BIOMOre
An Alternative Mining Concept

A new mining concept for extraction metals from deep ore deposits by using biotechnology

Deliverable Number 5.5
Impact of in-situ leaching from a stimulated ore body on the sustainability of the industry based on evaluated indicator values

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under grant agreement No 642456.

Public Document

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" D5.5 Impact of in-situ leaching from a stimulated ore body on the sustainability of the industry based on evaluated indicator values "

Due date of Deliverable	2018-07-30
Actual Submission Date	2018-07-30
Start Date of Project	2015-02-01
Duration	42 months
Deliverable Lead Contractor	Kemakta Konsult AB
Revision	Version 1.0
Last Modifications	2018-07-30
Nature	Report
Dissemination level	Public
Public Summary enclosed	No
Reference / Workpackage	5
Digital File Name	De-180621-0045 - D5.5 Impact of in-situ leaching from a stimulated ore body on the sustainability of the industry based on evaluated indicator values
Document reference number	De-180621-0045
No of pages	46
Keywords	Sustainable development indicators; baseline values
In bibliography, this report should be cited as follows:	Grundfelt B., Lahtinen T (2018). BIOMOre Deliverable 5.5: Impact of in-situ leaching from a stimulated ore body on the sustainability of the industry based on evaluated indicator values. Kemakta Konsult AB, Stockholm

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List of abbreviations

EC	Economic (abbreviation used in sustainable development indicators)
EITI	Extractive Industries Transparency Initiative
EN	Energy (abbreviation used in sustainable development indicators)
EUR	Euro
EW	Electrowinning
G4	An edition of the Global Reporting Initiative's sustainable development indicators
GRI	Global Reporting Initiative
ISO	International Organisation for Standardisation
ISR	In situ recovery
M_L	Magnitude of a seismic event on the Richter scale
NO_x	Nitrous gases
PLN	Polish złoty
PLS	Pregnant Leach Solution
SDI	Sustainable Development Indicator
SO	Social (abbreviation used in sustainable development indicators)
SO_x	Sulphur oxides
SX	Solvent extraction
WP5	Work Package 5 of the BIOMOre project
UN	United Nations

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Executive summary

The BIOMOre project has aimed at developing a process for in situ recovery of metals from deep-lying ores by injection of a lixiviant and extraction of a pregnant leach solution through boreholes from the ground surface. The lixiviant consists of sulphuric acid containing ferric iron as an oxidising agent. The ferric iron is microbially regenerated in a ferric iron generating bioreactor located on the surface and containing an adapted strand of bacteria adsorbed to activated carbon. The objective of Work package 5 of the project has been to assess the environmental impacts of the BIOMOre technology and whether it can contribute in a positive way to the sustainable development of the European mining industry.

An assessment methodology consisting of the following steps was developed:

1. Select a set of Sustainable Development Indicators, SDI
2. Assign values to selected SDIs for baseline technology
3. Assess the impact of the new technology
4. Assign values selected SDIs for the new technology

The first two steps were reported by Keith-Roach and Grundfelt (2015). The baseline technology was selected to be the technology currently used to produce copper from the ore in the Rudna mine owned and operated by, KGHM Polska Miedź S.A. The third step was reported by Grundfelt et al. (2018).

This report is an account of the assessment in step 4. The main conclusions from this step are:

- The energy consumption of the BIOMOre technology is about 30 % of that for the baseline technology. A likely explanation is that no crushing, grinding or extensive material transport is needed in the BIOMOre technology.
- The amount of land needed for the BIOMOre technology could be 10 % or less of that needed for the baseline technology. The value for the baseline technology is dominated by the smelter and the tailings management facility.
- The greenhouse gas emissions are somewhat higher for the BIOMOre technology than for the baseline technology. About 25 % of the emissions from the BIOMOre technology derives from the manufacturing of chemicals used. This is probably not included in the data for the baseline technology.
- The amount water discharged from the BIOMOre process is significantly larger than for the baseline technology.
- The amount of solid waste is less in the BIOMOre technology than in the baseline technology. This value is dominated by the process waste from hydrometallurgical plant which in turn depends on the high amount of gypsum and iron compounds produced in the process.

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The overall picture is that the BIOMOre technology has a smaller negative impact on the environmental parameters than the baseline technology. The difference could be interpreted as smaller than what could be anticipated. The impacts from the BIOMOre technology are partly dependent on the content of carbonate rock in the ore deposit. Thus, selecting an ore deposit with a, from this perspective, more benign composition could further reduce the impacts.

The study has demonstrated that the applied method for studying the impact of a new technology on the sustainable development of an industry has merits. In the present case, not all indicators could be evaluated due to a lack of data. The primary reason for this is that the project aimed at proof of concept rather than planning of operations on a full commercial scale.

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Contents

1. Introduction

The BIOMOre project aims at developing a new mining concept for extracting metals from deep ore deposits using in-situ recovery, ISR. The technology involves drilling boreholes from the surface to the ore horizon, stimulation of the ore body by hydraulic fracturing followed by in-situ leaching using a lixiviant consisting of a sulphuric acid solution containing ferric iron as an oxidation agent. The ferric iron will be regenerated by acidophilic bacteria in a Ferric Iron Generating Bioreactor, FIGB, located on the ground surface, and the so regenerated lixiviant will be reinjected into the ore deposit. The technology will employ pairs of parallel boreholes, so called doublets. One of the boreholes will be used for introducing the lixiviant and the other for extracting the pregnant leach solution, PLS. A bleed stream of the circulating lixiviant/PLS will be stripped from its content of metals in a hydrometallurgical plant and electrolytic copper will be produced by cathodic reduction in an electrowinning, EW, process.

Although the BIOMOre technology in principle could be used for in-situ recovery of a variety of metals, the focus in the project has been on extraction of copper from sulphide ore. Also, the remainder of this report assumes that the target metal for the application of the BIOMOre technology is copper.

The technology has several potential environmental advantages compared to conventional mining, e.g.:

- No ore or waste moved
- No creation of open pits, underground mine workings, large waste dumps, leach pads or tailings ponds
- Less energy used and less greenhouse gas release
- Minimal visual disturbance
- Minimal noise, dust, greenhouse gas emissions and other emissions

There is, however, also a need to safeguard against potential negative environmental impacts, e.g.:

- Environmental impacts by leachate escape outside the mining area
- Seismic and rock mechanic impacts
- Post operational chemical or microbial impacts on the deposit
- Impacts from sludge and other process waste

The objectives of Work Package 5 (WP5) of the BIOMOre project are to assess the environmental impacts of the BIOMOre technology and whether it can contribute in a positive way to the sustainable development of the European mining industry. This report, BIOMOre Deliverable 5.5, sets out to compare the BIOMOre ISR technology metal production with a baseline technology based on extraction of metals by conventional underground mining. The baseline has been defined as the mining

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process implemented at the Rudna copper mine in Poland operated by KGHM Polska Miedź S.A. including auxiliary facilities necessary for the copper production.

The comparison makes use of a set of Sustainable Development Indicators (SDI) selected and evaluated for the baseline technology within the BIOMOre project (Keith-Roach and Grundfelt, 2015). A broader evaluation of environmental impacts of the BIOMOre technology has been performed in BIOMOre Deliverable 5.4 (Grundfelt et al., 2018).

The report is organised such that Chapter 2 summarises the selection of SDIs, Chapter 3 gives a brief account of the estimated SDI values for the baseline technology, Chapter 4 discusses the expected SDI value outcome for the BIOMOre technology and Chapter 5 gives the overall conclusions of the technology comparison performed in BIOMOre Work Package 5, WP5.

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2. Selection of Sustainable Development Indicators

The concept sustainable development integrates environmental policies and development strategies to satisfy current and future human needs, improve quality of life and protect the environment that we depend on for life support services; it is "*a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED 1987). The use of minerals and metals are clearly a part of sustainable development.

Sustainable development indicators, SDI, provide metrics for the state of a system or for monitoring a trend in the development of the system. SDIs have been developed for different purposes and in different contexts by a variety of organisations. The set of SDIs that has been deemed to be best suited for the BIOMOre project is that contained in the G4 sustainability reporting guidelines of the Global Reporting Initiative, GRI (GRI, 2013a). This reporting guidance is judged to provide a comprehensive and well documented indicator set that describes a process whereby organisations can generate reliable and relevant information on their material (significant) economic, environmental and social impacts in a standardised yet flexible format. The main industrial BIOMOre partner, KGHM Polska Miedź, uses the GRI G4 guidelines in its sustainability reporting, which further strengthens the case for selecting SDIs from the GRI G4 guidelines for assessing the BIOMOre in-situ recovery technology.

