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A case study of three innovative water treatment technologies

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DOI
10.1016/j.wri.2022.100176

Publication date
2022

Document Version
Final published version

Published in
Water Resources and Industry

Water Resources and Industry 28 (2022) 100176

Contents lists available at ScienceDirect

Water Resources and Industry

journal homepage: www.elsevier.com/locate/wri

Challenges in preparing for Environmental Technology Verification in a demonstration project: A case study of three innovative water treatment technologies

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ARTICLE INFO

Keywords:
Performance claims
Environmental technology verification
Forward feed - Multiple effect distillation
Multi feed plug flow reactor crystalliser (MF-PFR)
Eutectic freeze crystallization (EFC)

ABSTRACT

The European Union's Environmental Technology Verification (ETV) program aims to foster innovative environmental technologies to reach the market and reassure potential users. This paper presents an investigation of using ETV for three technologies, being developed within the EU Zero Brine research and innovation project. The technologies were designed to recover high quality water, salts and minerals from brine solutions. The technologies in focus are the forward feed MED evaporator, the Multi Feed – Plug Flow Reactor Crystalliser and Eutectic Freeze Crystallization. The study sought to understand the challenges of the ETV process, the readiness and eligibility of technologies, and possible preparations within the project lifetime. Challenges identified included: understanding what sufficient market readiness is, and achieving this within the duration of a project (also linked to funding allocation for the ETV process); and developing suitable performance claims, supported with sufficient levels of test data. A simple framework is presented to aid the integration of ETV into the development process. It promotes the use of life cycle assessment to understand the environmental added value of the technology and aid the development of performance claims.

1. Introduction

There are many well documented environmental challenges currently facing society, with water stress and water pollution being of the utmost concern [1,2]. Water treatment technologies offer hope to tackle many of these issues but as with many other environmental technologies, they face numerous obstacles in going from concept to market [3]. A prominent hurdle is adequately demonstrating the added value of the new technology to potential investors and customers. For example, one survey launched by the European Commission found that only 11% of potential customers trusted the claims of vendors [4].

One tool specifically tailored to help environmental technologies the market is Environmental Technology Verification (ETV).

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https://doi.org/10.1016/j.wri.2022.100176
Received 7 December 2021; Received in revised form 19 May 2022; Accepted 20 May 2022
Available online 27 May 2022

Innovative environmental technologies are defined within the program as "technologies presenting a novelty in terms of design, raw materials and energy involved, production process, use, recyclability or final disposal, when compared with relevant alternatives [5].

The EU ETV aims to provide a transparent, robust and credible process, in which a third-party expert assesses the performance claims of the technology provider [5]. It strives to confirm the performance claims of environmental innovation, as opposed to proving compliance to regulatory thresholds. This aligns with previous ETV programs in other countries [6]. ETV has a long history globally, having been used in the US since the late 1990's and has been implemented in several other countries [7]. It differs from certification or assessment standards as the technologies are not assessed against predefined criteria or standards, but stated claims [8]. It therefore facilitates flexibility in which parameters are verified, so that technologies whose performance are not covered through regulations, standards or existing schemes (e.g. labelling) can be included. In Europe it has recently been made a permanent programme to aid the development and marketing of innovative technologies [8].

The pilot programme for the EU ETV began in 2011 and was implemented together with the Eco-innovation Action Plan (EcoAP) to promote and support eco-innovation [9]. To date, there have been 278 applications for the ETV, with 123 initiated verifications and 47 verified technologies [10].

The ETV process uses the ISO 17020 standard to support the impartiality and quality of the ETV procedure and the verification body should be accredited to comply with its requirements [8]. ISO 17020 provides the standard for conformity of bodies (organisations) that perform inspections. The quality of the provided performance test data must also be compliant to the requirements stipulated in ISO 17025 and the Verification body is responsible for deciding which requirements of ISO 17025 are relevant [5]. The outcome of the EU ETV is a Verification Report and Statement of Verification that present the verified performance claims [11]. ETV is targeted at "market ready" innovative solutions within the categories of Water Treatment and Monitoring, Energy Technologies or Materials, Waste and Resources [8]. Nonetheless, there are challenges for technology developers and research teams not familiar with the ETV process, to understand the terminology, data and procedural requirements. For instance, it may initially be unclear what is meant by a "sufficient level of technological innovation" with regard to design, raw materials, production process and recyclability, that the website discusses [8]. The General Verification Protocol (GVP) contains definitions [5] but interpreting the information can still be challenging for an ETV applicant. The website therefore encourages applicants to contact a registered verification body which will eventually lead to a cost but can aid the initial process [8].

There is a paucity of academic literature on ETV and limited examples of its application within research and development projects. Molenda and Ratman-Kłosińska [7] provide a summary and review of the EU ETV Pilot Programme. Marruci et al. [12] examine sustainable production and consumption tools for the circular economy and provide a comparative review of ETV against EMS and Ecodesign. Whereas ETV evaluates the environmental performance of technologies, the Ecodesign Directive sets requirements for products [12]. Marruci et al. [12] suggest that the connection of these tools to the circular economy (CE) could be improved by embedding a life-cycle perspective. In other words, if the tools are to facilitate progress towards a CE for improved environmental performance the full life cycle performance of the system should be assessed. This is to avoid adoption of technologies that enable circular solutions (e.g. the recovery of constituents from water) but transfer or increase the environmental burdens (e.g. increase in overall climate change impact of the system). This aligns with CE literature that stresses the use of life cycle assessment (LCA) over circularity indicators, which only measure circularity of material or value, and not environmental impact [13]. The few technical examples of ETV include an approach in China to use ETV to analyse earthwork composting technology [14] and a US example where air monitoring technology was assessed under the US EPA ETV programme [15].

