Life Cycle Assessment for sustainability evaluation of a coal mine wastewater desalination plant

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Summary

Coal mines are associated with negative environmental impacts, including the emission of greenhouse gases and the production of saline wastewaters that end up in surface water bodies and thus provoking salinization. [1]
High salinity level affects the aquatic life of a surface water body, threatens public health, and challenges the water management of a region. [2]
An innovative system has been designed to treat coal mine effluents before being discharged into surface waterways, facilitating the implementation of the Water Framework Directive.
The system aims to recover valuable salts and minerals with more than 90% purity. The prototype system will be installed in the Ziemowit coal mine, which is in the Silesian Voivodeship, in the town of Lędziny.

Aim

This work demonstrates an advanced desalination system to eliminate the water pollution of the area, by treating the coal mine effluent ending up in it, with the direct recovery of valuable salts and minerals. Moreover, results of a preliminary life cycle assessment study are presented, in order to evaluate the environmental effects of the technologies applied in the project.

Materials & Methods

The LIFE Brine-Mining project suggests the operation of an advanced desalination system, which will treat 0.8 m³/h of coal mine effluent, recovering end-products with high exploitation perspective (Figure 1).
Precipitation reactors will be used for the recovery of $Mg(OH)_2$, $CaCO_3$, $CaSO_4$, while NaCl and clean water will be recovered by electrodialysis, evaporation, and crystallization technologies.

