution of LFO consumption classified in three major areas of operation, mining, milling and support organisations is presented in table 3.

Supporting organisations are defined as actors that are not actively participating in the actual production process, but work in collaboration with the production, with several fields of expertise such as EHSQ-department, ERT and ore exploration.

TABLE 3. CO_2 emission distribution generated from LFO consumption according to Scope 1.

Mining	Emissions (tCO_2)	Distribution
Hauling trucks (Komatsu, CAT)	38908	87,05 %
Drilling	1944	4,35 %
Dozers, excavators, grader, wheel loaders	1687	3,78 %
Loading machines	1197	2,68 %
Maintenance	35	0,08 %
Ancillary	848	1,90 %
		99,83 %
Supporting organisations		
Environmental department	4	0,01 %
Information technology	2	0,01 %
Storage facility	57	0,13 %
No information applicable	10	0,02 %
		0,16 %
Milling		
Light vehicles	5	0,01%
		0,01 %

The register for light vehicles was not available for analysing the LFO consumption distribution between the classified operational areas and was allocated to milling department. The scope 1 emission calculations are presented in appendix 1.

4.2 Purchased electric energy (scope 2)

The total amount of purchased electric energy in Kevitsa during the year 2021 was 449 947 MWh. The average overall monthly consumption was 37 496 MWh, from which on average 7,32 % was consumed in mining operations and the monthly variance was from minimum 6,01 % (July 2021) to maximum 9,17 % (June 2021). The average monthly consumption of total consumption was approximately 92,68 % in mill department. The monthly average electric energy consumption in mining operations was 2 721 MWh and 34 776 MWh in milling.

The average electric energy consumptions are presented in table 4. The monthly electric energy consumptions in 2021 are presented in appendix 2.

The CO_2 emission factor for purchased electric energy in Finland during 2021 was 116,8 g/kWh. National emission factors are purchased from International Energy Agency (IEA). The total CO_2 emissions from purchased electric energy in Kevitsa during the year 2021 was 52 554 tons. Approximately 48 740 tCO_2 was generated via the electric energy consumption in mill department and 3 814 tCO_2 in mining process. The emission distribution of purchased electric energy is presented in table 4. The monthly CO_2 emission distribution from purchased electric energy is presented in appendix 2.

TABLE 4. The electric energy consumption distribution in Kevitsa and the calculated CO_2 emissions from purchased electric energy.

	Mine	Mill
Avg. monthly consumption (MWh)	2 721	34 776
Avg. monthly consumption (%)	7,32 %	92,68 %
Total consumption 2021 (MWh)	449 947	
CO_2 emissions (tCO_2)	3 814	48 740
Total CO_2 emissions (tCO_2)	52 554	

4.3 Indirect emissions (scope 3)

The total amount of CO_2 emissions generated in the value chain was approximately 14 807,78 tCO_2 in 2021. The major CO_2 emission source was contractor LFO consumption, resulting in approximately 60,2 % of overall scope 3 emissions. Second largest contribution to CO_2 emissions is the concentrate road transportation from Kevitsa to Kemi port, approximately 23,8 % of overall scope 3 emissions. The scope 3 CO_2 emissions and distribution are presented in table 5.

Table 5. Scope 3 CO_2 emissions and distribution.

Source	Emissions (tCO_2)	Distribution
Railway transportation	120	0,8 %
Road transportation	3520	23,8 %
Shipping	1675	11,3 %
On site contractors LFO	8918	60,2 %
On site contractors diesel	575	3,9 %
Total	14 808	100 %

Finally, the sum of the total CO_2 emissions of Boliden Kevitsa resulted in approximately 114 550 tCO_2 in 2021.

4.4 Electric mine truck emission factor

The trolley line test drive data from 1.-5.11.2021 included 88 test drives. Average distance travelled along the electric trolley line was approximately 304 meters. The average electric energy consumption during the test drives was approximately 34 kWh. Total mass of the transported rock was 214 tons. The CO_2 emission factor for gCO_2 per ton of rock per meter (C_{elm}) was calculated using formula 2 and resulted in approximately 0,06 gCO_2 per ton of rock per meter. The CO_2 emission factor for the completed trolley line (1300 m) was calculated with formula 1 and resulted in 79,85 gCO_2/t of transported rock. Results are presented in table 6 and calculations in appendix 3.