This paper is part of a special issue on the EU Zero Brine project, a four-year Research and Innovation project running from 2017 to 2021. The project consists of four case studies with specific industrial brine effluents that utilise tailored Zero Brine systems to treat the effluents and recover useful by-products, including salts. The systems consist of existing technologies combined with three innovative technologies being developed within the research project. The three technologies are eutectic freeze evaporation (EFC), Multi Feed Plug Flow Reactor Crystalliser (MF-PFR) [16] and a forward-feed multiple effect distillation (MED) evaporator [13]. The objectives of the paper are to:

- Understand the ETV process requirements.
- Review the technologies and readiness levels for ETV.
- Identify which preparations could be made within the Zero Brine project.
- Highlight the challenges involved.
- Suggest a framework to aid technology vendors in preparation for the ETV

The focus within the project was to prepare for undergoing an ETV and not complete the process within the project timespan. Section 2 describes the methodology used to support the technology developers (herein referred to as the proposers) in this project. Next, section 3 presents the ETV process, the review of the technologies, preparing for the ETV and identification of the challenges involved. Finally, the paper ends with a discussion and framework for how to prepare for the ETV within a research and innovation project.

2. Methodology for ETV preparation

The ETV work began in 2018 before the EU ETV programme became permanent. The partners involved in the ETV consisted of a facilitator (task leaders and researchers at IVL Swedish Environmental Research Institute) helping three proposers (participating in the Zero Brine project) to understand and prepare for the ETV process. These consisted of two universities TU Delft in the Netherlands and

Università degli Studi di Palermo (UNIPA) in Italy, and an SME focussed on brine treatment technology called SEALEAU. The three water technologies are (described in detail in section 3):

1 Multiple Effect Distillation, forward-feed design evaporator from SEALEAU.
2 Multi Feed Plug Flow Reactor Crystalliser (MF-PFR) from ResourSEAs (UNIPA spin-off company).
3 Eutectic Freeze Crystallization (EFC) from TU DELFT.

As discussed in Section 1, these technologies are integrated in configurations with other technologies, in four cases studies in the Zero Brine project, to treat brine effluents and recover valuable compounds. Brine is a growing concern due to its impacts on aqueous systems, increasing industrial volumes and associated costs. Common industrial water treatment processes such as nanofiltration (NF), reverse osmosis (RO) and ion exchange (IEX) all produce both clean water and a brine waste stream.

Bench scale tests were first carried out for each of the technologies, allowing further development and optimisation. Each of the technologies were then utilised within a treatment system at pilot scale at one or more of the case studies within a Zero Brine system (for further information see Ref. [17].

The methodology for assessing and preparing for the ETV consisted of the following steps:

1. Understand ETV process requirements.
2. Review the technologies
3. Preparation for ETV within Zero Brine
4. Identify challenges and next steps.

These are discussed in the following sections.

2.1. *ETV process requirements*

The first task was to understand the ETV process and its requirements. This would help determine whether the technologies were suitable, their readiness, data and testing requirements, and what could be performed within the scope of the Zero Brine demonstration project. It was not known for instance whether historical test data such as bench and pilot scale were required. This task consisted of first reviewing the academic literature and available ETV documentation to support the proposers in the ETV process.

2.2. *Review the technologies*

The purpose of reviewing the technologies was to comprehend: i) what they do and ii) the technological readiness (e.g. Technology Readiness Level) for the ETV. From this we could deduce how to prepare for the ETV within Zero Brine.

The first stage consisted of gathering the technical and performance information of the technologies. To form a mutual understanding of the task, a workshop was held with the Proposers. The workshop explained the ETV process, and the proposers presented their technologies, and discussed the TRL status.

To assess and compare the readiness of the technologies they were assessed against the high level TRL and ETV requirements. In this project we did not conduct and LCA on the individual technologies, although a LCA was conducted on the Zero Brine four case studies, on a complete system basis [17].

2.3. *Preparations for ETV within Zero Brine*

After reviewing the ETV process and readiness of the technologies, the preparations that could be made within the project were to i) begin developing performance claims; and ii) complete a quick scan form for each technology; iii) contact a verification body.

The performance claims and quick scan documents were developed on an iterative basis between the task leaders and the proposers. A second workshop was held to discuss and aid the process of completing the quick scan. A verification body was subsequently contacted to review the quick scans and assess whether the technologies were ready and appropriate for ETV.

2.4. *Identify challenges and next steps*

The final step in the study was to identify and collate the challenges that were experienced by the facilitator and the proposers. This consisted of retrospective analysis of the issues that have been highlighted, discussed and collated in the process of preparing the technologies and proposers for the ETV.

3. Results

This section describes the review of the ETV process and the available information, the review of the technologies and preparations for ETV that were performed within the Zero Brine project. Finally, the challenges experienced in preparing for the ETV are summarised.

3.1. Understanding the ETV process

At the start of this research (2018), less information was available on the ETV website than is currently, but the ETV process was described in an online video, flyer and several documents [10]. These include the Comprehensive Guide for Proposers to the EU Environmental Technologies Verification Pilot Programme [11] and the Environmental Technology Verification pilot programme report that replaces the GVP [5]. In addition, the standard ISO 14034 (Environmental Verification Technology) details verification principles, testing and data quality to meet the ETV requirements. However, the standard was not purchased since we were not undergoing a complete ETV within the Zero Brine project.

