Dynamic predictive solution for sustainable water balance management in mining

SERENE

D4.4 v.2 (public version)

Overall sustainability of the solution and openLCA sustainability model

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Public version of the report

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Executive Summary

This deliverable presents and discusses the overall sustainability results of the novel water balance management technologies. Both qualitative and quantitative methods have been applied for the calculation of impacts and risks for environmental, social, and economic aspects and stakeholders. The main goal is to provide the audience with sustainability information regarding the project application and its potential benefits and drawbacks for the environmental and economic dimension. This information relies on the results of an environmental Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). The social dimension is addressed separately and in a qualitative way. Both a generic and a site-specific life cycle (LC) models have been created for the assessment of the SERENE solution. The consideration of a broader non-site-specific Water Balance Monitoring and Management Tool for Mine Sites (WQQM) framework aimed at creating a LC model that could be easily adapted to different geographical and technological contexts.

The study shows that the implementation of the WQQM technologies at a certain site in a water positive area can be overall beneficial from a sustainability point of view. Direct benefits derive from an improved water balance management in terms of both water quantity (reduced raw water intake and water discharge) and water quality (monitoring of substances load in tailings and dam water). Furthermore, the WQQM can contribute to a potential improvement in the field of environmental risk management. This means that the solution can reduce certain risks (especially exceeding permission limits and excess use of raw water), while a decrease of the environmental impacts generated by conventional site operation might not be significant. However, impacts on climate change and ionizing radiation may be reduced thanks to a decrease in the pumping energy for freshwater intake and water discharges if these water flows are reduced, but also thanks to a more efficient ore processing which would require less electricity and chemicals; on the other hand, an increase in water recycling rates can require more pumping energy for water circulation within the plant/site. Further electricity and chemicals may be needed for higher amounts of process water to be treated before being circulated back to plant.

Given the boundaries of the study, novel WQQM technologies would not create higher costs than those that the mines need to face without the water balance management and, specifically, direct cost savings can be achieved on site for a number of mining processes, such as flotation and filtration and waste water treatment. However, it should be considered that more water to be recycled and the introduction of further waste water treatment technologies for process water may create additional costs, which have not been included in the current study (except for electricity cost for pumping more recycled water to plants).

Finally, the deliverable gives insights on the generic copper life cycle model which was built to perform the calculations in the openLCA software and which is made available along with this report.

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1 INTRODUCTION

1.1 SERENE – a dynamic predictive solution for sustainable water balance management in mining

The SERENE project foresees an innovative water balance management solution to achieve a dynamic, predictive water balance control capability, reduce water related risks, and increase water recycling. The validation of the project comprises the sustainability assessment of the solution in order to investigate and communicate potential positive and negative impacts deriving from the implementation of these new technologies. The study of the potential impacts addresses all three dimensions of sustainability (environmental, social, and economic).

1.2 The aim and structure of the deliverable

This deliverable presents and discusses the overall sustainability results of the novel water balance management technologies. Both qualitative and quantitative methods have been applied for the calculation of impacts and risks for environmental, social, and economic aspects and stakeholders. The deliverable starts with the definition of the goal and scope of the study according to the ISO 14040 and 14044 standards. This is followed by the description of the approach of the work in terms of materials and methods for the sustainability assessment. After that, results (including sensitivity analysis), discussion and interpretation are the core of the report. Finally, the deliverable gives insights on the openLCA life cycle model which was built to perform the calculations in the openLCA software and which is made available along with this report.

1.3 D4.4 v.1 Generic sustainability model and results

The report D4.4 v.1 was delivered in May 2019 to support the WQQM launch by the Outotec Marketing department with generic sustainability models and results. The deliverable contained the results from a sustainability hotspots screening, including a causal loop diagram, literature research and an environmental, social, and economic Life Cycle Assessment (LCA) screening. Furthermore, the report focused on the definition of the goal and scope of the study and the creation of the life cycle models together with some preliminary results. The goal and scope of the study has been updated for the current final version of the deliverable, as presented in the next chapter. The life cycle models described in D4.4 v.1 served as the basis for the calculation and discussion of sustainability results extensively presented in this report D4.4 v.2.

2 GOAL AND SCOPE OF THE STUDY

Defining goal and scope is typically the first and one of the very key steps when performing life cycle assessments and similar analyses. The idea is to clearly specify "what the analysis and modelling will cover, for whom it is intended, and how it is planned to be used." ISO 14040 lists the elements that are expected in a goal and scope specification of an LCA[1]. This is very helpful to understand results of a model and analysis, as well as possible limitations, and can thus be used for any type of model and analysis.

2.1 Goal of the study

2.1.1 *Goal and intended application*

This study arises in the context of the validation of the sustainability of the Water Balance Monitoring and Management Tool for Mine Sites (WQQM), besides its technical evaluation performed by other WPs in the SERENE project. The main goal is to provide the audience with sustainability information regarding the project application and its potential benefits and drawbacks for the environmental and economic dimension. This information relies on the results of an environmental Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). The social dimension is addressed separately and in a qualitative way.

The objective is to develop and assess both a generic and a site-specific life cycle (LC) model for the SERENE solution. The consideration of a broader non-site specific WQQM framework aims at creating a LC model that could be easily adapted to different geographical and technological contexts. This is pursued by the identification of the main variables that affect the WQQM performance and the parameters which are influenced by the solution. The evaluation of those variables and parameters goes beyond water-related ones as it is crucial for the study to explore WQQM positive and negative effects on all impact categories, for instance to avoid burden shifting.

Furthermore, the assessment of a generic WQQM life cycle model is expected to support the WQQM market launch and sales, hence the related sustainability outcomes are planned to be integrated into marketing material as well. The results are intended to be disclosed to the public.

2.1.2 *Reasons for carrying out the study*

The main reason for conducting the study is to explore the solution provided by SERENE from a sustainable point of view, considering environmental and economic aspects. Thus, the results of the environmental LCA and LCC are planned to integrate the other technical outcomes and on-site testing, hence offering a comprehensive and meaningful description of the SERENE project and its advantages and disadvantages.

2.1.3 *Intended audience*

The intended audience is formed by internal stakeholders, the participants to the implementation and validation of the SERENE project at first. Secondly, the results of the study are foreseen for a broader target audience, such as potential industrial customers, academia, and local communities.

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[1] ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework, ISO 2006, section 5.2

2.2 Scope of the study

2.2.1 *Product system and function of the product system*

The product system to be assessed is represented by the ore mining and beneficiation operations with the application of the WQQM new technology. Specifically, the solution is related to a modular and scalable service which includes:

- Monitoring data on mine site´s water balance with the transmission of real-time information on process and natural waters collected with wireless online monitoring stations and sensors.
- Managing the dynamic water balance and quality information with the development of short-term forecasts and scenarios for operational conditions.
- Predicting and evaluating process optimization, water treatment options and expansion projects.

A customer support model is planned to be developed both for local maintenance of monitoring systems and back office expert support.

The generic life cycle model is developed for a generic site with a positive water balance and referred to copper ore mining and processing.

2.2.2 *Functional unit*

As for the functional unit of the generic LC model, the concentrate resulting from the multiple ore beneficiation steps can be considered as the product of interest. In most cases, mine´s sites process ore with different grades and multiple mineral/metal content. Therefore, when defining the functional unit, it is necessary to consider the different metals and mineral components and their different grades in concentrate. Overall, thus, the copper equivalent is selected as a common measure to assess the sustainability performance of a generic mine site. The copper equivalent is calculated using the following formula:

$$CuEq.\% = Cu\% + (\textstyle\sum_i R_i V_i G_i) / (V_{Cu} R_{Cu})$$

where,

R is the metallurgical metal recovery rate

V is the metal price

G is the metal grade in percent of concentrate

Therefore, 1 t of Cu eq. in concentrate is assumed as the FU for the generic life cycle model.

The life span of the monitoring stations is assumed to be 2 years. This information is considered when performing the LCC.

2.2.3 *System boundary*

The study evaluates the impacts of the SERENE solution in the context of mine and plant operation. Specifically, the following phases and processes are included in the generic model, i.e. the foreground system, with the related supply chain, i.e. background system:

- Mine operation (ore mining and waste rock management)
- Ore processing (comminution, flotation, and filtration)
- Tailings management
- Waste water treatment.

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The development of the generic model includes all input (water, consumables and energy) and output (water and emissions) flows within the system boundaries.

2.2.4 *Allocation procedures*

Allocation is applied to partition the flows of a process when this produces two or more products as output. No allocation is needed for the generic LC model as all processes are referred to copper ore mining and processing only.