Table 6. CO_2 emission factor results for electric mine trucks.

Average distance (d_1)	304,30 m
Average electric energy consumption (E_{el})	34,02 kWh
Mass of rock (m_{rock})	214 tons
Purchased electric energy CO_2 factor 2021 (c)	116,8 gCO_2/kWh
CO_2 factor (C_{elm})	0,06 gCO_2/tm
CO_2 factor for complete trolley line (C_{el})	79,85 gCO_2/t

The purchased electric energy CO_2 factor is subject to a change each year and should be updated yearly in line with factor provided by IEA.

4.5 LFO operated mine truck emission factor

Formula 5 was used to calculate the mass of LFO consumption. The calculations are based on estimated maximum momentary fuel consumption of the mine truck while ascending on full throttle. The mass of used LFO during the distance of 338 meters was approximately 9,76 kg.

The emission factor for LFO operated mine truck (C_{LFOm}) was calculated using formula 4. With the fuel consumption of 9,76 kg LFO, the emissions factor resulted in 0,408 gCO_2/tm.

The emission factor for completed trolley line (1300 m) using LFO operated mine truck (C_{LFO}) was calculated using formula 3. The emission factor resulted in 530,61 gCO_2/t. The calculation results are presented in table 7 and calculations are presented in appendix 4.

Table 7. The CO_2 emission factor results for LFO operated mine truck.

Distance (d_1)	0,33796 km
Speed (v)	13 km/h
LFO density (ρ)	0,834 kg/l
Maximum instantaneous fuel consumption (f_{max})	450 l/h
LFO consumption (m_{fuel})	9,76 kg
Energy factor	43,1 GJ/tn fuel
Emission factor	70,2 tCO_2/TJ
Mass of rock transported (m_{rock})	214 tons
LFO mine truck emission factor per meter (C_{LFOm})	0,408 gCO_2/tm
LFO mine truck emission factor 1300m (C_{LFO})	530,61 gCO_2/t

4.6 Emission reduction

The trolley line has a significant impact towards the total CO_2 emissions of the mine. The calculations that applied the 2021 production tonnage, emission data and CO_2 factor for purchased electric energy, resulted in 13 % reduction in CO_2 emissions (approximately 15 000 tCO_2), assuming that all rock was transported from the pit using the trolley line of 1300 meters. Calculations in appendix 4.

5 DISCUSSION

5.1 Summary of results

In 2021, the total direct CO_2 emissions (scope 1) of Boliden Kevitsa mine resulted in approximately 47 188 tCO_2. From which 94,72 % was generated by light fuel oil combustion, mainly in waste rock and ore transportation, contributing in 38 908 tCO_2 eq.

Boliden Kevitsa produces heat energy with on-site district heating plant by burning mainly biobased fuels and therefore scope 2 CO_2 emissions in Boliden Kevitsa are generated from purchased electric energy. Total CO_2 emissions from purchased electric energy was approximately 52 554 tCO_2 eq. 92,68 % of the electric energy consumption is allocated in mill department.

The CO_2 emissions reported as scope 3 were approximately 14 808 tCO_2 and approximately 64 % of the emissions were generated by fuel consumption of contractors working on site.

In order to estimate the impact of the electric trolley line, the total amount of CO_2 emissions in Boliden Kevitsa in 2021 was summed from all three scopes. The total CO_2 emissions was approximately 114 550 tCO_2 in 2021.

The trolley line impact was studied by first calculating the emission factor for a ton of rock transported via electric trolley line and similar emission factor for combustion engine mine truck and finally by multiplying the emission factor difference with the total tons transported from the pit in 2021. The calculated emission factor for a ton of rock transported via the electric trolley line resulted in 0,06 gCO_2/tm or 79,85 gCO_2/t on a 1300 meters long trolley line. Emission factor for combustion engine mine truck was found to be 0,41 gCO_2/tm or 530,61 gCO_2/t on an equal distance which is significantly higher compared to electric trolley line. Finally, the emission reduction on an annual level (applying the 2021 production figures) would potentially have resulted in a significant 13 % emission reduction, meaning approximately 15 000 tCO_2 emission reduction regarding the total CO_2 emissions in 2021.