The EU scheme for the ETV process is well described in various publicised materials and is shown in Fig. 1 [11,5]. It shows that there are six main phases to the ETV process, with outcomes shown in the right side of the figure. The verification begins when the Proposer contacts a Verification Body, who can aid the Proposer in the completion of a Quick Scan form. The Quick Scan consists of gathering the information shown in Table 1, which is then reviewed by the Verification Body. This is an additional step to ISO 14034 and is intended as an initial, less demanding exercise where the Verification Body can determine the eligibility and readiness of the technology for ETV. At this stage the Verification Body can also provide additional details on the process, required information and costs. It is the individual Verification Body that determines the level of exchange provided before engaging in a contractual arrangement.

The purpose of the Quick Scan is therefore to assess the technology against the criteria in Table 1, including clarity of description, market readiness, environmental added value, innovativeness, and performance. Most critical is the market readiness, which according to the ETV guidelines on the eligibility assessment of technologies, refers to one of two criteria: “the technology is available on the market”; or “the technology is at least available at a stage where no substantial stage affecting the performance will be implemented before introducing the technology on the market” [18]; pg. 9).

If the technology is eligible, the Proposer and Verification Body can enter into a contractual agreement to develop a test plan and verification report, which leads to the Statement of Verification. The Statement of Verification provide a summary description of the technology, the verified performance, the procedures followed (including the test bodies) and other information that may aid the description of the technology.

For a research and innovation project such as Zero Brine, which involves demonstration and pilot plants several gaps were identified. These include a lack of simple user-friendly guides, and practical examples to aid demonstration projects to:

i. Understand the TRL requirements,
ii. Aid the development of performance claims, and
iii. Help understand the test data requirements for demonstrating the environmental added value and maturity of the technology.

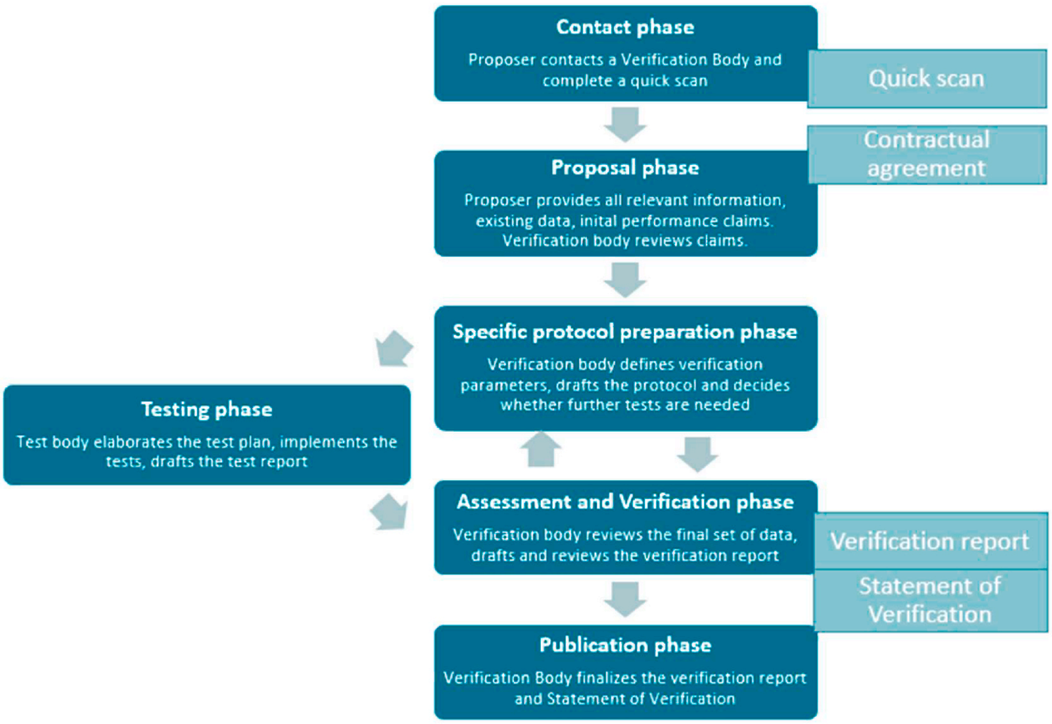

Fig. 1. Phases of the EU ETV procedure (dark green) and outcomes (light green). Adapted from Ref. [5]. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Main components of the ETV Quick Scan.

• Technology area – water treatment and monitoring, materials waste and resources, energy technologies or other.	• Innovation level – that covers novelty compared with alternatives, e. g. design, raw materials, energy, recyclability.
• Description of the technology – context and main purpose	• Environmental added value
• Relevant alternatives – to help determine the added value	• Life cycle phases – extraction to end-of-life
• Scientific or technical principles of new technology	• Potential to meet user needs
• Verifiable, quantifiable performance claim – as a starting point	• Fulfilment of legal requirements
• Conditions of performance	• Intellectual Property Rights (IPR)
• Availability of standards or guidelines that already cover the technology	• Existing data
• Market readiness	• Assessment of technology description

3.2. Review of the technologies

This section provides an overview of the functioning of the three technologies.