The GRI G4 references several other established frameworks and links to some of these in the standard disclosures, notably the OECD Guidelines for Multinational Enterprises (OECD 2011), the "Ten Principles" of the United Nations Global Compact (UN 2012; 2014) and the United Nations Guiding Principles on Business and Human Rights (UN 2011). In addition, GRI has published several documents describing how the G4 guidance is linked to other frameworks, codes and norms for sustainability and social responsibility, including ISO 26000 (GRI, 2010).

The SDIs in the GRI G4 sustainability reporting guidelines (GRI, 2013a) are sorted into the standard economic, environmental and social *categories*. In within each category the SDIs are organised into *aspects*. Some of these aspects have been strengthened specifically for the metals and mining sector, and five additional aspects have been defined specifically for this sector (GRI, 2013b).

The selection of SDIs for the BIOMOre project was carried out in two stages (Keith-Roach and Grundfelt, 2015). First, relevant aspects were identified using a screening process. Then the individual SDI from the relevant aspects were reviewed and the selection made. The initial screening of the SDI identified 10 aspects that are relevant to the expected impacts of the BIOMOre technology.

The final selection included SDI from seven of the ten relevant aspects. The overall aspect was not included as the SDI relates to cost of environmental protection, which is difficult to interpret directly in terms of the environmental impacts of a technique. The occupational health SDI were not included due to a lack of relevant data for the in-situ

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recovery technology being developed. It is, however, recommended that occupational health SDI are addressed when data become available, as the risk of accidents and work place air quality are key safety considerations in mines.

The SDI selected for the BIOMOre project are shown in Table 1. The full text from the G4 guidance for these SDIs are given in Annex 1.

Table 1 SDI selected for BIOMOre

Aspect	SDI number and title
Economic Performance	G4-EC1 Direct economic value generated and distributed (+ sector additions for mining and metals)
Materials	G4-EN1 Materials used by weight or volume
Energy	G4-EN3 Energy consumption within the organisation
Biodiversity	MM1 Amount of land (owned or leased, and managed for production activities or extractive use) disturbed or rehabilitated
Emissions	G4-EN15 Direct greenhouse gas (GHG) emissions (scope 1)
Emissions	G4-EN21 NOx, SOx, and other significant air emissions (+ sector additions for mining and metals)
Effluents and Waste	G4-EN22 Total water discharge by quality and destination
Effluents and Waste	MM3 Total amounts of overburden, rock, tailings, and sludges and their associated risks
Local communities	G4-SO2 Operations with significant actual and potential negative impacts on local communities

The potential advantages and risks associated with the in-situ recovery technology that were outlined in Section 1 are listed below with the relevant SDI given in brackets afterwards:

- No ore or waste moved (G4-EN3, G4-EN15)
- No creation of open pits, underground mine workings, large waste dumps, leach pads or tailings ponds (MM1, MM3)
- Minimal visual disturbance (G4-SO2)
- Minimal noise, dust, greenhouse gas emissions and other emissions (G4-SO2, G4-EN15, G4-EN21)
- Environmental impacts by leachate escape outside the mining area (G4-EN22)
- Seismic and rock mechanic impacts (G4-SO2)
- Post operational chemical or microbial impacts on the deposit (MM3)
- Impacts from sludge and other process waste (MM3)

The SDIs selected therefore address all the main advantages and risks identified. It should be noted that seismic issues are not addressed directly in the GRI G4 SDI but were assigned to G4-SO2 as a potential negative effect on the local community. Two

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SDI selected (G4-EC1 and G4-EN1) are not directly relevant to the main advantages and risks identified but are important considerations nevertheless. The in-situ recovery technology developed must be financially competitive and a reduction in the use of raw materials is an integral part of sustainable development.

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3. Baseline SDI values

This section describes the data selection process for characterising the baseline technology in terms of the selected BIOMOre SDIs. A complete account of the data selection process is reported by Keith-Roach and Grundfelt (2015).

KGHM Polska Miedź's copper mining and processing activities take place at three underground mines (Lubin, Polkowice-Sieroszowice and Rudna), and three metallurgical plants (two at Głogów and one at Legnica). The Rudna mine is the site of the BIOMOre experimental pilot scale in-situ bioleaching plant, thus SDI values have been derived for ore from this mine specifically. The tailings management facility at Żelazny Most receives tailings from all three mines and is also important in terms of waste and water management. The copper ore is crushed, milled and beneficiated by flotation at the mining sites. The dried ore concentrate is then transported to the metallurgical sites, and the tailings are transported as a sludge via pipelines to the Żelazny Most tailings pond (KGHM, 2012a).

The ore concentrate from the Rudna mine is processed in all three of the KGHM smelters, see Table 2 (KGHM, 2012a). The smelters currently apply different technologies, although Głogów I is currently being upgraded to the same modern flash furnace technology as Głogów II (KGHM 2015). Legnica applies the more traditional, multi stage shaft furnace technology and is a leading Polish recycler of non-ferrous metals (KGHM, 2013). The copper produced in the smelters is then electro-refined on site. Table 2 shows how much of the ore concentrates from the three mines that is processed in the three smelters.

Table 2 Percentage of ore concentrate from each mine site sent to each of the smelters (KGHM, 2012a)

	Legnica	Głogów I	Głogów II
Lubin (%)	52	47	1
Polkowice-Sieroszowice (%)		82	18
Rudna (%)	14	30	56

KGHM Polska Miedź's 2014 integrated annual report presents relevant SDI data for their overall activities, from all the sites described above. There are significant differences between the grades of the ores from the three mines (Table 3), which are expected to affect the costs, energy demand, waste production and emissions associated with mining and processing the ore per tonne of copper produced. Data from 2009-2012 and information from KGHM (2014) have been used to convert the total amounts of ore mined and copper produced in 2014 to site specific estimates (Table 3). The estimate for Rudna agrees with information on the KGHM website (KGHM, 2015), that the average annual extraction of ore from the Rudna mine is 12 million tonnes.

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Table 3 Copper content of the ore and ore concentrate from each mine, percentage of the ore mined, and copper obtained that comes from each mine 2009-2012 (KGHM, 2012a), and estimated amounts of ore mined, and copper produced in 2014.

	Lubin	Polkowice-Sieroszowice	Rudna
Grade of the ore, % copper	1.0	1.8	1.8
Copper content of the ore concentrate, %	14	24	26
Percentage of the total ore extracted that comes from each site	24	36	39
Percentage of the copper produced that comes from each site	15	41	44
Estimated mass of ore mined in 2014 (million tonnes)	7.5	11	12
Estimated mass of copper produced in 2014 (thousand tonnes)	63	170	190

When deriving data for each SDI for the baseline technology, the following steps were taken to ensure compatibility between the data reported for conventional mining and the BIOMOre in situ bioleaching technology:

- The data reflect the mining and refining processes up to and including the production of electrolytic copper
- Numeric values assigned to each SDI for each technology are, as far as reasonably possible, given per tonne of electrolytic copper produced
- The data reflects full scale production rather than from the underground experimental site or a future pilot installation.

Although the data used are extracted from sources spanning 2009-2014, the amount of ore extracted per year in this period had a standard deviation of less than 4%. Therefore, the year-to-year variations are judged to be relatively small.

The values of the selected BIOMOre SDIs derived for the baseline technology are summarised in Table 4. Except for indicators G4-MM1 (amount of land disturbed or rehabilitated) and the water quality parameters of indicator G4-EN22 (Total water discharge by quality and destination), all values are given per tonne of copper produced.

It has not been possible to derive a meaningful value for the indicator G4-EN-1 from the data sources available. KGHM Polska Miedź's (2014) integrated annual report states the mass of ore extracted in 2014 as 31 million tonnes. No information is given on the amounts of chemicals used.

Some of the values relevant to the SDI G4-SO2 have been evaluated for other SDIs:

- Visual impact: Relates to area disturbed (MM1) and waste volumes (MM3)
- Dust and emissions: Addressed in G4-EN21
- Groundwater and surface water contamination: Water quality is addressed in G4-EN22

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Table 4 SDI values for the baseline technology.