2.2.5 *Data requirements*

Secondary data are needed for all inputs and outputs of the generic LC model. Beside the ecoinvent 3.5 APOS database (unregionalized version), data are also collected from literature and public reports from mining companies, paying attention to geographical and technical conformance. Information on source and, if needed, harmonization is reported for all data included in the study, as a basis for data quality assessment. As for LCC, ecoinvent 3.5 database is the starting point for the evaluation (background model) which is further adjusted with comprehensive generic costs of the mining activity (foreground model), provided by expert judgement and external sources.

2.2.6 *Impact assessment methodology and selected impact categories*

To conduct the environmental LCA, worldwide accepted methods are selected for the representativeness of their impact categories in the framework of the study. Specifically, ILCD 2011 Midpoint+ method is chosen after the evaluation of the different methods applied for the initial environmental screening, which was performed before the present study. In addition, a specific method for evaluating water related impacts is selected, i.e. AWARE, considering the relevance of the topic in the context of the study. Normalization is applied, following EC-JRC Global, Equal weighting normalization set from the ILCD 2011 Midpoint+ method.

As for LCC, it uses the value added calculation feature provided by openLCA, which is the software used for performing the life cycle modelling and calculations.

2.2.7 *Interpretation of results*

This procedure starts with the performance of a contribution analysis to identify key hotspots and main drivers of impacts. Results will be compared with the outcomes of the previous screening study.

Furthermore, as recommended by ISO14044, a completeness and consistency check is performed. Besides, a sensitivity analysis is foreseen, for instance to evaluate how results change if risk probability or WQQM advantages and disadvantages vary.

2.2.8 *Assumptions*

Assumptions are linked to data used to create the life cycle models. The generic copper life cycle model was created starting with data referred to copper mining and processing in Australia, a water scarce area. This information was, therefore, developed and adapted to reflect copper mining and processing in a water positive area. For the data on the water balance for the generic model, the site-specific model referred to a Scandinavian site was taken as a reference and adapted to the generic copper model. A complete list of input and output data used for the model is available in Annex I – Data used for the creation of the generic life cycle model and Annex II – Data used for the water balance of the generic life cycle model. Source, reference year and ore and any remarks are specified for each piece of information in the annexes. Although a number of sources used in the generic model are referred to underground mining in Australia, the model can still be considered to represent copper mining in a water positive area. This is because information on Australian copper mining was used when site location and mine type are less relevant for ore processing and beneficiation. Water balance was instead adapted to reflect water management in a water positive area, based on the case study in a Scandinavian site. On the other hand, it was possible to highlight the dependence of several data on the ore grade, 1.8% copper in the case of the generic model.

Assumptions had to be made also on the increase or decrease of the amount of energy, consumables, water flows and plant performance achievable with the implementation of the WQQM on site. The assumptions for the generic model were made with the support of Outotec. The assumptions were further tested with sensitivity analyses.

Assumptions are further clarified in the following Section 3 “Approach” and considered for the interpretation of results.

2.2.9 *Limitations*

Limitations are linked to the assumptions of the study.

Results are referred to the mining activity conducted in the following areas: water positive regions for the generic model. If results need to be applied to other geographic locations, further investigations should be carried out to adapt data and results obtained from the present study.

Regarding WQQM infrastructure, only monitoring stations and sensors are included in the system boundaries; the WQQM IT platform is excluded from the boundaries due to lack of data.

Furthermore, concerning LCC, at present the costs reported by ecoinvent are not referred to any specific geographic location.

2.2.10 *Data quality requirements*

Secondary data from journal articles are preferred for the generic LC model. Furthermore, data quality is tracked for all information used and received.

2.2.11 *Critical review*

It is not foreseen. However, results are presented and evaluated by the participants to the SERENE project.

2.2.12 *Type and format of the report required for the study*

Report (digital).

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3 APPROACH

3.1 Materials and methods for the environmental sustainability assessment of the SERENE solution

3.1.1 *Approach for a comparative environmental LCA: impacts with and without WQQM implementation*

The first step of the environmental sustainability assessment is the comparison of impacts with and without (i.e. the current situation on site) the implementation of the WQQM technologies at a certain site. This comparison is conducted using the generic copper life cycle model as a basis. Hence, the model created with data reported in “Annex I – Data used for the creation of the generic life cycle model” and “Annex II – Data used for the water balance of the generic life cycle model” is used to reflect the current situation on site, without the WQQM. Afterwards, this model is taken as a starting point to add the WQQM technologies in terms of:

- WQQM infrastructure: 3 monitoring stations and related sensors added to the model
- Changes in water flows: water intake and discharge, and recycled water
- Changes in energy consumption
- Changes in chemicals consumption
- Changes in plant performance: concentrate grade.

Figure 1 reports the “best case scenario” achievable if the WQQM is implemented on site. The assumptions have been made in collaboration with Outotec.

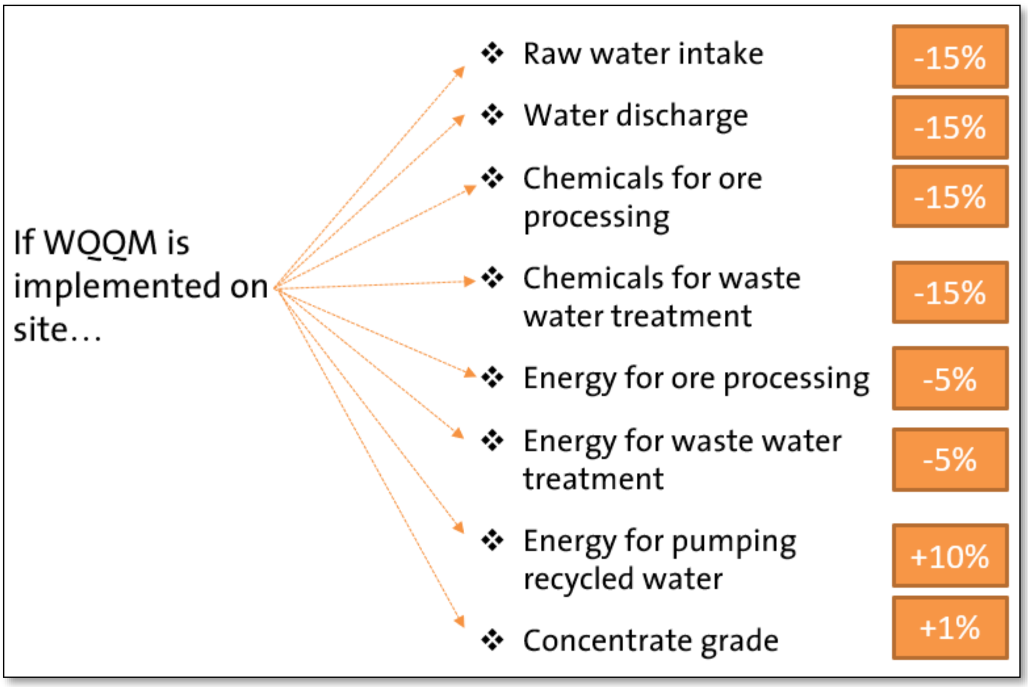

Figure 1: Maximum changes achievable if the WQQM is implemented on site

The assumptions in Figure 1 have been adapted to the copper model to maintain the water and mass balance, hence resulting as reported in Table 1. As a second step, a sensitivity analysis will be conducted to investigate how results change if some of the assumptions vary.

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Table 1: Assumed changes in the generic life cycle model if the WQQM is implemented on site

WQQM implementation may affect…	
PARAMETER	VARIATION
Raw water intake	-10%
Water discharge	-5%
Chemicals for processing	-15%
Chemicals for WWT	proportional to waste water
Energy for processing	-5%
Energy for WWT	proportional to waste water
Energy for pumping recycled water	+5%
Concentrate grade	+1%
Recycled water	+5%

3.1.2 *Sensitivity analysis*

Sensitivity analysis is performed to investigate how results vary if underlying assumptions (e.g. regarding data amounts and system boundaries) in the study change. Specifically, the following sensitivity analysis is performed:

- Case 1: variation in the changes of the amount of consumables, energy and plant performance expected with the WQQM implementation for the generic copper life cycle model (scenario without WQQM, scenario with WQQM, scenario -50% benefits with WQQM: chemicals for processing -7.5%, energy for processing -2.5%, concentrate grade +0.5%).