5.2 Data acquisition

Three different development targets were identified during the work on this thesis. It was discovered that there was a lack of comparable measurement data considering the fuel consumption of combustion engine mine truck along the pilot trolley line. The calculations of combustion engine mine truck emission factor are based on estimation of maximum momentary fuel consumption and travelling speed, as the mine truck usually ascends the WRA ramp with full throttle. It is important to note that the emission reduction calculations should not be implemented in the mine's energy and environmental reporting until sufficient measurements on fuel consumption have been executed and consumption data is available.

The electric trolley line measurement data consisted of 88 individual test drives along the pilot trolley line in November 2021. Several test drives have been executed after November and the measurement data should be included in the emission factor calculations in order to improve the accuracy of the results. Also, similar measurements are required on WR-trolley line once the construction project is completed, for the reason that the incline of the road might differ from the pilot trolley line and effect the energy consumption.

It was also noted that the current electric energy consumption measurements did not take into account the electricity losses that occur before the electric mine truck. In order to measure the total electric energy consumption of the trolley line (including losses along the feed), the electric energy consumption measurements should be adjusted to measure the electric energy input to the electric trolley line grid, rather than observing the energy consumption of the mine truck itself.

5.3 Observations and future recommendations

During the work of this thesis, two observations were made regarding to the emission reporting and energy consumption. The scope 3 emissions reporting could be reviewed in the future since the contractor operations are closely related to essential construction, transportation, and maintenance work in aspect of the mine processes. Reporting emissions that are generated from, for example dam raisings and construction material transportation as indirect emissions generated in value chain could create contradictions in further examination.

The second observation regarding the electric energy consumption and emissions was that the electric energy consumption will increase as a result of mine truck electrification and at its current state, it will evidently lead to increased emissions in the scope 2. The country specific emission factor for purchased electric energy which is provided by IEA is changing every year, which will also have a significant effect on to scope 2 emissions. The emissions from purchased electric energy could be mitigated by switching towards low carbon electric energy solutions.

In addition, two observations regarding the trolley line impact calculations were made. First, the data acquisition for the energy consumption of electric trolley line needs to be reviewed in order to improve the accuracy of emission factor for electric trolley line. The automation engineering department in Kevitsa has access to data regarding the electricity feed in trolley line. Consumption should be measured according to the date and time of test drives in the pilot trolley line, so that all power losses are accounted in trolley line electric energy consumption. Similar monitoring should be applied once the actual trolley line is established in the pit.

Secondly, the fuel consumption and travelling speed of regular combustion engine mine trucks ascending the pilot trolley line should be measured for reliable calculations on emission factor and CO_2 reduction. It should be declared whether the momentary fuel consumption along the pilot trolley line can be recorded, and total fuel consumption derived from the data. Alternatively, the total fuel consumption could be measured by filling the fuel tank before ascending the pilot trolley line and filling the tank again on top of the ramp.

The calculation model for CO_2 emission factors and reduction was successfully established and can be implemented in yearly CO_2 emission budgeting once the required measurements regarding to the forementioned electric energy consumption of trolley line and fuel consumption of regular mine truck have been completed.

REFERENCES

Boliden Group. 24.1.2022. Instructions for monthly AARO reporting of environmental data. INST-23140-v.12.0. Available in Boliden Group internal document management system BMS. Read on 20.1.2022

European Comission. 2001. Guidance in EIA – Scoping. ISBN 92-894-1335-2. Luxembourg. Read on 3.5.2022. https://ec.europa.eu/environment/archives/eia/eia-guidelines/g-scoping-full-text.pdf

Global Reporting Initiative. 2016. GRI 305: Emissions. Read on 10.2.2022. https://www.globalreporting.org/standards/media/1012/gri-305-emissions-2016.pdf

IEA. 2022. Annual GHG emission factors for World countries from electricity and heat generation. Read on 3.3.2022. https://www.iea.org/data-and-statistics/data-product/emissions-factors-2021#documentation

IPCC, 9.8.2021. Climate Change 2021: The Physical Science Basis. Read on 24.4.2022. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

IPCC, 4.4.2022. Climate Change 2022: Mitigation of Climate Change. Read on 24.4.2022. https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

Official Statistics of Finland. 30.1.2021. Emissions into air by industry 2019. ISSN 2323-7600. Helsinki. Read on 14.2.2022. https://www.stat.fi/til/tilma/2019/tilma_2019_2021-09-30_en.pdf

Partamies, R. 15.3.2022. Trolley line project description. E-mail.