Sustainable Development Indicator	Unit	Baseline
G4-EC1: Direct economic value generated and distributed, Cost of copper production with silver discount	EUR/tonne Cu	2,780[1]
G4-EN1: Materials used by weight or volume	-	No information
G4-EN3: Energy consumption within the organisation	Total, GJ/tonne Cu	38
	Direct energy source, GJ/tonne Cu	20
	Electricity produced off site, GJ/tonne Cu	18
G4-MM1: Amount of land disturbed or rehabilitated	Total, ha	5,485
	Głogów smelter, ha	2,045
	Legnica smelter, ha	212
	Tailings facility, ha	3,072
	Rudna mine, ha	92
	Ore concentrators, ha	64.5
G4-EN15: Direct greenhouse gas emissions	kg CO_2 equivalent/tonne Cu	3,300
G4-EN21: Direct of NO_x, SO_x and other significant air emissions	kg NOx/tonne Cu	2.7
	kg SOx/tonne Cu	10.3
	kg dust/tonne Cu	0.87
	kg Cu/tonne Cu	0.02
	kg Pb/tonne Cu	0.01
G4-EN22: Total water discharge by quality and destination	Volume, m^3/tonne Cu	5.6
	Dissolved minerals, g/dm^3	287
	Cl^-, g/dm^3	169
	SO_4^{2-}, g/dm^3	2.7
G4-MM3: Total amounts of overburden, waste rock, tailings and sludges and their associated risks	Total waste, tonne/tonne Cu	76
	Hazardous waste, Tonne/tonne Cu	0.53
	Non-hazardous waste, tonne/tonne Cu	2.5
	Extractive industry waste, tonne/tonne Cu	73
G4-SO2: Operations with significant actual and potential negative impacts on local communities	-	

Risks of groundwater contamination from the mine are relatively low while the mine is active since the main flow of water is into the mine, where it is pumped out. The mine water is then used in the flotation process and recycled via the Żelazny Most tailings pond. The pond is known to have affected groundwater quality and dynamics, the water quality of the Odra River and the local air and soil quality due to dusting (data received from KGHM). The risks associated with groundwater contamination after the

[1] Cost evaluated to be 11,825 PLN/tonne Cu and translated with the exchange rate 0.23 EUR/PLN.

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eventual closure of the mine and tailings facility is beyond the scope of this analysis and depends on the actions of the company.

With regard to seismic risks, between 525 and 581 mining-induced earthquakes were reported to occur per year in the period 2010-12 (KGHM, 2012b). The expenditure incurred at the Rudna mine for the prevention and repair of mining-induced damage was between 1.97 and 2.31 MPLN[2] per year (2010-2012; KGHM 2012b). Orlecka-Sikora et al. (2009) published data on the frequency of seismic events in the Legnica-Głogów Copper District as a function of magnitude and energy (Table 5), for events with a magnitude, M_L, ≥ 2 in the period 1993-99.). These data give a useful representation of mining-induced seismic events in the area due to the baseline technology.

Table 5 Annual number of events per magnitude class in the Legnica-Głogów Copper District in the period June 1993 – August 1999. M_L denotes the local magnitude, E the energy (Orlecka-Sikora et al. 2009)

M_L Year	**2**	**2.5**	**3**	**3.5**	**4**
1993-1999	122	55	34	5	1

The data compiled and manipulated in this chapter provide values for the majority of the BIOMOre SDIs. Overall, the SDI values presented should be robust for the purposes of comparing this baseline technology with the novel in situ bioleaching technology developed in BIOMOre. The main limitation in the baseline data is that it was not possible to obtain values for all the data listed in Annex 2.

[2] 1PLN = €0.23 on 07/12/15

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4. SDI values for the BIOMOre ISR technology

4.1. Basis for the analysis

The objective of the BIOMOre project has been to develop and demonstrate a process for in-situ recovery by bioleaching in a hydraulically stimulated ore deposit based on laboratory and pilot scale experiments. Much work remains to develop the process further and to eventually arrive at an engineering plan and a design of a commercial size production plant based on the BIOMOre technology. Hence, it has not been possible to assign numeric values to the selected indicators for the whole process. This is further discussed below for each of the selected indicators.

For the sake of the project, a flow sheet describing the main features of a future production plant has been produced, see Figure 1. In the figure the process steps in the green oval represent the construction and preparation of the well field, the orange oval encircles the well field decommissioning and reclamation, the blue oval includes the main in-situ recovery circuit including the FIGB. The purple oval contains the hydrometallurgical plant and the red oval the waste treatment processes.

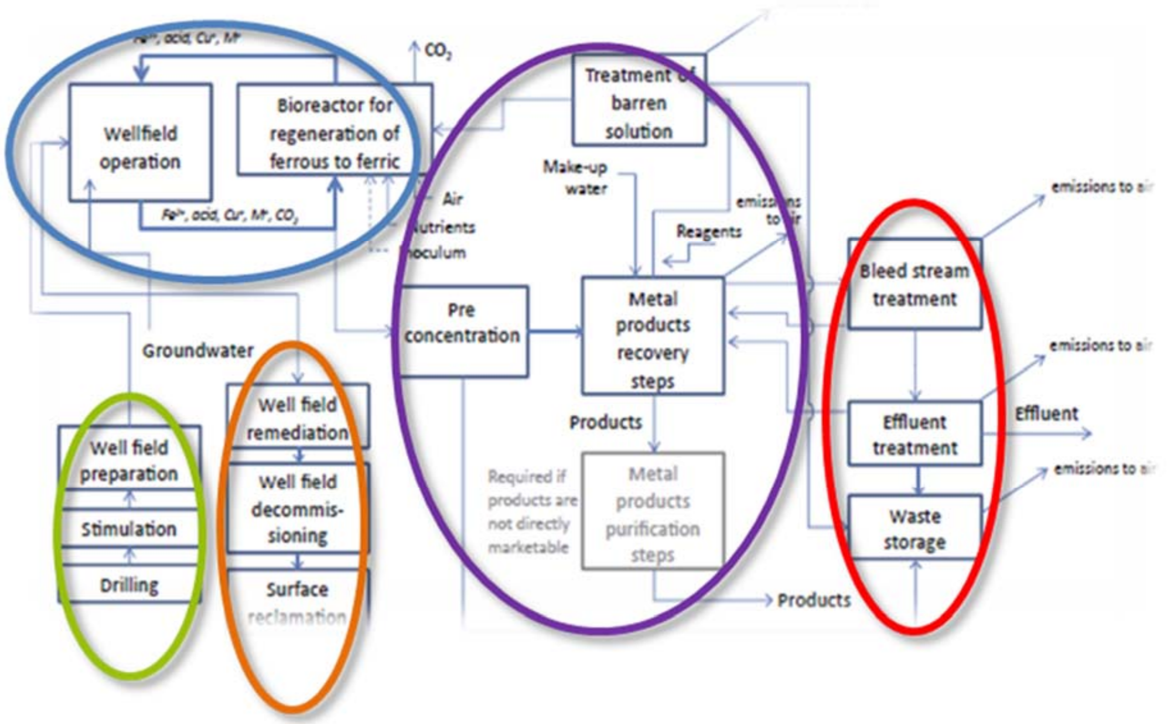

Figure 1 Schematic flow sheet of the BIOMOre copper production process. The coloured ovals delimit different parts of the flow sheet according to the description in the text. Outgoing arrows indicate product streams and potential emissions from the process.

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The BIOMOre process has been flow-sheeted as a basis for an economic assessment (UIT, 2018). The hydrometallurgical plant is assumed to be based on stripping of the pregnant leach solution (PLS) by solvent extraction (SX) and production of cathodic copper by electrowinning (EW). The main assumptions in the economic assessment are a copper production rate of 20,000 tonnes per year (~2.4 tonnes/hr) extracted from an ore deposit with the same mineral composition as the sandstone layer of the KGHM deposit. The flow of PLS has been assumed to be about 950 m^3/h with a copper content of 2.5 g/l.

Model simulations (Kahnt et al., 2018) assume a well field consisting of 5 doublets with a horizontal spacing of 100 m between the doublets and up to 1,000 m long horizontal borehole sections through the deposit. The thickness of the deposit has been assumed to be 30 m. The volume of the deposit leached by such a well field is about 30 million m^3 corresponding to approximately 75 million tonnes. Assuming an ore grade of 0.5 % and that 5 % of the copper content in the deposit is leached every year the annual copper production from the well field would be 18,700 tonnes. During a 10-year life of the wells an estimated 60 % of the copper in the deposit corresponding to 225,000 tonnes would be leached.

4.2. G4-EC1: Direct economic value generated and distributed

Hatch Associates Ltd. (2016) estimated that the *direct economic value generated* in the form of *revenue* should be about 4800 €/t Cu (~20,600 PLN/t Cu). They also estimated the operational costs to be about 613 €/t Cu (~2,600 PLN/t Cu). The baseline mine largely benefits from additional sales of silver side product, which is not produced by the ISR process, while also the recovery of other metals (mainly zinc, nickel and cobalt) is not economically viable for the Rudna mine ore and resulting PLS composition (Hatch Associates Ltd. 2016).

Most *components* contributing to *distributed economic value* (e.g. *Payments to government*, *Payments to providers of capital* and *Community investments*) are expected to be either company specific or equal with the baseline technology.

To give a rough estimate, the Florence copper ISR project, currently under testing and construction, has been estimated to create 796 jobs in the US state of Arizona (annual average through the project's estimated 30-year lifespan). The number includes jobs that are indirectly created, such as jobs related to health care or food services, out of which 146 are expected to be required for mineral recovery during the production phase. The project is expected to generate average personal income to direct and indirect employments in Arizona amounting to 66.1 million USD annually over the project's 30-year life (Hoffman and Madly, 2013).

