B-WaterSmart

Water-smart technologies and concepts

Deliverable 2.14

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Deliverable 2.14

Summary
This deliverable is a synthesis report on the results of all the technologies in the different case studies within the B-Watersmart project. As the final report on the outcome of the technology demonstrations, it provides a public synthesized overview and encompasses all Living labs. The document begins by clarifying its objectives in the first section. Section 2 provides a concise description of the technologies applied in each living labs, the achieved results and the challenges encountered during implementation. It also provides lessons learnt for future implementation of the technologies in other places. Section 3 provides the description of the achieved and expected impacts of the technologies on the Living labs. Finally, section 4 summarizes the activities and presents the common trends, lessons learned are and overarching impacts, highlighting cross-cutting aspects and synergies of the different technologies.

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List of Acronyms and Abbreviations

AC	Activated Carbon
AE	Autoencoder
AGMD	Air Gap Membrane Distillation
AMA	Aguas Municipalizadas de Alicante, Empresa Mixta
API	Application Programming Interface
AS	Aeration Stripping
BAC	´Biologically Active Carbon Filter
BMP	Biomethane Potential
CCP	Critical Control Points
CCRO	Closed Circuit Reverse Osmosis
CET	CETaqua
CEVAP	Cartridge Evaporator
CFU	Colony Forming Unit
CMSP	Camposampiero Wastewater Treatment Plant
COD	Chemical Oxygen Demand
CS	Column Stripping
CSTR	Continuous stirred-tank reactor
DCMD	Direct Contact Membrane Distillation
DMK	Deutsches Milchkontor GmbH
DNA	Deoxyribonucleic acid
DOC	Dissolved Organic Carbon
Dx.y	Deliverable y of WP x
EBCT	Empty Bed Contact Time
EC	Electro-Chlorination
EDI	Electro-Deionization
EDR	Electrodialysis Reversal
ENV	Envirochemie GmbH
FAC	Free Available Chlorine
FU	Fusina Wastewater Treatment Plant
GAC	Granular Activated Carbon

GDPR	General Data Protection Regulation
GPR	Gas Production Rate
HPC	Heterotrophic Plate Counts
HRT	Hydraulic Retention Time
ICC	Intact Cell Counts
I/I	Infiltration/Inflow
KPI	Key Performance Indicator
LL	Living Lab
LOQ	Limit of Quantification
LOW	Liquid Organic Waste
LRV	Light Reflective Value
LSTMAE	Long-Short-Term Memory Autoencoder
M	Month
MD	Membrane Distillation
MED	Multi-Effect Distillation
MNF	Minimum Night Flow
MS	Milestone
MSF	Multi-Stage Flash Distillation
NDMA	N-Nitrosodimethylamine
NE	Northeast
OFMSW	Organic Fraction of Municipal Solid Wastes
OPEX	Operational Expenditure
ORP	Oxidation-Reduction Potential
O3	Ozonation
PCA	Principal Component Analysis
PFAS	Per- and Polyfluoroalkyl Substances
QCRA	Quantitative Cost Risk Analysis
QMRA	Quantitative Microbial Risk Assessment
rRNA	ribosomal RNA

RO	Reverse Osmosis
SDI	Silt Density Index
SE	Southeast
SEC	Specific Energy Consumption
SED	Selective Electrodialysis
SWM	Smart Water Meters
SWMM	Stormwater Management Model
TCC	Total Cell Counts
TOC	Total Organic Carbon
THM	Trihalomethanes
Tx.y	Task y of WP x
UF	Ultrafiltration
UV	Ultraviolet Disinfection
UWWTP	Urban Wastewater Treatment Plant
VAE	Variational Autoencoder
VS	Volatile Solids
WAS	Waste Activated Sludge
WP	Work Package
WRR	Water Recovery Rate
WWRF	Water Resources Recovery Facility
WWTP	Wastewater Treatment Plant

B-WaterSmart

Executive summary

This deliverable is a synthesis report on the results of all the technologies in the different case studies within the B-WaterSmart project. As the final report on the outcome of the technology demonstrations, it provides a public synthesized overview and encompasses all six Living labs. The B-WaterSmart project has tested a total of 15 different technologies across the six living labs. The technologies are grouped in three main categories; advanced treatment of vapour and condensate for reuse in the dairy industry; recovery of energy and materials from water and wastewater; and smart management of water systems and infrastructure. The document begins by clarifying its objectives in the first section. Section 2 provides a concise description of the technologies applied in each living labs, the achieved results and the challenges encountered during implementation. It also provides lessons learnt for future implementation of the technologies in other places. Section 3 provides the description of the achieved and expected impacts of the technologies on the Living labs. Finally, section 4 summarizes the activities and presents the common trends, lessons learned are and overarching impacts, highlighting cross-cutting aspects and synergies of the different technologies. For the future need for further testing and potential challenges with a full-scale implementation of the different technologies section 4 is intended to be used as the point of departure for future work as well as contribution to the necessary knowledge to achieve the societal need of transformation into a water smart society for a sustainable and just water future.

1 Purpose of this document

The main purpose of this document is to provide an overall summary of the fifteen technologies tested across the six Living Labs (LL). It is in this respect a successor and building on the internal deliverables D2.16 and D2.17 – the first and second intermediate synthesized reports of technology progress and state of play across all the LLs.

It provides an overview of the technologies at each Living Lab, of the testing and assessment performed for each technology at the LLs, and a summary of the main findings and results with respect to the assessment criteria in the B-WaterSmart project and overall potential for future full-scale implementation. For each of the LLs the following objectives are fulfilled:

1. Description of each technology tested in the Living Lab.
2. Results reported by technology and assessed with respect to the criteria in the Grant Agreement.
3. Challenges experienced with the technologies or external factors with affected the planned activities.
4. The lessons learned for each of the technologies from the testing and especially focused on the knowledge base for the road ahead.

Figure 1 shows the general project timeline for WP2 and the tightly interconnected WP3 as outlined in D1.7 to provide context and overview over the project as planned.

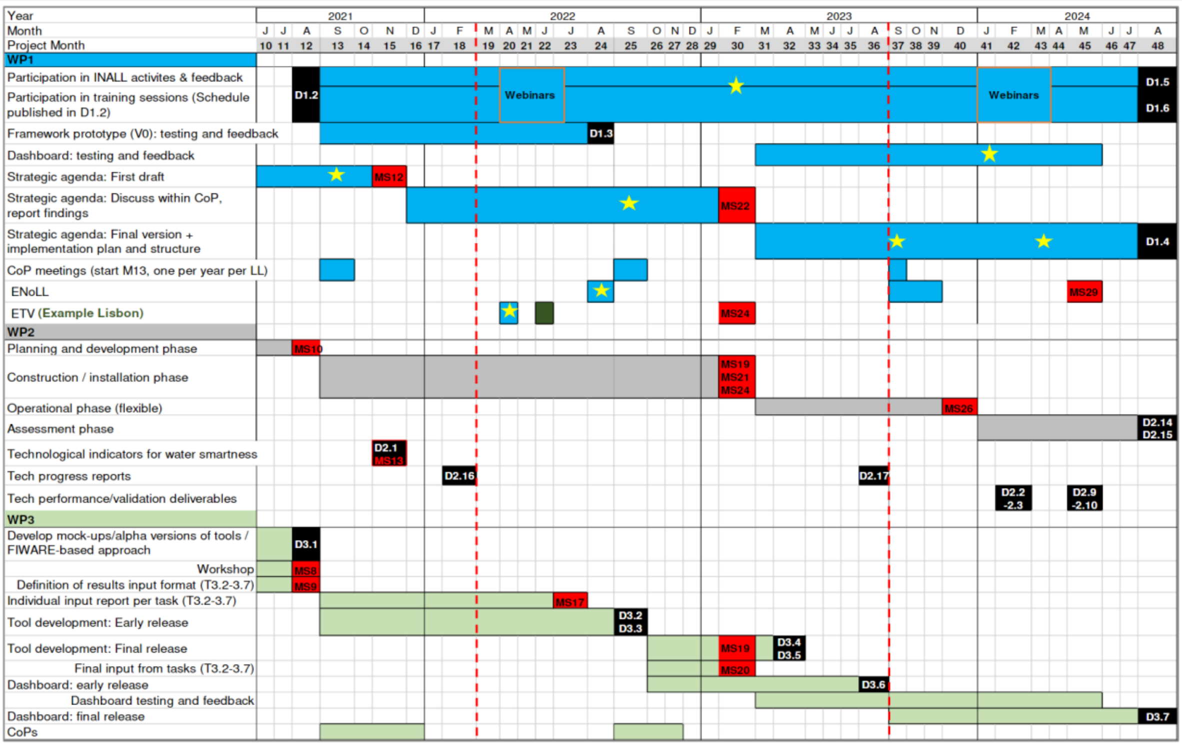

Figure 1: B-WaterSmart timeline and activities M10-M48 for WP1-3. Stars indicate checkpoints for KPI progress (identical with Figure 2 in D1.7).

The original workplan as defined in the GA had foreseen that at MS24 (M30, Feb 2023) all technologies would have completed their construction and set-up phase and were ready for the actual demonstration phase. Due to the following reasons this was only achieved in time for six technologies (#1, #2, #3, #4, #10, #11 and #14). However, the risk management measures, and contingency plans have turned out to be effective, and 12 of 14 technologies have achieved the demonstration phase (technology #12 is no physical technology but a feasibility study) by M36. The remaining ones (#9 and #15) had minor delays (M39, and M37 respectively) but all technologies had sufficient demonstration time to enable their assessment.

2 Technologies applied in the B-WaterSmart Living Labs

2.1 Alicante

The ambitions of Alicante LL are to boost water re-use and circular economy in the region. Through the B-WaterSmart project in four subtasks (T2.1.1 – T2.1.4), LL Alicante has evaluated different technologies to recover and reuse the following resources from the water system: energy (#10, #13), nutrients (#7, #9), and salts from RO brine (#8) and mineral materials (#10).

2.1.1 Description

2.1.1.1 Co-digestion of oils, fats and food waste (T2.1.1)

Anaerobic digestion is a widely adopted technology for the treatment of sewage sludge, primarily due to its ability to reduce waste volume and produce biogas, a valuable renewable energy source. Recent efforts have been directed towards enhancing biogas yields through co-digestion, where sewage sludge is combined with other organic wastes to provide a richer substrate mix. Extensive experience exists in the large-scale co-digestion of sewage sludge and livestock farm wastes. Anaerobic digestion of food wastes or the organic fraction of municipal solid wastes (OFMSW) has gained popularity in recent years, and several plants have been installed for treating these wastes in urban WWTP. This is the case in Sabadell Riu Ripoll WWTP (NE Spain) and in Murcia Este WWTP (SE Spain), where both plants are co-digesting the sewage sludge generated in the primary and secondary treatments together with local wastes available.

However, improvements in performance and faster conversion rates are essential to enhance the financial viability of these plants and to identify configurations that strike a balance between process efficiency and operating costs. In addition, each substrate possesses unique characteristics, such as biochemical composition, nutrient content, and degradation rates, which can significantly impact the overall performance of anaerobic digestion. Therefore, co-digestion performance innovation lies not only in exploring co-digestion but also in meticulously evaluating each substrate. This focused assessment is imperative to discern the individual nuances of substrates, ensuring a comprehensive understanding of their behaviour in anaerobic environments. And to that end, co-digestion studies need to be assessed at pilot scale prior to its full-scale implementation. In the Alicante LL, two co-substrates have been evaluated and promising results have been demonstrated towards increasing biogas production. In this sense, both co-substrates tested could be introduced in the digesters and this is the plan of Aguas de Alicante in the coming years.

The pilot plant (see Figure 2) for co-digestion has already been demonstrated and reported in the public Deliverable 2.2 - Valorization of oil and fats and food waste to improve co-digestion performance. The demonstration phase consisted in an initial stage of anaerobic digestion of sewage sludge alone to set the baseline production of biogas. Following this, the demonstration of the co-digestion proceeded by mixing the sewage sludge with different co-substrates (i.e., food industry waste as e.g., ice cream in Figure 2) and assess the evolution of the biogas production. The demonstration phase of this subtask was extended until M40, although the corresponding deliverable was submitted on time (M42).

Figure 2: Left: Pilot plant installed in Rincón de León WWTP; Right: Ice cream co-substrate.

2.1.1.2 Microturbines (T2.1.2)

Micro- and picoturbines are small turbines that can produce electricity from various fuel sources. In water networks, microturbines can be used to recover energy from the excess pressure in the pipelines, which is typically dissipated through pressure-reducing valves. These kinds of turbines are commonly installed in river basins taking advantage of high flows and high heads. Most turbine technologies do not fit wastewater treatment plants since turbines typically require a pressure difference and/or high heads, which are not available in WWTP. Since the Turbulent technology is an open channel technology and only minimal heads are required, the technology might be adaptable to WWTP installations. Turbulent has already successfully installed a turbine at the WWTP installation of Suez at Paris-Versailles. Nevertheless, this installation showed that a specific approach was required. Further evaluation of multiple WWTP sites shows that in most cases, a turbine (sometimes multiple turbines) of an even smaller size than the actual product range is required for this market.

The microturbine was installed in Monte Orgegia WWTP in May 2023 (see Figure 3) and its demonstration was extended until M42. The results of this technology have already been reported in the public Deliverable 2.3 - Micro-turbines for energy recovery in WWTP. The extension for this subtask has been due to the need of re-designing the turbine, the execution of the civil works necessary and its appropriate installation.

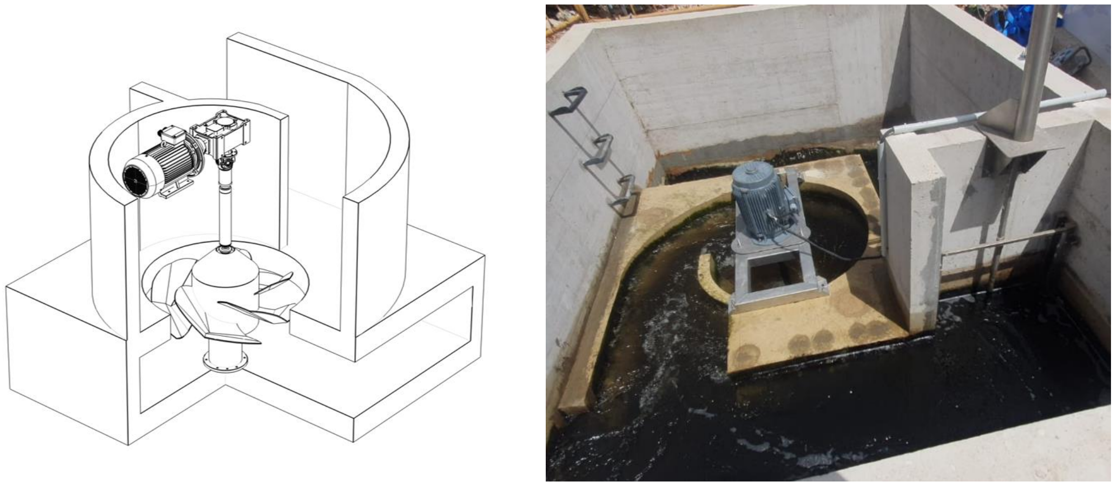

Figure 3: Left: Conceptual design of spiral basin and turbine. Right: final setup of the picoturbine installed at Monte Orgegia WWTP.