3.2 Materials and methods for the economic sustainability assessment of the SERENE solution

The economic sustainability assessment for the SERENE solution focused on the comparison of economic impacts with and without the implementation of the novel WQQM technologies. The generic copper life cycle model was used for the performance of Life Cycle Costing. Data for the foreground system were collected mainly from expert judgment from project partners, as reported in Table 2.

Table 2: Items and related costs in the life cycle model

Item	Unit	Value	Geographic coverage	Source
Blasting	EUR/kg	0.964	GLO	ecoinvent
Electricity	EUR/kWh	0.055	Nordic	expert judgment
Diesel	EUR/kg	1.33	Finland	CNR France
Steel (equipment abrasion)	EUR/kg	3.5	generic	expert judgment
Lime	EUR/kg	0.25	generic	expert judgment
Chemical-collector	EUR/kg	1.6	generic	expert judgment
Chemical-depressant	EUR/kg	2.6	generic	expert judgment
Chemical-flocculant	EUR/g	0.0025	generic	expert judgment
Copper	EUR/t	5223	generic	Geology for investors
Monitoring stations	EUR/item	3379	Finland	expert judgment

Maintenance costs are expected to be 7810 EUR/year.

Increase or decrease in costs for energy and chemical consumption and variations in water flows and plant performance achievable with the implementation of the WQQM solutions are calculated based on the same assumptions used for the environmental assessment.

Ecoinvent database is used as cost source for all the background data. The economic sustainability assessment, hence, provides two different information:

- Calculation of added value for the foreground model
- Calculation of added value for the whole life cycle model (foreground + background models).

Added value calculation is provided by the openLCA software as the output of LCC and it is the difference between all costs and revenues in the life cycle of the product under investigation.

Furthermore, the overall cost of the monitoring stations is the sum of the infrastructure cost (initial capital cost) and the maintenance cost during the life span of the stations (2 years). This overall cost is available both as undiscounted and as Net Present Value (NPV), considering the Discount Rate (DR). The DR is included as a parameter in the model so that it can be easily modified as applicable. The NPV for the monitoring stations is calculated using the following formula (considering a life span of 2 years):

$$NPV = - C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2}$$

where,

C_0 is the initial investment, the capital cost of 3 monitoring stations;

C_1 is the net cash flow in the first year, i.e. the maintenance cost in the first year;

C_2 is the net cash flow in the second year, i.e. the maintenance cost in the second year;

r is the discount rate.

4 RESULTS

4.1 Environmental sustainability results

The comparison of environmental impacts with and without the implementation of the WQQM technologies for the generic copper life cycle model shows that impacts with the water balance (WB) management solution are reduced for all impact categories and up to 6%. See Figure 2 and Figure 3 for more details.

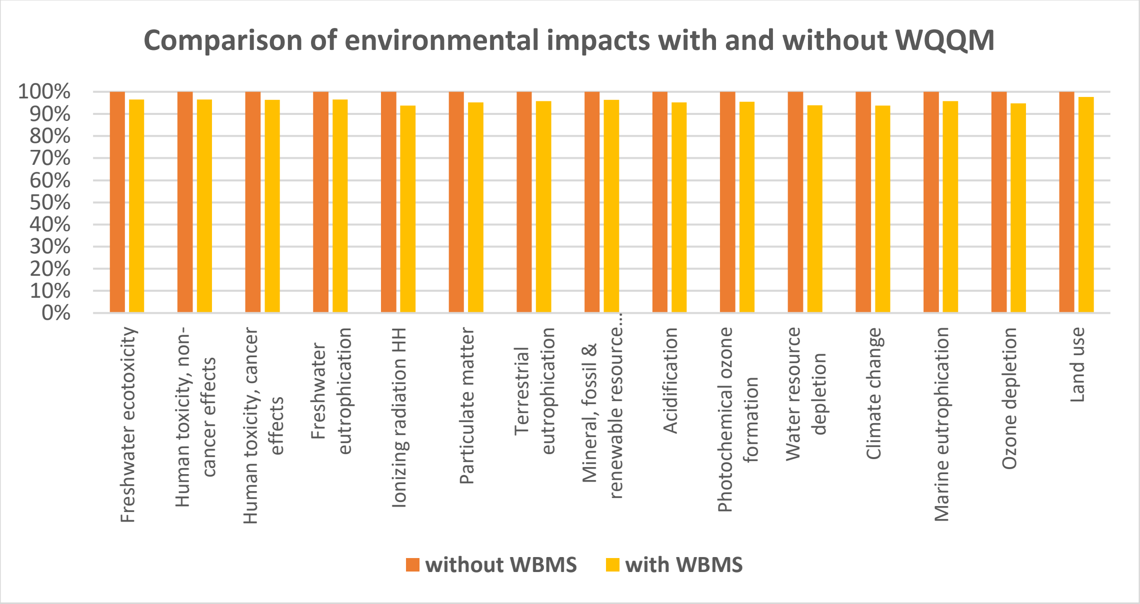

Figure 2: Comparison of environmental impacts with and without the water balance (WB) management technologies. Generic copper life cycle model, open pit mining

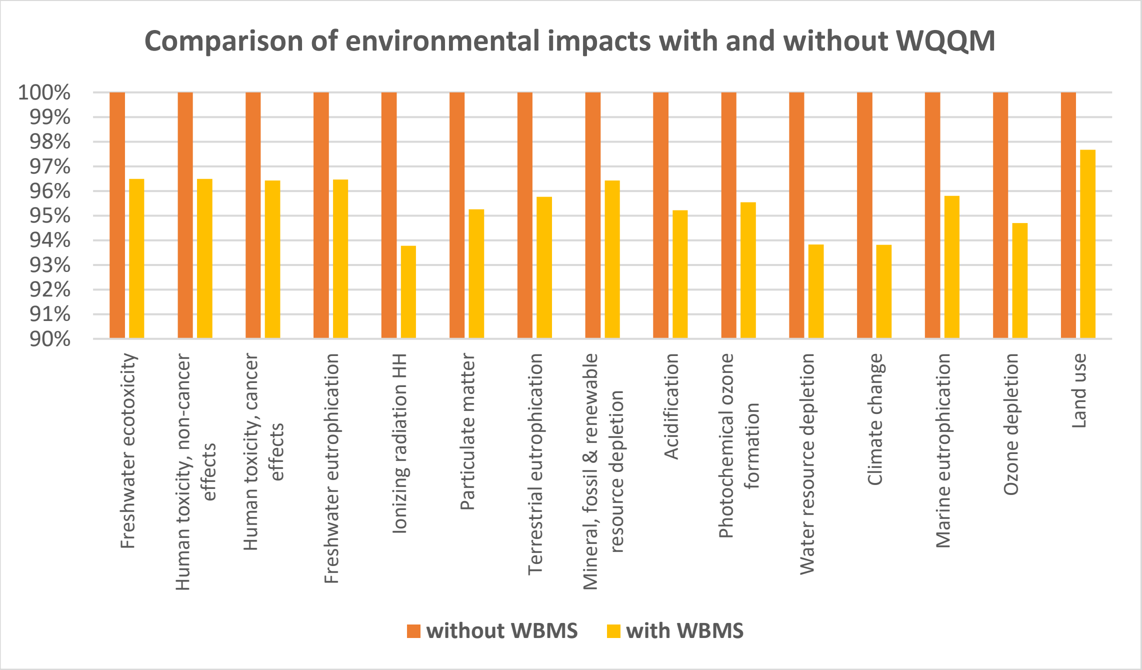

Figure 3: Comparison of environmental impacts with and without the water balance (WB) management technologies (zoom). Generic copper life cycle model, open pit mining. Calculations with ILCD 2011 Midpoint+

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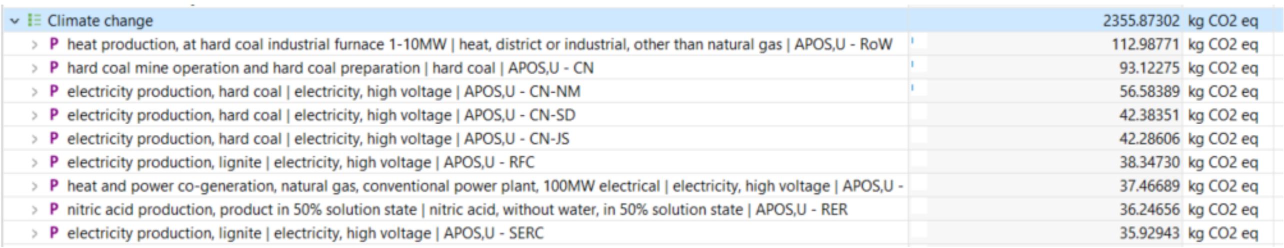
The impact categories which show the highest improvement are:

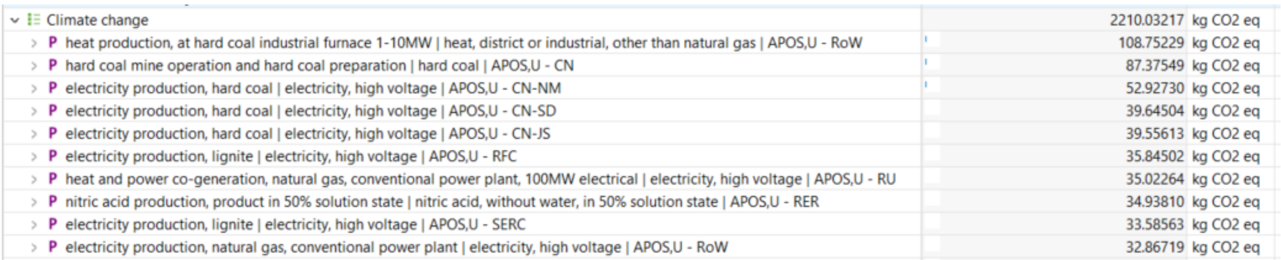
- Ionizing radiation HH (Human Health)
- Climate Change
- Water resource depletion.

