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ZERO BRINE

Unified Approach for prospective environmental and economic assessment

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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

2 **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

Contents

Nomenclature

CAPEX	Capital Expenditure
CrIEM	Crystallisation with ion exchange membranes
DWP	Demineralised water plant
ED	Electrodialysis
EFC	Eutectic Freeze Crystallisation
FF-MED	Forward-feed evaporator
IEX	Ion exchange
LCA	Life cycle assessment
LCC	Life cycle costing
MD	Membrane distillation
MED	Multi-effect Distillation
NF	Nanofiltration
OPEX	Operating Expenditure
RCE	Remote Component Environment
RO	Reverse Osmosis
TOC	Total organic carbon
UA	Unified Approach

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1. Introduction

The Zero Brine (ZB) project focuses on developing innovative recovery solutions to close the loop of saline impaired effluents (brines) generated by the process industry. It aims to eliminate wastewater discharge and minimise environmental impact of industrial operations through the integration of several existing and innovative technologies. These technologies are targeted to recover high quality end products with high purity to provide optimum market value.

ZB therefore aims to close the loop of these problematic effluents through the recovery of water and valuable components of the effluents that include minerals (e.g. sodium chloride, sodium sulphate), regenerated acids, caustics, and magnesium. ZB consists of four case study projects to develop and demonstrate the ZB approach under different industrial circumstances:

- Demineralised water effluent in The Netherlands.
- Coal mine effluent in Poland.
- Textile industry effluent in Turkey.
- Silica industry effluent in Spain.

This document describes the Unified Approach for the prospective life cycle assessment (LCA) and a life cycle costing (LCC), as part of a sustainability evaluation. The UA is to be used as guiding approach to harmonize the sustainability evaluations of the case studies.

The four case studies utilise different configurations of water treatment technologies to treat and recover the various constituents of the water. The ZB systems combine existing technologies such as reverse osmosis (RO) and nanofiltration (NF) with newly developed innovative technologies: eutectic freeze crystallisation, crystallisation with ion exchange membranes (CriEM) and a forward-feed multiple effect distillation (MED) evaporator. Each case study requires different configurations of these technologies and forms a case specific water treatment and recovery systems, herein referred to as the ZB system.

Work package 7 of the ZB project involves a comprehensive sustainability assessment of the ZB systems to verify the sustainability performance of the industrial applications. The assessment will combine LCA, LCC and a Social LCA (SLCA). The aim is to compare the performance of the ZB systems against the existing treatment processes. The initial LCA and LCC for the project has been published (see Harris et al. 2019) and the assessment and development and application of the unified approach is described in Harris et al. (2021).

Comparing the existing treatment process with the ZB technologies is however not a straightforward process since ZB technologies are emerging technologies. In order to compare technologies in different development phases, mature vs. emerging, specific evaluation methods are needed. One such method for this purpose is prospective LCA, which enables modelling of an emerging technology at a future phase (Arvidsson et al., 2018) so that it can be compared with mature technology. Within the ZB project, three different teams are performing the assessments for the four case studies (meaning the same team performs the assessment for the Polish and Turkish case studies). In order to increase the robustness of the assessment approach and ensure consistency across the case study assessments, it was agreed to develop a Unified Approach (UA).

The next section briefly outlines the different case studies, Section 3 describes the overall framework of UA and Section 4 outlines the UA for LCA, whilst Section 5 outlines the UA for the LCC.

2. Case studies overview

2.1 Water plant in the Netherlands

The case study is located at a Demineralized Water Plant (DWP) in Rotterdam, owned by EVIDES. Two separate ZB systems are designed to treat brine discharges (totalling 2.5 million m^3/year) from an ion-exchange (IEX) softening and a Reverse Osmosis (RO) process. The systems are shown in Figure 1A and 1B. The system treating the IEX effluent consists of a combination of NF, membrane crystallisation and evaporation. A large-scale demonstration is developed for the RO effluent (Figure 1B) consisting of IEX, RO, NF, evaporation, TOC removal and eutectic freeze crystallization. Part of the energy for the brine treatment is derived from waste heat. The aim is to eliminate brine effluent and recover high purity magnesium products, NaCl solution (for IEX regeneration) and sulphate salts.

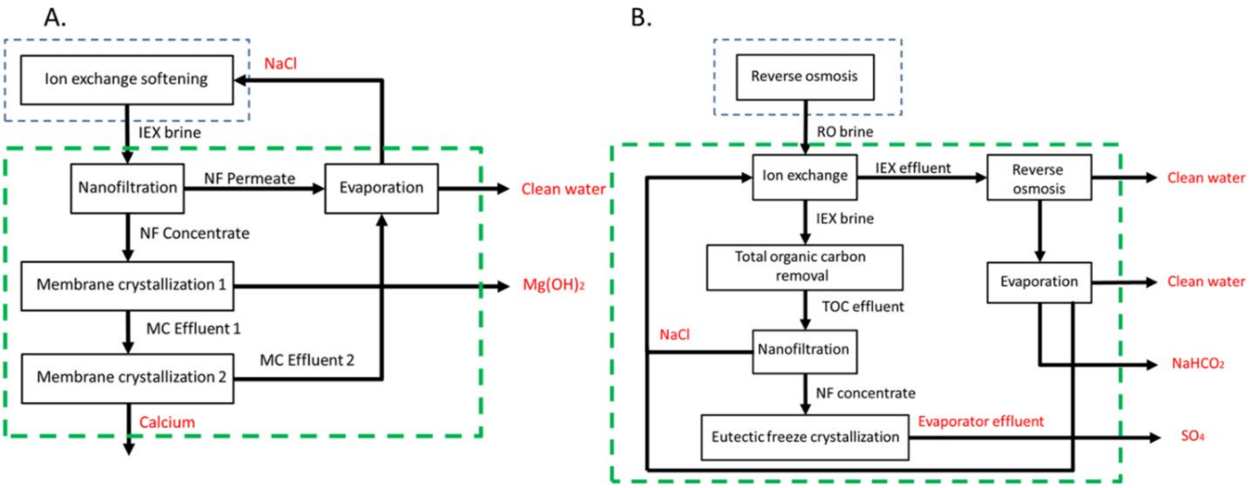

Figure 1. The two ZB system for the DWP. A: ZB system for the IEX brine. B: ZB system for the reverse osmosis brine. Source: Tsalidis et al. (2020).