2.1.1.3 Selective Electrodialysis (SED) and electro-chlorination (EC) (T2.1.3)

The current state-of-the-art in brine management uses conventional desalination methods like reverse osmosis (RO), multi-stage flash distillation (MSF), and multi-effect distillation (MED). While these methods reduce brine volume and recover water, they are energy-intensive, prone to membrane fouling, and create concentrated brine disposal challenges, often neglecting brine valorisation and resource recovery. In contrast, the integration of selective electrodialysis and electro-chlorination evaluated in Alicante LL represents a significant advancement. This approach separates monovalent ions from brine streams through selective electrodialysis, enhancing downstream process efficiency. Electro-chlorination then converts these ions into sodium hypochlorite for water disinfection, mitigating environmental impacts and creating valuable products. This dual-stage process embodies a circular economy by transforming waste into useful products, thus improving sustainability and economic viability. Additionally, this valorisation strategy is applied to urban wastewater desalination, unlike traditional efforts focused on seawater or industrial brines. Urban wastewater presents unique challenges due to its lower salinity and variability, making this application innovative and expanding the benefits of advanced brine valorisation to urban water systems.

The pilot plants (see Figure 4) were installed in Rincón de León WWTP at the beginning of M30, and their operation started at M34. The operation phase was extended until M42 to ensure sufficient time for validating the technologies. The results of the pilot plant operation were reported in the confidential Deliverable 2.9 (contact at CET/AMA), which was submitted in M45.

Figure 4: Right: Selective electrodialysis membrane stack; Left: Brine valorisation pilot plant installed at Rincón de León WWTP.

2.1.1.4 Ammonia recovery and fertilizer production (T2.1.4)

Ammonia recovery typically includes the separation and concentration of ammonia from wastewater and transforming it into usable and economically viable products. Several methods are known for ammonia recovery, including stripping techniques, membrane technologies such as membrane distillation, electrodialysis and reverse osmosis, chemical precipitation and ion exchange or adsorption. Evaporators are widely used in industries such as food processing, chemical processing, and wastewater treatment to concentrate liquids or recover valuable substances from solutions. In the wastewater treatment domain, they play a significant role in industrial wastewater treatment processes by concentrating wastewater streams and reducing their volume. The main disadvantages of evaporators include high energy consumption required to heat and evaporate the water (resulting in high OPEX) and susceptibility to scaling and fouling, which make them less attractive to some industrial sectors, including urban water treatment, where water utilities or municipalities may find the high operating costs prohibitive.

On the other hand, the CEVAP technology is a vacuum-based evaporator that can be driven by low-grade waste heat sources to maintain low operational costs, which enables innovative applications across various industries. CEVAP was previously validated in the project LIFE Remine Water for recovering water from brines produced in the mining sector while minimizing the volume of high-salinity brine waste. In the B-WaterSmart project, CEVAP has been validated for recovering ammonia from rejected streams produced during the dehydration process of digested sewage sludges. Even though the recoveries have not been promising, this approach advances the state-of-the-art and generates knowledge on innovative technologies to recover nutrients from wastewater.

The reception of the CEVAP pilot plant at Rincón de León WWTP (see Figure 2) was rescheduled to M39 and a contingency plan was set to achieve its demonstration in time before the end of the project. All contingency actions were carried out and the technology was operated from M40 to M45. The results of its operation have been reported in the confidential Deliverable 2.10 - Ammonia recovery from co-anaerobic sludge applying CEVAP (contact at CET), which was submitted in M45.

Figure 5: CEVAP pilot plant installed at Rincón de León WWTP

Experiments using membrane distillation (MD) to recover nitrogen were conducted from M33 to M43 using a lab-scale SolarSpring MD (see Figure 6). MD was used to recover ammonia nitrogen (NH_4-N) from real wastewater generated from the liquid fraction of digested liquors and wastewater from sludge dewatering at the Rincón de León wastewater treatment plant (Alicante). The cell used here has an area of 0.0415 m^2 and can operate at a maximum flow rate of 200 l/h.

Membrane distillation is a thermally driven process where the difference of temperature between the condenser and evaporator creates a temperature gradient to create a vapour pressure difference that drives the water (and volatile substances) vaporisation and permeation across a hydrophobic microporous membrane. However, the inevitable competition among volatile substances (e.g., ammonia) and water lowers separation efficiency. Inducing an alkaline condition leads to a conversion of the ammonia present in the wastewater to more volatile, free ammonia, which can then transfer to the permeate together with water vapour through the hydrophobic pores of the MD membrane.

Figure 6: Lab scale SolarSpring GmbH (Germany) membrane distillation (MD) setup at Eurecat (Manresa).

MD can be operated in the various configurations where the most common are direct contact membrane distillation (DCMD) and air gap membrane distillation (AGMD). The main difference is the additional air gap in AGMD between the hot feed solution and the cooling or permeate side, enabling internal heat recovery inside the module as any liquid can be used on the cooling side e.g. the feed solution itself. The air gap in AGMD created by the addition of an impermeable film towards the cooling side, provides a much higher insulation between the channels. This lowers the flux compared to DCMD but also reduces the conductive heat transfer across the combined membrane and gap. However, when the aim is to recover nitrogen DCMD isn't normally applied, the direct contact between the condenser and the permeate.

2.1.2 Results

2.1.2.1 Co-digestion of oil, fats and food waste (T2.1.1)

A physico-chemical characterization as well as the biomethane potential of several co-substrates was carried out together with the sewage sludge of Rincón de León WWTP to determine their suitability for co-digestion. Two co-substrates, out of the four initially identified, showed potential (high chemical oxygen demand (COD), biomethane potential (BMP) and biodegradability): ice cream waste from cream industry and fruit waste from food unit. Oil and fats from the supernatant of the WWTP were discarded due to low volatile solids (VS) content and low availability.

The operation of the pilot plant was started with sewage sludge alone to set the baseline biogas production, which resulted in 0.33 L/min or 10.94 Nm^3 biogas/m^3 SS and a COD removal of 48.2%, which are comparable results to those obtained in the on-site digesters in the WWTP. After validating the baseline, the ice cream waste was mixed with sewage sludge in a 95-5% ratio in volume basis and after more than 70 days of operations the biogas production increased up to an average 0.82 L/min, which is 2.48x times the production with sewage sludge alone. Then, the pilot plant was operated with a waste consisting of fruit and vegetables waste as co-substrate and the same volume ratio mixture with sewage sludge. The biogas production was found to be in 0.56 L/min, an increase factor of 1.7 compared to mono-digestion.

2.1.2.2 Microturbines (T2.1.2)

The flow selected as nominal flow for the turbine was 0.3 m^3/s (370 l/s) together with a head of 0.8 m. It was concluded that the picoturbine had a reduced efficiency in comparison to the standard range, which is to be expected as the efficiency of engines and electronics increase with machine size. The resulting peak performance of the picoturbine was in the range of 48-51%, caused mainly by the small size of the machine, knowing that several parameters affecting hydraulic efficiency do not scale down linearly with size, and to the fact that several mechanical and electrical losses do not scale linearly either

2.1.2.3 Selective Electrodialysis and electro-chlorination (T2.1.3)

The selective electrodialysis was operated both in batch mode and feed and bleed mode, with the objective of separating monovalent ions (Na+, Cl-) from divalent ions in brines generated from the reverse osmosis step in de Rincón de León desalination plant. In the batch operation it was observed a significant recovery of the monovalent ions in the concentrate stream as well as a high recovery of divalent ions (Ca^{2+}, $Mg^{2+)}$ in the “diluted” stream. Then, with the conversion into a feed and bleed configuration, the pilot plant was capable of further concentrate monovalent ions up to a Cl- concentration of around 29 g/l. The softening step, necessary to reduce some elements prior to the electro-chlorination, resulted in a 20% removal of the monovalent ion but achieved a stream suitable for the technology.

The electro-chlorination unit was finally continuously operated with real RO brine from the Rincón de León IRAD previously concentrated in salt by the selective electrodialysis, and it resulted in the production of a maximum flow of 90 L/h of concentrate synthetic brine in the electrodialysis reversal (EDR) with a conductivity up to >22 mS/cm with. The electro-chlorination unit was capable of continuously producing a product flow of 140 l/h of sodium hypochlorite at 3,500 ppm of free available chlorine (FAC), meeting the technical specifications of the technology.

2.1.2.4 Ammonia recovery and fertilizer production (T2.1.4)

The CEVAP technology was operated with the drained water stream coming from the thermal dehydration of sludges in the cement local industry, which according to its characterization presented an ammonia concentration of around 800 mg/L. Preliminary batch tests at different temperatures (81, 85 and 89ºC) were carried out resulting in similar results regardless the temperature. At all temperatures the ammonia was concentrated from 860 up to 1,200 mg/L. The only difference between the varying temperature conditions was the resulting flow, meaning that the higher the temperature, the higher the flow and the faster the process of concentration. In another set of batch experiments conducted at temperatures ranging from 80 to 89ºC, the pH of the feed solution was adjusted at pH above 10.5 using a commercial solution of caustic soda (NaOH) at 50%. This adjustment was aimed at promoting the equilibrium of ammonia towards NH_3. Significantly higher ammonia concentrations were obtained in the condensate stream reaching 3,172 mg/L in the test at 85ºC. The temperature 89ºC was discarded due to instabilities in the conditions.

Finally, the concentrated stream of several batch tests was operated in a loop mode in the CEVAP at 85 ºC to further concentrate the ammonia in the condensate stream. This recirculation experiment resulted in the production of a condensate flow of 63.5 L/h at a concentration of 5,000 mg/L of ammonia, achieving a concentration factor of nearly 6x considering the initial concentration. It needs to be highlighted that an ammonia mass balance revealed that only 41.5% of the initial ammonia was recovered through the condensate stream.

Air Gap Membrane Distillation (AGMD) configuration was used to recover nitrogen of wastewater, where the NH4-N concentration measured approximately 600 mgL^{-1}. The wastewater first underwent filtration using a 0.33 m^2 ultrafiltration membrane (CUT, Germany). This step served to eliminate suspended solids and prevent membrane fouling. Since low grade waste heat can be used to apply the necessary thermal energy required to power the process, all the experiments were developed to work on an initial temperature at the evaporator of 50oC and a flow rate of 200 Lh^{-1} at a pH of 10 in order to create a condition to favour the transformation of NH_4-N to a NH_3-N form, which in turn facilitates evaporation and hence, increase the recovery ratio. Four experiments were performed at 4 different ΔT (i.e. temperature deltas between condenser and evaporator) with the temperature at the evaporator held constant at 50°C. As expected, the permeate flux exhibited a linear correlation with ΔT, highlighting the significant impact of temperature on the process (see Figure 7). Boxes cover the 25th to the 75th percentile of the data, while the orange line indicates the sample median. The whiskers span 1.5 times the interquartile range. The black circles indicate outliers, and the blue line represents a linear fit (ordinary least squares regression) for delta T as independent variable and the respective median values as dependent variable.

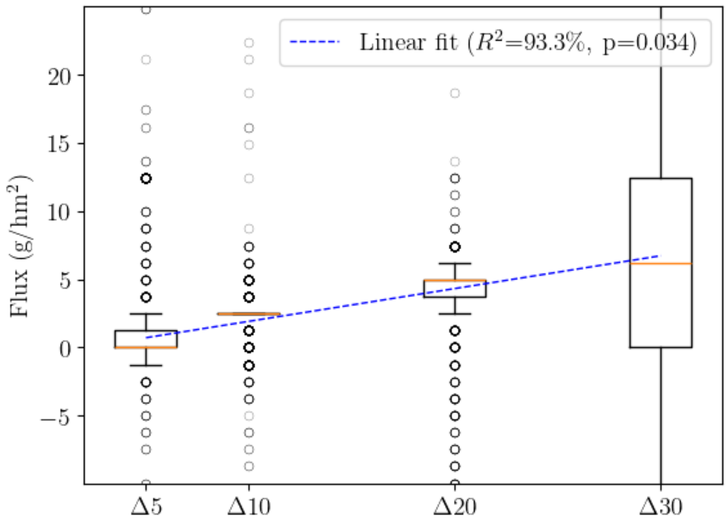

Figure 7: Boxplots showing the permeate flux on the y-axis for the 4 different temperature conditions ΔT on the x-axis, with the initial NH_4-N concentration at approximately 600 mgL^{-1} and Q=200 L/h.

When the ΔT is 5, flux is the lowest, 0.5 g/hm^2, the recovery of NH_4-N is approximately 20% after 100 hours of operation. However, as ΔT increases to 30 the recovery is above 80% when operating the setup for 100h (see Figure 8). These preliminary studies using MD have demonstrated its potential as a promising technology for recovering nitrogen from wastewater.