In the case of Ionizing radiation HH and Climate Change, the improved performance is due to energy savings achievable with WQQM, for instance because of less electricity needed for waste water treatment and ore processing. Figure 4 and Figure 5 display the most contributing processes to "Climate change" without and with the implementation of the novel water balance management technologies.



Climate change	2355.87302	kg CO2 eq
P heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | APOS,U - RoW	112.98771	kg CO2 eq
P hard coal mine operation and hard coal preparation | hard coal | APOS,U - CN	93.12275	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | APOS,U - CN-NM	56.58389	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | APOS,U - CN-SD	42.38351	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | APOS,U - CN-JS	42.28606	kg CO2 eq
P electricity production, lignite | electricity, high voltage | APOS,U - RFC	38.34730	kg CO2 eq
P heat and power co-generation, natural gas, conventional power plant, 100MW electrical | electricity, high voltage | APOS,U -	37.46689	kg CO2 eq
P nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | APOS,U - RER	36.24656	kg CO2 eq
P electricity production, lignite | electricity, high voltage | APOS,U - SERC	35.92943	kg CO2 eq

Figure 4: Most contributing processes (direct impacts) to Climate change without the implementation of WQQM. Calculations with ILCD 2011 Midpoint+



Climate change	2210.03217	kg CO2 eq
P heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | APOS,U - RoW	108.75229	kg CO2 eq
P hard coal mine operation and hard coal preparation | hard coal | APOS,U - CN	87.37549	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | APOS,U - CN-NM	52.92730	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | APOS,U - CN-SD	39.64504	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | APOS,U - CN-JS	39.55613	kg CO2 eq
P electricity production, lignite | electricity, high voltage | APOS,U - RFC	35.84502	kg CO2 eq
P heat and power co-generation, natural gas, conventional power plant, 100MW electrical | electricity, high voltage | APOS,U - RU	35.02264	kg CO2 eq
P nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | APOS,U - RER	34.93810	kg CO2 eq
P electricity production, lignite | electricity, high voltage | APOS,U - SERC	33.58563	kg CO2 eq
P electricity production, natural gas, conventional power plant | electricity, high voltage | APOS,U - RoW	32.86719	kg CO2 eq

Figure 5: Most contributing processes (direct impacts) to Climate change with the implementation of WQQM. Calculations with ILCD 2011 Midpoint+

Concerning Water resource depletion, less raw water intake for ore processing due to an improved water balance management with WQQM is an important driver for the decrease of water related impacts. In addition, a reduced consumption of electricity is again one of the main drivers for a better performance in this impact category with the WQQM technologies. This is mainly related to a reduced use of water resources for cooling purposes during electricity generation. See Figure 6 and Figure 7 for the most contributing processes to the impact category Water resource depletion without and with WQQM. The ILCD method considers that a water emission to water is a positive impact (therefore with a negative sign), because a water resource is released back to the environment; this is why the process "waste water treatment" which discharges water as final output presents a higher (negative) value without WQQM: water discharge is reduced with WQQM, but, when applying the method, this results in a lower positive impact (negative sign) than without WQQM. However, it should be considered that less water discharged with the implementation of WQQM technologies implies less substances (e.g. sulfate, nickel) discharged to the environment, also if below the limits set by the environmental permit.

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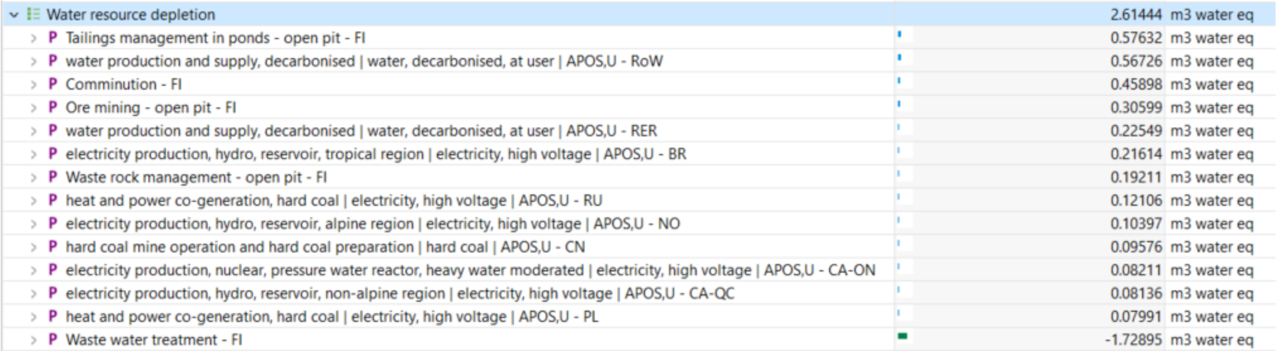
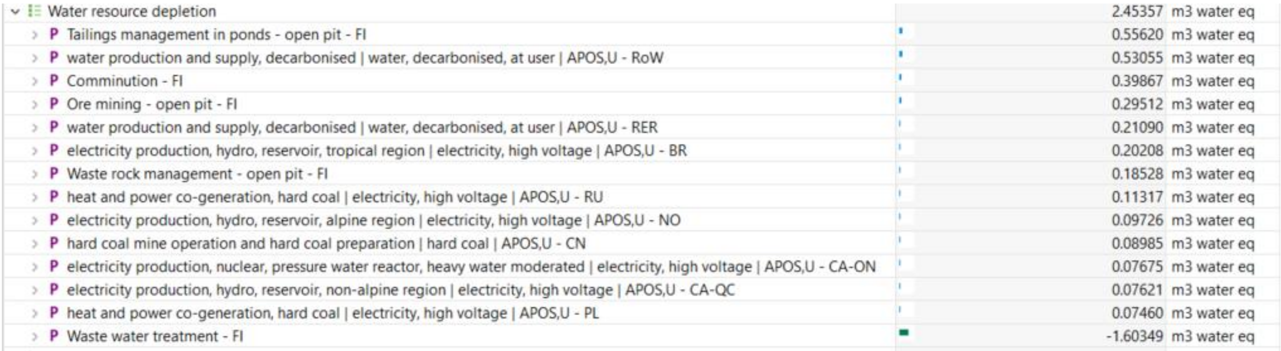


Water resource depletion	2.61444	m3 water eq
P Tailings management in ponds - open pit - FI	0.57632	m3 water eq
P water production and supply, decarbonised | water, decarbonised, at user | APOS,U - RoW	0.56726	m3 water eq
P Comminution - FI	0.45898	m3 water eq
P Ore mining - open pit - FI	0.30599	m3 water eq
P water production and supply, decarbonised | water, decarbonised, at user | APOS,U - RER	0.22549	m3 water eq
P electricity production, hydro, reservoir, tropical region | electricity, high voltage | APOS,U - BR	0.21614	m3 water eq
P Waste rock management - open pit - FI	0.19211	m3 water eq
P heat and power co-generation, hard coal | electricity, high voltage | APOS,U - RU	0.12106	m3 water eq
P electricity production, hydro, reservoir, alpine region | electricity, high voltage | APOS,U - NO	0.10397	m3 water eq
P hard coal mine operation and hard coal preparation | hard coal | APOS,U - CN	0.09576	m3 water eq
P electricity production, nuclear, pressure water reactor, heavy water moderated | electricity, high voltage | APOS,U - CA-ON	0.08211	m3 water eq
P electricity production, hydro, reservoir, non-alpine region | electricity, high voltage | APOS,U - CA-QC	0.08136	m3 water eq
P heat and power co-generation, hard coal | electricity, high voltage | APOS,U - PL	0.07991	m3 water eq
P Waste water treatment - FI	-1.72895	m3 water eq