3.2.1. Multiple effect distillation, forward-feed design evaporator (FF-MED)

The MED evaporator was designed to recover high quality water from brines and a high purity brine concentrate. The pilot scale unit was demonstrated at a demineralised water plant in the Netherlands, in a treatment system to recover water and salts from the waste brine.

The MED evaporator is made up of two consecutive effects (as shown in Fig. 2) and operates below atmospheric pressure. In each of the MED effects, brine is evaporated resulting in the production of two subsequent streams: (i) a water vapour stream that is then condensed and recovered as fresh water and (ii) a concentrated brine stream. The vapour stream of the first effect is used to heat the concentrated brine produced in the second effect. This is then sprayed on top of the bundle and runs down over the tubes by gravity. Therefore, the necessary latent heat for brine vaporization in the second effect is provided by internal heat gain and energy recovery. The vapour stream produced by the second effect is used to pre-heat the inlet brine, using a heat exchanger. Steam is the main heat supply and heats the brine in the first effect using another heat exchanger. A steam trap removes any remaining water or condensate in the system. The evaporator unit can work with waste heat or electricity.

A mathematical model was developed for each MED's components, based on mass and energy balances. These models were used for the development of a simulator that was built in Visual Basic Environment [19]. The models are utilised to select suitable materials that minimize the formation of limescale or fouling by other deposits, at the high TDS concentration conditions. The aim is to utilise the lowest cost materials to reduce investment cost and provide a competitive advantage, whilst reducing life cycle greenhouse gas emissions.

3.2.2. Multiple feed plug flow reactor (MF-PFR) crystallizer

The MF-PFR facilitates the recovery of minerals from brine with the use of a reagent solution. It is a modular reactor that mixes the reactants (e.g. brine and an alkaline-water solution) to generate sufficient contact [16] to remove compounds from effluents such as divalent ions. In the first step, the brine is mixed with an alkali solution, for example sodium hydroxide, to precipitate/remove magnesium. Next, the pH is increased using a basic solution (e.g., sodium hydrogen-carbonate) to separate calcium ions. The accurate control of the pH is of primary importance and is enabled by the geometries of the MF-PFR, as illustrated in Fig. 3. This shows that the brine in vessel (a) is fed into the MF-PFR (b) along with NaOH to achieve the precipitation of magnesium as a hydroxide at a pH of 10.4. Subsequently, the resulting slurry is collected in a decanter (c) to allow the magnesium hydroxide crystals to settle. When the crystals

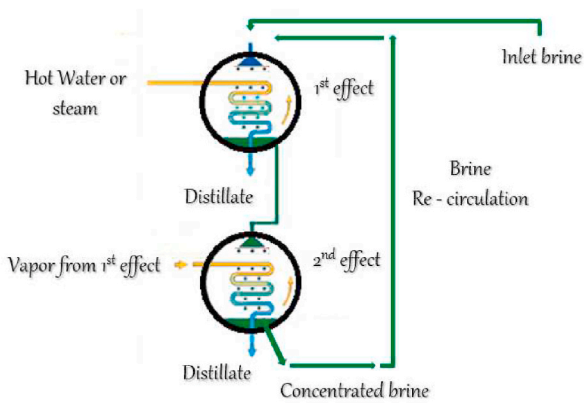

Fig. 2. MED evaporator working principle.

have settled, the clarified brine is collected in another feed tank (d) from where it is returned to the crystallizer, along with additional NaOH solution. The calcium then precipitates in the form of calcium hydroxide at a pH above 13. Finally, the resultant slurry is collected in a second decanter to settle the calcium hydroxide crystals.

When compared to a conventional crystallizer such as the Continuously Stirred Tank Reactors (CSTR), the MF-PFR technology achieves better performance in terms of product purity, control of the crystals size distribution and energy efficiency. The MF-PFR was demonstrated in a Zero Brine case study to recover magnesium and calcium from brine in the form of hydroxides (brucite and portlandite).

3.2.3. Eutectic Freeze Crystallization

Eutectic freeze crystallization can recover pure water and salt (such as $Na_2SO_4*10H_2O$) from waste and process streams of aqueous electrolyte solutions. It can be used for the treatment of concentrated solutions, including salty brines and retentates from reverse osmosis. It takes advantage of the lower energy consumption of fusion (crystallization from freezing) compared to evaporation which is 6.01 kj/mol compared to 40.65 kj/mol, respectively [20]. When saturated solutions of various compounds are super-cooled, two solid phases consisting of ice and inorganic crystals, separate from solution simultaneously (as illustrated in Fig. 4a). The ice floats and the inorganic crystals settle, leaving behind an aqueous solution of concentrated ions consisting of the more-soluble inorganic compounds (Fig. 4b).

Yields of ice and salt are controlled via the heat flux withdrawn from the crystallizer. The outlet of the crystallizer is connected to the solid separator, where ice and salt are separated by gravity. The underflow of the separator is fed to a filter, where liquid is removed from the salt crystals and recycled to the crystallizer. The top flow of the separator, containing the ice crystals, flows into a wash column. Ice is washed by a reflux stream of molten ice crystals and pure water leaves the top of the column. Wash liquor leaving the bottom of the column is recycled to the crystallizer.

3.2.4. Assess the status of the technologies

Table 2 compares the technologies against the main TRL and ETV requirements. The EFC which began at a TRL 3, rose to TRL 5 during the Zero Brine project, whilst the MF-PFR went from TRL 4 to 7 and the FF-MED from TRL 5 to TRL 7. For ETV requirements, none of the technologies are ready for commercialisation. However, the MF-PFR and MED are considered close as no substantial changes affecting the performance are expected.