4.3. G4-EN1: Materials used by weight or volume

Materials required by the mine are listed in Table 6. Water consumption is given expecting a 75% water recycling rate.

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Table 6 Resource consumption of the final facilities during production stage.

Resource	Unit	BIOMOre ISR
H_2SO_4	t/tonne Cu	34.86
LIX 84N	kg/tonne Cu	0.84
Kerosene	kg/tonne Cu	1.68
Limestone	t/tonne Cu	0.504
Water	m^3/tonne Cu	71.4

4.4. G4-EN3: Energy consumption within the organisation

The energy consumption of the facilities is expected to be roughly 3 MWh/tonne Cu (10.8 GJ) during the production stage. The majority of the electricity is consumed during electrowinning. According to Michaud (2017), the power consumption of a modern EW plant is about 2 MWh/tonne Cu. Electric pumps needed for well-field operations will also require substantial amounts of energy.

4.5. MM1: Amount of land disturbed or rehabilitated

Grundfelt et al. (2018) estimated the land footprint to be between 50ha and 500ha, based on existing ISR uranium mines in the United States.

4.6. G4-EN15: Direct greenhouse gas emissions

Haque and Norgate (2014) estimated CO_2 emissions from ISR of copper mining in Australia to be on average 4,780 kg CO_2 equivalent/t Cu. They further estimated that 60% of those emissions were from extraction and metal production (solvent extraction/electrowinning), 25% were due to chemical usage (sulphuric acid consumption) and 15% resulted from well-field operations (mainly electricity production for pumps).

4.7. G4-EN21: NOX, SOX and other significant air emissions

NRC (1997) estimated the annual total releases and average air concentrations for well-field activities of a uranium ISR facility in Crownpoint, New Mexico, USA (Table 7). Further, NRC (2009) estimates NO_x and SO_x emissions from uranium ISR leaching to be largest during the construction phase. They also comment that the emissions should be very small during operation and be mostly related to small releases from pipeline venting.

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Table 7 Estimated annual total releases and average air concentrations for gaseous and particulate emissions from well-field activities. Values are estimates from the final environmental impact statement for a uranium ISR facility constructed into Crownpoint, New Mexico, USA (NRC, 1997)

Emission type	Annual total (tonnes)	Annual average concentration (µg/m³)
Sulphur dioxides (SO_x)	7.1	1.8×10^{-10}
Nitrous oxides (NO_x)	84.0	2.1×10^{-9}
Hydrocarbons	10.8	2.7×10^{-10}
Carbon monoxide	70.2	1.8×10^{-9}
Particulates	11.0	2.8×10^{-10}
Aldehyde	1.5	4.0×10^{-11}

The values for the BIOMOre copper ISR might differ considerably from the values drawn from uranium ISR facilities. However, the air emissions are going to be largest during the construction phase and the most significant air quality impacts are going to be related to dust from uncovered ground surfaces and unpaved roads.

4.8. G4-EN22: Total water discharge by quality and destination

Assuming that 75% of water in the process cycle is reused the amount of water discharge would be 12.6 m³/t Cu. The chemical composition of this effluent from the process has not been estimated.

4.9. MM3: Total amounts of overburden, rock, tailings and sludges and their associated risks

The overburden from the construction phase will be temporarily stored in piles for re-contouring done upon site closure. Piles will be vegetated to avoid dusting (Grundfelt et al. 2018). Amount, composition and quality of overburden depend strongly on final site location.

Drilling waste is expected to account to 0.5 m³ per metre borehole (Grundfelt et al. 2018), totalling about 2,500 m³ of waste for a single well doublet. Grundfelt et al. (2018) further estimated that 70 % of the drilling waste consists of solid material (cuttings) and 30 % are liquid wastes. This accounts to 5,500 t, assuming 2.20 g/cm³ density for the cuttings. Translating this into a value per produced ton of copper introduces large uncertainties. For a 10-year operation of the the 5-doublet well field discussed in Section 4.1 this would mean generation 5×5,500 tonnes of drilling waste for 225,000 tonne Cu produced = 0,12 tonnes /tonne Cu.

The operation of the hydrometallurgical plant produces solid wastes at a rate of 55.6 tonnes/tonne Cu. This waste consists primarily of gypsum (76 %) and, in addition, iron hydroxides and iron sulphate compounds. Solid wastes will be deposited into a tailings impoundment or a pit fitted with artificial liners and surrounded by low-permeability material. The biggest risks are dusting of the wastes before a groundcover is placed, and potential leaks in the pit structure.

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4.10. G4-SO2: Operations with significant actual and potential negative impacts on local communities

Potential negative impacts of mine operation are identified and evaluated in Table 8. Many of the impacts are at least partially site dependent.

Table 8 Potential negative impacts of site operation and the severity of these impacts on local communities. Based on Grundfelt et al. (2018).

Impact	Description	Severity of impacts (Low/Moderate/High)
Groundwater quality	Risk of uncontrolled mining fluid excursions outside the intended production zone, mainly by accidents or operator negligence. In the past, the highest environmental impacts associated with ISR projects have been related to groundwater contamination.	High
Bedrock mechanics	Production will intentionally fracture bedrock and remove material from it by leaching. Severity of the impacts is considerably limited by the depth of the production zone (>1 km), which makes for example ground subsidence less likely.	High/Moderate
Soil quality	Disposal of solid wastes in tailings ponds (leaks in liners) and potential leaks of pipes cause a risk of soil contamination. Risk level and severity depend on the actions of the site operator.	High/Moderate
Accidents	Possible accidents could be related to for example fluid spills (from leaking pipes, machinery, chemical containers etc.), which could result in soil and shallow groundwater contamination. Risks can be actively limited by e.g. worker training, promotion of work safety and maintained mine safety programs. Can also negatively affect project's social licence.	High/Moderate
Increased waste quantities	The mine will produce wastes in the form of solid wastes and liquid effluents. Severity of impacts caused by increased waste volumes can be minimized by proper waste management. For example, waste water volumes are limited by multiple evaporation ponds and high recycling rates in the production cycle.	Moderate
Land use and zoning	Land footprint of the final facilities will be substantial and will likely affect land use planning in local level. Severity of impacts are strongly dependent on final site location.	Site specific (Low – High)
Landscape and cultural environment	Due to fairly high population density and long existing previous infrastructure, some impacts to landscape and cultural environments are likely, yet their severity is largely dependent on the final site location.	Site specific (Low – High)
Noise and vibration	Noise and vibrations can be distracting during site construction, but effects should be considerably smaller after the construction, drilling and induced fracturing have finished. Seismic vibrations from the fracturing are mostly too small to be felt on ground surface (M < 0.8). Noise will peak during the drilling stage, but can be efficiently limited by noise barriers etc. if necessary.	Site specific (Low/Moderate)
Climate and air quality	Site operation will produce some direct and indirect greenhouse gas and other air emissions. Largest impacts on air quality will be caused by dust, resulting from uncovered ground surfaces. Dust control might be required. Severity of the impacts is dependent on distance to closest population.	Site specific (Low/Moderate)
Ecology	Severity of impacts are going to be highly specific to final site location and size. Some negative impacts to local vegetation and local fauna are likely, majority of which are related to the construction stage. Impacts include possible loss, alteration or fragmentation of habitats, displacement of wildlife and direct or indirect mortalities from site construction and traffic.	Site specific (Low/Moderate)
Recreation and health	During normal site operation, impacts on human health are minimal. Biggest risks are caused by accidents, and especially the risk of groundwater contamination. Final site location will have a large impact on how the mine affects recreational use of land.	Site specific (Low/Moderate)
Traffic volumes, -routes and -safety	Site operation will increase both freight and passenger traffic on the area. Traffic will likely focus on road traffic, but rail traffic is also a possibility depending on site location. Routes and safety factors are also largely dependent on site location, but risks can be minimized by e.g. limiting driving speeds. Traffic volumes will peak during the construction period, but during regular operation traffic volumes are going to be substantially smaller and, overall, the associated risks can be considered small.	Low
Economical	Impacts are largely positive due to increases in employment and tax revenue. Mine operation will, however, lead to exhaustion of the ore reserve in the production zone and prevents utilizing it in the future.	Low

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5. Conclusions

In this study the values of selected Sustainable Development Indicators, SDI, for copper production by the BIOMOre technology and by a baseline technology consisting of conventional ore extraction from an underground mine followed by beneficiation by floatation and copper production by smelting have been compared. The SDI values for the baseline technology have been derived in an earlier deliverable from the BIOMOre project (Keith-Roach and Grundfelt, 2015).