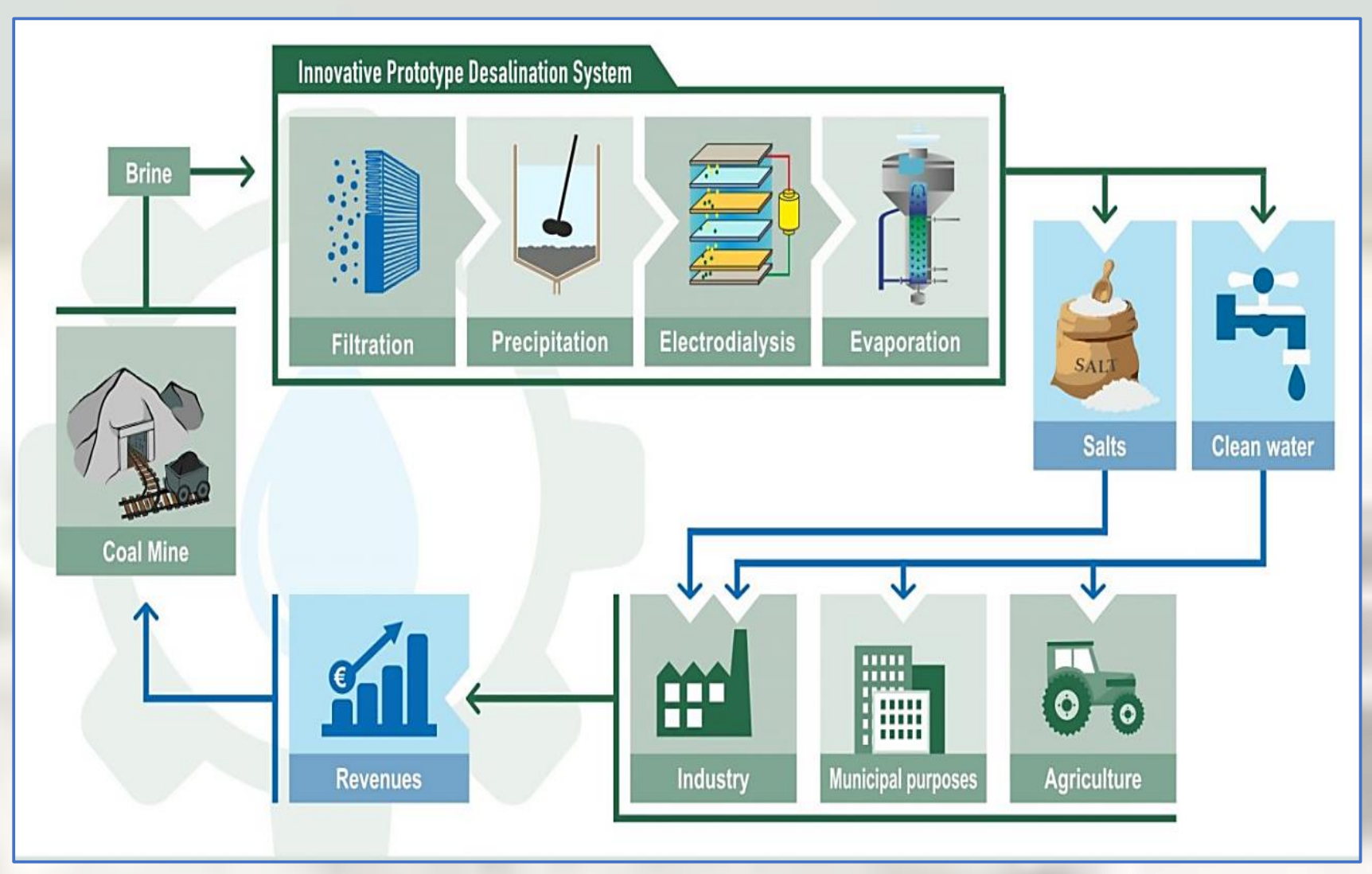

Figure 1: Advanced desalination system recovering valuable end-products, rising the coal mine revenues.

In order to evaluate the environmental effects of the applied technologies, a preliminary life cycle assessment analysis (LCA) was conducted. LCA is a framework for assessing the sustainability of a wastewater treatment plant design and contains four stages: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and interpretation of the results. The results of the analysis can be used to improve the configuration of the system, in order to ensure an optimal solution regarding the energy consumption (electricity consumption), the raw materials and the sustainability of the system.

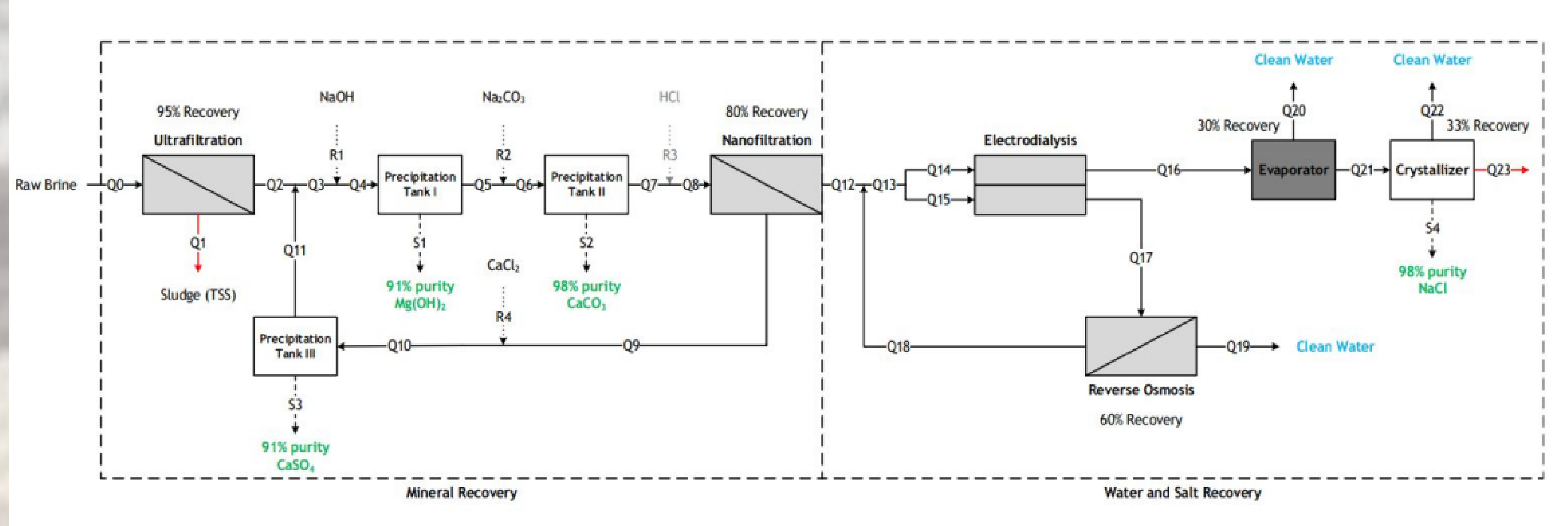

Figure 2: Process Flow Diagram – System Boundaries definition.