2.2 Coal mine in Poland

The case study is located at the ZG Bolesław Śmiały Coal Mine operated by Polska Grupa Górnicza (PGG). The aim is to demonstrate the benefits of the ZB system to effectively treat the mine water salinity, whilst recovering magnesium hydroxide. The goal is to decrease the energy consumption by 50% compared to the energy consumption of a RO-vapour compression system, which represents current best practice. The proposed ZB system consists of two NF units, precipitation, crystallisation and electrodialysis (ED) as shown in Figure 2. Recovered by-products are salt, $Mg(OH)_2$, gypsum and clean water, which will be reused in the mining operation.

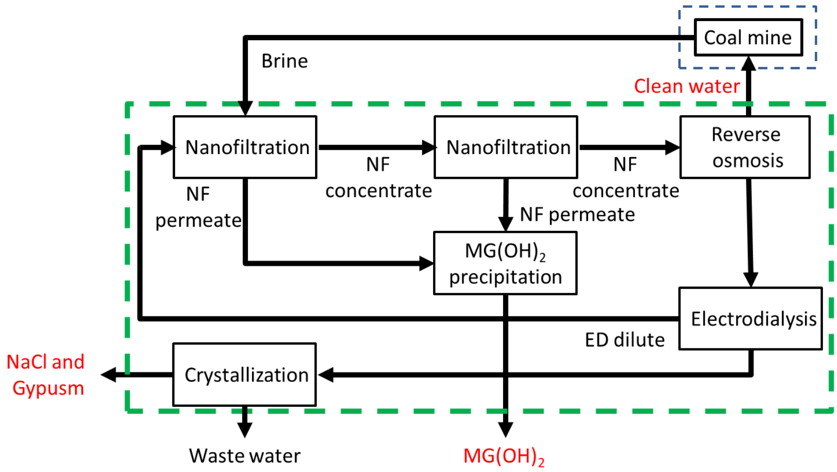

Figure 2. Technology configuration of the ZB system for the coal mine. Source: Tsalidis et al. (2020).

2.3 Textile industry in Turkey

This case study examines the potential of a ZB system to be located at the ZORLU Textile and Energy Groups at Büyükkarıştıran- Lüleburgaz, Kırklareli, Turkey. The site produces brine from the use of salt in the dyeing and water softening processes. The ZB system shown in Figure 3 is designed to treat the brine from the RO unit of the current wastewater treatment plant (WWTP) and consists of IEX, ozonation, and RO. Clean water and recovered concentrated brine will be reused in the textile plant.

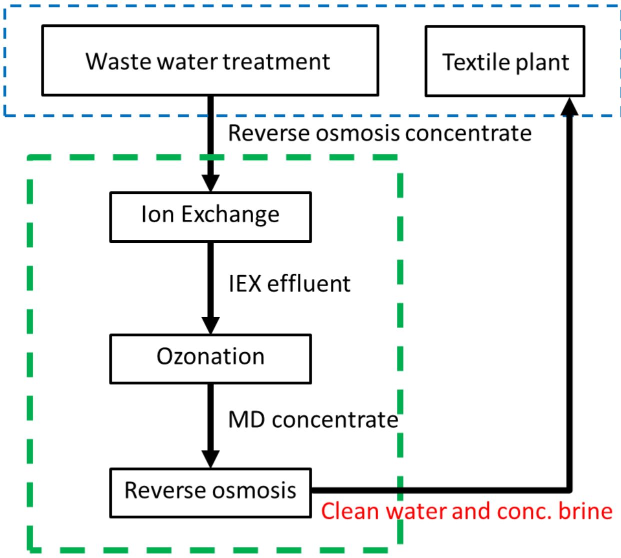

Figure 3. Technology configuration of the ZB system for textile plant brine. Source: Tsalidis et al. (2020).

2.4 Silica industry in Spain

The silica plant of Industrias Quimicas del Ebro (IQE) in Zaragoza, Spain, is the location of the fourth ZB case study. Currently the brine effluent is sent to the municipal WWTP. The ZB system will treat the effluent to recover water for reuse in the plant and sodium sulphate (Na_2SO_4) for sale. It consists of physico-chemical pretreatment (pH modification, chemical addition and sand filtering), NF and EFC, shown in Figure 4. A novel addition is the use of regenerated RO membranes from a desalination plant for use in the NF.

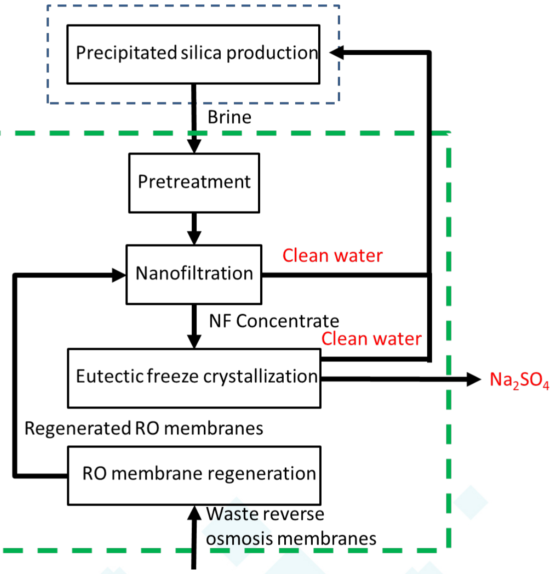

Figure 4. Technology configuration of the ZB system for the silica plant brine. Source: Tsalidis et al. (2020).