The BIOMOre technology consists of in situ recovery by bioleaching of an ore deposit that has been stimulated by hydraulic fracturing. The lixiviant consists of sulphuric acid containing ferric iron as an oxidant. During the in situ leaching the ferric iron is reduced to ferrous iron. The ferric iron is then regenerated by microbial oxidation in a Ferric Iron Generating Bioreactor, FIGB. Within the project the process has been demonstrated in a lab scale (litres) and on a pilot scale (~100 m^3). Modelling efforts aiming at upscaling the technology has been performed for the in-situ leaching (Kahnt et al., 2018) as well as for the hydrometallurgical processing (UIT, 2018).

The objective of the project has been to achieve the step “proof of concept” rather than planning or designing commercial size facilities. Hence, any data for the BIOMOre technology are associated with significant uncertainties. It should also be pointed out that the compatibility of the premises for the BIOMOre technology data and those for the baseline technology are difficult to ascertain depending on inter alia the lack of full scale experience for the BIOMOre technology.

Table 9 shows the values obtained for the selected SDIs for both technologies. The table indicates that:

- The energy consumption of the BIOMOre technology is about 30 % of that for the baseline technology. A likely explanation is that no crushing and grinding is needed in the BIOMOre technology.

- The amount of land needed for the BIOMOre technology could be 10 % or less of that needed for the baseline technology. The value for the baseline technology is dominated by the smelter and the tailings management facility. Note that this indicator does not lend itself to scaling against the copper production.

- The greenhouse gas emissions are somewhat higher for the BIOMOre technology than for the baseline technology. About 25 % of the emissions from the BIOMOre technology derives from the manufacturing of chemicals used. This is probably not included in the data for the baseline technology.

- The amount water discharged from the BIOMOre process is significantly larger than for the baseline technology.

- The amount of solid waste is less in the BIOMOre technology than in the baseline technology. This value is dominated by the process waste from

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hydrometallurgical plant which in turn depends on the high amount of gypsum and iron compounds produced in the process.

The overall picture is that the BIOMOre technology has a smaller negative impact on the environmental parameters than the baseline technology. The difference could be interpreted as smaller than what could be anticipated. The impacts from the BIOMOre technology are partly dependent on the content of carbonate rock in the ore deposit. Thus, selecting an ore deposit with a, from this perspective, more benign composition could further reduce the impacts.

The study has demonstrated that the applied method for studying the impact of a new technology on the sustainable development of an industry has merits. In the present case, not all indicators could be evaluated due to a lack of data. The primary reason for this is that the project aimed at proof of concept rather than planning of operations on a full commercial scale.

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Table 9 Comparison of BIOMOre technology SDI values with values for the baseline technology.

Sustainable Development Indicator	Unit	Baseline	BIOMOre technology	Comment
G4-EC1: Direct economic value generated and distributed, Cost of copper production.	EUR/tonne Cu (0.23 EUR/PLN)	2,780	Revenue 4800 Operational cost 613	The value for the baseline technology includes a silver discount. The values for the BIOMOre technology are taken from an assessment of relative costs for alternative flow sheets.
G4-EN1: Materials used by weight or volume	-	No information	~35 t H_2SO_4 and 71.4 t H_2O per t Cu	This indicator could not be quantified for the baseline technology due to lack of data.
G4-EN3: Energy consumption within the organisation	Total, GJ/tonne Cu	38	10.8	The main part of the BIOMOre technology energy requirement comes from the electrowinning stage with pumps for lixiviant/PLS circulation in second place.
	Direct energy source, GJ/tonne Cu	20		
	Electricity produced off site, GJ/tonne Cu	18		
MM1: Amount of land disturbed or rehabilitated	Total, ha	5,485	50 – 500	BIOMOre technology value based on experience from uranium ISR
	Głogów smelter, ha	2,045	–	
	Legnica smelter, ha	212	–	
	Tailings facility, ha	3,072	–	
	Rudna mine, ha	92	–	
	Ore concentrators, ha	64.5	–	
G4-EN15: Direct greenhouse gas emissions	kg CO_2 equivalent/tonne Cu	3,300	4,780	60 % of BIOMOre technology emissions come from the hydrometallurgical plant, 25 % from chemicals used and 15 % from well field operations.
G4-EN21: Direct of NO_x, SO_x and other significant air emissions	kg NOx/tonne Cu	2.7	–	No data available that can be assured to be compatible with the baseline technology data.
	kg SOx/tonne Cu	10.3		
	kg dust/tonne Cu	0.87		
	kg Cu/tonne Cu	0.02		
	kg Pb/tonne Cu	0.01		
G4-EN22: Total water discharge by quality and destination	Volume, m^3/tonne Cu	5.6	12.6	Assuming a 75 % reuse of water.
	Dissolved minerals, g/dm^3	287	–	
	Cl^-, g/dm^3	169	–	
	SO_4^{2-}, g/dm^3	2.7	–	
MM3: Total amounts of overburden, waste rock, tailings and sludges and their associated risks	Total waste, tonne/tonne Cu	76	56	Data for the BIOMOre technology are dominated (55.6 tonnes/tonne Cu) by sludge from hydrometallurgical processing consisting primarily of gypsum. Applying the technology at a deposit with a lower content of carbonate rocks would significantly reduce the amount of process waste.
	Hazardous waste, Tonne/tonne Cu	0.53		
	Non-hazardous waste, tonne/tonne Cu	2.5	–	
	Extractive industry waste, tonne/tonne Cu	73	–	
G4-SO2: Operations with significant actual and potential negative impacts on local communities	-			See Section 4.10 for BIOMOre technology impact.

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Annex 1 Full text of the BIOMOre SDI set

The full text is given for the BIOMOre SDI in alphanumeric order; and taken directly from Global Reporting Initiative (2013a, b)

G4-EC1: DIRECT ECONOMIC VALUE GENERATED AND DISTRIBUTED

a. Report the direct economic value generated and distributed (EVG&D) on an accruals basis including the basic components for the organization's global operations as listed below. If data is presented on a cash basis, report the justification for this decision and report the basic components as listed below:

- Direct economic value generated:
  - Revenues
- Economic value distributed:
  - Operating costs
  - Employee wages and benefits
  - Payments to providers of capital
  - Payments to government (by country)
  - Community investments
- Economic value retained (calculated as 'Direct economic value generated' less 'Economic value distributed')

b. To better assess local economic impacts, report EVG&D separately at country, regional, or market levels, where significant. Report the criteria used for defining significance.

Additional disclosure requirements for mining and metals sector

Report countries of operation that are either candidate to or compliant with the Extractive Industries Transparency Initiative (EITI).

IMPLEMENTATION GUIDANCE

Relevance

Information on the creation and distribution of economic value provides a basic indication of how the organization has created wealth for stakeholders. Several components of the economic value generated and distributed (EVG&D) also provide an economic profile of the organization, which may be useful for normalizing other performance figures. If presented in country-level detail, EVG&D can provide a useful picture of the direct monetary value added to local economies.

Compilation

Compile the EVG&D data, where possible, from data in the organization's audited financial or profit and loss (P&L) statement, or its internally audited management accounts.

Revenues

- Net sales equal gross sales from products and services minus returns, discounts, and allowances
- Revenue from financial investments includes cash received as interest on financial loans, as dividends from shareholdings, as royalties, and as direct income generated from assets (such as property rental)
- Revenues from sale of assets include physical assets (such as property, infrastructure, and equipment) and intangibles (such as intellectual property rights, designs, and brand names)

Operating costs

- Cash payments made outside the organization for materials, product components, facilities, and services purchased. This includes property rental, license fees, facilitation payments (since these have a clear commercial objective), royalties, payments for contract workers, employee training costs (where outside trainers are used), or employee protective clothing

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Employee wages and benefits

- Total payroll comprises employee salaries, including amounts paid to government institutions (such as employee taxes, levies, and unemployment funds) on behalf of employees. Non-employees working in an operational role are normally not included here, but rather under operating costs as a service purchased
- Total benefits include regular contributions (such as to pensions, insurance, company vehicles, and private health), as well as other employee support such as housing, interest-free loans, public transport assistance, educational grants, and redundancy payments. They do not include training, costs of protective equipment, or other cost items directly related to the employee's job function

Payments to providers of capital

- Dividends to all shareholders
- Interest payments made to providers of loans. This includes interest on all forms of debt and borrowings (not only long-term debt) and also arrears of dividends due to preferred shareholders

Payments to government

- All organization taxes (such as corporate, income, property) and related penalties paid at the international, national, and local levels. This figure does not include deferred taxes because they may not be paid. For organizations operating in more than one country, report taxes paid by country. Report the definition of segmentation used

Community investments

- Voluntary donations and investment of funds in the broader community where the target beneficiaries are external to the organization. These include contributions to charities, NGOs and research institutes (unrelated to the organization's commercial R&D), funds to support community infrastructure (such as recreational facilities) and direct costs of social programs (including arts and educational events). The amount included accounts for actual expenditures in the reporting period, not commitments
- For infrastructure investments, the calculation of the total investment is meant to include costs of goods and labor, in addition to capital costs. For support of ongoing facilities or programs (such as an organization funding the daily operations of a public facility), the reported investment includes operating costs
- This excludes legal and commercial activities or where the purpose of the investment is exclusively commercial. Donations to political parties are included but are also addressed separately in more detail in G4-SO6
- Any infrastructure investment that is driven primarily by core business needs (such as building a road to a mine or factory) or to facilitate the business operations of the organization is not included. The calculation of investment may include infrastructure built outside the main business activities of the organization, such as a school or hospital for employees and their families

Documentation sources

Potential sources of information include the organization's finance, treasury, or accounting departments.