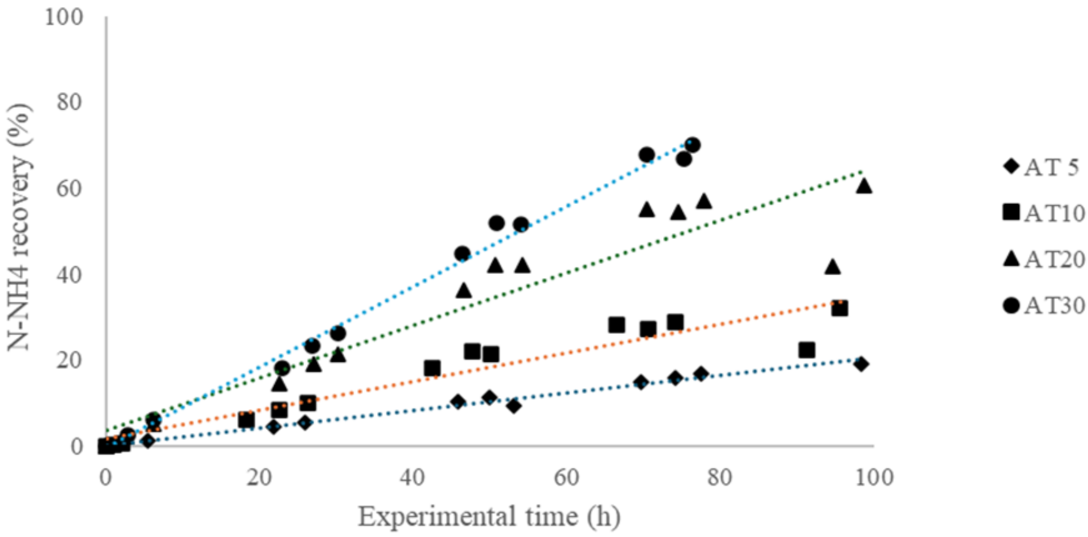

Figure 8: NH_4-N percentage recovery at 4 different ΔT (keeping constant the temperature in the evaporator at 50°C); initial NH4-N concentration ~600 mg L^{-1} and Q=200 L/h.

2.1.3 Challenges

In the B-WaterSmart project, the evaluated technologies have been operated over a relatively short period and at a pilot scale. While this allowed us to demonstrate their initial feasibility and gather valuable performance data, it is important to recognize that the pilot scale does not fully capture the complexities and potential challenges that may arise when scaling these technologies to full-scale operations. Many of the challenges discussed below, such as feedstock variability, operational optimization, and long-term efficiency, were not encountered during our pilot tests but could potentially occur in a full-scale implementation. The main challenges encountered at the pilot scale include the simultaneous operation of several pilot plants, coping with delays in pilot construction and installation at the site, and dealing with multiple technology providers, some of whom are international. Additionally, we faced operational failures in some pilots, necessitating the replacement of damaged equipment, all while striving to meet the project timelines. In the following subsections, the challenges for the full-scale implementation of the different technologies are briefly discussed.

2.1.3.1 Co-digestion of Oil, Fats and Food Waste (T2.1.1)

- **Consistency of Co-substrates:** The quality and consistency of co-substrates like ice cream waste and fruit waste can vary significantly, affecting biogas production efficiency. Seasonal variations and supply chain inconsistencies can result in fluctuating chemical compositions and biodegradability of the feedstock.
- **Contaminants:** Potential contaminants in food waste, such as plastic, metals, or other non-organic materials, can disrupt the digestion process, leading to operational inefficiencies and potential damage to the equipment.
- **Mixing and Homogeneity:** Ensuring a homogeneous mixture of sewage sludge and co-substrates is crucial for optimal digestion. Inadequate mixing can lead to uneven digestion and reduced biogas yields.
- **Impurities in Biogas:** The presence of impurities like hydrogen sulphide and ammonia in the biogas can corrode equipment and reduce the overall efficiency of the biogas utilization systems.

2.1.3.2 Microturbines (T2.1.2)

- **Size-Related Efficiency Losses:** The reduced efficiency of the picoturbine, primarily due to its small size, poses a significant challenge. The non-linear scaling of hydraulic, mechanical, and electrical losses affects the overall energy conversion efficiency.
- **Performance Optimization:** Achieving peak performance requires precise calibration and optimization of the turbine components, which can be technically demanding and resource intensive.
- **Available head and flow:** The requirements of pico- and microturbines in terms of head and (most importantly) flow mean that reasonable payback periods can be expected only in large WWTPs.

2.1.3.3 Selective Electrodialysis and Electro-chlorination (T2.1.3)

- **Ion Selectivity and Separation Efficiency:** Achieving high selectivity for monovalent ions while minimizing the removal of divalent ions requires precise control over operational parameters, which can be technically challenging.
- **Scaling and Fouling:** The membranes used in electrodialysis are prone to scaling and fouling, especially when treating brines with high concentrations of salts and other impurities, reducing the efficiency and lifespan of the system.
- **Process Integration:** Seamlessly integrating the electrodialysis unit with the electro-chlorination system to ensure continuous and efficient operation requires careful design and synchronization of the two processes.
- **Operational Stability:** Maintaining stable operation in the electro-chlorination unit, especially under varying feed conditions, is crucial for consistent production of sodium hypochlorite at the desired concentration.

2.1.3.4 Ammonia Recovery and Fertilizer Production (T2.1.4)

- **Recovery Rates:** The recovery rate of ammonia, which was only 41.5% in the pilot tests, indicates significant losses that need to be addressed to improve overall process efficiency and economic viability.
- **Temperature Control:** Maintaining optimal temperature conditions for ammonia concentration without causing instabilities is a technical challenge that requires precise control systems.
- **Handling of Caustic Solutions:** The use of caustic soda for pH adjustment poses safety and handling challenges, necessitating strict operational protocols and safety measures.
- **Scalability:** Demonstrating that the technology can be effectively scaled from pilot to commercial scale, maintaining efficiency and economic feasibility, is a critical challenge.
- **Market Acceptance:** Ensuring that the recovered ammonia and produced fertilizers meet market standards and regulatory requirements is essential for commercial acceptance and success.
- **AGMD limitations:** While AGMD demonstrated promising potential for ammonia nitrogen recovery, achieving high recovery rates (>80%) necessitated specific operating conditions. Notably, pH adjustment to levels exceeding 10 and a substantial temperature difference (over 30°C) were required. These conditions, while effective, contribute to increased energy consumption, presenting a trade-off between recovery efficiency and operational costs. Furthermore, the experiments were conducted using a small-scale laboratory module (0.0415 m^2), being able to treat just over 20L of wastewater every 5 days, resulting in low permeate fluxes. AGMD enables internal heat recovery inside the module as any liquid can be used on the cooling side e.g. the feed solution itself. On the other hand, this process enables the possibility to use waste heat, which would make this process energy efficient. Perhaps in the

future, trials should be done integrating the process together with the heat produced in a digester of a wastewater treatment plant.

2.1.4 Lessons learned

The lessons learned in general terms are:

- Including pilot plants recycled from previous or concurrent projects makes it really important to thoroughly assess existing systems and meticulously plan the resources needed for equipment updates and repairs to prevent disruptions and deviations.
- Setting a well-conceived mitigation plan is crucial for expediting decision-making and subsequent actions in case of deviations led by pilot plants.
- The commissioning of pilot plants at the facility requires careful planning, including thorough consideration of health and safety factors. These factors may include heat during the summer months and the potential presence of mosquitoes.
- Global electronic component shortage occurred in 2022-2023, which delayed the construction of pilot units.

More specifically, the lessons learned for each technology are summarised in Table 1.

Table 1: Lessons learned for each technology evaluated in Alicante LL.

Technology	Lessons learned
CEVAP (#9)	As part of the contingency plan set for this technology, an in-person training at the facilities where it was installed before Alicante to the AMAEM staff in charge of its operations was highly useful. Relying on recycling the pilot unit from another ongoing project has led to delays in installing the pilot at Alicante LL. The CEVAP can concentrate ammonia to a certain level, but far from a commercial ammonia reagent, due to evaporation losses that cannot be quantified. Being an evaporative technology, increasing the temperature (i.e. OPEX) is a requirement although temperatures necessary are much lower than in conventional evaporators. This could be achieved with waste heat generated in the cement industry that currently carries out a thermal drying of the sewage sludges of Alicante WWTP.
Brine valorisation treatment train (#8)	A training was carried out at the subcontracted engineering firm that constructed the pilot plant before its transport and installation at the WWTP. This action helped the operators to gain knowledge and time before its commissioning. The brine treatment train consisted of technologies from different technology providers and its integration. Preliminary tests of the integration of pilot units are a complex task and needs sufficient time allocation to guarantee a successful integration.

Microturbines (#13)	Carrying out a preliminary design with dimensions and site specifications and requirements is fundamental for a smooth task progress and turbine construction. In WWTP it is important to have previously identified and in mind the seasonal and daily variations of water flow for an optimal design. Energy production through microturbines with water effluents in WWTP would make more sense in much bigger installations than Rincón de León WWTP that treat higher water flows.
Co-digestion (#10)	A good relationship was established with two local companies from the beginning of the project and were willing to collaborate providing waste. The co-substrates assessed in the project are suitable for co-digestion, but their current production (tons/year) are not enough for full scale implementation. The business model of waste management and co-digestion needs to be carefully evaluated together with the waste producers. A waste manager as mediator can offer the service of managing waste from industries and provide it for co-digestion. Seasonal variations of waste production from the companies are also a key point to consider for co-digestion studies.

2.2 Bodø

Bodø is a small city above the Arctic Circle in Norway with a population of 53,000 inhabitants. Key challenges include the growing resident population and economy, increased pollution, and untapped efficiency potential. Under WP2, the tools selected for LL Bodø were split into two sub-tasks, T2.2.1 'The smart water meter pilot area' and T2.2.2. 'The sludge to energy feasibility study', as seen in Figure 9.

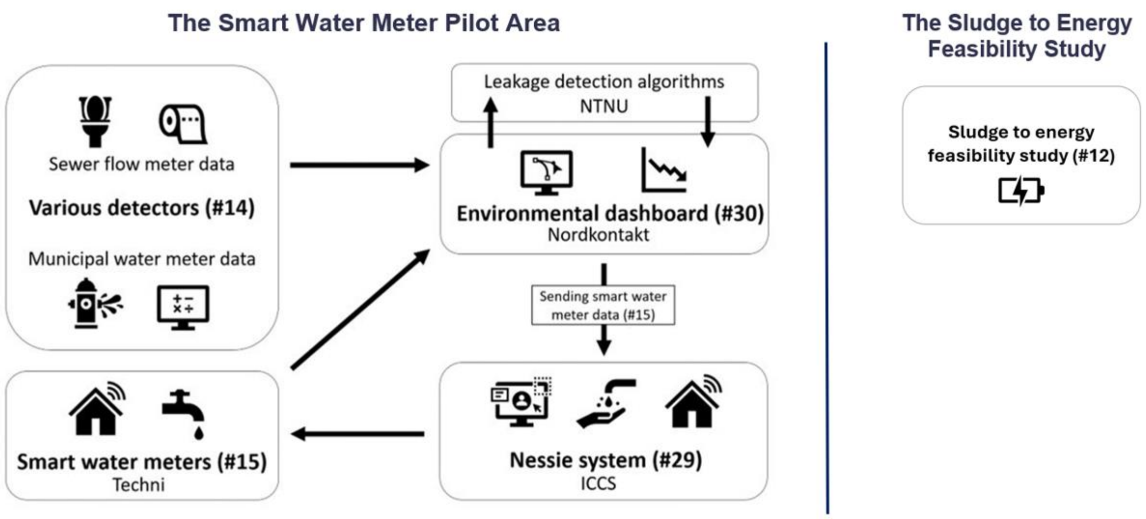

Figure 9: LL Bodø overview and connections between the technologies and tools.

2.2.1 Description

2.2.1.1 The Smart Water Meter Pilot Area (T2.2.1)

Subtask 2.2.1 involves the study and development of monitoring and communication technologies, algorithms, approaches for leakage and infiltration/inflow quantification, detection, and localization (#14). The application of self-powered smart water meters (#15) allows for the acquisition, storage and communication of flow, pressure, and temperature data with a high temporal resolution of up to one minute. In conjunction with the existing district meters of the municipality, this data was the basis for both the application of existing methods for leakage quantification and the development of new data-driven algorithms for leak detection. To test both sets of leakage detection algorithms, an artificial leak scenario was designed and carried out in the field, providing openly available test data for future studies.

Two sewer flow meters (#14) were installed in the pilot area for infiltration and inflow estimation. Several infiltration and inflow methods were explored and evaluated for applicability resulting in the application of a method based on a sewer flow measurement campaign. Furthermore, a proof of concept for the possibility of modelling the interdependency between leakage out of the water distribution system and infiltration into the sewer was developed.

Two dashboards were developed under WP3 and closely connected to T2.2.1. The Nessie Dashboard (#29) provides homeowners with a detailed view of the consumption in the household, as well as the Environmental Dashboard (#30) is designed for a municipal overview of the water system. Detailed data collection and accessibility through the Environmental Dashboard's and the Nessie System's APIs empower better decision-making in water and wastewater infrastructure projects and for homeowners' personal use.

More detailed information and findings can be found in the public Deliverable 2.4 - Leakage and infiltration detection techniques.

2.2.1.2 The Sludge to Energy Feasibility Study (T2.2.2)

Subtask 2.2.2. is based on the sludge to energy feasibility study (#12) which explores potential energy recovery in the form of biogas production from different solid waste/sludge streams of different characteristics, i.e., municipal sludge from wastewater treatment plants (WWTPs) and solid wastes from different sources (e.g., food, aquaculture, and agriculture wastes). This is addressed for both sludge inputs originating solely from Bodø and its surrounding areas. The study provides a technical overview of treating and recovering digestate and reject water post-biogas production. It explores alternative methods for handling biosolids post-anaerobic digestion, including their further processing into compost, bio pellets, or biochar.

Further information regarding the study is found in the public Deliverable 2.5 - Technical performance and overall waster smartness and sustainability of alternatives for energy production from sludge treatment.

2.2.2 Results

2.2.2.1 The Smart Water Meter Pilot Area (T2.2.1)

The smart water meters (#15) use a combination of a turbine/generator in combination with a bypassing valve for excess flow to generate the energy for the water meter from the flow of water, which differentiates them from all existing water meters. The deployment of those smart water meters within a residential area enabled real-world testing of energy balancing models which is crucial for comparing energy generation versus energy consumption. The energy balance of the SWMs indicates that a sustainable balance has been achieved. This means that an inflow and outflow from the battery is guaranteed in a manner that projects a “infinite” life from an energy point of view at 60 seconds data transmission. The energy level of most meters remained at a high level. The water meters did connect to the network for most of the meters. A group of meters lost their connection at a high charge state, but at this point, the underlying reason has not been identified. Condensation has been observed on the outside of several water meters, but no water or onsets of corrosion have been found internally in the housing. Apart from one water meter with a drifting pressure sensor, the pressure data has been consistently reported from all the meters. All the meters have provided water and ambient temperature data consistently. Table 2 shows the resolution and frequency of the measured parameters.

Table 2: SWM resolution and logging and sending frequency.