3. Framework of the prospective Unified Approach

3.1 Staged approach

The aim of the UA is to provide a framework to ensure consistency across the prospective LCA's and LCC's of the case studies. This will help to ensure that the analysis is done to the highest standard and that the results can be compared across the case studies.

A main objective is to utilise the LCA and LCC results in the design and development process of the ZB systems. There is significant value in gaining an early understanding of how different unit processes, configurations and materials, affect the environmental and economic performance. Therefore, the approach of the UA is prospective (i.e. used at an early stage of developing the ZB technologies) rather than being performed retrospectively. The LCA is performed in three stages to enable staged evaluation of the ZB development and provide input on optimisation, configuration of processes, energy considerations, as well as choice of chemicals and materials.

The UA stipulates that the LCA and LCC assessments are to be conducted over three stages as illustrated in Figure 5 and described below:

1. **Initial sustainability evaluation** – is based primarily on data from bench scale tests, literature, calculations and simulation. It consists of an LCA and LCC analysis that aims to model full-scale industrial scale operations. Certain parameters may need to be left out due to limited data availability as well as some inconsistency in how the LCA and LCC is conducted.
2. **Draft sustainability evaluation** – is based on improved data from pilot plant operations and test data, but complemented where necessary with bench scale data and some simulation. It consists of an LCA and LCC analysis that aims to represent full-scale industrial operation of the ZB systems. The outcome of the analysis should be compared to the outcome of 1 and communicated to the case study leaders to aid the design and optimisation.
3. **Final sustainability evaluation** – aims to be the most representative and robust LCA and LCC analysis of full-scale industrial implementation with improved data quality and less uncertainty. It should be based on pilot plant test data and optimization, modelled to full-scale and backed up with simulation data from the RCE software (RCE stands for Remote Component Environment and was developed by German Aerospace Center (DLR) as an open source software framework (Seider et al., 2012)). The outcome is to be used to validate the feasibility of the ZB system implementation as well as to prepare for commercialization and further development of the process.

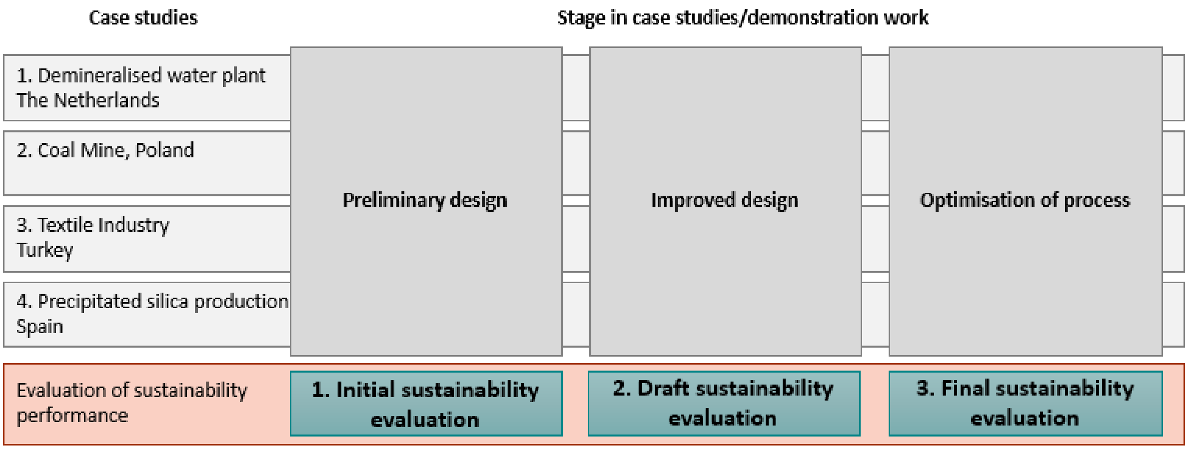

Figure 5. illustrates the three-stage sustainability assessment process and the link to the progress of the project and the case studies included.

3.2 Modelling of the full-scale – prospective approach

Critical to the successful and consistent LCA and LCC is the method used to utilise data from the bench scale and pilot scale as a basis of the assessment of the full-scale ZB plant. The approach aligns with recent advances on prospective LCA's of emerging technologies, which have challenges with comparability, data availability and quality, scaling, and uncertainty (Moni et al,. 2019; Thonemann et al. 2020).

The main challenge for ZB is the upscaling of data so that the model of analysis is representative of the full-scale plant. In order to do this the following hierarchy (Parvatker and Eckelman 2019) is suggested in order of preference:

1) Utilise the results from the RCE simulation software tool as full scale input parameters for the LCA's and LCC's (on material, energy and economic performance).
2) Technology developers provide modelled/adjusted data based on their computer models or expert knowledge.
3) Estimations based on data and literature review are made by the LCA team.

The upscaling methodology and the source of the data used should be documented. In addition, key data uncertainties should be noted so that they can be tested in the sensitivity analysis.

4. Unified Approach – Life Cycle Assessment

4.1 Introduction

The main aim of the LCA is to provide an assessment of the full-scale ZB system (using modelled or actual data) in comparison with the current (reference), treatment or disposal system. The purpose of this UA is to maintain consistency of the LCA approach particularly with regard to:

- Goal and scope including functional unit and definition of system boundaries.
- Use of terminology.
- Methods to address lack of data due to development stages of ZB technology and low Technology Readiness Level's (TRL) status of some technologies.
- Foreground and background data to avoid temporal mismatch in a prospective assessment.
- Assessment reporting and communication.

These are covered in the following sections.