Statistics Finland. 12.2.2021. Fuel classification 2021. Excel datasheet. Read on 14.2.2022. https://www.stat.fi/tup/khkinv/khkaasut_polttoaineluokitus.html

Wiedmann, T. and Minx, J. (2008). A Definition of 'Carbon Footprint'. In: C. C. Pertsova, Ecological Economics Research Trends: Chapter 1, pp. 1-11, Nova Science Publishers, Hauppauge NY, USA. Read on 28.4.2022 https://www.novapublishers.com/catalog/product_info.php?products_id=5999.

APPENDICES

Appendix 1. Scope 1 emission calculations

Table 1

	Fuel (t)		tCO_2		Total tCO_2
	mill	mine	mill	mine	
LFO	0	14475	360	44335	44696
Diesel	113	114	314	315	629
Blasting				1864	1864
total					47188

Emission calculations:
Total tCO2 = mass of fuel * calorific value * CO2 factor / 1000
LFO calorific value: 43,2 GJ/t
LFO CO2 factor: 70,90 tCO2/TJ
Diesel calorific value: 42,8 GJ/t
Diesel CO2 factor: 64,70 tCO2/TJ
Explosive CO2 factor: 0,17 tCO2/TJ

Table 2 – Emission distribution

LFO % of CO2 emissions	94,72 %
Diesel oil % of CO2 emissions	1,33 %
Blasting % of CO2 emissions	3,95 %
Total	100,0 %
Fuel % of total CO2 emissions	41,2 %

Emission distribution calculations:
Component emission % = Component / Total scope 1 emissions (table 1)

Table 3

LFO Emission distribution		
Emission source	tCO2	LFO-%
Ancillary	848	1,90 %
Cat 793 haul trucks	4845	10,84 %
D65 drilling	1944	4,35 %
Dozer	1239	2,77 %
Environment	4	0,01 %
ERT	0	0,00 %
Excavators	152	0,34 %
Grader	263	0,59 %
Information technology	2	0,01 %
Kevitsa NME exploration	0	0,00 %
Komatsu 830E-5 haul trucks	33410	74,75 %
Komatsu HD785-8E0 haul trucks	653	1,46 %
Light vehicles	5	0,01 %
Loading machines	1197	2,68 %
Maintenance workshop	8	0,02 %
Mobile fleet maintenance	26	0,06 %
Sampling	0	0,00 %
Small trucks	0	0,00 %
Store	57	0,13 %
Wheel loaders	33	0,07 %
#N/A	10	0,02 %
Total		100 %

LFO emission distribution:
Component emission (tCO2) = LFO tCO2 (table 1) * LFO-%
LFO-% based on data from Boliden Kevitsa financial department

Table 4

Internal CO2 Composition	LFO-%	LFO (tCO2)
Mine department	99,83 %	44621
Mill department	0,01 %	3
Support organisation	0,16 %	73
total	100 %	

Internal CO2 composition:
Each department identified by color (table 3 & 4)
Composition = Sum of LFO-% (table 3)
LFO (tCO2) = LFO-% * Total LFO tCO2 (table 1)

Table 5

Mine department	(tCO2)	%
Hauling	38908	87,05 %
Drilling	1944	4,35 %
Dozers, excavators, grader	1687	3,78 %
Loading machines	1197	2,68 %
Maintenance	35	0,08 %
Ancillary	848	1,90 %
Light vehicles	2,72445	0,01 %

Mine department emission distribution.
tCO2 & % calculated by summing the values in table 3