Therefore, Table 2 suggests that the MF-PFR and FF-MED may be ready to begin preparations for ETV by developing performance requirements, contacting a verification body and initiating a quick scan document.

3.3. Prepare for ETV within Zero Brine

3.3.1. Initiate performance claims

This section presents the performance of the technologies based on the pilot plant tests and how these relate to the development of suitable performance claims.

3.3.2. MF-PFR

The MF-PFR was first tested in the laboratory and then at the industrial case study company with waste brine. It performed well recovering high quality magnesium and calcium hydroxides with purities above 98% (for further information on test results see: Ref. [21]. The performance claims of the MF-PFR focus on the purity of the precipitated minerals, the control of the particle sizes distribution, and reduced electrical energy compared to the conventional Continuously Stirred Tank Reactor (CSTR) crystallizers. The quantification and comparison with the best alternative technology (BAT) is shown in Table 3.

3.3.3. FF-MED

The evaporator technology was first tested at pilot scale during the EU SOL-BRINE project [22,23] and then its upgraded version (utilisation of waste heat) piloted at the Evides Site I and Evides Site II with industrial brine water. The performance claims of the MED focus on achieving an increased concentration factor that results in three times the amount of water recovered, compared to a standard

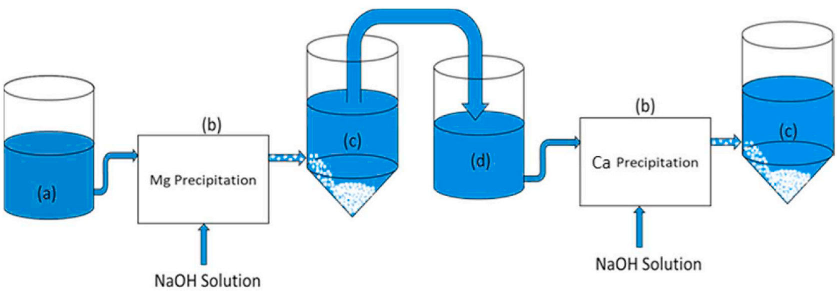

Fig. 3. Practical application of the MF-PFR from ResourSEAs for the fractionated removal of magnesium and calcium as hydroxides.

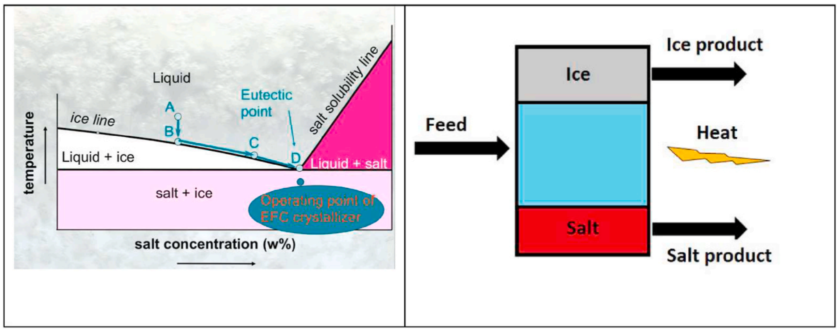

Fig. 4. a) Phase diagram of salt – liquid -ice system. At the eutectic point the phases may be separated. This is the operating point of the EFC. b) The basic working principle of the EFC technology.

Table 2
Technology readiness level of the three technologies (X denotes level has been reached).

Technology Readiness Level & requirements	MF-PFR	FF-MED	EFC
TRL 9. Actual system proven operational environment	–	–	–
TRL 8. System complete and qualified	–	–	–
TRL 7. System prototype demo in operational environment	X	X	–
TRL 6. Technology demonstrated in relevant environment	X	X	–
TRL 5. Technology validated in relevant environment	X	X	X
TRL 4. Technology validated in lab	X	X	X
ETV requirements	MF-PFR	MED	EFC
Environmental technology “sufficient levels of innovation”	X	X	X
Within scope – water tech, energy or material, waste and resources	X	X	X
Ready for commercialisation	–	–	–
Meets users’ needs	X	X	–
Performance characteristics not covered by existing regulations or standards	X	X	X

Table 3
Proposal for the initial performance claims of the MF-PFR.

Performance claim	BAT (CSTR)	MF-PFR	Comments
Purity of recovered magnesium hydroxide	>95%	>99.5%	MF-PFR recovers separated salts in steps.
Particle sizes distribution	Based on market requirements	Based on market requirements	It can be tuned for specific products
Electrical energy consumption	Unknown (specific to brine tested)	5 kWh/m^3	Pilot scale only, full scale is estimated at 1.5 kWh/m^3

desalination system (e.g., RO). It can also utilise low-grade waste heat from industrial processes and solar energy, to reduce greenhouse gas emissions. The performance claims compared to BAT are shown in Table 4.

3.3.4. EFC

The EFC technology was tested at three locations within the project: the Evides Site II with industrial brine from the RO unit, a coal mine site (PGG) with brine effluent and a chemical industry (IQE) with high salinity wastewater from silica production. At the pilot test at Evides Site II the EFC recovered 81% of available water and Na_2SO_4 salt with a purity of 99.97%. The coal mine tests showed that the EFC could recover salt even with highly contaminated feed water. The pilot plant at IQE compared the EFC with evaporation. This

Table 4
Proposal for the initial performance claims of the MED.