4.2 Goal and scope

The goal of the LCA is to:

- Assess the environmental impact of the current (reference case) treatment system and/or effluent disposal to identify potential environmental hot spots.
- Assess the potential (prospective) environmental impact of the ZB system and generated effluent and identify potential environmental hot spots.
- Compare the environmental impact from the current system to the system including the ZB system.
- Identify areas for improvement and evaluate optimization proposals.

4.2.1 Type of LCA

The LCA should be based on attributional-partial consequential[3] LCA methodology which means that the environmental impact from treating 1 m^3 of brine is to be evaluated. This approach is preferred since the aim of the LCA is to map and compare the environmental impact and potential hot spots as a result of the current water treatment and the ZB treatment.

Currently resources are lost when brine is emitted to nearby water bodies, and there is a potential impact on the environment. This can be avoided by treating the brine with the ZB technology. As highlighted above, systems expansion should be used to assess the potential benefit of recovering and

[3] As allocation is avoided through systems expansion to account for the by-products and their reuse, and marginal data is used where possible.

reusing the by-product resources in the brine, with the assumption that the recovered resource replaces similar market products.

4.2.2 Functional unit

The functional unit used in the assessment should be 1 m^3 of brine entering wastewater treatment (wastewater before current or future ZB treatment). This unit describes the functions of both the current brine treatment and future ZB treatment (in the treatment of brine) and enables a comparison of the ZB technology to the current brine treatment and effluent on the specific locations. In addition, the content of the elements in the brine should be specified.

4.2.3 Reference and ZB system comparison

As discussed above the goal is to assess and compare two disposal/treatment and recovery systems:

1. The reference/current brine handling/treatment systems and discharge of effluent.
2. ZB system, recovery and discharge of effluent.

Figure 6 illustrates the current and future ZB system to be studied. ZB represents a potential future installation of brine treatment.

The reference system should ideally reflect the impact of the current situation. In the case of the textile and silica plant, the brine is currently treated in a wastewater treatment plant (WWTP). For these case studies the WWTP should represent the reference system. For the DWP and coal mine there is currently no treatment facility other than settling of solids (for the coal mine) and/or dilution before discharge to the local water body. Unfortunately, the substances that the brine consist of are not characterised in any known method to incorporate the deleterious impacts within LCA. Therefore, for these case studies, the comparison should be made with at least one of two scenarios, as shown in Table 1. The first should include the current situation with energy use, e.g. from pumping, and other resource requirements, and impacts where possible to include. This should at least include a supportive qualitative analysis where it is not possible to assess quantitative impacts (see section 4.3). Since the impacts of the reference scenario cannot be adequately accounted for in the coal mine and DWP and because future legislation may push for zero brine discharge, a second scenario should be included. This will compare the ZB system with the best available alternative technology to treat water and reduce discharge of chloride ions to regulatory requirements (and thereby recovering the salts).

Table 1: Status of current treatment and disposal system and required comparison scenarios.

Case study	Current situation	Reference scenario	2nd scenario
1. DWP	Dilution with fresh water before sea discharge	Current discharge with resource requirements and quantified local impacts.	Best available alternative technology
2. Coal mine	Solid settlement, dilution with industrial wastewater and discharge to local river	Current discharge with resource requirements and quantified local impacts	Next best available technology
3. Textile plant	Company owned WWTP	Current WWTP	N/A
4 Silica plant	Municipal WWTP	Current WWTP	N/A

The ZB system represents the full-scale future recovery and treatment system. In cases where the brine is pre-treated before being introduced to ZB installations both the pre-treatment and the ZB processes are part of the product system studied. If no pre-treatment occurs the product system reflects ZB processes only and impact from resulting effluent to water body.

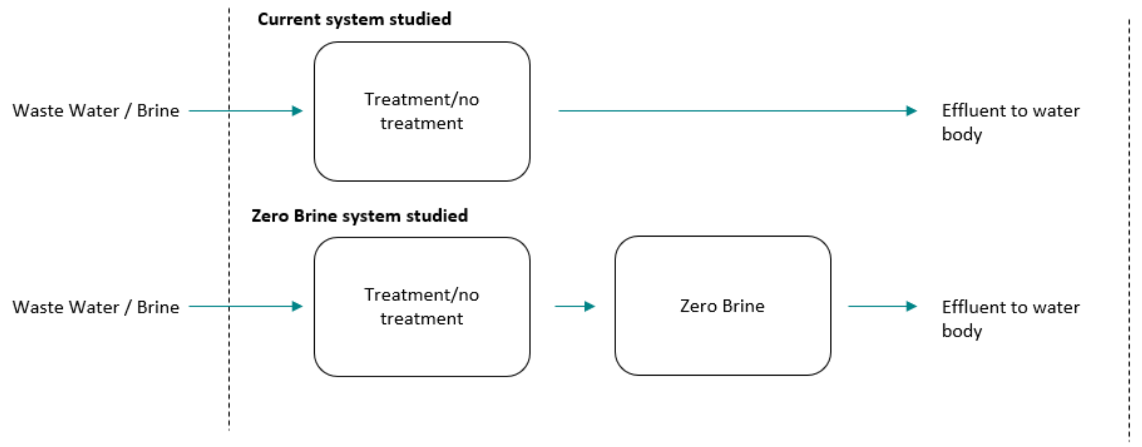

Figure 6. The two product systems studied (current system and future Zero Brine system)

4.2.4 System boundaries

The system boundaries of the analysis are gate-to-grave which means that the analysis starts with brine entering the system, that it is treated and then emitted to a near-by water body. This is referred to as the foreground system of the analysis and is the system that the project directly can influence through ZB and optimization activities. Processes that generate brine are not included in the assessment.

Raw materials, energy, and other axillaries used directly or indirectly in the foreground system are also included in the analysis and are referred to as the background system of the analysis. The system boundaries for the background system is cradle to grave. The background system cannot directly be affected by the project and the ZB technologies. But changes in the design of the foreground system will likely change the total impact of the background system. Figure 7 illustrates the difference between foreground and background system in the project.