Figure 6: Most contributing processes (direct impacts) to Water resource depletion without the implementation of WQQM. Calculations with ILCD 2011 Midpoint+



Water resource depletion	2.45357	m3 water eq
P Tailings management in ponds - open pit - FI	0.55620	m3 water eq
P water production and supply, decarbonised | water, decarbonised, at user | APOS,U - RoW	0.53055	m3 water eq
P Comminution - FI	0.39867	m3 water eq
P Ore mining - open pit - FI	0.29512	m3 water eq
P water production and supply, decarbonised | water, decarbonised, at user | APOS,U - RER	0.21090	m3 water eq
P electricity production, hydro, reservoir, tropical region | electricity, high voltage | APOS,U - BR	0.20208	m3 water eq
P Waste rock management - open pit - FI	0.18528	m3 water eq
P heat and power co-generation, hard coal | electricity, high voltage | APOS,U - RU	0.11317	m3 water eq
P electricity production, hydro, reservoir, alpine region | electricity, high voltage | APOS,U - NO	0.09726	m3 water eq
P hard coal mine operation and hard coal preparation | hard coal | APOS,U - CN	0.08985	m3 water eq
P electricity production, nuclear, pressure water reactor, heavy water moderated | electricity, high voltage | APOS,U - CA-ON	0.07675	m3 water eq
P electricity production, hydro, reservoir, non-alpine region | electricity, high voltage | APOS,U - CA-QC	0.07621	m3 water eq
P heat and power co-generation, hard coal | electricity, high voltage | APOS,U - PL	0.07460	m3 water eq
P Waste water treatment - FI	-1.60349	m3 water eq

Figure 7: Most contributing processes (direct impacts) to Water resource depletion with the implementation of WQQM. Calculations with ILCD 2011 Midpoint+

In order to better capture water related impacts, the leading method for water footprint "AWARE" (Boulay et al. 2018) is used in addition to the ILCD 2011 Midpoint+ method applied for the calculation of the results displayed above. The location for the processes part of the foreground model is assumed to be Finland. The calculation of the "Water use" impact category shows that impacts are reduced up to 6.8% with the inclusion of WQQM technologies into the life cycle model, see Figure 8.

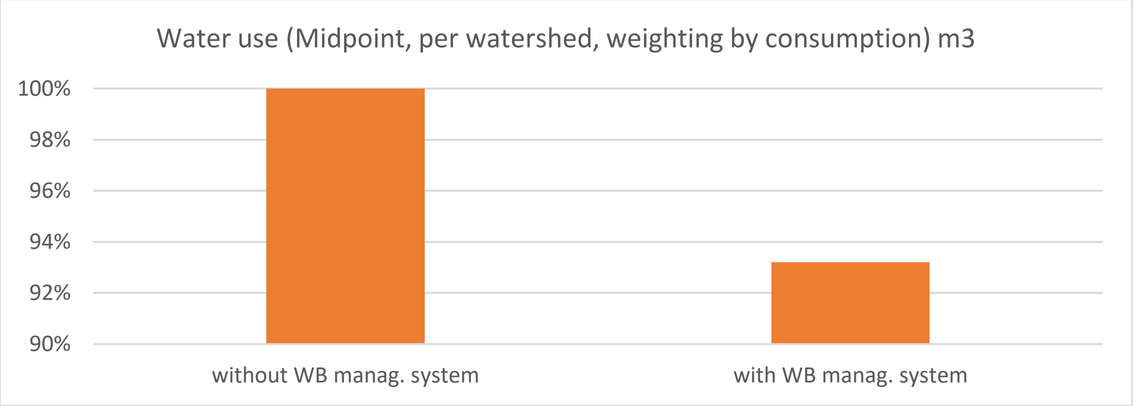


Figure 8: Comparison of environmental impacts with and without the water balance (WB) management technologies (zoom). Generic copper life cycle model, open pit mining. Calculations with AWARE

4.1.1 *Sensitivity analysis*

Sensitivity analyses are performed according to the hypotheses presented in Section 3.1.2.

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- Case 1: variation in the changes of the amount of consumables, energy and plant performance expected with the WQQM implementation for the generic copper life cycle model:
- scenario without WQQM,
- scenario with WQQM,
- sensitivity analysis-> scenario -50% benefits with WQQM: chemicals for processing -7.5%, energy for processing -2.5%, concentrate grade +0.5%).

The sensitivity analysis for the case 1 shows that results can be placed between the scenarios with and without the WQQM. If normalized results are considered, the toxicity categories (freshwater ecotoxicity and human toxicity, non-cancer and cancer effects) can be highlighted as the top 3 impact categories also with the sensitivity analysis, see Table 3.

Table 3: Sensitivity analysis – case 1. Calculations with ILCD 2011 Midpoint+. Normalized results, EC-JRC Global, equal weighting

Impact category	without WQQM	with WQQM	Sensitivity analysis
Freshwater ecotoxicity	723.24795	697.88487	711.78469
Human toxicity, non-cancer effects	699.18713	674.69037	688.11651
Human toxicity, cancer effects	340.09823	327.91995	334.57675
Mineral, fossil & ren resource depletion	14.35241	13.83985	14.11577
Freshwater eutrophication	10.49952	10.12795	10.33146
Ionizing radiation HH	1.37225	1.28679	1.33214
Particulate matter	0.9257	0.88184	0.90525
Terrestrial eutrophication	0.55622	0.53268	0.54528
Acidification	0.46382	0.44162	0.45346
Photochemical ozone formation	0.40588	0.38777	0.39744
Climate change	0.33322	0.31259	0.32352
Marine eutrophication	0.31468	0.30148	0.30857
Water resource depletion	0.03795	0.03561	0.0370
Ozone depletion	0.01737	0.01645	0.01694
Land use	0.00043	0.00042	0.00043

4.2 Economic sustainability results

The generic copper life cycle model was used for the calculation of LCC with and without the implementation of the novel WQQM technologies. If only the foreground system with mining-related processes is considered, it is possible to calculate the added value for each process without the supply chain. Results are reported in Table 4: the added value is the difference between revenues and costs; therefore, for each process, a negative value means a cost, a positive value means a revenue. It is considered that selling the final product "copper equivalent in final copper concentrate" generates a revenue, while all other process in the foreground system generate costs to produce the final product. Intermediate revenues are not considered (e.g. value of the ore after comminution).

The discount rate is set to 0% for the calculation of capital and maintenance cost of monitoring stations and sensors. Moreover, the cost of the WQQM platform is not included in the model, due to lack of data at this stage of the project. All results reported in this section are referred to the Functional Unit defined in the Goal and Scope of the study (see Section 2.2.2), i.e. 1 ton of Cu eq.

Table 4: Calculation of added value for processes in the foreground system, without the supply chain, with and without the WQQM

	without WQQM	*with WQQM*
Process	**Added value EUR**	**Added value EUR**
Comminution	-350.86	-335.53
Copper equivalent	5278	5278
Filtration	-10.17	-9.23
Flotation	-83.68	-70.97
Ore mining - open pit	-216.82	-209.12
Tailings management in ponds - open pit	-23.18	-24.03
Waste rock management - open pit	-11.35	-10.94
Waste water treatment	-0.76	-0.71

Most cost savings with the implementation of WQQM are achievable in the flotation and filtration and waste water treatment processes (see Figure 9), because of a reduced use of electricity and chemicals. Ore mining and waste rock management are not largely affected by the novel technologies, hence the cost savings are limited. Finally, tailings management sees an increase in costs, if it is assumed that more electricity is needed for pumping in the case of water recycled to a higher extent than without WQQM.