Parameter	Frequency	Resolution
Water Volume	Consumption in the last 60s, in L	8 ml per step
Pressure	Every 60s	0,1 bar
Temperature	1/h	0,1 degree
Battery	1/h	0,01 Volt

The various detectors (#14) tested were applied to estimate and detect leakages in the water distribution system and I/I in the sewers. For leakage estimation a water balance approach was applied to conform with Norwegian guidelines, based on the API of the Environmental Dashboard (#30). For leak detection data-driven models using encoder-decoder models were used. To evaluate the applicability of deep-learning models, three classes of encoder-decoder models were developed – (i) simple autoencoder (AE), (ii) long-short-term memory autoencoder (LSTMAE) and variational autoencoder (VAE). These models take pressure measurements as inputs and reconstruct those signals as outputs. If there exists one or more leaks in the network, the reconstructions from these models vary significantly representing the onset of leaks. For I/I estimation the focus was laid on well-tested and proven methodology and its impact and first-time application in a utility with similar challenges and possibilities as LL Bodø to allow a more effective use in practice of available knowledge/tools, as well as capacity building for the involved personnel. The main results of these approaches can be summarized as follows:

- **Creation of a Novel Artificial Benchmark Dataset:** A unique benchmark dataset was developed through simulated leakages by strategically withdrawing water from various fire hydrants in the pilot area. This dataset utilizes the smart water meters’ pressure sensors, as well as municipal flow meters The dataset is publicly available for future research and development in leakage detection and water management technologies.
- **Leakage detection testing:** SWMs with high granularity can be used for in-house leakage detection, customer behaviour analysis, demand, and leakage quantification, but findings have concluded that the smart water meters alone are not reliable enough to detect leaks in the distribution system. The inflow measurements, however, obtained from Bodø Municipality’s DMA system reflected the simulated leak events. Further, despite no significant changes in pressure measurements from SWMs, the flow measurement for one SWM showed a possible inhouse plumbing fault and significant variations during simulated leaks. This indicates that in-house leaks could be detected with the availability of SWMs as long as the uncertainty matches the sampling frequency, but in the current setup not for the distribution system.

- **Mapping and Monitoring of Infiltration/Inflow:** Examining flow estimates at the research region's entry and exit points during rainy seasons reveals notable differences that point to a significant inflow into the study area. In particular, the maximum average flow rate at the point of exit is 3.3 times greater and the multi-net fault (MNF) value is almost 4.3 times higher during the rainy season than it is during the dry period within the pilot area. The results of this study highlight the value of flow measurement investigations in detecting a variety of problems, including illicit rainwater connections and improperly connected stormwater pipes to the sewage network. The method has proven to be robust and easily applicable for the utility.
- **Proof of concept for interconnected sewer/ Water Distribution System Models:** To combine sewer flow measurements with the SWMs and leak estimates, we investigated the interconnectivity of urban water system models and the infiltration of leaked water from the water network into the sewer pipes through a combination of EPANET and Stormwater Management Model (SWMM). A conceptual model was developed to identify and model the relations between the water distribution system and the sewer network.

More detailed information and findings can be found in the public Deliverable 2.4 - Leakage and infiltration detection techniques.

2.2.2.2 The Sludge to Energy Feasibility Study (T2.2.2)

The study focused on improving resource recovery from wastewater in an efficient way given the small scale and decentralized wastewater treatment plant structure in Bodø with six small wastewater treatment plants. Alternatives (see Table 3) were assessed to evaluate the potential of biogas production from different sludge and solid waste streams from Bodø and the surrounding area in Salten. The technical assessment was extended to compare the water smartness and sustainability of the alternatives using the Water Smartness and Sustainability Index developed in the H2020 project WIDER UPTAKE, which is collaboration with B-Water Smart in the CIRSEAU cluster.

Table 3: Summary of the alternatives assessed in the study

Alt.	Technology		Input					Output	Possible marketed output
	Sludge	Reject water	Bodø sludge	Salten sludge	Food waste	Garden waste	Fish sludge		
Alt.0	THP + AD + Composting	MBBR	YES	NO	NO	NO	NO	biogas, compost	Heat, electricity, compost
Alt.1	THP + AD + Composting	MBBR MBBR + Struvite + Anammox	YES	YES	YES	YES (in composting)	YES	biogas, compost	Heat, electricity, compost
Alt.2	THP + AD + Pelletizing	MBBR + Struvite + Anammox	YES	YES	YES	NO	YES	biogas, biopellet	Heat, electricity, biopellet
Alt.3	THP + AD + Pyrolysis	MBBR + Struvite + Anammox	YES	YES	YES	YES (in pyrolysis)	YES	biogas, biochar	Heat, electricity, biochar
Alt.4	THP + UASB + Pyrolysis	MBBR + Struvite + Anammox	YES	YES	YES	YES (in pyrolysis)	YES	biogas, biochar	Heat, electricity, biochar
Alt.5	2 lines (THP + AD + Composting)	MBBR + Struvite + Anammox	YES	YES	YES (separated)	YES (in composting)	YES	biogas, compost	Heat, electricity, compost

Recovering the solids as compost in cold climate countries can require additional energy during winter and land field spreading of compost will depend on the availability of sufficient agricultural land with crops that allow use of wastewater sludge for soil improvement close to the treatment plant. These factors will influence the viability of alternatives 0, 1 and 5, whereas bio pellets, biochar and bio-oil from alternatives 2, 3 and 4 are valuable products that can be sold on the market as fertilizer for the 2 first, or directly reused as fuel for different processes (bio pellets or bio-oil). A specific study of the market opportunities is recommended to be carried out in the area of implementation.

Reject water treatment should comply with the industrial effluent directive. For all alternatives, reject water treatment can be by a traditional end of pipe solution or, alternatively, be with implemented with recovery of Struvite fertilizer. For both cases optimization of the design will be required to ensure compliance with the expected discharge standards. The results of the energy calculations (see Figure 10) indicate that Alternative 3 has highest net energy balance, closely followed by Alternative 4. However, Alternative 4 with UASB as a digester is the most compact alternative with the lowest footprint compared to other alternatives using AD (results not shown here but in D2.5).

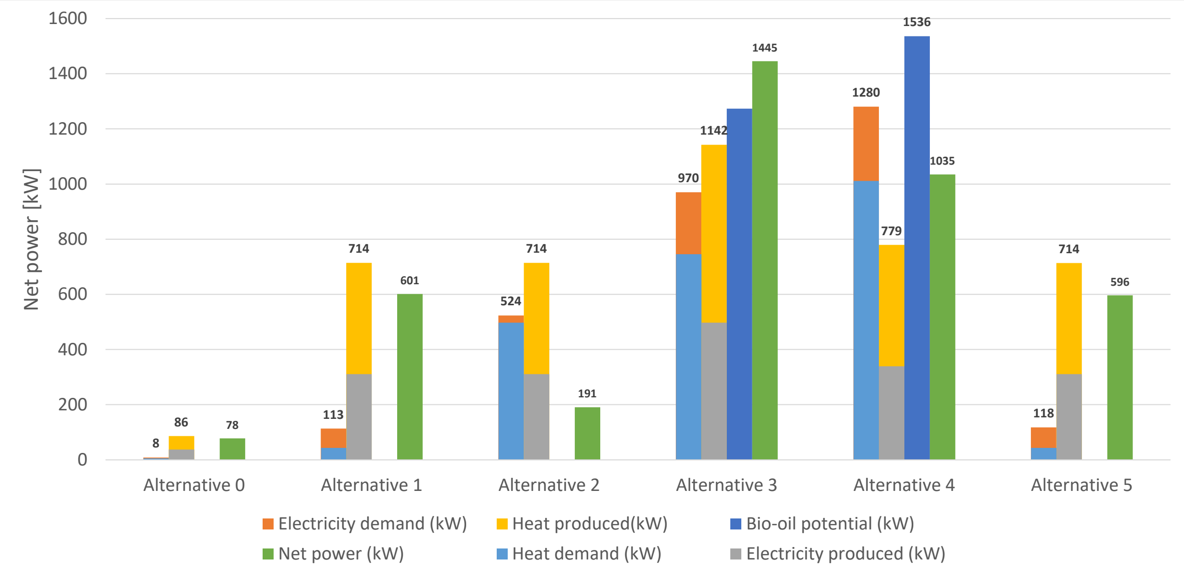

Figure 10: Net energy balance for the different alternative solutions.

The results from the water smartness and sustainability assessment showed clearly that data availability was an issue. One should therefore consider the results as preliminary. However, the assessments confirm the need for more sludge than available in Bodø municipality and that aiming for other products than compost in addition to biogas is favourable. Overall, the assessments indicate that Alternative 4 will be the preferred solution. This is mainly due to a combination of having valuable products (biogas, biooil and biochar), saving volume and presumably investment costs by using an UASB instead of an anaerobic digester, and having a favourable energy balance. However, as noted, one should take this only as a preliminary conclusion that should be verified considering the uncertainties in the value chain for biooil and biochar and the level of accuracy in the technical evaluation.

2.2.3 Challenges

2.2.3.1 The Smart Water Meter Pilot Area (T2.2.1)

- **Pandemic-Related Delays:** The Corona Virus Pandemic created a limited availability of company parts and required a hefty smart water meter redesign.
- **GDPR Documentation:** The creation of data processor agreements between several project partners, risk analysis matrices and homeowner contracts for General Data Protection Regulation (GDPR) is more complex than initially anticipated.
- **Security certificate delay:** The smart water meters were rendered temporarily inoperable, due to a Microsoft update.
- **Volunteer Participation:** Volunteer participation challenges regarding the installation of SWM in private residences with shared dwellings.

- **Equipment and Data Challenges:** Loss of sensors and troubleshooting of SWM.
- **Data noise** from flow meters for inflow and outflow measurements obtained from the Bodø Municipality as well as SWM data found in multiple repeated samples. To tackle this, data preprocessing was done carefully to discard spurious samples and remove duplicates.

2.2.3.2 The Sludge to Energy Feasibility Study (T2.2.2)

- **Sludge Quantity:** Lack of sufficient quantity of sludge posed challenges in generating and utilizing more energy throughout the sludge generation process.
- **Data Availability:** Lack of sufficient data to assess all aspects of the solution with the same degree of accuracy.
- **Leadership Transition:** The study experienced a task leadership change midway due to the departure of a project member, necessitating a restart of the study based on the previous partner's findings.

2.2.4 Lessons learned

2.2.4.1 The Smart Water Meter Pilot Area (T2.2.1)

- **Energy balancing:** The field tests confirm the energy balancing simulation executed in development as we observe that a sustainable energy balance has been found in most of the water meters, meaning the generated energy balances the consumption of energy at the given logging resolution and sending frequency.
- **Sound Issues:** SWM produce a turbine noise during water flow, which is amplified through the house piping. Future revisions of the SWM should focus on noise reduction.
- **GDPR Documentation:** It is essential to allocate sufficient time for the preparation and management of GDPR-related documentation.
- **Leakage detection:** Leakage detection methods and algorithms found that the obtained pressure and flow data from SWM did not show any correlations concerning leak events on the municipal network, however, in-house leaks were easily detected. This was also evaluated using analysis of signal reconstructions from the AE models.

2.2.4.2 The Sludge to Energy Feasibility Study (T2.2.2)

- **Sludge Quantity:** The amount of sludge produced in Bodø is insufficient to meet the energy generation needs, highlighting the need for additional sources.
- **Market Opportunities:** A further specific study of the market opportunities is recommended to be carried out in the area where the sludge-to-energy system will be implemented.
- **Local Involvement**: This study may take the current as a point of departure and should also be guided by the conclusion of the study conducted by the local stakeholder Iris who has not been a partner in B-Water Smart.

2.3 East Frisia

In East Frisia the feasibility of converting whey vapours into high quality water has been demonstrated on pilot scale. If complying with hygienic prerequisites and considering lessons learnt in this project, a hygienically safe water quality can be produced to successfully substitute drinking water consumption. The produced water then hygienically fulfils the requirements of the German drinking water ordinance. The water produced in the pilot plant operated by LL East Frisia did not only contain low cell numbers directly after treatment, but also displayed a regrowth potential equal to that of the local drinking water.

2.3.1 Description

The LL East Frisia aimed at demonstrating the feasibility of converting whey vapour condensates (referred to as `cow water`) that are a side product in the dairy industry into high quality water. The project was performed at a dairy company processing approximately 1 million tons of milk every year with a drinking water footprint in the same magnitude. Treating whey and whey vapour condensates for internal water reuse has the potential to substantially reduce the drinking water demand and therefore to reduce the necessity of ground water abstraction for drinking water production.

A pilot plant for treating COW water was installed on site for demonstration purposes. Treatment followed a multi-barrier treatment approach. The applied technologies included different bioreactors (fixed bed & fluidized bed reactor, multilayer filter) for biological treatment and ultrafiltration (UF) and reverse osmosis (RO) for physical treatment (see Figure 11).

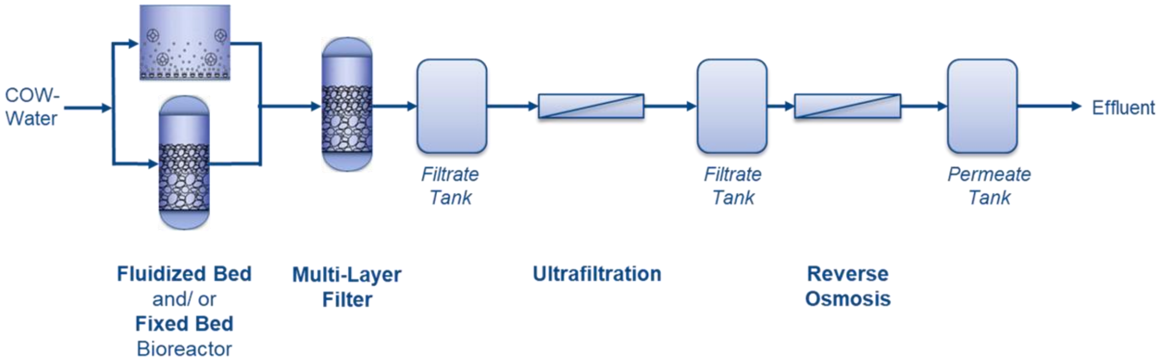

Figure 11: Simplified process diagram of the hybrid treatment train comprising biological and physical treatment stages.

Whereas the parallel fluidized and fixed bed bioreactors aimed at the conversion of the organic load contained in the cow water into biomass, the latter was removed by the multilayer filter and the subsequent ultrafiltration (UF). Salts and trace substances were eventually removed by reverse osmosis (RO). The pilot plant (see Figure 12) was accommodated in two overseas containers (12.5m x 7m). The containers were located on one of the production sites of the participating dairy company "Deutsches Milchkontor" (DMK) in Edewecht, Germany.

The results of the pilot plant operation were reported in the confidential Deliverable 2.11 (contact at ENV), which was submitted in M45.