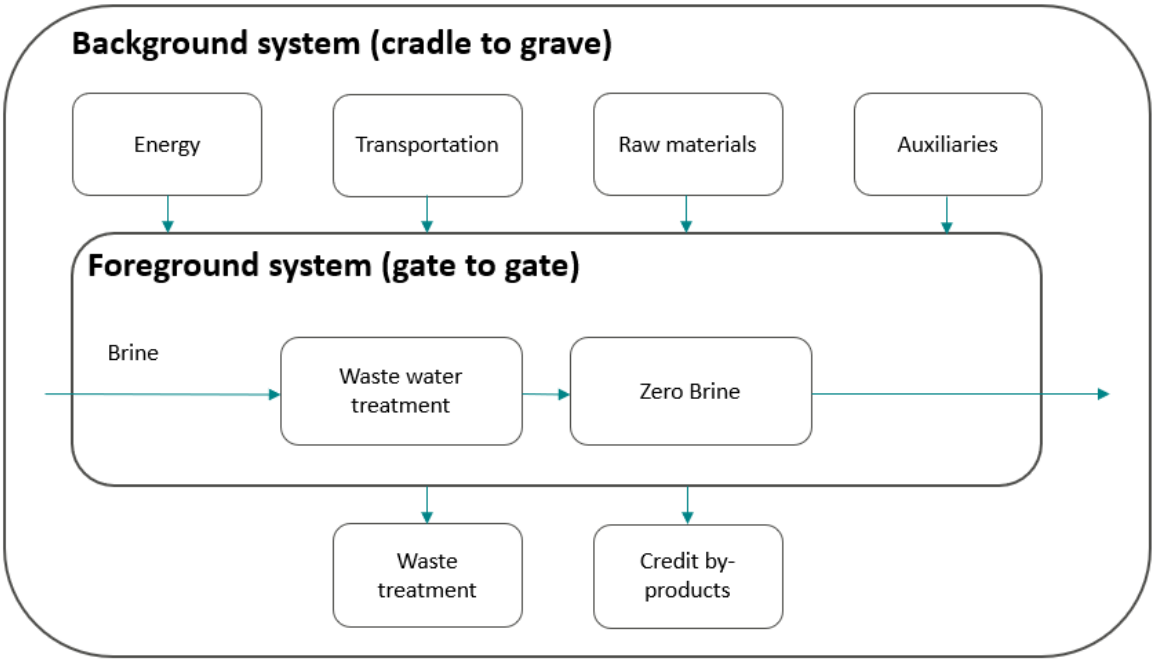

Figure 7. Illustration of the system boundaries of the study and the relation between background and foreground system.

4.2.4.1 Foreground system

The foreground data should be based on actual operational data for the four cases within the project. It should reflect the current water treatment installation and effluent and be based on one year of operations (preferably the most recent year).

For ZB, data should be selected based on availability as the project progresses and the stage of the analysis as discussed in Section 3.1. For the preliminary assessment the availability of data is predicted to be limited. But as the ZB technologies will be developed and simulated, data availability is expected to improve. At the final stage of the project, it is expected that data from the pilot plants are available and can be used as input to model the impact for a full-scale industrial implementation. The hierarchy presented in section 3.2 should be used to model the full-scale implementation of ZB the system.

4.2.4.2 Background system

The background data should preferably be based on data reflecting the actual circumstances of the case studies in the project and reflect local, regional or national conditions. If this is not possible to accomplish due to limited data availability European or global averages can be used. Table 2 specifies the criteria for selection of background data in the analysis and is used as guidance in the project.

Table 2. Criteria used to select data for the background system of the analysis.

Aspect	1st choice	2nd choice
Power	Site and supplier specific grid mix, impact assessed by average power generation process	National grid mix, impact assessed by average power generation process
Heat and Steam	Site specific, impact assessed by average heat/steam process	Natural Gas, impact assessed by average heat/steam process
Raw materials	European average*	Global average
Mode of transport	European average	Global average
Distance of transport	Case specific	500km
Waste treatment	Site specific waste management process, impact assessed by average process data	European waste management process, impact assessed by average process data

*specific data from suppliers could be used where readily available.

Data sets used to represent the foreground and the background system (for which there should not be any temporal mismatches between) that have a significant impact on the result should be documented and described. The data source should be disclosed including specific information and assumptions that may be important for interpreting the results.

4.2.5 Key Assumptions

The environmental benefit from recovering resources (by-products) from ZB should be calculated by applying substitution. This means for this study that the environmental benefit of recovering by-products and supplying those to the market will result in environmental benefits since those are assumed to replace similar raw materials in the market. The environmental benefit should be calculated by rewarding the by-product 1:1 with a viable market alternative (product with similar quality of the product it replaces). If the quality of the by-product is lower (e.g. contaminated) than products in the market the benefit should be adapted accordingly. This could be done through reducing the benefit by a proportional amount to the expected reduction in value due to the reduced quality. Therefore, the percentage reduction in value should be estimated and applied to the environmental credit associated with the by-product.

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4.3 Life cycle impact assessment

The overall life cycle impact assessment method that primarily should be used for the case studies is ILCD 2011[4] and the impact categories in Table 3. These impact categories are chosen to cover a broad, but not overly extensive, range of possible environmental impacts from the existing treatment and ZB systems. Early analysis has suggested that these are adequate to highlight any key differences in the systems.

Table 3. Selected impact categories according to ILCD 2011 midpoint EC-JRC (2012).

Impact categories ILCD 2011	Unit
Freshwater Eutrophication Potential	kg P eq.
Freshwater Ecotoxicity Potential	CTUe eq.
Global Warming Potential (GWP 100 years)	kg CO_2 eq.
Acidification	mole H^+ eq.
Abiotic resource depletion - mineral, fossils, and renewables	kg PSb eq.