References

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G4-EN1: MATERIALS USED BY WEIGHT OR VOLUME

a. Report the total weight or volume of materials that are used to produce and package the organization's primary products and services during the reporting period, by:

- Non-renewable materials used
- Renewable materials used

IMPLEMENTATION GUIDANCE

Relevance

This Indicator describes the organization's contribution to the conservation of the global resource base and its efforts to reduce the material intensity and increase the efficiency of the economy. These are expressed goals of the Organisation for Economic Co-operation and Development (OECD) Council and various national sustainability strategies. For internal managers and others interested in the financial state of the organization, material consumption relates directly to overall costs of operation. Tracking this consumption internally, either by product or product category, facilitates the monitoring of material efficiency and cost of material flows.

Compilation

Identify the organization's primary products and services.

Identify total materials used. This includes, as a minimum:

- Raw materials (that is, natural resources used for conversion to products or services such as ores, minerals, wood)
- Associated process materials (that is, materials that are needed for the manufacturing process but are not part of the final product, such as lubricants for manufacturing machinery)
- Semi-manufactured goods or parts, including all forms of materials and components other than raw materials that are part of the final product
- Materials for packaging purposes, which include paper, cardboard and plastics

For each material type, identify whether it was purchased from external suppliers or sourced internally (such as by captive production and extraction activities).

For each material type identify whether it was derived from non-renewable or renewable sources.

State whether this data is estimated or sourced from direct measurements. If estimation is required, state the methods used. Usage data is not to be further manipulated and is to be presented 'as is' rather than by 'dry substance/weight'.

Definitions

See Glossary in *Implementation Manual*, p. 244

- Non-renewable materials
- Renewable materials

Documentation sources

Potential sources of information include the organization's billing and accounting systems, and the procurement or supply management department.

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G4-EN3: ENERGY CONSUMPTION WITHIN THE ORGANIZATION

a. Report total fuel consumption from non-renewable sources in joules or multiples, including fuel types used.
b. Report total fuel consumption from renewable fuel sources in joules or multiples, including fuel types used.
c. Report in joules, watt-hours or multiples, the total:

- Electricity consumption
- Heating consumption
- Cooling consumption
- Steam consumption

d. Report in joules, watt-hours or multiples, the total:

- Electricity sold
- Heating sold
- Cooling sold
- Steam sold

e. Report total energy consumption in joules or multiples.

f. Report standards, methodologies, and assumptions used.

g. Report the source of the conversion factors used.

IMPLEMENTATION GUIDANCE

Relevance

Energy consumption has a direct effect on operational costs and can increase exposure to fluctuations in energy supply and prices. The environmental footprint of an organization is shaped in part by its choice of energy sources. Changes in the balance of these sources can indicate the organization's efforts to minimize its environmental impacts.

For some organizations, electricity is the only significant form of energy they consume. For other organizations, other energy sources might also be important, such as steam or water provided from a district heating plant or chilled water plant.

The consumption of non-renewable fuels is usually the main contributor to direct greenhouse gas (GHG) emissions (Scope 1), which are reported in Indicator G4-EN15. The consumption of purchased electricity, heating, cooling, and steam contributes to an organization's energy indirect (Scope 2) GHG emissions, which are reported in Indicator G4-EN16.

Compilation

Identify the types of energy (fuel, electricity, heating, cooling, and steam) consumed within the organization.

Identify the amount of energy (fuel, electricity, heating, cooling, and steam) consumed within the organization, in joules or multiples.

When reporting self-generated energy consumption, the organizations does not double-count fuel consumption. For example, if an organization generates electricity from coal and then consumes the generated electricity, the energy consumption is counted once under the fuel consumption.

Energy may be purchased from sources external to the organization or produced by the organization itself (self-generated). Only energy consumed by entities owned or controlled by the organization is expected to be reported in this Indicator.

Fuel

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Report fuel consumption separately for non-renewable and renewable fuel sources as follows:

- Non-renewable fuel sources include fuel for combustion in boilers, furnaces, heaters, turbines, flares, incinerators, generators and vehicles, which are owned or controlled by the organization. Non-renewable fuel sources cover fuels purchased as well as fuels generated by the organization's activities, such as mined coal and gas from oil and gas extraction
- Renewable fuel sources are sources owned or controlled by the organization, including biofuels (purchased for direct use) and biomass

Electricity, heating, cooling, and steam
Using the identified types of energy purchased for consumption and self-generated, calculate the total energy consumption within the organization in joules or multiples using the following formula:
Total energy consumption within the organization = Non-renewable fuel consumed + Renewable fuel consumed + Electricity, heating, cooling and steam purchased for consumption + Self-generated electricity, heating , cooling and steam – Electricity, heating, cooling and steam sold

Organizations are expected to report standards, methodologies, and assumptions used to calculate and measure energy consumption, with a reference to the calculation tools used. Organizations subject to different standards and methodologies should identify the approach to selecting them.

Organizations are expected to apply conversion factors consistently for all data reported under the Energy Aspect. Local conversion factors to convert fuel to joules, or multiples, are to be used when possible. When local conversion factors are unavailable, the generic conversion factors may be used.

Organizations are expected to select a consistent Boundary for energy consumption. When possible, the Boundary should be consistent with the Boundary used in Indicators G4-EN15 and G4-EN16.

Organizations may further disaggregate energy consumption data where this aids transparency or comparability over time. For example, they may disaggregate data by:

- Business unit or facility
- Country
- Source type (See Definitions for the listing of non-renewable and renewable energy sources)
- Activity type

Definitions
See Glossary in *Implementation Manual*, p. 244

- Non-renewable energy sources
- Renewable energy sources

Documentation sources
Potential sources of information include invoices, measurements or calculations, or estimations. The reported units may be taken directly from invoices or meters, or converted from the original units to the reported units.

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G4-EN15 DIRECT GREENHOUSE GAS (GHG) EMISSIONS (SCOPE 1)

a. Report gross direct (Scope 1) GHG emissions in metric tons of CO_2 equivalent, independent of any GHG trades, such as purchases, sales, or transfers of offsets or allowances.

b. Report gases included in the calculation (whether CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3, or all).

c. Report biogenic CO_2 emissions in metric tons of CO_2 equivalent separately from the gross direct (Scope 1) GHG emissions.

d. Report the chosen base year, the rationale for choosing the base year, emissions in the base year, and the context for any significant changes in emissions that triggered recalculations of base year emissions.

e. Report standards, methodologies, and assumptions used.

f. Report the source of the emission factors used and the global warming potential (GWP) rates used or a reference to the GWP source.

g. Report the chosen consolidation approach for emissions (equity share, financial control, operational control).

IMPLEMENTATION GUIDANCE

Relevance

This Indicator covers the disclosure of the direct (Scope 1) GHG emissions, in CO_2 equivalents, of the GHGs covered by the UN 'Kyoto Protocol' and the WRI and WBCSD 'GHG Protocol Corporate Accounting and Reporting Standard':

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)
- Nitrogen trifluoride (NF_3)

GHG emissions are a major contributor to climate change and are governed by the UN 'United Nations Framework Convention on Climate Change'100 and the subsequent UN 'Kyoto Protocol'. Some GHGs, including methane (CH_4), are also air pollutants that have significant adverse impacts on ecosystems, air quality, agriculture, and human and animal health. As a result, different national and international regulations and incentive systems (such as tradable emission permits) aim to control the volume, and reward the reduction of GHG emissions.

Direct (Scope 1) GHG emissions come from sources (physical units or processes that release GHG into the atmosphere) that are owned or controlled by the organization.

Direct (Scope 1) GHG emissions include, but are not limited to, the CO_2 emissions from the fuel consumption reported in Indicator G4-EN3.

This Indicator may be used in combination with Indicators G4- EN16 (energy indirect Scope 2 emissions) and G4-EN17 (other indirect Scope 3 emissions) to report an organization's total GHG emissions.

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The combination of direct and indirect emissions provides insights into the cost implications of taxation or trading systems. It also provides insight into an organization's carbon footprint and environmental performance.