Figure 12: Impressions of the pilot plant of LL East Frisia. The treatment technologies were located in the blue containers. The inside of the containers is depicted below.

2.3.2 Results

Various aspects are employed in the assessment of plant performance. Alongside process steps, analytically recorded water quality parameters and hydraulic performances are used for evaluation. Continuously monitored quality parameters are measured through online assessments, encompassing Total Organic Carbon (TOC) concentration in the pilot plant's feed, TOC concentration in the treated water of the pilot plant, and the electric conductivity in the treated water of the pilot plant. The hybrid of biological and physical treatment lowered TOC concentrations from a starting concentration of > 6 mg/L to < 0.1 mg/L. Up to 90% of the TOC was hereby removed by the combined biological treatment stages underlining their importance in the overall treatment.

Another important aspect was assuring the hygiene of the treated water. Microbiological monitoring showed high colony counts for biological treatment steps in line with microbiological degradation activities. Physical treatment on the other hand led to a strong reduction of actual cell numbers (see Figure 13).

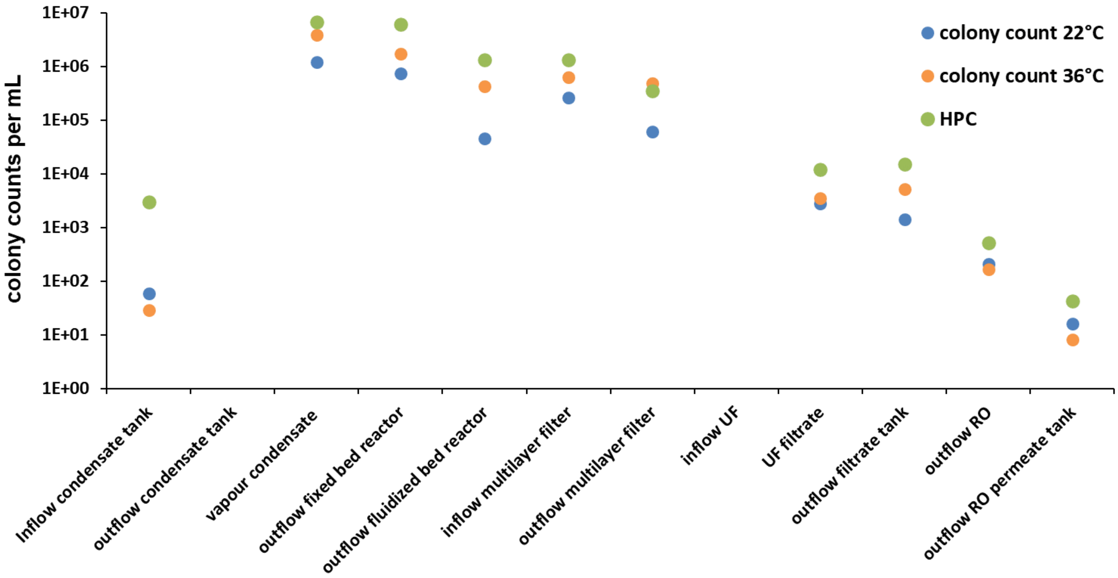

Figure 13: Changes in colony counts determined by culture at 22°C or 36°C and heterotrophic plate counts (HPC) along the treatment train. Data refers to sampling round 2 (23.05.2023).

The decline in colony counts (as determined by culture) was in good agreement with a decline in cell numbers for the membrane processes as assessed by flow cytometry. Flow cytometry was also used to quantify the bacterial regrowth potential based on the overall nutrients contained in the sample. The overall bacterial regrowth potential was reduced by approx. 97 % relative to the highest value obtained for the vapour condensates (see Figure 14). This value is in good agreement with the TOC removal efficiency. The absolute bacterial regrowth potential of the RO permeate was comparable with the maximal regrowth potential of local drinking water with approx. 105 intact cells/ml.

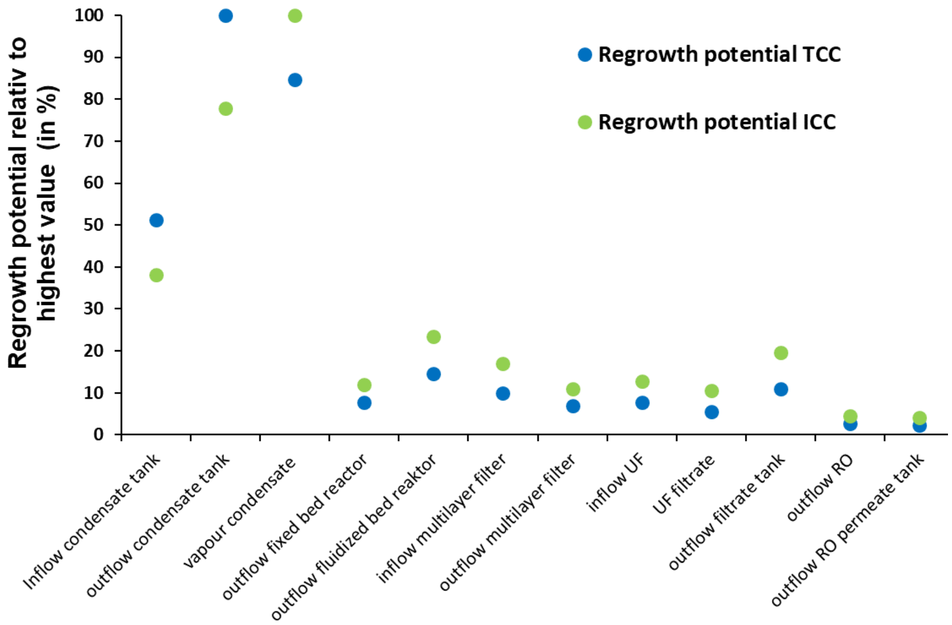

Figure 14: Regrowth potentials of total and intact cell concentrations (day 7 values) relative to the highest value obtained for vapor condensate. Data refers to sampling round 2 (23.05.2023).

It was thus shown that (I) the removal of nutrient load and (II) the subsequent removal of biomass can be successfully achieved in practice. It could further be shown that ultrafiltration results in a "microbiological reset" of the bacterial population. The bacterial population before and after ultrafiltration showed a pronounced dissimilarity. Changes of the bacterial community on the genus level along treatment (as determined by 16S rRNA gene sequencing using Oxford Nanopore technology) are shown in Figure 15. Whereas too little biomass was contained in the ultrafiltrate alone, sequences were obtained from the outflow of the UF filtrate tank. The sample showed a distinctly different bacteria community composition in comparison with samples earlier in the treatment.

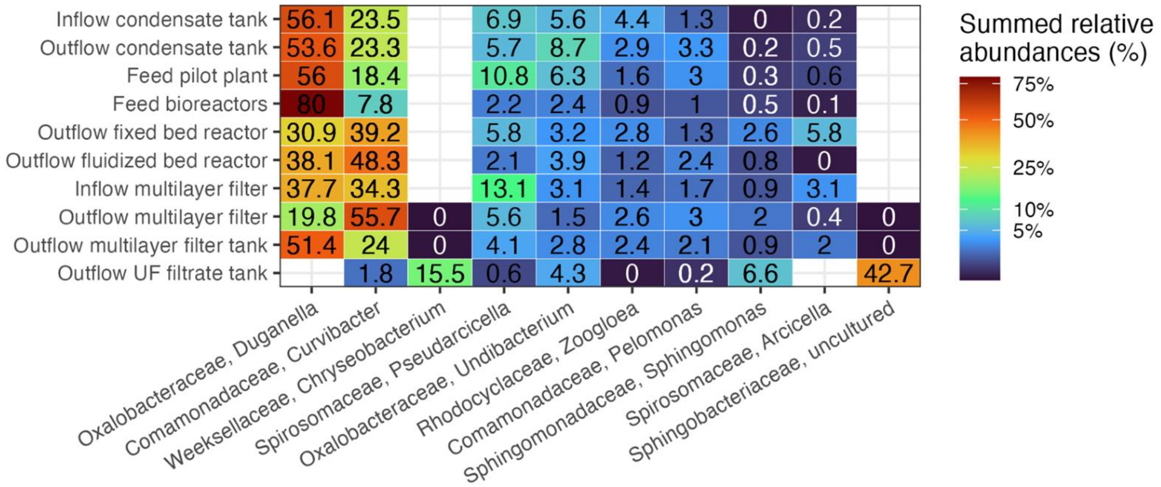

Figure 15: Changes in relative bacterial abundances along cow water treatment on genus level. Data are based on full length 16S rRNA analysis using nanopore sequencing of genomic DNA extracted from samples taken on 11.12.2023.

The pronounced difference of the bacterial community profile of the UF filtrate tank sample was also visible when performing principal component analysis (PCA, see Figure 16). On the first axis explaining 61.08 % of the variance, the bacterial community profile of the UF filtrate tank sample was greatly distinct from the other samples.

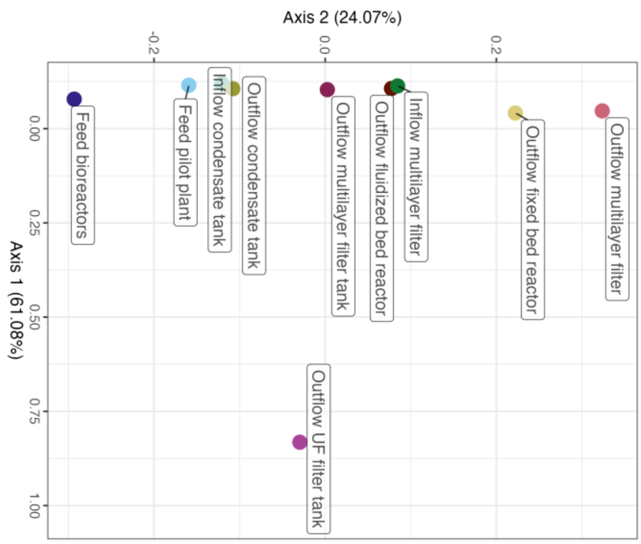

Figure 16: Principal component analysis of 16S rRNA full length sequences. Data is based on samples taken on 11.12.2023.

The second PCA-axis explaining 24.07 % of the difference, suggests that bacterial communities prior to the bioreactors were distinct from samples from the bioreactor effluent samples. The data reflect a gradual change in bacterial communities during biological treatment from the inflow of the condensate tank to the bioreactor effluents. The result corroborates that ultrafiltration is an efficient microbiological barrier. The final water (RO permeate) was free of the hygienically relevant organisms or hygiene indicators E. coli, intestinal enterococci, Clostridium perfringens, Pseudomonas aeruginosa and Legionella in the RO permeate.

Overall, the performance of the pilot operated for more than one year was shown to be promising for the implementation of full-scale treatment. Gaining permission by food authorities for using reused water in dairy processes would be a significant contribution to conserve natural drinking water resources and to reduce local ground water abstraction. Adding more examples in different industries will eventually lead to the corporate motivation of good-practice water governance.

2.3.3 Challenges

The treatment process was optimized over the duration of the research project. Despite a high overall treatment performance, challenges were seen in the fact that the biological treatment process remained sensitive against load variations and temperature drops which is mainly based on low hydraulic and sludge retention times. The sensitivity of the biological treatment process was seen as the most severe issue of this water reuse solution. It was concluded that a mixing and equalization basin and/ or a wastewater switch should be considered in large-scale.

Another challenge encountered in the project was to establish efficient nitrification to cope with higher ammonium concentrations. Ammonium oxidizing bacteria did not establish in the biological reactors used in this project. A membrane bioreactor might be another treatment option for this purpose as sludge retention time can easily be adjusted as required.

2.3.4 Lessons learned

From a microbiological perspective a lesson learnt was the benefit of inoculation of the bioreactors prior to their first operation with biological material from similar treatment processes. This strategy has the potential to greatly accelerate the buildup of a microbial community with the metabolic capabilities required for the nutrient transformation. In cases where hygienic problems are of concern, this “probiotic” approach might furthermore strongly reduce the likelihood of the establishment of undesired bacteria in the initial phase of operation. The idea is to give hygienically non-relevant microbes a competitive advantage. Increased microbial competition and occupation of ecological niches would accelerate the buildup of a stress-resilient microbial community with the desired biochemical capabilities and at the same time decrease the probability that hygienically undesired microbes establish.

2.4 Flanders

Belgium is categorised as a country with “Extreme water stress”, indicating it is using more than 80% of its supply. In fact, in 2019 Belgium was ranked 18th in the national water stress rankings from the World Resources Institute, in Europe only preceded by Cyprus (ranked 2nd) and San Marino (ranked 17th). The main reason is the high population density resulting in a large water demand, an intensive water usage in combination with a limited infiltration capacity resulting in limited groundwater recharge and poor reuse of run-off water. The imbalance between water supply and demand makes Belgium very sensitive to climate change. Groundwater recharge is even more threatened and sudden demand increases during periods of drought cannot be met.

With the vision of becoming more water-smart, within B-WaterSmart, LL Flanders is looking to the application of alternative water resources (e.g., water reuse) and more efficient water use to improve the robustness of the water system in Flanders. More specifically, LL Flanders is looking at expanding drinking water treatment capacity with advanced purification systems and exploring the potential and basic requirements for effluent reuse for drinking water purpose and looking at options for rainwater run-off reuse for irrigation to address water demand for agriculture and reduce pressure on groundwater use (see Figure 17). These applications are described in the next sections, including key results, challenges and lessons learned. The applications considered are comprehensively elaborated in the public Deliverables 2.6 - Demonstration of effluent reuse and treatment of off spec raw water with reverse osmosis and 2.7 - Stormwater reuse for agriculture.