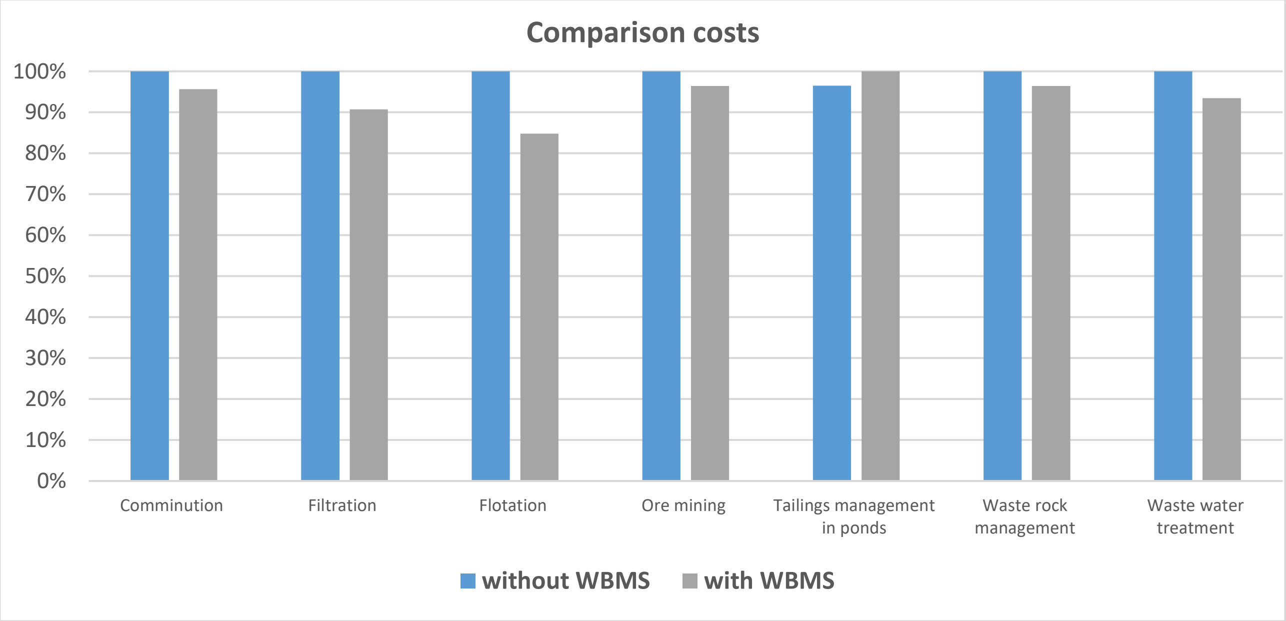

Figure 9: Comparison costs with and without water balance (WB) management technologies

The calculation of total added value in the life cycle is provided in Table 5: the added value with WQQM is higher than without the novel technologies. Indeed, this is affected by a decrease of total costs in the foreground system when WQQM technologies are implemented.

Table 5: Calculation of total added value in the life cycle and total costs in the foreground system, with and without the WQQM

	without WQQM	*with WQQM*
	Amount EUR	**Amount EUR**
Total added value	4971.82	4981.59
Total costs foreground system	-696.82	-660.53

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4.2.1 *Sensitivity analysis*

If case 1 sensitivity analysis (variation in the changes of the amount of consumables, energy and plant performance expected with the WQQM implementation, see Section 3.1.2) is performed, the LCC is also affected by the consideration of -50% benefits achievable with the WQQM, see Table 6. However, the most affected processes in the foreground system are flotation and waste water treatment which show the highest cost improvement, while tailings management sees a further increase in costs. The total added value calculation still remains higher than a situation on site without WQQM if -50% benefits with WQQM are considered.

Table 6: Calculation of added value with and without WQQM, and sensitivity analysis

	without WQQM	*with WQQM*	*Sensitivity analysis: -50% benefits with WQQM*
Process	**Added value EUR**	**Added value EUR**	**Added value EUR**
Comminution	-350.86	-335.53	-343.62
Copper equivalent	5278	5278	5278
Filtration	-10.17	-9.23	-9.71
Flotation	-83.68	-70.97	-77.36
Ore mining - open pit	-216.82	-209.12	-213.27
Tailings management in ponds - open pit	-23.18	-24.03	-24.5
Waste rock management - open pit	-11.35	-10.94	-11.16
Waste water treatment	-0.76	-0.71	-0.72
Total value added	4971.82	4981.59	4975.72
Total costs foreground system	-696.82	-660.53	-680.34

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5 DISCUSSION OF RESULTS

The study shows that the implementation of the WQQM technologies at a certain site in a water positive area can be overall beneficial from a sustainability point of view. Direct benefits derive from an improved water balance management in terms of both water quantity (reduced raw water intake and water discharge) and water quality (monitoring of substances load in tailings and dam water). Advantages concerning a better management of water loads directly affect the impact category “water use” and “water resource depletion”, depending on the impact assessment method considered. Benefits in terms of an improved water quality achievable with WQQM are not accounted for within the mentioned water related impact categories. However, human and freshwater toxicity are directly influenced by the release of substances from tailings and dam water to e.g. groundwater or surface water: hence, less water discharged will reduce the amount of toxic substances released to the environment and water quality monitoring in ponds will reduce the occurrence of toxicity risks. Indeed, the WQQM can contribute to a larger potential improvement in the field of environmental risk management. This means that the solution can reduce certain risks (especially exceeding permission limits and excess use of raw water), while a decrease of the everyday environmental impacts generated by conventional site operation might not be significant.

The sustainability of the WQQM can be assessed in a comprehensive way if the consequences of a predictive water balance management solution are studied not only in relation to direct impacts on water flows and waste water treatment, but also in relation to indirect effects on concentrate grade and consumables needed for ore processing and beneficiation (e.g. electricity and reagents). Impacts on climate change and ionizing radiation may be reduced thanks to a decrease in the pumping energy for freshwater intake and water discharges if these water flows are reduced, but also thanks to a more efficient ore processing which would require less electricity and chemicals; on the other hand, an increase in water recycling rates can require more pumping energy for water circulation within the plant/site. Further electricity and chemicals may be needed for higher amounts of process water to be treated before being circulated back to plant. Finally, the monitoring stations infrastructure will not lead to a visible increase of environmental impacts as the stations consume a very low amount of energy and the impacts of the manufacturing phase are distributed over a 2-year-life span.

From an economic point of view, cost benefits can be highlighted for flotation and filtration and waste water treatment processes due to a reduction of electricity and chemicals achievable with the WQQM, while a cost increase may occur in tailings and water pond management area if a higher amount of recycled water needs to be pumped back to the plant and treated before being used for processing. Therefore, when calculating costs and revenues for the implementation of the novel water balance management technologies, it may be important to define the additional costs coming from a higher volume of recycled water. These additional costs will depend on site-specific factors, e.g. the current recycling rate and process water quality requirement for ore processing. In an LCC perspective, the added value created by mining operations with the WQQM technologies is higher than without. However, if the additional added value created with the WQQM is evident if the foreground system (i.e. mining processes) is considered, the overall additional added value brought in with the WQQM is rather limited if also supply chains are taken into account. Given the boundaries of the study, it can be concluded that the novel WQQM technologies would not create higher costs than those that the mines need to face without the water balance management and, specifically, direct cost savings can be achieved on site for a number of mining processes.

Finally, as suggested by Outotec, it should be noted that if there are sophisticated measurements and control measures already in place at a certain site, there might be limited room for improvement with

WQQM. However, benefits in terms of risk management can still be important thanks to the predictive capability of the WQQM.

5.1 Strengths and limits of the study

A life cycle approach was crucial for the present study to be able to detect not only impacts related to mining operations, but also those occurring in the supply chain. This was, for instance, important in the case of the added value calculation for the economic assessment and for the environmental LCA.

Due to a lack of site-specific data, a generic copper life cycle model had to be created to provide a comprehensive answer to whether the SERENE project provided an improvement from a sustainability point of view. Despite the limitations of this generic model (see Section 2.2.9), a fully flexible and parametrized life cycle model is made available to the users and can be easily adapted to reflect mining operations in different contexts and for different ores.

Regarding the limitations of the study, it should be considered that if more water is recycled at a certain site with the WQQM technologies, novel water treatment technologies for process water might be needed on site. These additional water technologies are not included in the SERENE project nor in the sustainability results. The H2020 ITERAMS project[2] is working on this topic and is expected to provide interesting outcomes on the topic. Furthermore, some details related to the marketing of the WQQM solution had not yet been defined when the study was performed, e.g. the market price for the WQQM IT platform. Therefore, some variations in the economic results may be expected once that all variables have been set by Outotec.