Performance claim	BAT (RO)	MED	Comments
Exit concentration of waste brine (TDS)	7%	Up to 20%	Able to concentrate 3 times more compared to RO
Water recovery		x3 compared to BAT	Due to increased concentration factor
Waste heat recovery	No	Low-grade heat integration	The evaporator is working under vacuum able to operate with hot water at 80 °C

showed that the EFC recovered a higher purity salt ($Na_2SO_4 \cdot 10H_2O$ at 99.9%), with lower energy consumption (2–4 fold reduction) and higher total salt recovery. In addition, when operating in continuous mode the EFC can recover over 85% of water. Although the water quality was slightly lower than that recovered by the evaporator, it could still be reused internally at IQE.

Due to the currently low TRL level, the development and identification of adequate performance claims was challenging and is still ongoing. The initial proposed claims are shown in Table 5 and are linked to the benefits of the lower operating temperature and associated energy consumption, in comparison to conventional evaporation. This results in minor thermal degradation of heat sensitive compounds and minimal corrosion of the construction material. In addition, chemical addition is not required and the large difference in density between salt and ice enables easier separation. In addition, separation by gravity can be incorporated and operating costs are typically 85% of evaporation crystallization [20].

3.3.5. Quick scan

The proposers of the MF-PFR and FF-MED were able to complete a quick scan for the technologies, which was submitted to a verification body for an initial review. However, the EFC was not sufficiently developed to allow the proposers to adequately complete a quick scan. The Verification Bodies for the MF-PFR and FF-MED assessed the Quick Scans as shown in Table 6 (further details are confidential). Both technologies were deemed suitable for the ETV verification process, and offers were received on the estimated costs to engage the Verification Bodies for the process.

Only the MF-PFR was assessed as potentially market ready, although a further check of the test plan, methods and suitability of the test body are required by the Verification Body during the process. For the FF-MED the Verification Body provided several comments asking for further information and clarification. For example, they asked whether the technology can treat any kind of brine, and highlighted that the verification statement could not be used with other types of water. Furthermore, because the proposer stated that each unit would be designed and customised to match each purpose, there is a need to understand whether this would influence the performance, of the technology, which could impact the Verification Statement.

3.4. Challenges in preparing for the ETV

The three technologies are in various stages of development and have faced different challenges in preparing for the ETV process within the project. In summary, we identified the following challenges in preparing the three technologies for ETV:

1. Locating and interpretating explanations of the terms and requirements for ETV, particularly with regard to its application within the scope of a demonstration project. Several guides are available but information is therefore spread across multiple documents, meaning that time is needed to fully understand the process and requirements. For example, the quick scan has many requirements and it was difficult to find adequate explanations of requirements, particularly with regard to demonstration projects and whether response would be acceptable. The proposers had difficulties knowing how to prepare and what can be done before engaging a verification body, such as how to collect, structure and present data relevant for the ETV. Although, it is stated in the GVP that this must conform to ISO 14034.
2. Defining market readiness sufficient for an ETV and achieving this within the duration of a project. It is clearly stated that the technology should be market ready, or at a level where the performance does not change. However, the wording “where no substantial stage affecting the performance will be implemented before introducing the technology on the market” is still open to interpretation.
3. Developing performance claims for the technologies - was challenging for the technology vendors. This was due to the potential for further development of the technologies and insufficient levels of test data (and ongoing tests) to help quantify the performance claims. In addition, there was insufficient knowledge on the market needs and innovation requirements for the challenge that the technologies are aiming to address.
4. Funding of the ETV process and testing within a research and demonstration project. In-house testing by proposers within a research project may not be sufficient to meet the quality requirements of an ETV. Therefore, if an ETV is targeted within a research project there is a need to budget for both additional testing, internal time of the proposer and engagement of the verifier. We estimate a need for funding of €10–40,000 to engage a verifier and support the process internally (costs obtained from verifiers within this project). We did not determine additional costs for tests that conform to relevant ISO standards.

These are further discussed in the next section.

Table 5
Proposal for the initial performance claims of the EFC.

	BAT (evaporation)	EFC	Comments
Operating temp	>100C	< -5C	Less heat degradation of components
Energy consumption kWh/m^3	200–300	2 to 4 times reduction	Comparing the heat of evaporation with heat of fusion only.
Salt purity	Mixed salt or higher than >98%	Up to 99.9%	Can potential separate different salts
Water purity	Pure	>98% pure	Sufficient quality achieved for internal reuse
Water recovery	80%	86.3%	

Table 6
Quick Scan Assessment of the proposal by the Verification Bodies.

Assessment aspect	FF-MED Assessment	MF-PFR Assessment
The technology fits in the scope of the EU ETV programme?	Yes	Yes
Description/principles clear?	–	Yes
Clear and verifiable performance claim(s)?	Yes	Yes
Ready-to-market?	No	Yes
Prototype in advanced stage of development?	Yes	Yes
Technology shows innovative characteristics?	Yes	Yes
Potential to meet user needs?	Yes	Yes
Fulfilling legal requirements (limited to VB's expertise)?	Yes	Yes
Technology shows environmental benefits?	Yes	Yes
Life-cycle aspects described?	No	Yes
Test results are available?	Yes	Yes
Further testing would/could be necessary?	Yes	To be checked during assessment
Conclusions	Acceptable for ETV. Offer provided.	Test results to be verified during the assessment. Offer provided to proposer.