The functional unit of the study is "the treatment of 1 m^3 of coal mine wastewater". The system boundaries include all the stages, processes, inlet and outlet flows of the system. The imported wastewater stream, the energy consumption and the chemicals are considered inlet flows and the products and by-products derived by the processes are considered outputs. In the following table, the data requirements for the life cycle inventory are presented:

Table 1: Life Cycle Inventory data requirements.

SITE1	Inflow			Outflow		
Ultrafiltration	Raw brine	0,8	m³/h	UF permeate	0,76	m³/h
	Electric energy	4	kWh/h	UF retentate	0,04	m³/h
	Citric Acid (50%)	0,2	L/m²			
	NaOCl (13.8%)	0,2	L/m²			
	Membrane Surface Area	6	m²			
Precipitation tank 1	Feed water	0,95	m³/h	$Mg(OH)_2$ effluent	0,95	m³/h
	NaOH	5421	g/m³	$Mg(OH)_2$ stream	3,55	kg/h
	Electric energy	0,67	kWh/h	(purity 91%)		
Precipitation tank 2	Feed water	0,95	m³/h	$CaCO_3$ effluent	0,95	m³/h
	Na_2CO_3	17457	g/m³	$CaCO_3$ stream	5,27	kg/h
	Electric energy	0,67	kWh/h	(purity 98%)		
Nanofiltration	Feed water	0,95	m³/h	NF permeate	0,76	m³/h
	RO clean L403	0,065	L/m²	NF concentrate	0,19	m³/h
	RO clean L211	0,065	L/m²			
	Membrane Surface Area	39,5	m²			
	Electric energy	4	kWh/h			
Precipitation tank 3	Feed water	0,19	m³/h	$CaSO_4$ effluent	0,19	m³/h
	$CaCl_2$	46530,00	g/m³	$CaSO_4$ stream	2,69	kg/h
	Electric energy	0,67	kWh/h	(purity 91%)		
Electrodialysis	Feed water	1,08	m³/h	ED diluate	0,75	m³/h
	HNO_3 (53%)	0,15	L/m²	ED concentrate	0,31	m³/h
	NaOH (50%)	0,15	L/m²			
	Membrane Surface Area	120	m²			
	Electric energy	40	kWh/h			
Reverse Osmosis	Feed water	0,75	m³/h	RO permeate	0,45	m³/h
	RO clean L403	0,065	L/m²	RO concentrate	0,3	m³/h
	RO clean L211	0,065	L/m²			
	Membrane Surface Area	37	m²			
	Electric energy	9	kWh/h	condencate (clean water)	0,09	m³/h
Evaporator	Feed water	0,31	m³/h	concentrate (NaCl)	0,22	m³/h
	Electric energy	5	kWh/h			
Crystallizer	Feed water	0,22	m³/h	condencate (clean water)	0,18	m³/h
	Electric energy	12	kWh/h	concentrate (NaCl) (purity 98%)	39,18	kg/h

Results

As presented in Table 1, for the life cycle inventory, the data requirements include inlet flows, the energy consumption of each individual unit process and chemical reagents for operational and cleaning purposes.

- ☐ The life cycle assessment was conducted using the SimaPro software.
- ☐ Emissions (LCIs) are presented as environmental impacts.
- ☐ The data are classified and recorded in the defined impact categories.
- ☐ The calculations carried out by the software reflect the relative contribution of each technology to the environmental impact categories examined.
- ☐ Life cycle impacts have been assessed with the use of ILCD v1.11 method as recommended by EU 2013.

The following graph illustrates the contribution of each process for the impact categories examined.
The impact categories which are examined are the following: Climate change, Ozone depletion, Human toxicity, Particulate matter, Radiation, Photochemical ozone formation, Acidity, Eutrophication, Freshwater ecotoxicity, Land use, Water resource depletion, Mineral, fossil and renewable resources depletion.