Appendix 2. Monthly electric energy consumption and emissions

	Total MWh	Total Emissions (tCO2)	Mine (MWh)	Portion	Emissions (tCO2)	Mill (MWh)	Portion	Emissions (tCO2)
January-21	40 143	4 689	3 245	8,08 %	379	36 898	91,92 %	4310
February-21	36 329	4 243	2 372	6,53 %	277	33 957	93,47 %	3966
March-21	40 755	4 760	2 855	7,01 %	334	37 900	92,99 %	4427
April-21	39 617	4 627	2 827	7,14 %	330	36 790	92,86 %	4297
May-21	40 752	4 760	3 053	7,49 %	357	37 699	92,51 %	4403
June-21	27 948	3 264	2 531	9,06 %	296	25 417	90,94 %	2969
July-21	37 108	4 334	2 233	6,02 %	261	34 876	93,98 %	4073
August-21	27 414	3 202	2 303	8,40 %	269	25 111	91,60 %	2933
September-21	38 825	4 535	2 432	6,26 %	284	36 393	93,74 %	4251
October-21	40 102	4 684	2 555	6,37 %	298	37 547	93,63 %	4385
November-21	38 575	4 506	3 027	7,85 %	354	35 548	92,15 %	4152
December-21	42 379	4 950	3 221	7,60 %	376	39 158	92,40 %	4574
Yearly total	**449 947**	**52 554**	**32 654**	**7,26 %**	**3814**	**417 294**	**92,74 %**	**48740**
Monthly average	37 496		2 721	7,32 %		34 774	92,68 %	

CO2 factor (gCO2/kWh) 116,8

Appendix 3. Electric trolley line emission factor calculations

Date	Total Miles	Total Km	Ascend distance	Ascend distance	Total MWH Accumulative	Ascend MWh	Ascend kWh	Motoring	Motoring	Speed	Mass of rock (t)	Electricity factor (2021) (gCO2/kWh)	Emission factor for electric mine truck (gCO2/t*m)	Emission factor for electric mine truck 1300m (gCO2/t)
	(miles)	(km)	kilometers	d_1	(mw-hrs)	(MWh)	E_{el}	(sec)	(h)	km/h	m_{rock}	c	C_{elm}	C_{el}
'2021-11-01 10:20:41.352	36,75	59,14			5,70			52,30						
'2021-11-01 10:25:53.855	36,96	59,48	0,34	337,96	5,74	0,04	40,00	58,80	0,02	20,69	214	116,8	0,06	83,98
'2021-11-01 10:30:38.852	37,16	59,80	0,32	321,87	5,78	0,04	40,00	57,70	0,02	20,08	214	116,8	0,07	88,18
'2021-11-01 10:34:21.852	37,36	60,13	0,32	321,87	5,81	0,03	30,00	56,80	0,02	20,40	214	116,8	0,05	66,13
'2021-11-01 10:38:27.351	37,56	60,45	0,32	321,87	5,85	0,04	40,00	53,60	0,01	21,62	214	116,8	0,07	88,18
'2021-11-01 10:58:02.851	37,66	60,61	0,16	160,93	5,87	0,02	20,00	25,30	0,01	22,90	214	116,8	0,07	88,18
'2021-11-01 11:02:30.854	37,85	60,91	0,31	305,78	5,90	0,03	30,00	42,40	0,01	25,96	214	116,8	0,05	69,61
'2021-11-01 11:07:22.851	38,03	61,20	0,29	289,68	5,94	0,04	40,00	42,30	0,01	24,65	214	116,8	0,08	97,97
'2021-11-04 10:24:13.853	50,3	80,95	0,31	305,78	8,14	0,04	40,00	43,30	0,01	25,42	214	116,8	0,07	92,82
'2021-11-04 10:27:48.351	50,49	81,26	0,31	305,78	8,17	0,03	30,00	42,80	0,01	25,72	214	116,8	0,05	69,61
'2021-11-04 11:11:33.850	50,69	81,58	0,32	321,87	8,21	0,04	40,00	45,40	0,01	25,52	214	116,8	0,07	88,18
'2021-11-04 11:15:38.865	50,88	81,88	0,31	305,78	8,24	0,03	30,00	44,00	0,01	25,02	214	116,8	0,05	69,61
'2021-11-04 11:19:37.352	51,08	82,21	0,32	321,87	8,28	0,04	40,00	45,60	0,01	25,41	214	116,8	0,07	88,18
'2021-11-04 11:23:56.349	51,28	82,53	0,32	321,87	8,31	0,03	30,00	45,10	0,01	25,69	214	116,8	0,05	66,13
'2021-11-04 11:27:56.352	51,47	82,83	0,31	305,78	8,35	0,04	40,00	42,70	0,01	25,78	214	116,8	0,07	92,82
'2021-11-04 11:31:42.849	51,67	83,15	0,32	321,87	8,38	0,03	30,00	43,10	0,01	26,88	214	116,8	0,05	66,13
'2021-11-04 15:02:32.105	51,86	83,46	0,31	305,78	8,42	0,04	40,00	44,70	0,01	24,63	214	116,8	0,07	92,82
'2021-11-04 15:10:00.099	52,24	84,07	0,31	305,78	8,49	0,04	40,00	44,50	0,01	24,74	214	116,8	0,07	92,82
'2021-11-04 15:15:58.598	52,42	84,36	0,29	289,68	8,52	0,03	30,00	41,90	0,01	24,89	214	116,8	0,06	73,48
'2021-11-05 10:32:03.816	52,61	84,67	0,31	305,78	8,56	0,04	40,00	43,70	0,01	25,19	214	116,8	0,07	92,82
'2021-11-05 10:36:58.813	52,8	84,97	0,31	305,78	8,59	0,03	30,00	43,30	0,01	25,42	214	116,8	0,05	69,61
'2021-11-05 10:42:13.813	53,01	85,31	0,34	337,96	8,63	0,04	40,00	48,40	0,01	25,14	214	116,8	0,06	83,98
'2021-11-05 10:47:13.276	53,2	85,62	0,31	305,78	8,66	0,03	30,00	42,90	0,01	25,66	214	116,8	0,05	69,61
Average C_{el}				304,30		0,03	34,02			25,33			0,06	79,85
Length of trolley line (d_2)	1300													
Mile to km	1,609344													