4. Discussion

4.1. Summary of technology status

The three technologies have all advanced in TRL during the project, but they still cannot be considered as "market ready" for the ETV. Both MF-PFR and FF-MED reached TRL 7 whist the EFC reached TRL 5. Each of the technologies or variations of them, have been under development for several years and hence it is perhaps not surprising that market readiness was not achieved during the duration of the project.

The most advanced, the MF-PFR, has demonstrated excellent empirical results in the pilot demonstrations, with high purity of the recovered products and lower energy than conventional CSTR crystalliser. The performance claims require further development to establish the final quantities/values and other claims may be added based on further market understanding. The FF-MED also performed well and overcame challenges identified in a previous demonstration project (SOL-BRINE), including scaling of the heat exchangers and utilising waste heat. Scaling was reduced through a combination of nanofiltration and forward-feed evaporation. A follow-up EU research project (SEA4VALUE) will also test novel composite materials to reduce scaling. Furthermore, the integration of waste heat is critical to reduce energy intensity and GHG emissions. For example, an FF-MED utilising waste heat in an evaporator instead of current best practice could save 160,000 tons of CO_2-eq for desalination in Cyprus [24].

The EFC also demonstrated excellent results at the three pilot plants, recovering a high percentage of water (>80%) and a very high purity of salt, but with lower energy consumption than the alternative evaporation technology. It therefore has strong potential but did not reach a high TRL within this project and therefore was not ready for the ETV. Nonetheless, several commercial EFC units are available [25].

In summary, performance claims were developed for all three technologies, based on such factors as low energy consumption, high recovery of water and salts, as well as high salt purity. These are supported by the empirical and demonstration results, suggesting that when market ready the technologies can achieve their performance claims and attain ETV status.

4.2. Challenges with the ETV procedure in the Zero Brine project

The challenges identified in section 3.6 are discussed in the following sections.

4.2.1. Difficult for the uninitiated to assimilate ETV requirements

It was difficult for the project participants to understand what will be required and how preparations can begin. In conclusion a Verification Body should have been contacted at an earlier stage in the process to help clarify requirements.

During the early stages of the study, questions were raised on how to collect, structure and present data relevant for the ETV. Since the Proposers had conducted bench scale tests and pilot projects, it was not known whether this data could be used or how it could be structured. The critical issue is that the role of test data is to support the performance claims, and it is therefore necessary to first develop these. If the technology is not mature enough, it is not possible to plan for adequate testing compliant to the standards demanded by the ETV. Guidance could therefore promote the importance of developing performance claims relevant to market needs at an early stage in the technology's development (low TRL). This could also be beneficial for optimisation of life cycle design, to help the technology achieve the most environmentally beneficial performance.

4.2.2. Market readiness and timing

A further challenge is aligning the market readiness with project funding streams, so that market readiness, testing and verification occur when funding is available. For instance, EU Horizon funding is only available within the project lifetime as agreed in the grant agreement. The ETV documentation states that a full verification can only be performed once the technology is market ready. However, the verification can be started earlier, by starting with a Quick Scan form (although ideally at TRL 7, when there are no expected changes to performance). Hence, the verification procedure, from Quick Scan to full verification would need to correspond to the project funding period (if applicable). Normal times for a full verification are 9–18 months [26]. It is always challenging to ensure within a project that TRL advancement can be made, and contingency plans may therefore be needed in case the Verification and testing continues after the research project finishes.

4.2.3. Performance claims

The correct selection of the performance claims is one of the most critical aspects on which the technologies are verified and marketed upon. Appropriate claims were difficult to establish for technologies in this project, due to the low TRL in the case of the EFC, but also because tests were ongoing and further tests could help to assure performance claims.

It is evident that to fully utilise the potential of ETV for marketing, performance claims should be linked to market needs. Hence, a market analysis should be performed to understand customer requirements and market demand. An LCA could be utilised to further understand the potential environmental added value of the technology to refine the performance claims and increase the depth of knowledge.

Finally, the performance claims should also be quantitative and measurable. The chosen claims should show that the presented technology performs better than similar technologies on the market, or that the performance equals similar technologies but have less or minor drawbacks.

4.2.4. Funding sources for verification costs

Early documents suggested that the cost for an ETV including engaging a verification body and additional costs for a testing body could be as much as €90,000 (European Commission DG ENV, 2008). However, more recent evidence is much lower with average costs from the ETV pilot programme being €15,000 according to the website [10].

Nonetheless, the cost of performing tests in accordance with requirements relevant to the technology in accordance to ISO/IEC 17025 should be considered. This is dependent on the technology in question and the quality of the tests already conducted [27]. Grants are available but whether the full costs are covered by the grant depends on the timespan of completing the verification procedure. If the grant time runs out, alternative financing will be required to complete the ETV.

4.3. Utilising life cycle assessment

Performing a life cycle assessment (LCA) of the technology could aid the ETV process for several reasons. Firstly, it increases the knowledge of the system wide performance and the added value from an environmental perspective. For examples, the life cycle environmental impact of manufacturing a product where the technology is used as part of the manufacturing process. It can help to collect data for an ETV and provide evidence of environmental benefits compared to alternative/existing technologies. Secondly, it can aid the assessment of the eligibility of the technology for an ETV. Thirdly, a LCA can help to identify and define performance claims.