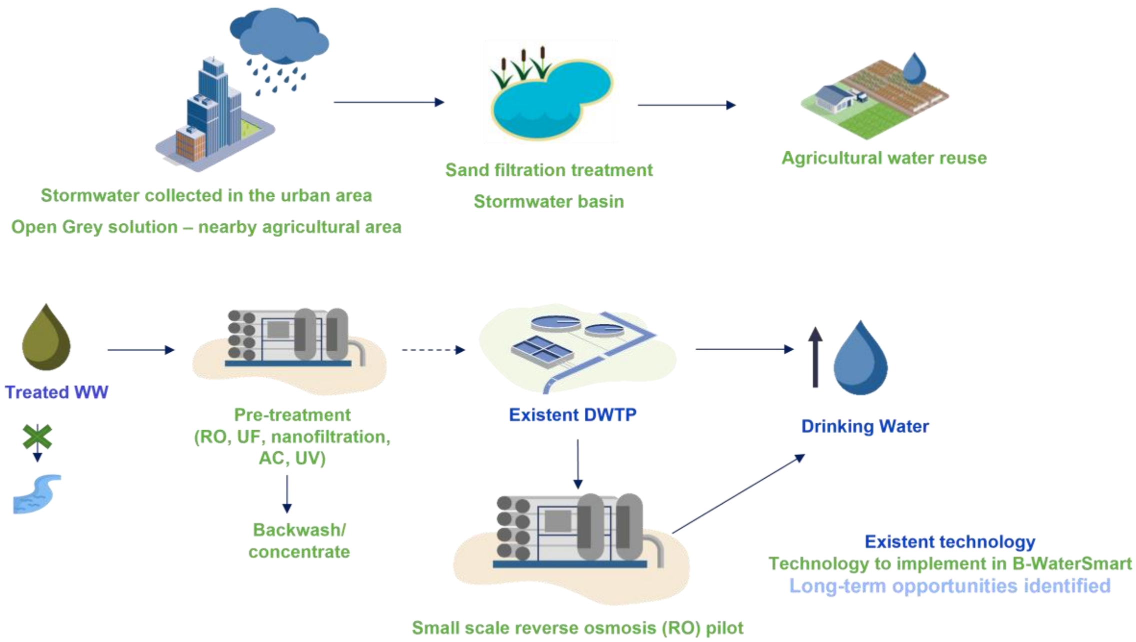

Figure 17: Solutions explored in LL Flanders.

2.4.1 Description

2.4.1.1 Effluent reuse and treatment of off spec raw water with reverse osmosis (T2.3.1)

The drinking water production facility De Blankaart of De Watergroep (Diksmuide, BE) produces drinking water from surface water. At the drinking water production facility, water availability is limited due to seasonal impact and surface water quality deterioration. Even if ample surface water is available in the region, the water quality may not fulfil the intake specifications defined by De Watergroep and tailored to the purification process to secure drinking water quality after the treatment. This is called off spec surface water.

Within B-WaterSmart, two scenarios are evaluated to overcome the water scarcity:

- Closed Circuit Reverse Osmosis (CCRO) for treatment of off spec surface water.
- Treatment of WWTP effluent as an alternative raw water source.

2.4.1.2 Stormwater reuse for agriculture (T2.3.2)

One of the sectors impacted by water stress and climate change is agriculture. When ground water levels drop, crop roots can no longer access this water necessitating irrigation practices to maintain crop growth, quality and survival. Water demand of the agricultural sector increases but due to the water scarcity, access to conventional sources such as surface water and groundwater is limited. The agricultural sector takes measures to reduce their dependency on conventional sources by taking water saving measures and collecting run-off from their own areas. But if this is insufficient to meet the water demand, additional resources are needed. Rainwater run-off is an interesting source, so there is interest in exploiting run-off from public domain. The demonstration site in Mechelen implements a smart control at a flood prevention buffer basin, allowing for optimised stormwater retention, while still mitigating flooding and additionally contributing both to groundwater replenishment and offering an alternative water source to meet irrigation needs through sub-irrigation technique.

2.4.2 Results

2.4.2.1 Effluent reuse and treatment of off spec raw water with reverse osmosis (T2.3.1)

To evaluate off-spec surface water use, a phased approach was implemented starting with a small-scale pilot to familiarise with RO technology, followed by a larger, more complex pilot located after the sand filtration step of the full-scale installation. A Closed-Circuit Reverse Osmosis (CCRO) system was chosen for its cyclic operational mode offering flexibility in operation, low scaling sensitivity and a high potential water recovery. The technology was tested at De Blankaart in Diksmuide between September 2022 to June 2023 (10 m3/h capacity). Water recovery was gradually increased from 85% to 95% without operational issues like scaling; chloride retention was 90%, and micropollutants were below drinking water standards. Conventional RO schemes typically operate at a water recovery of 70 to 80%. The CCRO outperforms the conventional RO systems on water recovery. This is specifically important for the LL Flanders case as water intake during wet periods is stored in a large reservoir to overcome long drought periods. A high efficiency for drinking water production is essential to overcome long periods without water uptake due to limited water availability in the region. Below are the key insights regarding CCRO for treatment of off spec surface water:

- CCRO operates stable, even with challenging feed streams.
- Water recovery up to 95% can be achieved.
- Even at high water recovery, pesticides and pharmaceutical residues are removed to below drinking water standards.
- Optimal pretreatment of the CCRO feed is required for full scale installation.

WWTP effluent reuse as an alternative source of intake water in drinking water production consisted of a pilot unit installed at the Woumen WWTP. Several treatment technologies were evaluated. Technologies were organised in modules, including:

- Prefiltration and ultrafiltration (UF).
- Reverse osmosis (RO).
- Granular activated carbon (GAC) and ultraviolet disinfection (UV).
- Chemical dosage.

The full treatment train consisted of UF-RO-GAC-UV. The treatment train can be modified to test different combinations of technologies, by bypassing individual modules. Initially, prefiltration fouling was frequent, attributed to technical issues and cationic polymer residues from wastewater treatment. Additionally, ineffective prefiltration caused irreversible fouling of the UF membranes. To address these issues and restart the pilot, modifications included prefiltration adjustments, UF membrane replacement, and switching from cationic to anionic polymers were done. However, due to extreme flooding in autumn 2023, pilot operations were stopped. As such, the pilot unit could only be operated stably during a limit period of time. Below are the key insights regarding treatment of WWTP effluent as an alternative raw water source:

- Activated carbon as sole treatment did not sufficiently remove micropollutants for drinking water use.
- UF-RO combination reduced chloride and micropollutant concentrations below intake standards at Blankaart.

To evaluate the impact of an additional treatment step and/or alternative feed water in a regional context, a model was built focusing on the drinking water production process only. Findings suggest that both scenarios contribute to a more robust drinking water production in the region. However, the model indicates that for scenario 1 (treatment of off spec water by CCRO) the installed capacity should be designed for a capacity of 20,000 m^3/day. A comparable impact can be achieved with a smaller unit (5,000 m^3/day) for scenario 2 (use of WWTP effluent). Economically, the second scenario is therefore preferred.

2.4.2.2 Stormwater reuse for agriculture (T2.3.2)

The demonstration site employs a smart control of the buffer basin based on weather predictions to optimise stormwater retention. The buffer basin's water level is managed by a cloud control algorithm with a 6-hour rainfall forecast, and local fallback settings ensure functionality if the cloud connection is lost. The retained water can be used in a subirrigation system in the nearby agricultural fields. In wet conditions, the system operates as conventional drainage, while in dry conditions, it functions as infiltration pipes for stormwater. This dual functionality allows for both excess water drainage and irrigation while increasing the resilience of the local water system, benefiting crops and the local ecosystem. Due to wet weather conditions in 2024, the contribution of the buffer basin on agricultural fields were not observed. However, previous demonstrations showed potential for high infiltration rates and improved crop growth. Below are the key insights stormwater reuse for agriculture:

- The buffer basin holds 1,400 m^3 of stormwater from an area upstream of about 3 ha. The buffer basin is also fitted with a pump system to transport treated water (monitored and treated though a sand filtration system) to a subirrigation system which supplies 4 ha of arable land. The irrigation process is optimised using soil moisture sensors, ground level sensors and pluviometers.
- The buffer basin and sub-irrigation system improves flood prevention and ensures water availability during dry periods. Simulations show the basin reduces runoff rates by 22-94% depending on the month.
- Subirrigation improves crop performance during droughts, with significant yield increases for pumpkins and celeriac.
- The subirrigation system can infiltrate stormwater, but effectiveness drops when groundwater levels are high.

2.4.3 Challenges

2.4.3.1 Effluent reuse and treatment of off spec raw water with reverse osmosis (T2.3.1)

The main challenges when applying the high-recovery reverse osmosis were:

- To keep within the advised Silt Density Index (SDI) value of 5, cartridge filters were used to remove particles and /or elements responsible for high fouling risk from feed water. Cartridge filters needed to be replaced twice a week. The high replacement frequency of cartridge filters is economically not acceptable for a full-scale unit. The issues observed during the pilot tests are at least partly caused by the suboptimal operation of the existing aged sand filters. The pre-treatment will be replaced by new multimedia filters. Afterwards a re-evaluation will be done whether the effluent after multimedia filters is acceptable for direct application on a CCRO system. If not, alternative options (e.g., UF) for prefiltration will need to be considered for full-scale implementation.

- Both CCRO and RO systems will generate a concentrate stream. Discharge of a concentrate streams needs to be in line with the European and Flemish regulations on discharge and are subjected to an impact assessment to obtain a discharge permit. Discussions with the relevant water authorities are ongoing to clarify the conditions under which a discharge permit could be obtained. A cooperation with the University of Ghent was setup to evaluate the technical options for advanced brine treatment. This work may benefit from the results generated in LL Alicante on brine valorisation (Technology #7 and #8) and Ammonia evaporation CEVAP (#9). Although the chemical composition of the concentrate will differ, the results of this study are both beneficial towards the CCRO concept and the effluent reuse.

Although all used technologies for effluent reuse for drinking water production are of TRL 9, their application on secondary effluent appeared to be very challenging, mainly concerning clogging and fouling of prefiltration and ultrafiltration. The main challenges observed were:

- Variations in effluent quality depending on the incoming flowrate of sewage to the WWTP influenced by prevailing meteorological conditions.
- Dosage of polyelectrolyte in the treatment train.
- Defining proper conditions for self-cleaning and backwash.
  - Prefiltration clogging occurred due to suspended solids or biological activity in the effluent resulting in a pressure drop in the filtration cycle.
  - Membrane fouling occurred in the UF unit after backwashing due to highly fluctuating feed quality conditions as a result of wet weather conditions.
- A theoretical recovery of 95% with the UF unit could not be achieved require an optimised design for the UF unit to obtain an acceptable recovery rate.
- The malfunctioning of components had a significant impact on the systems operation also requiring an optimisation of the system design.

2.4.3.2 Stormwater reuse for agriculture (T2.3.2)

Despite wet weather conditions preventing extensive testing of the capabilities of the subirrigation the results obtained underscore the potential for broader implementation of the application to effectively mitigate water scarcity and manage flood risks. Nevertheless, several challenges were observed including the need for clarity on the required water quality, defining a sound business model and putting in place a structure to clarify responsibilities.

- The required water quality for subirrigation is not clearly defined since it does not fit within the existing legislative framework in Flanders. It is an irrigation method, so protection of the plant and the operator of the network needs to be considered.
- Establishing a viable business model for water reuse (in particular to cover OPEX costs) is difficult due to availability of other low priced water sources, lack of guaranteed quality and availability of stormwater, and differing viewpoints on the beneficiaries of the stormwater (farmers, the environment, citizens and industry that would otherwise suffer from occasional flooding if the buffer basin would not have been built, etc.). Identifying alternative and innovative financing methods is needed to make a viable business case for stormwater management and reuse.

- Next to the financial arrangements is the practical and legal agreements between stakeholders in the context of sustainable implementation (i.e., operation and maintenance) of the application.

2.4.4 Lessons learned

2.4.4.1 Effluent reuse and treatment of off spec raw water with reverse osmosis (T2.3.1)

- Reverse osmosis is widely used in water treatment and reuse schemes. CCCRO or closed-circuit reverse osmosis is an innovative alternative operational way to operate reverse osmosis that allows a very high recovery, thus very minimal water losses.
- CCRO is a promising and a potentially highly efficient membrane technology. Especially the high level of water recovery is essential for successful integration.
- The study was not conclusive on the specific energy consumption (SEC). Although CCRO claims to be more energy efficient compared to standard reverse osmosis, this claim could not be validated due to technical limitations of the pilot.
- The use of reverse osmosis technology generates concentrate stream. The discharge of this concentrate stream may be subjected to discharge limitations and may require additional brine treatment. This aspect was not part of the work program of B-WaterSmart. A follow-up project has been setup together with the University of Ghent to address this issue.
- Effluent reuse is a valid option to enhance the robustness of the drinking water production center in Woumen, with the combination of UF-RO-UV-GAC suitable for drinking water production.
- The main quality barriers for direct potable reuse are nutrients, salts (mainly chloride), organic micropollutants and pathogens.
- UF/RO is a suitable technology to treat WWTP effluent as a preparation to intake in a drinking water production center for direct potable reuse. The main quality barriers are adequately removed.
- The need for further polishing with UV and/or AC as additional safety barriers depends on the technologies used in the drinking water production center. It cannot be decided based on concentrations (since these are below detection limits) and requires assessment with Quantitative Microbial Risk Assessment (QMRA)/ Quantitative Cost Risk Analysis (QCRA).
- The effluent contains a remaining load of organic carbon and nutrients resulting in a high biofouling and clogging potential. Prefiltration setup and backwash and cleaning mechanisms should be developed carefully to prevent biofouling.
- Some common practices in WWTP operation, such as dosing of polyelectrolyte for enhanced sludge settling, and some common patterns in WWTP operation such as fluctuating flow rates and quality introduce additional challenges concerning fouling. It is not enough to design the treatment for dry weather condition and mean quality characteristics.
- Case-specific challenges are disposal/treatment of the concentrate, availability of effluent depending on ecological needs in the receiving surface water, etc.

2.4.4.2 Stormwater reuse for agriculture (T2.3.2)

Integrating smart stormwater management and subirrigation systems at the Mechelen demonstration site offers an innovative solution to simultaneously address water scarcity issues and flood management in Flanders. By enhancing groundwater recharge, optimising stormwater use, and adapting drainage systems, these technologies contribute to a more resilient agricultural sector and ecosystem. Some key lessons observed from the demonstration are described below:

- The stormwater buffer basin has demonstrated the potential reuse of relatively large volumes of water for both with a groundwater recharge and irrigation function. While not the most

efficient compared to conventional irrigation, sub-irrigation was the best solution because of the dual functionality.
- The approach is replicable. However, each project needs its own design to offer context specific solutions.
- There is a need to place the technological demonstration in the broader context to assess how it can contribute to a more robust and smarter water system at a regional level.
- The legal status of rainwater and stormwater needs to be clear and linked with regional policy and regulations for reuse and infiltration methods, contributing to safeguarding health.
- Disparities between regional policies may emerge when EU legislation is translated differently in different regions in a country, which puts pressure on the policy coherence.
- Collaboration will be essential, with local organisations but also the private sector (e.g., nearby industry).
- Careful consideration needs to be made in selecting appropriate funding models. As such additional information or literature to support the approach and business case, especially concerning the positive impact on agriculture from certain funding models is needed.
- Trade-offs between flood-proofing and runoff reduction are necessary, especially in autumn and winter periods.
- Fields benefiting from subirrigation need to be in the immediate vicinity of a buffer basin.