In addition to the above the impact categories gross primary energy use (renewable and non-renewable) should be presented as well. This will further help to indicate whether the system uses a significant amount of non-renewable energy resources which is not part of abiotic resource depletion in Table 3.

4.3.1 Supportive comparison with reference system

As discussed in section 4.2.3, a main objective of the LCA is to assess the potential change in environmental impact as a result of reducing the emissions of brine to local water bodies through installing ZB technology. Unfortunately, there is currently no known characterization method to perform this within LCA. Therefore, the analysis of the scenarios should be accompanied with:

a) Quantity of chloride ions (kg) discharged to water per functional unit (for current system and ZB system).
b) Where justified (e.g. in the DWP and coal mine cases) a qualitative comparison of the reference and ZB system that discusses potential impacts that could not be quantified, such as potential loss of recreational amenity (e.g. where river flows drop, or fauna have been affected, or freshwater is used that could be better used for other purposes).

4.4 Sensitivity and uncertainty analysis

To validate the results and conclusions from the LCA, a sensitivity and uncertainty analysis should be performed following a similar approach to Clavreul et al., (2012). The first step involving a contribution

[4] https://eplca.jrc.ec.europa.eu/uploads/LCIA-characterization-factors-of-the-ILCD.pdf

analysis (showing impacts of process inputs and avoided burdens to total impacts) is performed as a standard part of the ZB analysis and is therefore not included in this section. Thus, the analysis should consist of the following tasks:

1) Perturbation analysis to assess parameter uncertainties calculating sensitivity ratios
2) Scenario analysis to assess model and scenario uncertainties

4.4.1 Perturbation analysis

The effect of a single parameter`s change on LCA results can be determined by perturbation analysis (Clavreul et al., 2012). Sensitivity Ratios (SR) are calculated for all parameters` +10% and -10% variations and higher value is kept for each parameter. The parameters that have high impact on the results are determined by this analysis. If a parameter`s SR is 2, it means that when its value is increased 10% the result increases 20% (Clavreul et al., 2012).

$$SR = \frac{\Delta result / initial\ result}{\Delta parameter / initial\ parameter} \quad (1)$$

4.4.2 Testing of scenario's

Scenarios to assess the role of energy production, and potential futures improvements should be explored. Hence the energy foreground and background systems should be alternatively set to renewable energy sources to explore the contribution to impact. In addition, a scenario should be created where the foreground system has reached a more plausible level for the year 2030, e.g. for energy profiles as modelled by a reliable source such as the International Energy Agency.

The importance of the environmental benefit of the recovered of by-product resources (by-products) should also be evaluated by adjusting the credits allocated to them, if this has not been adequately addressed in the contribution and perturbation analysis.

5. Unified Approach – Life Cycle Costing

5.1 Introduction

The main aim of the LCC is to provide an assessment of the full-scale ZB system (using modelled or actual data) compared to the current (reference) system, ZB treatment, or disposal. The purpose of this UA is to maintain consistency of the LCC approach particularly with regard to:

- Goal and scope including functional unit and definition of system boundaries.
- Use of terminology, (e.g. fixed and variable costs).

- Consistency with the assumptions in the LCA.
- Assessment reporting and communication.

These are covered in the following sections and the method described in the UA is based on the ISO-standard for LCC (ISO 15686-5:2017(E)).

5.2 Goal

The goal of the LCC analysis is to:

1. Assess the life cycle cost of current (reference case) wastewater treatment and generated effluent and identify potential financial hot spots.
2. Assess the potential (prospective) life cycle cost of the ZB system and generated effluent and identify potential financial hot spots.
3. Compare the life cycle cost of the current installation to the system including ZB.

5.3 Scope and definition of costs

The LCC should be based on the same functional unit and the system boundaries of the LCA. This will create alignment between the two assessments throughout the project. Consequently, the data used in the LCA should also be used as basis in the LCC which of course needs to be complemented by financial data for the items included. All cost data should be expressed in Euros and when needed currency conversion should be disclosed.

For the LCC both fixed and variable cost of the product system are considered. The cost items included are listed in Table 4 and further described below. For the fixed and operational cost calculations of the current installation full year data is preferred and should be based on operations of the studied product system in the most recent, representative year. It is important that the year is representative, in that it represents an average year that is not grossly affected by freak events such as natural or market disasters (e.g. caused by pandemics).

5.3.1 Fixed cost

The fixed costs are all costs which are independent of whether the process is operated or not and includes investment costs, maintenance cost, cost of staff and other costs such as permit costs, other contracted costs and R&D costs[5].

Investment of equipment should be distributed over 20 years assuming the equipment is depreciated linearly over the period. It is assumed that used equipment do not have an economical value after

[5] Should represent R&D costs once Zero Brine is commercialized.

retirement and consequently does not generate an income at its end-of-life. Cost for decommissioning the equipment is set to zero in the assessment.

Table 4. Cost items for fixed and variable costs included in the LCC

	Aspects to include in the LCC
Fixed cost	
	Investment and interest
	Maintenance
	Cost of staff
	Other: cost of permits, contracted costs and overhead e.g. R&D
Variable cost	
	Energy
	Raw materials
	Auxiliaries
	Waste management
	Transportation
	Revenue from by-products (income)

Cost of interest is included in the financial evaluation for activities where money is assumed to be lent, e.g. initial investment and periodical investments/maintenance. The cost is calculated based on applying an interest rate which is selected based on current country practice.

Maintenance costs should cover continuous maintenance as well as periodic maintenance and investments such as replacement of membranes. The interval for periodical maintenance and investments is specified by the project partners who are designing the equipment for ZB. Periodical investments are assumed to be depreciated linearly and follow the time interval for periodical investment need. For example, if membranes are replaced every fifth year the related cost is depreciated over the lifetime of the membranes which in this example is five years.