Compilation
Identify direct emissions of GHGs from sources owned or controlled by the organization, including:

- Generation of electricity, heating, cooling and steam. These emissions result from combustion of fuels in stationary sources (such as boilers, furnaces, turbines) and from other combustion processes such as flaring
- Physical or chemical processing. Most of these emissions result from the manufacturing or processing of chemicals and materials (such as cement, steel, aluminum, ammonia, and waste processing)
- Transportation of materials, products, waste, employees, and passengers. These emissions result from the combustion of fuels in mobile combustion sources owned or controlled by the organization (such as trucks, trains, ships, airplanes, buses, cars)
- Fugitive Emissions. These emissions result from intentional or unintentional releases, such as equipment leaks from joints, seals, packing, and gaskets; methane emissions from coal mines and venting; hydrofluorocarbon (HFC) emissions from refrigeration and air conditioning equipment; and methane leakages from gas transport

Using the sources identified, calculate the organization's gross direct GHG emissions using relevant GWP rates, in CO2 equivalents, during the reporting period. Exclude any GHG trades, such as purchases, sales, or transfers of offsets or allowances.

Organizations are expected to report standards, methodologies, and assumptions used to calculate and measure emissions, with a reference to the calculation tools used. Organizations subject to different standards and methodologies should describe the approach to selecting them.

Select a consistent consolidation approach for emissions, and apply it to calculate the gross direct (Scope 1) GHG emissions. When possible, select an approach that is consistent with the approach used in Indicator G4-EN16. Organizations select the equity share, financial control, or operational control methods outlined in the WRI and WBCSD 'GHG Protocol Corporate Accounting and Reporting Standard'.

Select and identify the base year for which emissions data are available, and identify the reasons for selecting that particular year. For recalculations of prior year emissions, organizations may follow the approach in the WRI and WBCSD 'GHG Protocol Corporate Accounting and Reporting Standard'.

Organizations may report biogenic CO2 emissions; however, such emissions are reported separately and not added to the total direct (Scope 1) GHG emissions. These emissions refer to CO2 emissions from combustion or biodegradation of biomass only, not to emissions of any other GHGs (such as CH4 and N2O), or to any GHG emissions that occur in the life cycle of biomass other than from combustion or biodegradation (such as GHG emissions from processing or transporting biomass).

Information on offsets may be reported in the DMA for the Emissions Aspect.

Methodologies used to calculate the emissions may include:

- Direct measurement of energy source consumed (coal, gas) or losses (refills) of cooling systems and conversion to GHG (CO2 equivalents)
- Mass balance calculations
- Calculation based on site-specific data (such as for fuel composition analysis)
- Calculation based on published criteria (emissions factors and GWPs)
- Estimations. If estimations are used due to a lack of default figures, the organization indicates the basis and assumptions on which figures were estimated
- Direct measurement of the GHG (such as continuous online analyzers)

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Organizations may further disaggregate direct (Scope 1) GHG emissions data where this aids transparency or comparability over time. For example, they may disaggregate data by:

- Business unit or facility
- Country
- Source type (stationary combustion, process, fugitive)
- Activity type

When possible, organizations apply emission factors and GWP rates consistently for the data reported under the Emissions Aspect. Emission factors may originate from mandatory reporting requirements, voluntary reporting frameworks, or be developed by industry groups. Estimates of GWPs change over time as scientific research develops. Organizations may use the GWPs from *Assessment Reports* from the Intergovernmental Panel on Climate Change (IPCC). As the GWPs from the IPCC *Second Assessment Report* are used as the basis for international negotiations under the UN 'Kyoto Protocol', such rates may be used for disclosing GHG emissions where it does not conflict with national or regional reporting requirements. Organizations may also use the latest GWPs from the most recent IPCC *Assessment Report*. GWPs are expressed over a number of different time frames within the IPCC *Assessment Reports*. Organizations use the factors for the 100-year time span.

Further details and guidance for this Indicator are available in the WRI and WBCSD 'GHG Protocol Corporate Accounting and Reporting Standard' and in documents from the IPCC.

Definitions

See Glossary in *Implementation Manual*, p. 244

- Base year
- Carbon dioxide equivalent
- Direct GHG emissions (Scope 1)
- Global warming potential (GWP)

Documentation sources

Potential sources of information on direct (Scope 1) GHG emissions include part of the data reported in Indicator G4-EN3.

References

- Carbon Disclosure Project (CDP), *Investor CDP Information Request,* updated annually.
- Intergovernmental Panel on Climate Change (IPCC), *Climate Change 1995: The Science of Climate Change, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change,* 1995.
- Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* 2007.
- United Nations (UN) Protocol, 'Kyoto Protocol to the United Nations Framework Convention on Climate Change', 1997.
- World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), 'GHG Protocol Corporate Accounting and Reporting Standard', Revised Edition, 2004.
- World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), 'Greenhouse Gas Protocol Accounting Notes, No. 1, Accounting and Reporting Standard Amendment', 2012.

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G4-EN21: NOX, SOX, AND OTHER SIGNIFICANT AIR EMISSIONS

a. Report the amount of significant air emissions, in kilograms or multiples for each of the following:

- NOX
- SOX
- Persistent organic pollutants (POP)
- Volatile organic compounds (VOC)
- Hazardous air pollutants (HAP)
- Particulate matter (PM)
- Other standard categories of air emissions identified in relevant regulations

b. Report standards, methodologies, and assumptions used.
c. Report the source of the emission factors used.

Additional disclosure requirements for mining and metals sector
IMPLEMENTATION GUIDANCE

Relevance

Air pollutants have adverse effects on climate, ecosystems, air quality, habitats, agriculture, and human and animal health. Deterioration of air quality, acidification, forest degradation, and public health concerns have led to local and international regulations to control air emissions. Reductions in regulated pollutants lead to improved health conditions for workers and neighboring communities. Reductions, or performance beyond compliance, can enhance relations with affected communities and workers, and the ability to maintain or expand operations. In regions with emission caps, the volume of emissions also has direct cost implications.

This Indicator can also measure the scale of the organization’s air emissions and demonstrate the relative size and importance of these emissions compared with those of other organizations.

Compilation

Identify significant air pollutants emitted by the organization and sources of significant air emissions release to the environment.

Using the air pollutants and their sources identified above, calculate the amount of significant air emissions released to the environment.

Organizations are expected to report standards, methodologies, and assumptions used to calculate and measure air emissions, with a reference to the calculation tools used. Organizations subject to different standards and methodologies should describe the approach to selecting them. Since calculating certain air emissions (such as NOX) requires complex quantification efforts, indicate the methodology used for calculations, selecting one of the following approaches:

Direct measurement of emissions (such as online analyzers)
Calculation based on site-specific data
Calculation based on published emission factors
Estimation (if estimations are used due to a lack of default figures, indicate the basis on which figures were estimated)
Organizations may further disaggregate air emissions data where this aids transparency or comparability over time. For example, they may disaggregate data by:
Business unit or facility
Country
Source type
Activity type

Definitions

See Glossary in *Implementation Manual*, p. 244

- Significant air emissions

Documentation sources

Potential sources of information include emissions measurements, calculations from accounting data and defaults, or estimations.

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G4-EN22: TOTAL WATER DISCHARGE BY QUALITY AND DESTINATION

a. Report the total volume of planned and unplanned water discharges by:

- Destination
- Quality of the water including treatment method
- Whether it was reused by another organization

b. Report standards, methodologies, and assumptions used.

IMPLEMENTATION GUIDANCE

Relevance

The amount and quality of the water discharged by the organization is directly linked to ecological impact and operational costs. By progressively improving the quality of discharged water or reducing volumes, the organization has the potential to reduce its impact on the surrounding environment. Unmanaged discharge of effluents with a high chemical or nutrient load (principally nitrogen, phosphorous, or potassium) can have a significant impact on receiving waters. This, in turn, can affect the quality of the water supply available to the organization and its relationship with communities and other water users.

Discharging effluents or process water to a facility for treatment not only reduces pollution levels, but can also lower the organization's financial costs and the risk of regulatory action for non-compliance with environmental regulation. All of this enhances the organization's social license to operate.

Compilation

Identify planned and unplanned water discharges (excluding collected rainwater and domestic sewage) by destination and indicate how it is treated. If the organization does not have a meter to measure water discharges, this figure needs to be estimated by subtracting the approximate volume consumed on-site from the volume withdrawn as reported in G4-EN8.

Organizations that discharge effluents or process water report water quality in terms of total volumes of effluent using standard effluent parameters such as Biological Oxygen Demand (BOD) or Total Suspended Solids (TSS). The specific choice of quality parameters will vary depending on the organization's products, services, and operations.

The selection of parameters is to be consistent with those used in the organization's sector.

Water quality metrics may vary depending on national or regional regulations.

Definitions

See Glossary in *Implementation Manual*, p. 244

- Total water discharge

Documentation sources

Potential sources of information about the volume of water discharged by the organization include flow meters (point-source discharges or when discharges are released through a pipe) and regulatory permits.