2.5 Lisbon

2.5.1 Description

A protocol was developed for safe direct potable reuse of water in the beverage industry (technology #1). It was based on a 24/7 pilot demo of different reclamation schemes including ultrafiltration (UF), ozonation (O3), biologically active carbon filter (BAC) and reverse osmosis (RO). The demo was conducted in Beirolas urban wastewater treatment plant (UWWTP), where reclaimed water started to be produced for unrestricted irrigation of two urban parks in its close vicinity (68 ha of total irrigated area, which are pilots of the project activities on the reclaimed water distribution safety). Data and new knowledge were produced, both on the water quality requirements and on the reclamation technologies. The aim was to provide scientific evidence of the safety of direct potable use of reclaimed water in the beverage industry, when the local water scarcity justifies it, and ultimately to promote the social acceptance of this alternative water source for current non-potable uses in Lisbon and beyond.

More detailed information and findings can be found in the public Deliverable 2.8 - A reclamation protocol for water reuse in craft beer production.

2.5.2 Results

Four advanced treatment technologies were pilot tested – UF, O3, BAC and RO, under the following operating conditions:

- Ultrafiltration: this unit operation was available at the UWWTP for the unrestricted urban irrigation, and it was therefore possible to assess its role on the reclaimed water quality without including it in the pilot.
- Ozonation: 1-2 mg O3/mg DOC (dissolved organic carbon), with 45 minutes contact time.
- BAC filtration: approximately 5 minutes empty bed contact time (EBCT), operated for 31 kBV (thousand bed volumes).
- Reverse osmosis: 3-stage RO (2:1:1) with 8-12 bar net driving pressure, 15-25 L/(m^2.h) permeate flux, 60-70% water recovery rate, concentrate recirculation, and 3 mg/L antiscalant dosing.

The pilot unit was demonstrated in an operational environment for approximately one year, achieving a Technology Readiness Level (TRL) 7. To compare different RO-based potable reuse schemes regarding water quality and operational performance, four treatment schemes were continuously (24/7) piloted. The system integrity monitoring was designed, including online UF and RO flowrate, pressure and turbidity, and RO pH and electrical conductivity, and three critical control points (CCPs) and the associated critical parameters to be monitored were established for the potable reuse schemes, as illustrated in Figure 18.

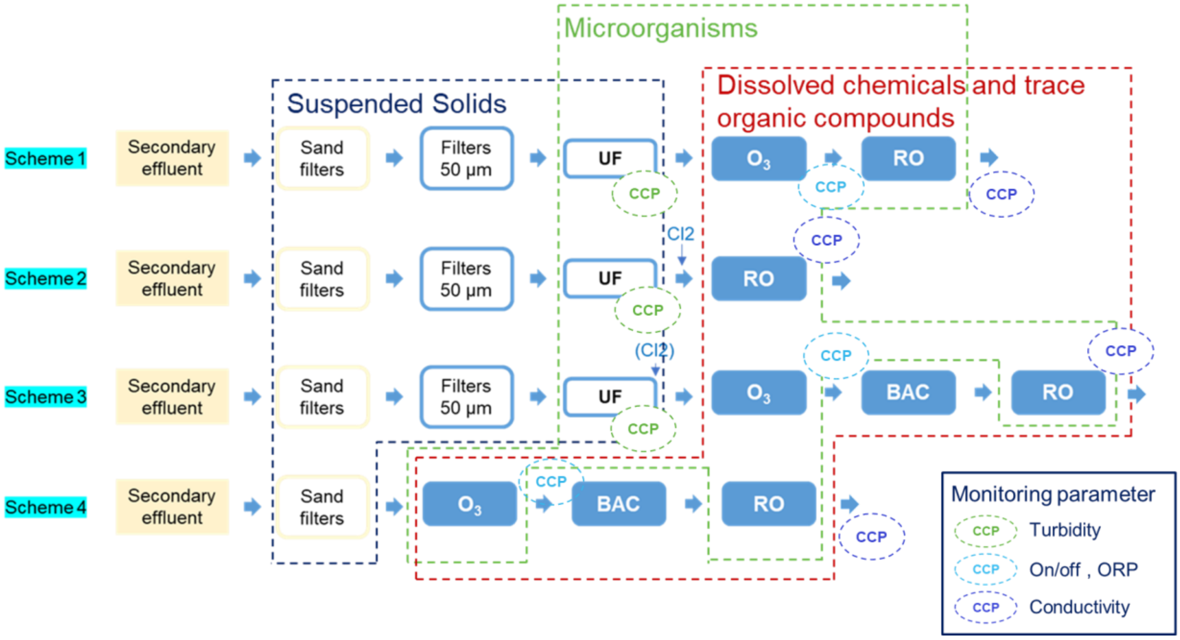

Figure 18: Multi-barrier potable reuse schemes demonstrated in the pilot unit at Beirolas WRRF, and critical control points established.

All four multi-barrier treatment schemes produced water that complies with EU and Portuguese drinking water quality standards and beyond. In terms of contaminants of emerging concern: 32 out of the 54 pharmaceutical compounds analysed were never detected and the remaining were always below the limit of quantification, LOQ (0.1 or 0.3 ug/L); 10 per- and polyfluoroalkylated substances (PFAS) were never detected and the remaining 10 were always below LOQ (0.3, 1 or 2 ng/L), far below the drinking water quality standard of 100 ng/L for PFAS-total; the ozonation by-product NDMA was below the international guidelines. As for regulated oxidation byproducts, total trihalomethanes, halo-acetic acids and bromate were always below LOQ, i.e. total THMs < 2 µg/L, HAAs < 2 µg/L, bromate < 3 ng/L. Pathogen indicators (of enteric bacteria and viruses, and protozoa) were absent.

Regarding the progress beyond the state of the art, overall, the pilot studies conducted show that the quality of the water produced is in accordance with other studies, namely also regarding contaminants of emerging concern, with most studies showing RO-based systems to provide robust removal PFAS compounds while Ozone/BAC-based advanced treatments mostly address long chain PFAS. With respect to the treatment process efficiency measured as log-reduction values of microbial indicators, our study was conducted with no spiking, to fully represent the real environment. Therefore, the conducted demonstration of the removal of naturally arising pathogens was limited by their low feedwater concentration. For example, regarding E. coli, the UF treated water (schemes 1, 2 and 3, in a total 30 analysis) showed E. coli values below the LOQ (1 CFU/100 mL) except during the commissioning phase (scheme 2), when a value of 3 CFU/100 mL was observed. The sand-filtered effluent varied from 3x103 to 3x105 and thus the LRVs obtained with UF were limited by these intake values, varying between >3.5 and >5.2, values fully aligned with the indicative LRVs compiled in the

US EPA Guidelines for Water Reuse, i.e., 4 to >6 LRV. When UF was not part of the treatment train (scheme 4) and ozonation was the first barrier, it was observed that an ozone dose of 2 mg O3/mg DOC was not always fully effective for E. coli inactivation, being observed values between 1 (LOQ) and 23 CFU/100 mL after ozonation. The calculated LRVs were between 1.8 and >3.4, also aligned with the indicative LRVs compiled in US EPA Guidelines for Water Reuse, i.e. 2 to 6.

Regarding the other microbial indicators analysed, i.e. Clostridium perfringens and its spores and Somatic coliphages, it was observed that UF was fully effective for their removal. Nevertheless, as the sand filtered effluents were not analysed, the UF LRVs could not be assessed. Again, it was observed in scheme 4 that ozonation was not fully effective for inactivating Clostridium perfringens and its spores, as expected by the US EPA Guidelines for Water Reuse, being observed values of 800 CFU/100 mL and 520 CFU/50 mL, respectively. The somatic coliphages were not detected in any of the 11 samples analysed. One should again stress that RO allowed the pathogen indicators tested to be absent in all finished waters of all schemes, which allowed concluding that safety was mainly provided by UF and RO. Also, the operational monitoring results showed higher normalised permeate fluxes for the treatment scheme comprising only UF and RO (scheme 2), indicating a lower energy demand by this scheme. As such, we may conclude that the studies conducted in the Lisbon LL and herein reported provide scientific evidence of the safety of direct potable use of reclaimed water in the beverage industry.

2.5.3 Challenges

One challenge encountered is related with the commercial offer for the water quality analysis, particularly, for contaminants of emerging concern, namely, (i) the high limits of quantification of the analytical methods for chemical microcontaminants/micropollutants (species at very low concentrations), such as pharmaceutical compounds and NDMA, a limitation which hampers the assessment of their removal efficiencies, (ii) the long time for reporting the results after sample collection, some analytical reports taking more than 2 months to be completed by the external laboratories, in addition to (iii) its high cost. Moreover, challenges arose in controlling biofouling within the treatment train, leading to an increase in RO system feed pressure. To address this challenge, system cleaning and maintenance were necessary and different pre-treatments were tested, the planned ozone and BAC, as well as mild pre-chlorination (up to 1 mg/L Cl_2 - see Figure 18). Furthermore, saltwater intrusion into the sewage system posed another significant challenge to the pilot operation. This intrusion increased the conductivity at the water intake, consequently raising the RO feed pressure. A close monitoring and adjustment of the operational conditions were necessary to balance these changes.

2.5.4 Lessons learned

The following lessons were learned from the year-long pilot demonstration in Beirolas WRRF:

- **Multi-barrier risk mitigation is of paramount importance:** Among the studied schemes, the one comprising UF, O3, BAC and RO (Scheme 3, see Figure 18) provided superior multi-barrier risk mitigation, with each family of hazards being targeted by more than one barrier. This redundancy minimizes the severity and likelihood of hazardous events.
- **Treatment processes and their effectiveness:**
    - UF ensured complete disinfection of its permeate and RO allowed the pathogen indicators tested to be absent in all finished waters of all schemes (including those with no UF); therefore, safety towards microbial quality was mainly provided by UF and RO. In addition, the treatment scheme comprising only UF and RO (scheme 2) showed higher normalised permeate fluxes, i.e. lower energy demand.

  - Ozonation, with a normalised dose of 1-2 mg O3/mg DOC, oxidized inorganic and organic chemicals.
  - BAC filtration, operating with an EBCT of 5 minutes, contributed to the removal of dissolved chemicals; to achieve higher removals, 15-30 minutes EBCT are recommended.
  - RO guaranteed the removal of oxidation byproducts and recalcitrant dissolved compounds; a pre-treatment chlorination step (with a low chlorine dosing of around 1 mg/L) and operating at 60% water recovery rate (WRR) showed to reduce biofouling.
- **Maintenance and monitoring:**
  - Regular maintenance such as checking for leaks, backwashing BAC filters, and replacing RO pre-treatment cartridges is critical; continuous monitoring of ozone generation, RO operating pressure and membrane permeability is necessary as triggers for maintenance.
  - Monitoring turbidity, oxidation-reduction potential (ORP), DOC, and electrical conductivity ensures effective process control (CCPs in Figure 18).
  - The reclaimed water quality should comply with drinking water quality, demonstrated by pathogen indicators of enteric bacteria and viruses and protozoa (e.g., coliform bacteria, Clostridium perfringens, somatic coliphages, bacteriophages) and physical-chemical parameters established in the Directive (EU) 2020/2184 or other comparable international guidelines; to ensure safety and risk mitigation, a higher frequency of sampling compared to that established in Directive (EU) 2020/2184 is recommended, particularly during the first year of operation.
- **Process operational guidelines:**
  - Ozonation: maintain a normalised dose of 1-2 mg O3/mg DOC with routine checks for leaks and preventive maintenance.
  - BAC: operate at an EBCT of at least 5 minutes (preferably 15-30 minutes) and conduct backwashing and GAC regeneration as needed.
  - RO: operate at a net driving pressure of 8-12 bar (for feed water with 3.6-9.9 mg C/L DOC and 0.5-4.1 mS/cm) with regular membrane flushing and clean-in-place procedures based on performance indicators like permeate flux and pressure drop.

2.6 Venice

The Venice LL in WP2 has aimed to demonstrate the possibility and convenience potential for i) industrial reuse of effluent from urban wastewater treatment plants (WWTPs) (Task 2.6.1) and ii) nitrogen recovery from the liquid concentrated streams inside the WWTPs processes, that are liquid streams coming from the anaerobic digestion (Task 2.6.2). To assure these targets, in T2.6.1, the effluent from Fusina WWTP were subjected to a compact combinatory/sequenced treatment pilot plant, provided by HYDROTECH, specifically designed to produce water to be reused in industrial processes (Solution #4). In T2.6.2 instead, nitrogen recovery potential from WWTP processes, has been assessed by subjecting liquid digestates from anaerobic digestion (and co-digestion) to technologies of ammonia stripping to produce ammonium sulphate salt (Solution #11). For this task, two pilot technologies were tested and compared: a column stripping plant (CS), supplied by DEPURACQUE, and an aeration stripping plant (AS), supplied by ETRA. Both technologies have been tested at TRL 7. As a further line of research linked to T2.6.2, the LL studied the co-digestion process of sludge and liquid organic waste (LOW), normally treated in the main line of purification plants, with the aim of improving nitrogen recovery and reducing the carbon footprint associated with its treatment in the WWTP.

The applications considered are comprehensively elaborated in the confidential Deliverables 2.12 - Combinatory treatment technologies for industrial water reuse and 2.13 - Ammonia recovery from concentrated WWTP streams (both contact at VERI).

2.6.1 Description

2.6.1.1 Industrial water reuse (T2.6.1)

The pilot plant consists of a series of consolidated technologies used to treat 1 m³/h of communal wastewater and obtains several qualities of water, including ultrapure water, as products, as shown in Figure 19.