Cost of staff covers the number of full time employees (FTE) required to operate the plant and the cost should reflect site and country specific conditions.

5.3.2 Variable cost

The variable costs are all costs that directly depend on whether the process is operated or not. This means that once the plant is not operated, or operated at limited capacity, the variable cost decreases. In this category costs for raw materials, energy and auxiliaries are included as well as waste management costs and transportations.

One could argue that parts of the maintenance costs are dependent on operating activities of the processes, but for simplicity all maintenance costs should be allocated to the fixed cost category.

Expected revenues from recovered products is included in the cost analysis and reflects primarily the market value of similar product in the market.

The specific costs data used in the assessment should primarily reflect prices in the local or regional market and if not feasible reflect market averages. Since the project aims to evaluate ZB at an industrial scale (full scale implementation) the specific cost used in the assessment should reflect prices of large purchasing volumes by industry. Consequently, the evaluation and especially the variable costs will not be overrated by using the price of small volume purchases such as the volumes needed for operating the pilot plants.

5.3.3 External cost

An additional aspect that is added to the LCC is the inclusion of external costs, also referred to as externalities and damage costs. These are typically indirect costs for the society that environmental degradation and emissions may cause. For the assessment of external costs, the Environmental Priority System (EPS) (Steen, 2015) should be used and the result should be presented next to the fixed and variable costs. The impact is expressed in Environmental Load Units (ELUs) or Euros and illustrates the magnitude of the total environmental damage costs for all future generations. In other words, it reflects how much money we should pay future generations because we consume their capital. The environmental damage cost can therefore not be added to the direct costs but be presented as its own category next to the total life cycle cost of fixed and operational cost. EPS version 2015dx[6] should be used and is available in e.g. the GaBi software.

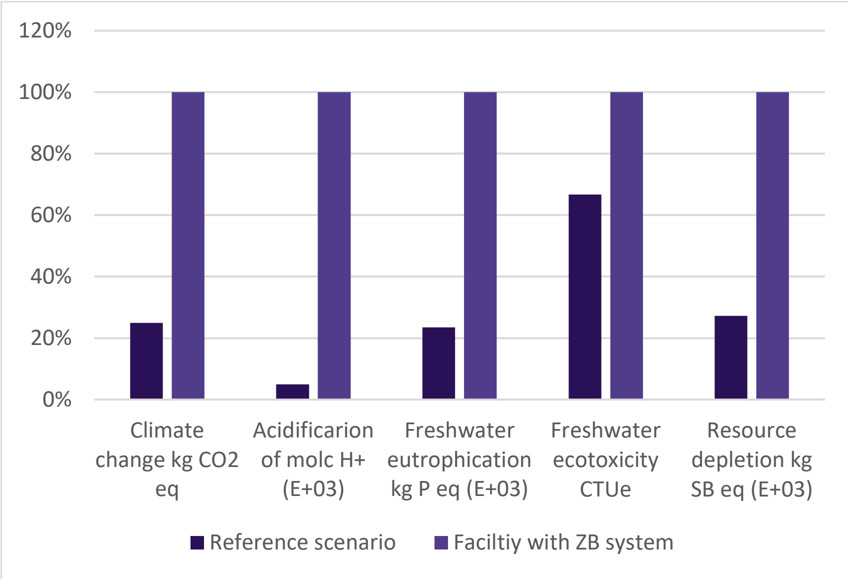
5.4 Sensitivity and uncertainty analysis

To validate the results and conclusions from the LCA, a sensitivity and uncertainty analysis should be performed following the same approach as for the LCA as presented in section 4.4.

6. Assessment reporting and communication

Communication is considered part of the UA to ensure consistency and comparability. The LCA results should consist of two figures (unless additional are required to show differences between configurations) and the also LCC two figures (unless additional detail is required). The first figure of the LCA should present the percentage comparison of impacts for 1 m^3 of brine for selected representative impact categories, with absolute values in a table, as shown in Figure 8

6 https://www.ivl.se/english/ivl/our-offer/our-focus-areas/consumption-and-production/environmental-priority-strategies-eps.html



Impact category	Ref scenario	With ZB system
Climate change kg CO2 eq.	5	20
Acidification of molc H+ (E+03)	3	60
Freshwater eutrophication kg P eq. (E+03)	0.8	3.4
Freshwater ecotoxicity CTUe	4	6
Resource depletion kg SB eq (E+03)	3	11

Figure 8. Percentage comparison (and quantities in table) of impacts for 1 m3 of brine for selected representative impact categories, with absolute values in table.

In the main presentation of the results, a second figure should present the contribution analysis of climate change of the ZB system compared to the reference system (Figure 9). However, contribution analysis should be performed for all five impact categories, but placed in the appendix unless there are significant deviances from the results (e.g. different hotspots) of the GHG that should be highlighted and discussed in the analysis. The contribution analysis should be categorised to illustrate the impact contribution from the key inputs (e.g. production of chemicals) and processes in the life cycle – and where in the life cycle the impacts occur.

