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

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According to Euracoal data (2019) Poland is the largest coal producer. Although coal mines provide power efficiency and employment opportunities, they are also associated with negative environmental impacts, including the emission of greenhouse gases and the production of saline wastewaters that end up in surface water bodies (Euracoal, 2021). Coal mine wastewaters are saline effluents, with high content of chlorides and sulfates. Their direct drainage to surface water bodies results in salination of water streams and degradation of ecosystems and water life (Mitko & Turek, 2021). Life Brine-Mining project aims in demonstrating an advanced technique for the elimination of coal mine wastewater with direct recovery of resources included in it, such as salt and minerals. The prototype system will be installed in the Ziemowit coal mine, which is in the Silesian Voivodeship, in the town of Lędziny. A zero liquid discharge (ZLD) approach is adopted by the innovative brine treatment technology. The treatment plant is composed of membrane technologies, including ultrafiltration, nanofiltration, reverse osmosis and electrodialysis as well as precipitation, crystallization, and evaporation units and aims to recover water from coal mines but also products of commercial value contained in the discarded brine (Loizidou, et al., 2021).

To evaluate the environmental effects of the project, a preliminary life cycle assessment analysis was conducted. Life cycle assessment (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. (Curran, 2006)

The main purpose of conducting the preliminary life cycle analysis for the Brine - Mining project is to determine the environmental impact of the applied technologies. 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. The functional unit of the study is “the treatment of 1 m^3 of coal mine wastewater”. Specifically, this wastewater refers to the composition of the wastewater stream stem from the coal mine from a depth of 650 m. (Loizidou, et al., 2021). As presented in the following image, 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.

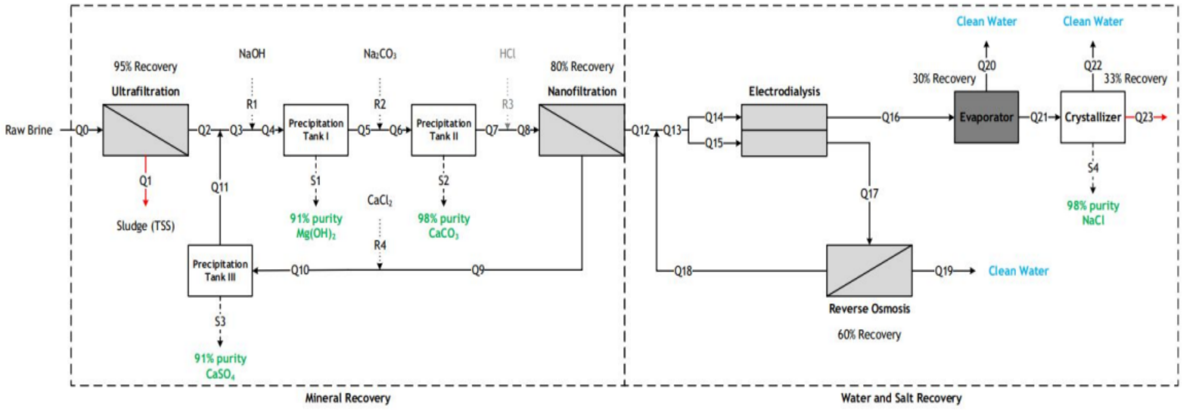

Figure 1: Process Flow Diagram – System Boundaries definition

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. To understand the environmental effects, emissions (LCIs) are presented as environmental impacts. Initially, the data are classified and recorded in the defined impact categories. Afterwards, the calculations carried out by the software reflect their relative contribution to the environmental impact, thus quantifying the effect every technology has on each impact category. 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 carried out in the system for the impact categories examined by the software. 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.

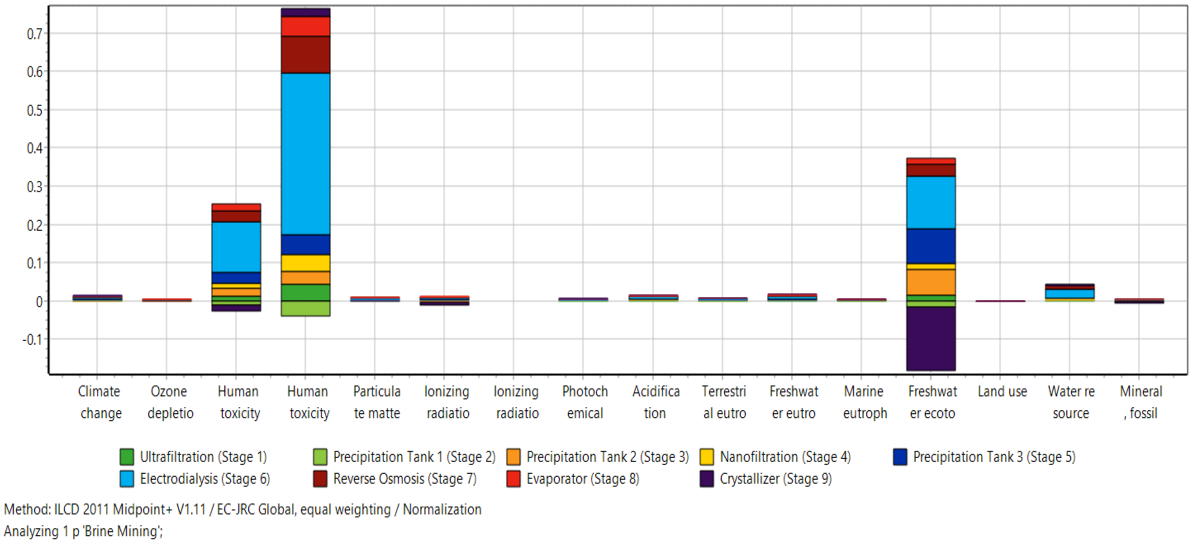

Figure 2: Assessment of the quantified contribution of the technologies in each impact category.

As presented in the graph, the biggest impact of the system on the environment occurs 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 considered during the life cycle assessment is shown by electrodialysis technology. The relevant effect is attributed to the fact this process displays significantly higher energy consumption compared to other technologies applied in the system. Electrodialysis depends on the electrically charged ions orientation towards the positively or negatively charged membranes. Therefore, the energy consumption for this technology is a direct function of the salt content of the treated wastewater. The environmental impact attributed to the processes carried out in precipitation tanks is mostly due to the consumption of chemical reagents. Crystallization technology, in overall, presents a 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). In conclusion, electrodialysis technology provides the highest environmental cost among the processes, due to the energy consumption, while crystallization provides environmental benefits for the system. The application of renewable energy sources provides the possibility for energy consumption reduction.

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