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G4-SO2: OPERATIONS WITH SIGNIFICANT ACTUAL AND POTENTIAL NEGATIVE IMPACTS ON LOCAL COMMUNITIES

a. Report operations with significant actual and potential negative impacts on local communities, including:

- The location of the operations
- The significant actual and potential negative impacts of operations

IMPLEMENTATION GUIDANCE

Relevance

Organizational operations related to entering, operating, and exiting can have a number of significant negative impacts on local communities. Indicators in the Guidelines, such as environmental emissions or economic data, will offer an overall picture of positive and negative impacts, but may not be able to present them in relation to local communities.

This Indicator is focused on significant actual and potential negative impacts related to operations and not on community investments or donations (which are addressed under G4-EC1).

The Indicator informs stakeholders about an organization's awareness of its impacts on local communities. It also enables an organization to better prioritize and improve its organization-wide attention to local communities.

Understanding operations with specific challenges, combined with information about organization-wide processes, enables stakeholders to better assess an organization's overall community performance. An analysis of negative impacts enables an organization to reflect its approach in management systems and consequently enhance the brand and reputation of the organization as a potential partner. It simultaneously strengthens the ability of an organization to maintain existing operations, and to initiate new ones.

Compilation

Identify internal sources of information about actual and potential negative impacts of operations on local communities, including sources such as:

- Actual performance data
- Internal investment plans and associated risk assessments
- All data collected with GRI Indicators (such as G4-EC8, G4-EN1, G4-EN3, G4-EN8, G4-EN12, G4-EN14, G4-EN20 to G4-EN27, G4-EN30, G4-LA7, G4-HR5 to G4-HR8, G4-SO11, G4-PR1, G4-PR2) as relates to individual communities

Identify significant potential negative impacts, including, as a minimum, consideration of:

- Vulnerability and risk to local communities from potential impacts due to factors, such as:
    - Degree of physical or economic isolation of the local community
    - Level of socio-economic development including the degree of gender equality within the community
    - State of socio-economic infrastructure (health, education)
    - Proximity to operations
    - Level of social organization
    - Strength and quality of the governance of local and national institutions around local communities

Identify the exposure of the local community to the organization's operations due to higher than average use of shared resources or impact on shared resources. This may include:

- Use of hazardous substances that impact on the environment and human health in general, and specifically reproductive health
- Volume and type of pollution released

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- Status as major employer in the local community
- Land conversion and resettlement
- Natural resource consumption

Identify the significant actual and potential negative economic, social, cultural, and environmental impacts on local communities and their rights. This may include consideration of:

- Intensity or severity of the impact
- Likely duration of the impact
- Reversibility of the impact
- Scale of the impact

Definitions

See Glossary in Implementation Manual, p. 244

- Local community
- Operations with significant actual and potential negative impacts on local communities

Documentation sources
Potential sources of information include organizational policies and risk assessment procedures; results of data collection from local community programs; and analysis results of external stakeholder forums, joint community committees, stakeholder reports, and other inputs.

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MM1: AMOUNT OF LAND (OWNED OR LEASED, AND MANAGED FOR PRODUCTION ACTIVITIES OR EXTRACTIVE USE) DISTURBED OR REHABILITATED

1. Relevance
Mining companies can own or hold licenses over very large areas of land. Often, the extraction sites, infrastructure, or other production activities may disturb a small proportion of that land holding. The impact on habitats and biodiversity is therefore more accurately assessed against the amount of land disturbed, and by the amount of land returned to beneficial use.

2. Compilation
2.1 This indicator should be reported in hectares.
2.2 This indicator refers to land disturbed by the company's operations.
2.3 This indicator refers to land that is owned or leased and is being managed for production activities or extractive use.
2.4 'Land' may refer to sea, lake or river beds if appropriate.
2.5 Report the following data:

- Total land disturbed and not yet rehabilitated (A: opening balance);
- Total amount of land newly disturbed within the reporting period (B);
- Total amount of land newly rehabilitated within the reporting period to the agreed end use (C);
- Total land disturbed and not yet rehabilitated (D= A+B-C; closing balance).

The above set of figures allows the reader to assess both the stock of land disturbed and the annual changes.

3. Definitions
Disturbance
May include physical or chemical alteration which substantially disrupts the pre-existing habitats and land cover.

Agreed end use
Use to which land is returned upon completion of rehabilitation, as a result of negotiation with affected parties where appropriate. 'Agreed use' does not necessarily mean returning land to its prior condition, as post-mining end use may result in a changed state (such as flooded open-cast workings creating wetland habitat).

4. Documentation
Sources of information will include the company's land holdings data (purchases and leases) together with site-level records of land management, and may include reports filed with regulatory authorities on compliance with environmental management plans specified in the regulator's approval for the operation.

5. References
None.

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MM3: TOTAL AMOUNTS OF OVERBURDEN, ROCK, TAILINGS, AND SLUDGES AND THEIR ASSOCIATED RISKS

1. Relevance
The mining sector deals with large quantities of material as a result of its extractive activities. Non-product materials (overburden) have to be removed to give access to product-bearing material (ores), which are processed, physically or chemically, to release them from their matrix and convert them into output products. Waste material can be generated at any or all of these stages, whether it be overburden, waste rock or processing tailings, slags, sludges, slimes or other process residues. These residues may be disposed of in a variety of different ways: in pits or underground; on site in engineered facilities; or off site.

Reporting on the presence, location (country level), quantities and the associated risk assessment regimes can indicate a company's ability to manage risks and mitigate any potential consequences.

2. Compilation

2.1 This indicator should be reported as tons.

2.2 The relevance of risks associated with specific types of waste will be determined by risk assessment. The combination of waste material and disposal location may define the risk; for example, acid generating rock materials may leach acid products into water systems; inert materials may blanket ecosystems if disposed of in inappropriate settings; poorly engineered or maintained impoundments may give rise to toxic spills or structural failures.

2.3 Report the total amounts of overburden, rock, tailings, and sludges generated and any associated risks as defined in 2.2.

3. Definitions
None.

4. Documentation
Information on quantities will be available from site production data. Hazard identification may be available from site risk assessments.

5. References
None.

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Annex 2 Optimal SDI information

Optimal information input for the baseline and in situ bioleaching technologies. All data must be adapted to values per tonne of copper produced

SDI number	Data for baseline technology	Data for ISR
G4-EC1	Excavation and mine infrastructure costs Investment in equipment and vehicles Investment in smelter and processing plant Annual costs at (1) Rudna mine and (2) Głogów, including energy, maintenance, materials, employment, waste prevention, waste management Cost of decommissioning	Investment in equipment Investment in boreholes and associated buildings for managing the in situ leaching Investment in processing plant Annual costs at (1) mine site and (2) processing site for materials used in leaching and processing, water, energy, transport, waste prevention, waste management, employment Cost of decommissioning
G4-EN1	Mass of each material used in processing each year	Mass of each material used in leaching and processing per year
G4-EN3	Energy (J) used at 1) Rudna mine and (2) Głogów, per type of energy source (e.g. electricity, fuel) during mining and processing each year	Energy (J) used per type of energy source (e.g. electricity, fuel) during mining and processing each year
MM1	Area of land associated with each mine and plant	Area of land disturbed if ISR and associated processing were to be carried out on a new site
G4-EN15	Direct and indirect greenhouse gas emissions, and the total CO_2 equivalents emitted from (1) Rudna mine and (2) Głogów each year	Direct and indirect greenhouse gas emissions, and the total CO_2 equivalents emitted each year
G4-EN21	NOx, SO_2, CO_2, Pb, Cu and PM_{10} dust emitted during mining, tailings management, smelting and processing from (1) Rudna mine and (2) Głogów each year	NOx, SO_2, CO_2, Pb, Cu and PM_{10} dust emitted during ISR, processing and waste management each year
G4-EN22	Volume, quality and destination of water discharged during	Volume, quality and destination of water discharged during mining,

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	mining, from the tailings facility, and any other waste disposal site, and from the processing plant each year. Dissolved concentrations of key chemical species.	processing and from the waste disposal site each year
MM3	Total amount of overburden, rock, tailings, and sludges and their associated risks (i.e. divided into hazardous and non-hazardous materials) as well as the method of handling (reuse, recycle, recover, landfill…) from (1) Rudna mine and (2) Głogów each year	Total amount of overburden, rock, tailings, and sludges and their associated risks (i.e. divided into hazardous and non hazardous materials) as well as the method of handling (reuse, recycle, recover, landfill…) each year*
G4-SO2	Seismic risks, risks from tailings management and groundwater contamination, visual disturbance, noise, dust and emissions,	Impacts must include seismic events and groundwater contamination through uncontrolled releases of metal-loaded acid leachate, as well as visual disturbance, noise, dust and emissions

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