Calculations for electric trolley line CO2 emission factor:

$$C_{elm} = \left(\frac{E_{el}}{d_1 * m_{rock}}\right) * c$$

$$C_{el} = \left(\frac{E_{el} * d_2}{d_1 * m_{rock}}\right) * c$$

Appendix 4. LFO mine truck emission factor & CO_2 reduction calculations

Date	Total Entered	Ascend distance (m)	Ascend distance	Speed (km/h)	LFO density (kg/l)	Consumption (l/h)	LFO mass (kg)	LFO mass (t)	Energy factor GJ/ton of fuel	Emission factor tonCO2/TJ	Mass of rock (t)	Emission factor for LFO mine truck (gCO2/t*m)	WR1 Phase one distance	Emission factor for LFO mine truck 1300m(gCO2/t)
	(#)	d1	kilometers (d_1)	v	rho	f_{max}	m_{fuel}	m_{fuel}			m_{rock}	C_{LFOm}	d_2	C_{LFO}
'2021-11-01 10:25:53.855	220	337,96	0,34	13	0,834	450	9,76	0,0098	43,1	70,2	214	0,41	1300	530,61

LFO mine truck emission factor:

$$C_{LFOm} = \frac{m_{fuel} * energy\ factor * emission\ factor * 10^3}{d_1 * m_{rock}}$$

$$C_{LFO} = \frac{m_{fuel} * energy\ factor * emission\ factor * d_2 * 10^3}{d_1 * m_{rock}}$$

C_{FLO}	C_{el}	m_{total}	CO2 reduction	CO2 reduction	Total CO2 emissions	Reduction
gCO_2/t	gCO_2/t	t	gCO_2	tCO_2	tCO_2	%
530,61	79,85	33 700 000	15190612000	15190,612	114550	13 %

CO2 reduction calculations:

$$CO_2\ reduction = (C_{FLO} - C_{el}) * m_{total}$$

Reduction % = CO2 reduction / total CO2 emission