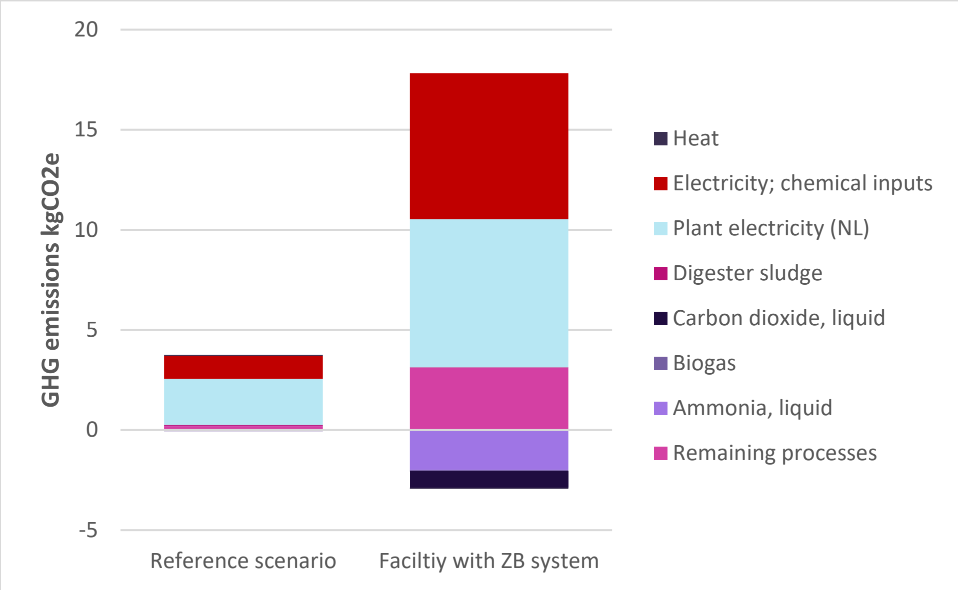


Figure 9. Example contribution analysis of climate change of ZB system compared to reference system (modelled with made up numbers).

The LCC results should be presented in terms of contribution analysis, as shown in Figure 10. An additional figure should then include the external costs.

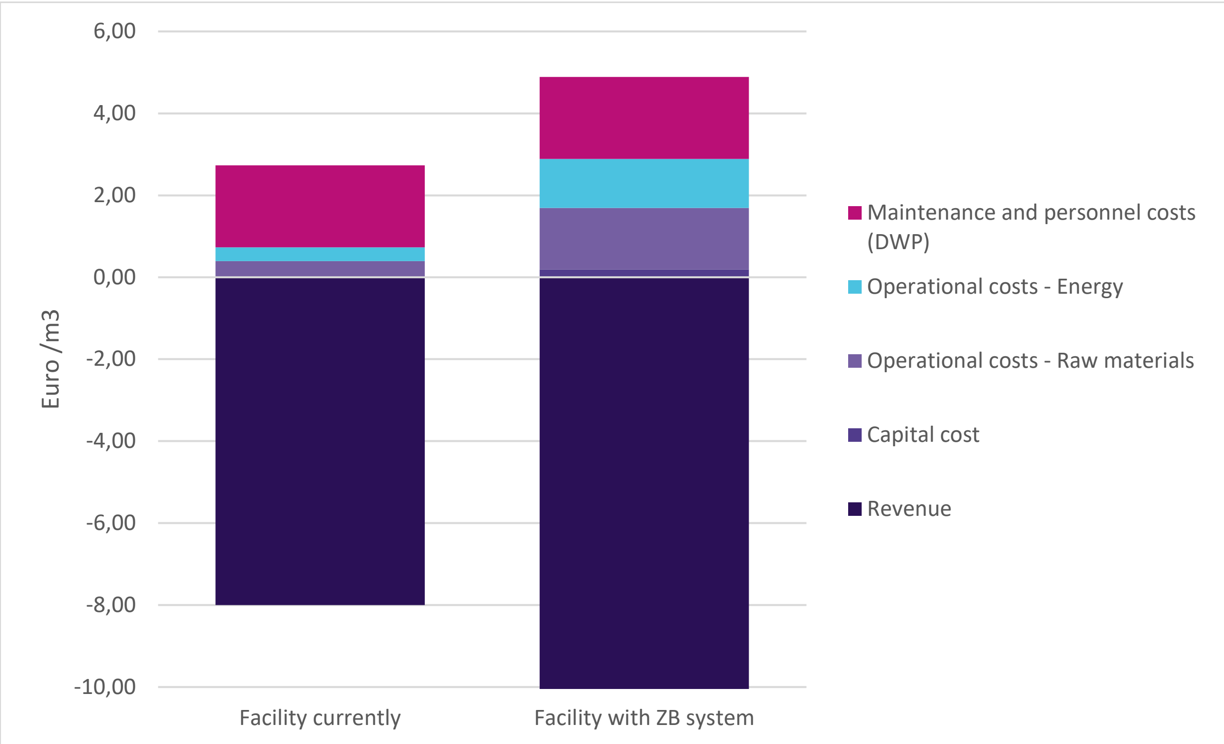


Figure 10. LCC results and contribution analysis for the reference scenario and the facility with ZB system and DWP.

In summary, the analysis should cover the aspects shown in Table 5: Guidelines for communication of results to achieve consistency between the case studies.

Table 5: Guidelines for communication of results to achieve consistency between the case studies

	Aspect to be covered	System studied	Communication tool	Further information
1	LCA indicators as per Table 3 (plus impact contribution)	ZB and reference case	Bar chart /table	The aim is to demonstrate the difference in performance between the two systems.
2	LCA indicator GWP contribution analysis	ZB and reference case	Bar chart	
3	LCC: Fixed and variable cost	ZB and reference case	Bar chart	The aim is to show the relative contribution from mapped processes
4	LCC: External costs and its relative impact to fixed and variable costs	ZB	Bar chart (and table if required to clarify detail)	The aim is to demonstrate the potential external costs and its relative contribution in comparison to fixed and variable costs

7. Conclusion and final remarks

This document has presented the UA for the prospective LCA and LCC analysis of the ZB systems. In addition to providing a basis for consistency across the assessment, the process of developing the UA was a valuable exercise. Crucially, it initiated the preliminary LCA and LCC analysis, which both provided an early assessment and helped identify gaps in data, knowledge and highlight inconsistencies in the approaches of the teams. This in turn helped strengthen the UA. We hope that the UA can also be used as a basis for other projects involving multiple case studies to support a prospective and consistent approach.

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