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[2] http://www.iterams.eu/

6 openLCA SUSTAINABILITY MODEL

The openLCA sustainability model used for the calculation is provided in Nexus[3]. The model is referred to a generic copper mine operation (open pit) in a water positive area for the production of copper concentrate. The model is referred to 1 ton of Cu eq. in concentrate which means a production of 3.66 t of Cu concentrate with Cu grade of 27.3%. The model includes the following foreground processes:

- Ore mining
- Waste rock management
- Comminution
- Flotation
- Filtration
- Tailings management
- Waste water treatment

All data used for the model are reported in Annex I – Data used for the creation of the generic life cycle model and Annex II – Data used for the water balance of the generic life cycle model. The main sources used for the study are reported in the annexes (Norgate and Haque 2010; Jeswiet and Szekeres 2016; Chen et al. 2001; Daffern et al. 2017) The model uses ecoinvent 3.5 APOS (unregionalized) as background database, hence a valid ecoinvent license is required to access the copper model.

The whole model is parametrized. This enables the user to easily change input and output data and to perform sensitivity analysis. The main features of the model can be summarized as follows:

- Energy for ore mining and processing and water for ore processing is dependent on the ore grade (1.8% copper grade) which is entered as a global parameter and can be changed by the user.
- Cost data for the foreground model from sources in Section 3.2 and for the background data from ecoinvent.
- The monitoring stations and sensors part of the novel WQQM solution are included in the model.
- The location for the foreground system is set to Finland.
- Allocation was applied in the foreground system when more than one product output occurred in a process. It should be noted that as all processes (and their outputs) contribute to the final functional unit, the choice of the allocation factors is not relevant for the final results which remain the same with any allocation method.
- Three product systems are available in the model:
- A product system reflecting the current status on site without WQQM technologies, see Figure 10;
- A product system reflecting the status on site with WQQM technologies (see Figure 11), including parameters to address the changes in consumption of flows such as electricity, chemicals, raw water;
- A product system reflecting the status on site with WQQM technologies, but with -50% of expected benefits as considered in the previous product system. This product system is used to perform the sensitivity analysis.

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[3] https://nexus.openlca.org/

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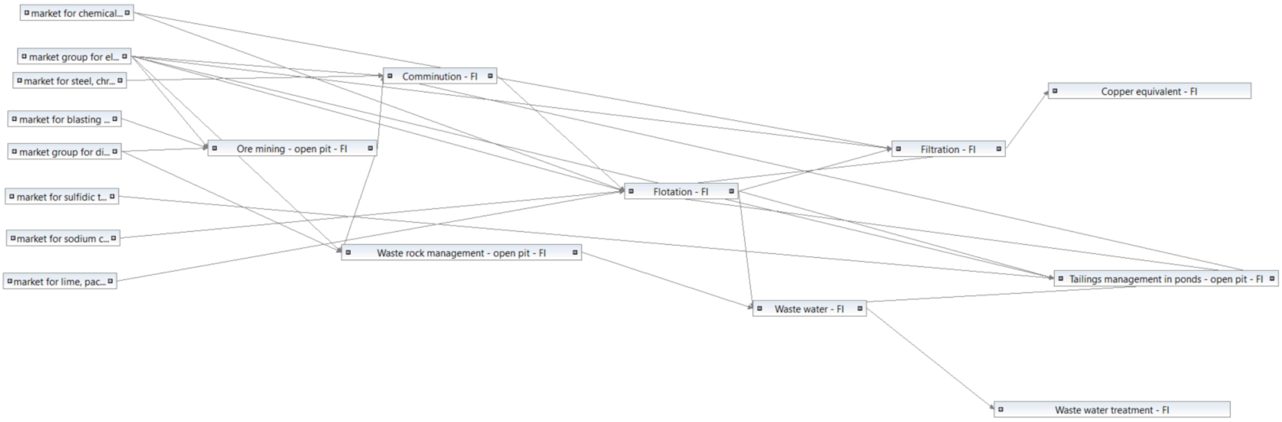

Figure 10: Model graph of the product system reflecting the current status on site without WQQM technologies

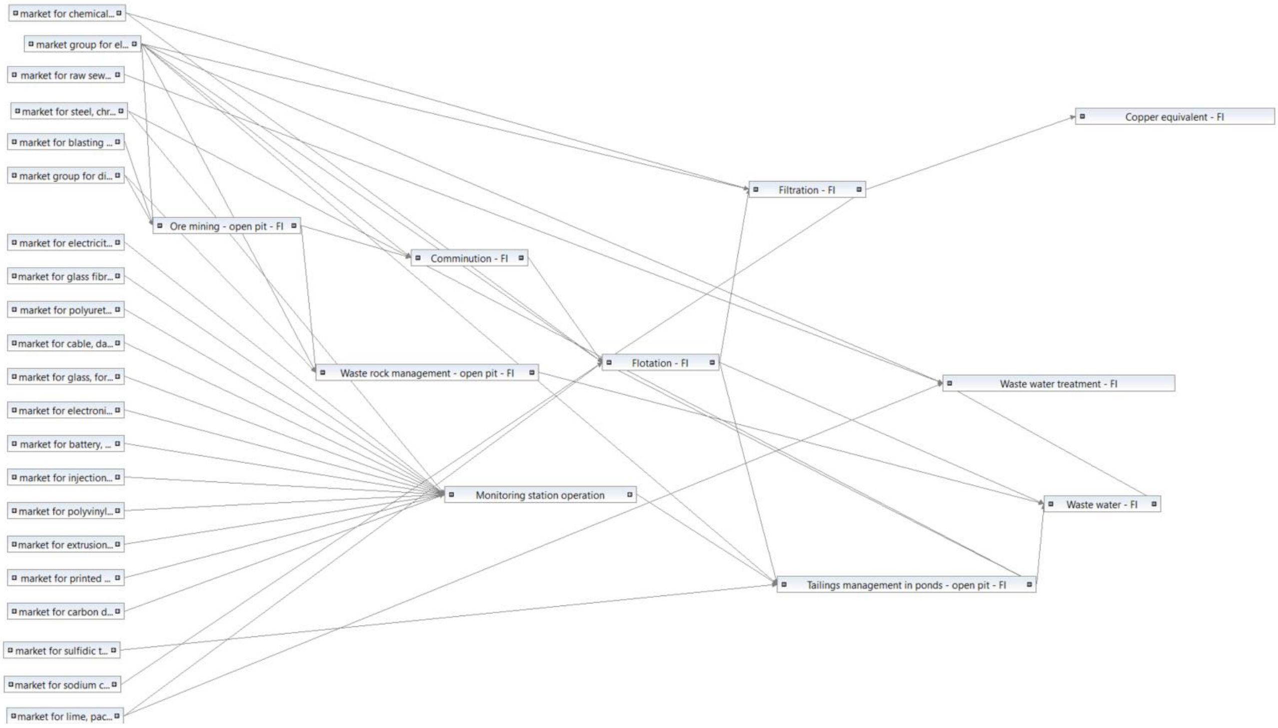

Figure 11: Model graph of the product system reflecting the current status on site with WQQM technologies

7 CONCLUSIONS

According to the study, the novel water balance management technologies show many advantages for the sustainability of mining operations. These benefits cover environmental, economic and social aspects, hence creating values for workers, local communities, mining companies and workers. The main disadvantage identified with the study in the event of WQQM implementation is a likely increase of electricity and chemicals consumption to treat higher loads of process water which is not supposed to be discharged anymore, but rather recycled back to the plant. This may also have an effect on the plant performance.

The main conclusions of the study can be summarized as following.

- From an environmental point of view, the WQQM is likely to reduce impacts on water resource depletion, by decreasing the amount of water withdrawn from nature. Impacts on human and freshwater ecotoxicity are also likely to be reduced if less water is discharged from the site to local freshwater sources. The WQQM may prevent water related risks occurrence, or at least reduce their probability. This risk reduction can be rather evident for excess raw water intake and exceeding permission limits for water quantity and quality. Climate change impacts of the operations can be decreased if less electricity is used for ore processing thanks to an improved water balance management. Overall plant performance may improve, affecting concentrate grade, depending on the site. As mentioned above, main tradeoffs can be highlighted if not only the overall water use for mining operations is reduced for WQQM, but also if more water is recycled and new waste water treatment technologies need to be introduced on site.
- From an economic point of view, most potential cost savings in mining processes can be identified for the waste water treatment and flotation and filtration processes if the WQQM is introduced. The new technologies are not expected to increase costs for the companies in a life cycle perspective. Risk prevention may generate more cost savings if the companies do not have to pay fines for not respecting the environmental permit; moreover, the fulfillment of environmental regulations can avoid that the operations are disrupted because the license gets cancelled. It should be considered that more water to be recycled and the introduction of further waste water treatment technologies for process water may create additional costs, which have not been included in the current study (except for electricity cost for pumping more recycled water to plants).
- From a social point of view, an improved water balance management can improve the relation and trust between mining companies and local communities, as a basis for establishing a SLO. It is, therefore, important that the companies use appropriate channels and ways to communicate sustainability information to the local communities- Finally, it should be noted that the trust relation between mining companies and communities is affected by many factors (e.g. perceived impacts, procedural fairness, distribution fairness of mining benefits). Hence, the companies should have in place a program to achieve, monitor and maintain a certain level of SLO, otherwise the social benefits achievable with the WQQM may not have a full reflection on mining acceptance from local communities.