In terms of performance claims this could help to widen the scope of those claims. For example, typical performance claims of water treatment technology can focus on reduced energy and improved water quality. LCA's however enable a full assessment of the system for application so could include reduced greenhouse gas emissions across the life cycle, or that recovered compounds (such as magnesium hydroxide) have a lower environmental footprint than conventional production. This could enable a wider range of performance claims. However, this may also lead to challenges in proving these claims within the ETV process, as they would only be applicable to specific cases. Therefore, performance claims, should be restricted to those that can be proven to be applicable in generic circumstances.

LCA's performed at a low TRL level also help with initiating data collection; thereby laying the foundations for subsequent stages to improve data quality [17]. The final LCA at TRL 7 or beyond, should aim to demonstrate the key improvements in environmental performance that the innovative technology provides in comparison to conventional or existing alternatives. The final LCA should be done before engaging in ETV so that the performance and performance claims do not change within the ETV process, as this would increase costs and process duration.

4.4. Summary and recommendations

In summary, we recommend that the proposer reviews the following at an early stage of technological development: the value of the ETV for their technology, the market needs and potential performance claims. In addition, as discussed above, a LCA performed at a low TRL (e.g., TRL 4) would help to understand potential environmental hotspots and benefits. A life cycle costing (LCC) would additionally provide similar knowledge on economic hotspots and opportunities for improvement. Furthermore, contacting a Verification Body early on would be beneficial.

These aspects are summarised in Fig. 5, which describes the process of preparing for the ETV within a technology development framework. During the initial stages of development (research) market analysis is performed to understand the market needs and how these are met by the technology. At the same time, LCA (and LCC) can be started to identify environmental hotspots, initiate data collection, understand full life cycle benefits and identify areas for improvement to inform the design process. Together, these form the basis for identifying the technologies selling points, which can be linked to the performance claims. Funding of the ETV process also needs to be considered at a low TRL and could be incorporated into research funding.

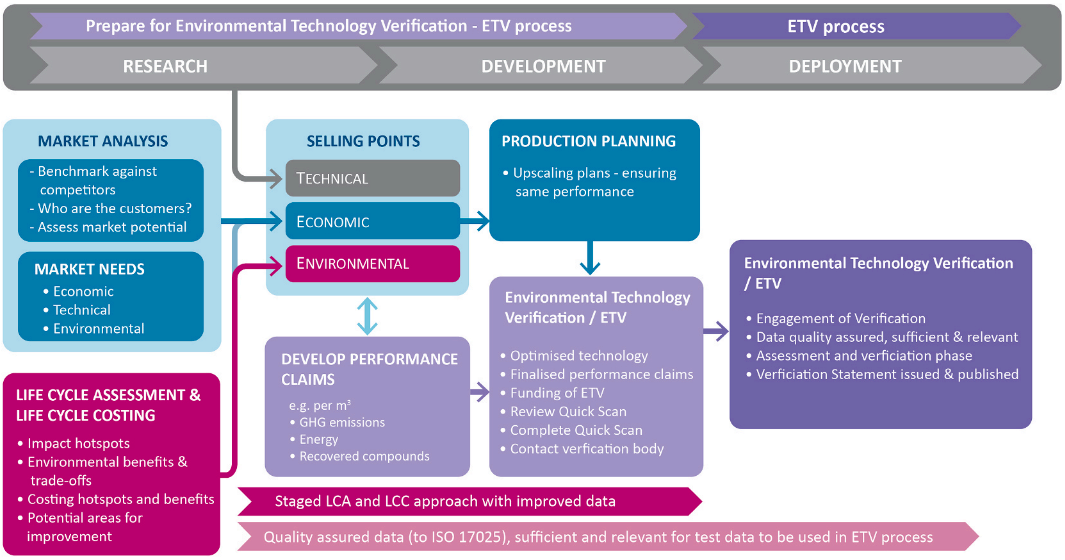

Fig. 5. Preparing for the ETV process throughout the development of a technology.

The ETV process can begin when the TRL increases above TRL 7, with the Quick Scan. It then proceeds to the next step when final performance claims are set and when "no substantial stage affecting the performance will be implemented before introducing the technology on the market" [18]. Fig. 5 also highlights that care should be taken with data quality that may be used in the ETV process. Test data used in the ETV needs to comply with relevant and assured quality management, such as ISO 17025 [5].

5. Conclusion

This paper presented the efforts made to prepare three technologies, being advanced in a demonstration project, for the ETV process. Within the four years of the Zero Brine project, two of the three technologies advanced to a sufficient level to develop performance claims and complete an ETV quick scan. The FF-MED and MF-PFR achieved TRL 7, whilst the EFC achieved TRL 5. Both the MF-PFR and FF-MED technologies are not expected to undergo substantial changes in performance, supporting their eligibility to begin the ETV process. However, performance claims need to be checked and finalised within the verification process.

Challenges identified in the paper include a lack of simple guidelines and practical examples to help understand TRL requirements, aid the development of performance claims and understand the test data requirements. To aid integration of ETV into the technology development process, a simple framework was introduced. This highlights the importance of a market analysis to develop selling points and performance claims. Whilst a life cycle assessment and life cycle costing can support identification of economic and environmental hotspots (impacts) and benefits. The LCA can help to identify the added environmental benefits of the technology and therefore aid development of performance claims for the ETV.

Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The Zero Brine project has received funding from the European Commission under the Horizon 2020 programme, Grant Agreement no. 730390. The opinions expressed in this document reflect only the author's view and do not reflect the European Commission's opinions. The European Commission is not responsible for any use that may be made of the information it contains.

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