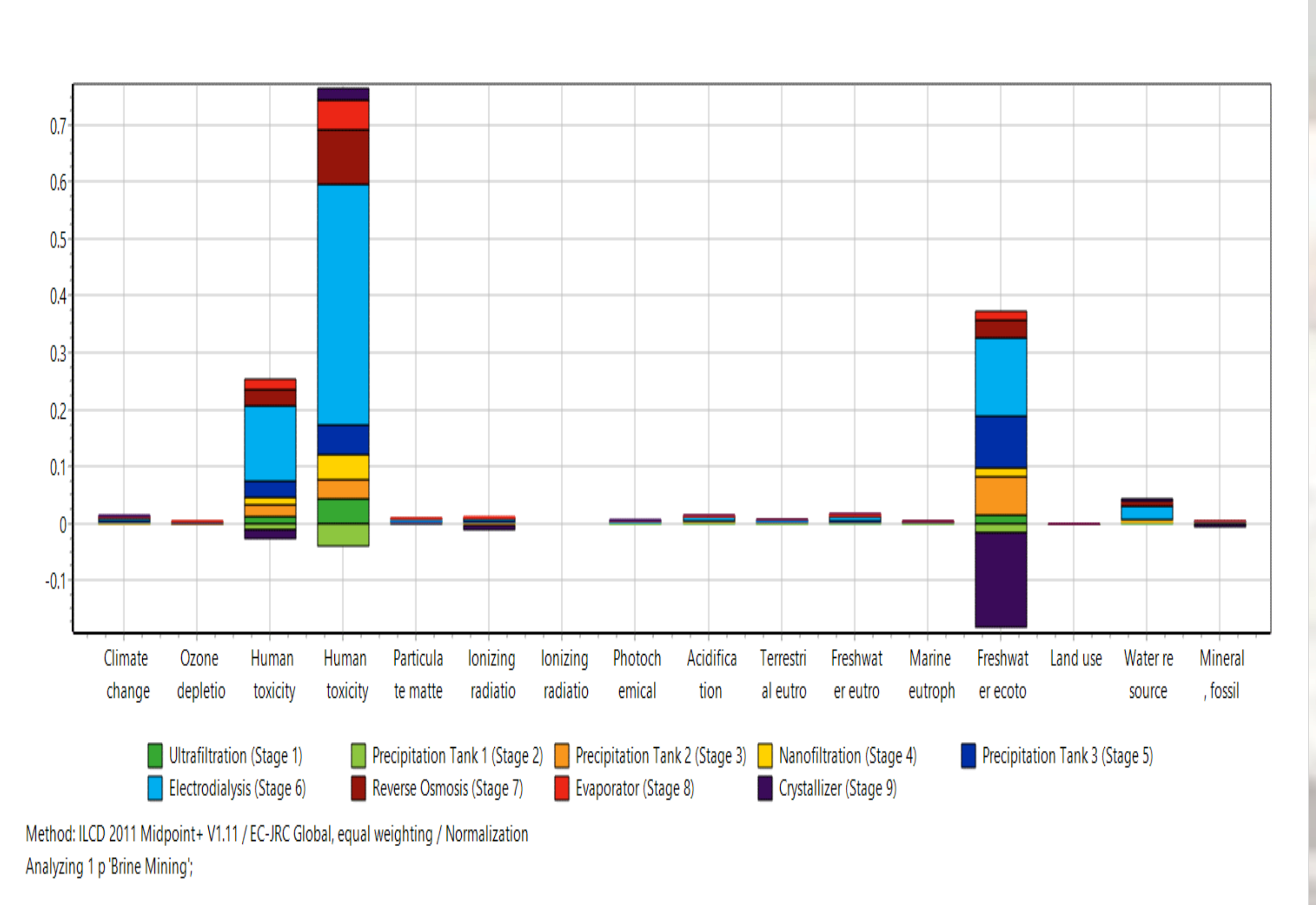

Figure 3: Assessment of the quantified contribution of the technologies in each impact category.

Conclusions

From the assessment of the quantified contribution of the technologies in each impact category, and from the obtained results of the study the following conclusions arise:

- ☐ The biggest impact of the system on the environment is observed in the categories related to toxicity (human toxicity and freshwater ecotoxicity). Toxicity relates to the effect of toxic substances on human health, soil and water.
- ☐ The highest percentage of participation in the impact categories is shown by electrodialysis technology. The relevant effect is attributed to the fact that this process displays significantly higher energy consumption compared to the other system technologies.
- ☐ The enviromental impact attributed to the processes carried out in precipitation tanks is mostly due to the consumption of chemical reagents.
- ☐ Crystallization technology, in overall presents negative participation rate in the impact categories. The specific technology does not affect the environment (at the point that zero participation rate is provided) or is even beneficial (negative participation rate) and provides the effect of mitigating the negative impacts caused by the rest processes (benefit).

Acknowledgments

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