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Annex I – Data used for the creation of the generic life cycle model

Ore mining - open pit								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Copper	INPUT	copper content in ore	%	1.8	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu	Cu ore grade - Underground mining - Australia
Electricity	INPUT	drilling	kWh/t ore mined	-				
Electricity	INPUT	groundwater pumping	kWh/t ore mined	3.8	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Assumed same as underground mining - Australia
Diesel	INPUT	loading and hauling	kg/ t ore mined	2.2	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	iron	Referred to open pit mining - Australia. Assumed as proxy for copper: open pit mining produces more waste rock than underground
Diesel	INPUT	drilling	kg/ t ore mined	0.03	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2011	iron	Open pit mining - Australia. Assumed as proxy for copper
Explosive	INPUT	blasting	kg/ t ore mined	0.5	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	iron	Open pit mining - Australia. Assumed as proxy for copper
Ore (rom)	OUTPUT	extracted ore	t/t concentrate	16.2	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Waste rock	OUTPUT	waste rock to dump	t/t ore mined	1.3	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	iron	Referred to open pit mining - Australia. Assumed as proxy for copper: open pit mining produces more waste rock than underground
Comminution								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Ore (rom)	INPUT	extracted ore	t/t concentrate	16.2	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Electricity	INPUT	crushing and grinding	kWh/t ore feed	18.5	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia. Represents 65% of electricity of total plant
Electricity	INPUT	Water pumping	kWh/m3 water intake	0.5	Assumption			Assumed the same as electricity for pumps for waste water pumping

Steel	INPUT	equipment abrasion	kg/t ore feed	1.4	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Grinding media. Underground mining - Australia
Dust air	OUTPUT	emissions (PM10, PM2.5)	kg/t ore feed	to be calculated	US EPA https://ndep.nv.gov/uploads/air-permitting-docs/ndep-mining-emissions-guidance.pdf	2017	metals	low moisture content
Ground ore	OUTPUT	crushed ore	t/t concentrate	16	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Flotation								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Ground ore	INPUT	crushed ore	t/t concentrate	16	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Electricity	INPUT	flotation circuit	kWh/t ore	7.12	Mining experts			25% of electricity of total plant
Reagents	INPUT	ph control - lime	kg/t ore	1.36	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Total reagents: 1.7 kg/ t ore. Assumed 80% lime, 12% xanthate, 8% sodium cyanide. Underground mining - Australia
Reagents	INPUT	collector - xantahte	kg/t ore	0.204	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Total reagents: 1.7 kg/ t ore. Assumed 80% lime, 12% xanthate, 8% sodium cyanide. Underground mining - Australia
Reagents	INPUT	depressant - sodium cyanide	kg/t ore	0.136	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Total reagents: 1.7 kg/ t ore. Assumed 80% lime, 12% xanthate, 8% sodium cyanide. Underground mining - Australia
Concentrate	OUTPUT	cu concentrate non-filtered	t	1	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Tailings	OUTPUT	tailings to pond or backfill	t/t concentrate	37	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Filtration								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Concentrate	INPUT	cu concentrate non-filtered	t	1	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Electricity	INPUT	filtration	kWh/t ore	2.85	Mining experts			10% of electricity of total plant

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Flocculant	INPUT	thickening	g/t ore feed to plant	6	zm-techreport 113017 Lundin mining	2017	Cu, Zn-Pb	Underground mine, ZINKGRUVAN MINE, SWEDEN
Thickened concentrate	OUTPUT	cu concentrate filtered	t	1	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	27.3% copper. Underground mining - Australia. 93.7% copper recovery
Waste rock management - open pit								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Waste rock	INPUT	waste rock to dump	t/t ore mined	1.3	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	iron	Referred to open pit mining - Australia. Assumed as proxy for copper: open pit mining produces more waste rock than underground
Electricity	INPUT	water pumping	kWh/t ore	0.014	Previous case studies		Cu	Assumed 0.2% of electricity used for tailings management
Diesel	INPUT	truck transport	l/km	0.33 loaded and 0.2 unloaded	Alibaba and quora	2019		8 t capacity dump truck
Tailings management in ponds - open pit								
Flow	Input or output	Description	Unit	Value (or range)	Source	Ref. Year	Ref. Ore	Remarks
Tailings	INPUT	tailings to pond	t/t concentrate	37	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010	Cu 1.8%	Underground mining - Australia
Electricity	INPUT	tailings pumping	kWh/t ore	4.98	Mining expert + “Energy Consumption in Mining Comminution” by Jack Jeswiet, Alex Szekeress	2016	gold and iron ore; copper.	70% of 20% of electricity for total plant + tails management
Electricity	INPUT	water pumping	kWh/t ore	2.13	Mining expert + “Energy Consumption in Mining Comminution” by Jack Jeswiet, Alex Szekeress	2017	gold and iron ore; copper.	30% of 20% of electricity for total plant + tails management
Emissions	OUTPUT	sulphur talings emissions	kg/t tailings	elementary flows	ecoinvent			treatment of high sulphur or low sulphur tails, off-site
Waste water treatment								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Electricity	INPUT	water pumping	kWh/m3 water treated	0.5	Scandinavian mine site	2018	clay mineral	

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Chemicals	INPUT	lime	kg/m3 water treated	0.175	Scandinavian mine site and previous studies	2018	copper, clay mineral	type of chemicals to be further investigating whenever possible
Waste sludge	OUTPUT	sludge to disposal	m3/m3 water treated	0.003	NEW APPROACHES TO MINIMIZE EXCESS SLUDGE IN ACTIVATED SLUDGE SYSTEMS. G H Chen, K J An, S. Saby, and H K Mo. The Hong Kong University of Science and Technology	2015		primary sludge (raw). 110-170 kg dry solids /1000 m3 of wastewater treated. Density of sludge=density of water: 1000 kg/m3

Annex II – Data used for the water balance of the generic life cycle model

Processing plant								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Raw water	INPUT	freshwater	m3/t ore	0.05	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010; 2018	Copper	Share obtained from case study at Scandinavian site
Recycled water	INPUT	water recycled back to plant	m3/t ore	0.43	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010; 2018	Copper	Share obtained from case study at Scandinavian site. (It includes thickener overflow = 0.02 m3/ t ore)
Pit dewatering	INPUT	water from pit dewatering	m3/t ore	0.03	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010; 2018	Copper	Share obtained from case study at Scandinavian site
Waste water	OUTPUT	water to be treated	m3/t ore	0.02	Scandinavian mine site	2018	copper, clay mineral	Share obtained from case study at Scandinavian site
Tailings and water pond management								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Rain	INPUT	rain water	m3/t ore	0.06	Scandinavian mine site	2018	copper, clay mineral	Share obtained from case study at Scandinavian site
Recycled water	OUTPUT	water recycled back to plant	m3/t ore	0.41	T. Norgate, N. Haque / Journal of Cleaner Production 18 (2010) 266–274	2010; 2018	Copper	Share obtained from case study at Scandinavian site. (It excludes thickener overflow = 0.02 m3/ t ore)

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Waste water	OUTPUT	water to be treated	m3/t ore	0.14	Scandinavian mine site	2018	copper, clay mineral	Share obtained from case study at Scandinavian site
Waste water treatment								
Flow	**Input or output**	**Description**	**Unit**	**Value (or range)**	**Source**	**Ref. Year**	**Ref. Ore**	**Remarks**
Waste water	INPUT	from tails	m3/t ore	0.14	Scandinavian mine site	2018	copper, clay mineral	Share obtained from case study at Scandinavian site (assumed 80% of waste water)
Waste water	INPUT	from plant	m3/t ore	0.02	Scandinavian mine site	2018	copper, clay mineral	Share obtained from case study at Scandinavian site (assumed 10% of waste water)
Waste water	INPUT	from WRD	m3/t ore	0.02	Scandinavian mine site	2018	copper, clay mineral	Share obtained from case study at Scandinavian site (assumed 10% of waste water)
Discharged water	OUTPUT	water discharged into freshwater	m3/t ore	0.18	Scandinavian mine site	2018	copper, clay mineral	Share obtained from case study at Scandinavian site

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