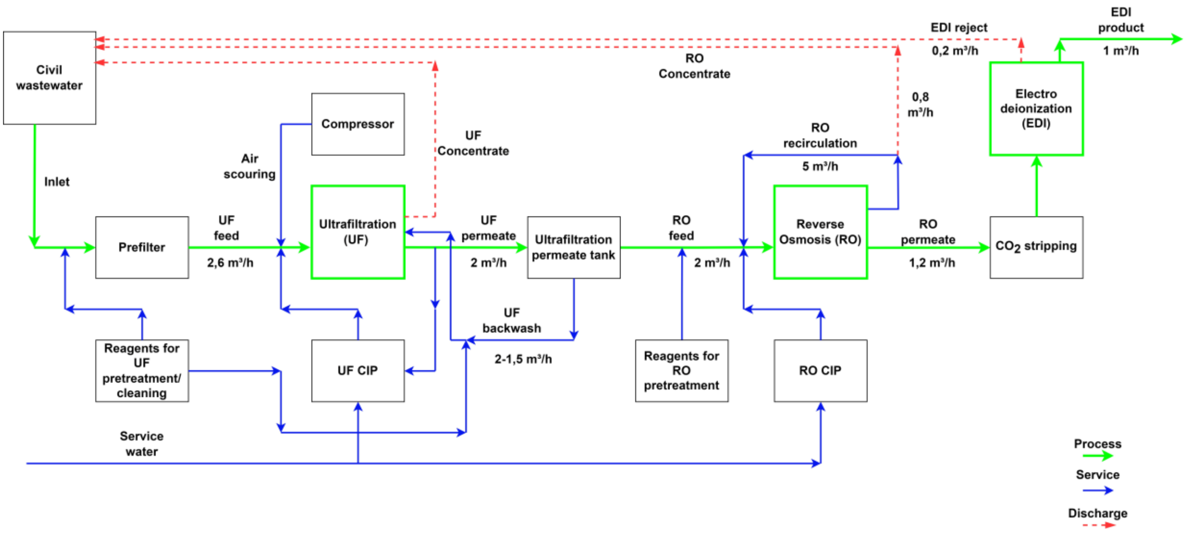

Figure 19: Pilot Plant process flow diagram.

The first part of the treatment is an ultrafiltration (UF) module (pore sizes from 0.01 to 0.10 µm): a pressure-driven membrane separation process that removes particulate matter like bacteria and most viruses, colloids and silt from aqueous solution. The second part of the treatment is a reverse osmosis unit (RO), which is a high-pressure membrane separation processes used to remove dissolved salts and particles with a molar weight above 100 Da. The last and final part of the treatment is an electrode ionization (EDI) system which is used to further remove ions from the RO permeate and obtain ultrapure water with low conductivity (as low as 0.1 µS/cm). The pilot was applied to the secondary treated effluent of the Fusina wastewater treatment plant to investigate the potential for reuse and synergy with the nearby industrial pole of the Porto Marghera area

2.6.1.2 Ammonia recovery (T2.6.2)

The column stripping plant (see Figure 20) consists of a stripping and absorption section with packed columns, preceded by a pre-treatment of the centrate to protect the columns from scaling and clogging caused by solids and compounds capable of precipitating at high temperatures. A chemical-physical reactor consisting of a conical plastic reactor with a mixer is used for flocculation, sedimentation, and pH adjustment of the centrate before entering the stripping column. The stripping column is a tall cylinder with a random-packed bed. The liquid flows downward while air or steam flows upward counter currently, maximizing the exchange interface and optimizing process performance. The air saturated with ammonia from the stripping column enters the absorption column, where an acid solution (usually sulfuric or nitric acid) is continuously recirculated in counter current. The purified air exits the top of the absorption column and can be reintroduced into the stripper column, forming a closed circuit. The system was designed for a maximum working flow rate of 400 l/h and expected inlet NH^{4+}

concentrations of 700-800 mg/l. The air/wastewater volumetric ratio was set between 900 and 1,000 to ensure effective ammonia stripping and avoid internal flooding phenomena.

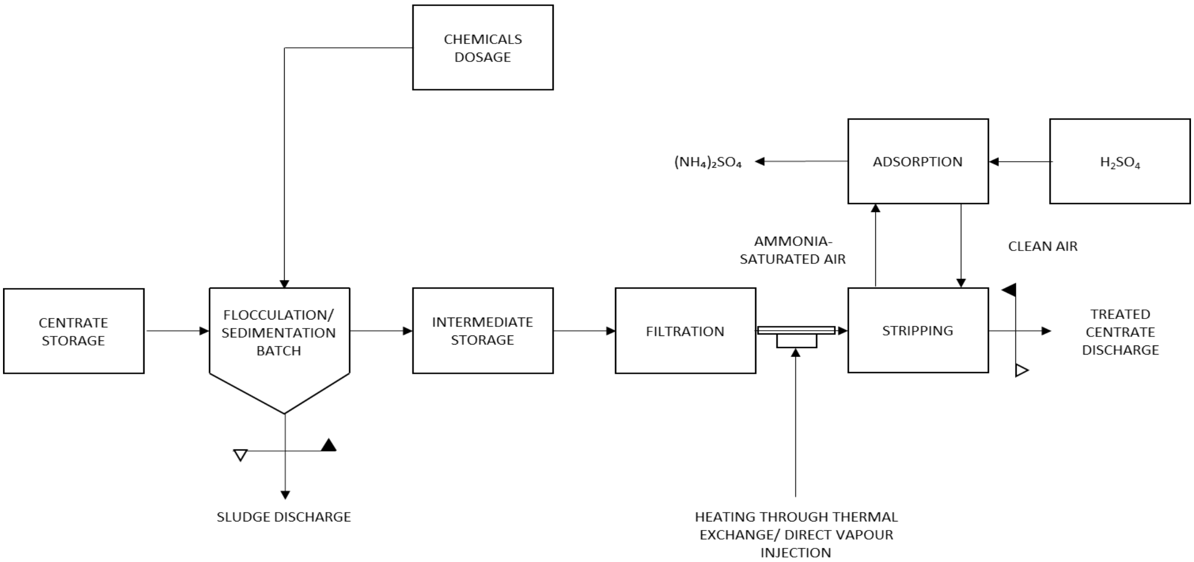

Figure 20: Column Stripping (CS) Pilot General Scheme.

Direct aeration stripping (AS) technology shares principles with column stripping (CS) but operates without a column, injecting air directly into a tank containing wastewater. Ammonia in the liquid binds with the air, transitioning from liquid to gas. The resulting air-ammonia mixture is then treated in a scrubbing column, where a salt solution is collected. Similarly to CS technology the key Parameters for Ammonia Stripping are temperature (heating centrate decomposes carbonates and bicarbonates, shifting the NH_4/NH_3 balance towards ammonia) and pH (Increasing pH through alkali addition, preferably sodium hydroxide, facilitates ammonia release). Two essential system features for ammonia stripping are: i) demisters, installed to remove droplets and foams from the air stream; ii) the air purge system, adopted to manage the excess CO_2 and ammonia in the airflow, which helps maintain the desired gas composition by preventing the accumulation of unwanted compounds. In

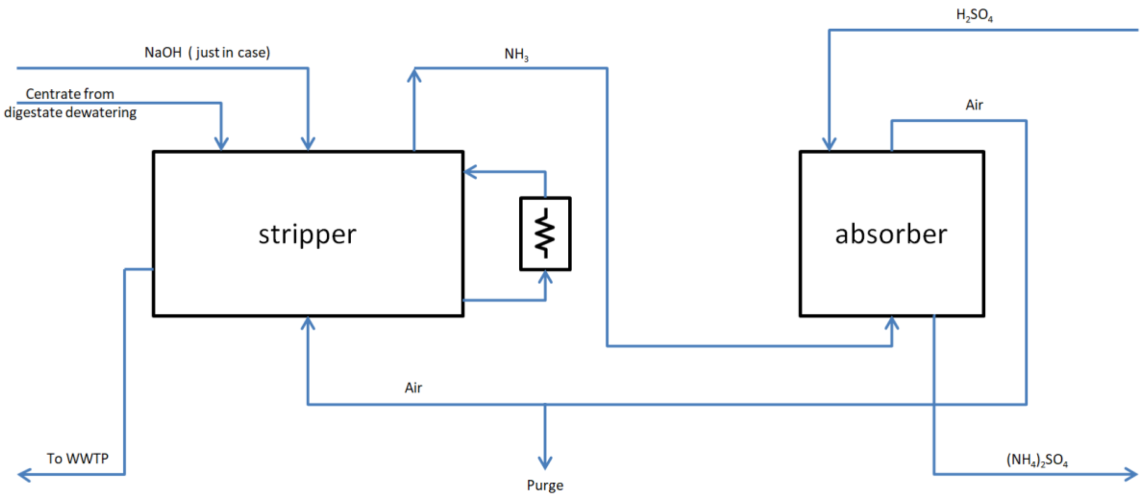

Figure 21, a general scheme of the whole Etra aeration stripping plant (AS) pilot is shown.

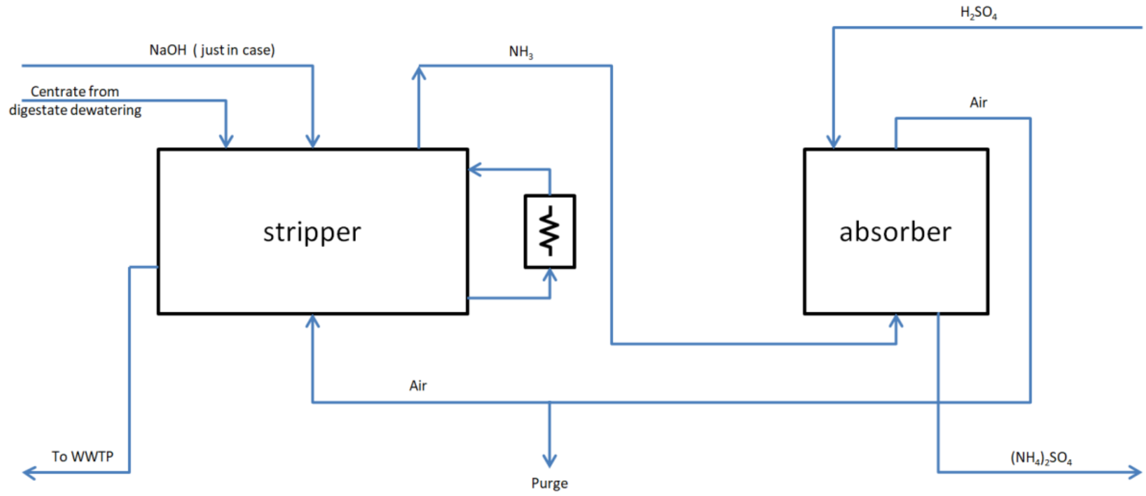

Figure 21: Aeration-stripping (AS) Pilot General Scheme.

Advantages of AS are: i) the fact that wastewater is treated without pretreatment, avoiding clogging and additional sludge production; ii) the ability of handling various wastewater types, including those with high solids and alkalinity. Main potential disadvantages are: i) lower potential yield with respect to the CS technology; ii) requiring of long hydraulic retention time (HRT >10 hours) to be effective (which in turns implies larger reactor volumes and higher energy for heating). The system is designed to treat up to 100 litres per hour, balancing efficiency and operational challenges.

The co-digestion process of sludge and liquid organic waste (LOW) was studied firstly using a batch pilot set-up, based on Nautilus Instrument (Anaero Technology Ltd.) platform specifically thoughts to compare the biomethane potential BMP of different substrates (15 stirred 1L bottles, in thermostatic batch, connected to gas flow meter and gas bags). Based on the results obtained from the batch tests, the co-digestion process was further investigated in a semi-continuous system (CSTR) to better simulate the full-scale operation (6 L reactor, equipped with stirring system, temperature control and connected to gas flow meter and gas bag).

2.6.2 Results

2.6.2.1 Industrial water reuse (T2.6.1)

The demonstration phase lasted more than a year and allowed the collection of more than 100 samples for the analysis of about 300 parameters, of which only about 20% had detectable levels in the secondary effluent of the Fusina treatment plant, i.e. the inlet to the pilot plant.

In terms of results: a total removal of microbiological parameters is stably obtained after the ultrafiltration unit, as well as for other components such as turbidity and particulate fraction of total organic carbon (TOC), which are affected by the ultrafiltration step. In general, the RO process ensures removal of almost all the very wide list of parameters monitored (below the detection limits DL of the respective advanced and sensitive method used). The final EDI treatment typically results in few very slight improvements in removal efficiencies, except for boron and aromatic organic compounds, for which some improved removals were observed. Results obtained allows to affirm that the UF-RO tertiary treatment system ensures that even the most stringent industrial requirements are met.

2.6.2.2 Ammonia recovery (T2.6.2)

DEPURACQUE's column stripping (CS) and ETRA's aeration stripping (AS) were evaluated through demonstration phases carried out at two operational sites: the Fusina (FU) and Camposampiero (CMSP) wastewater treatment plants. Both technologies were to be applied to the liquid fractions of the digestates available in each plant (for a total of four tests), but while the AS technology was able to directly treat the CMSP effluent, the CS technology, less flexible to variations in water quality, required a 20-fold dilution to adapt this wastewater to the design requirements. Table 4 provides an overview of the main characteristics of the liquid digestates treated by the two technologies in the four demonstration phases.

The AS technology was found to be more suitable for wastewaters with high solids and alkalinity loads, but it requires heating conditions for long retention times and contextual air purging ratios, which can have a significant impact on energy consumption in the absence of thermal waste to mitigate energy requirements. A 70% yield of ammonia removal was achieved by heating the effluent to just over 60°C, without any pre-treatment or addition of caustic soda, even when treating highly variable concentrates. The CS technology was found to be suitable where solids and alkalinity can be removed with a pre-treatment capable of preventing plugging and scaling in the stripping section. In this case, tests have shown yields more than 90% at pH 10 and the advantage of achieving the pH with lime, which is less expensive than sodium hydroxide.

In terms of quality, the ammonium sulphate produced was found to meet fertiliser quality characteristics, apart from the dilution problem, which was mainly due to the lack of adequate measures to remove air condensation in the pilot plants.

The results of both technologies, so far used in sectors other than water services (industrial water for CS and zootechnical wastewater for AS), have demonstrated the existence of promising application areas also in the recovery of ammonia in WWTPs. The interest in this application derives both from the possibility of obtaining marketable ammonium salts and from the reduction of energy consumption and carbon footprint, due to the decrease in the incoming nitrogen load entering the plants, currently removed mainly through nitro-de-nitro processes. The co-digestion of concentrated LOW and waste activated sludge (WAS) significantly increased biogas production compared to sludge digestion alone (up to 2.5 times higher gas production rate (GPR)), resulting in a promising approach to recover nitrogen while reducing N_2O gas emissions and increasing the potential energy self-sufficiency of WWTPs.

Table 4: Main characteristics of the centrates treated in the four demonstration phases (averages) Note: CS Column Stripping; AS Aeration Stripping; FU Fusina WWTP; CMSP Camposampiero WWTP; DM demonstration.

Phase	Technology	Site		pH	Residue at 105°C	TSS	N-NH4	Total Alkalinity
				[unit pH]	[mg/l]	[mg/l]	[mg/l]	[mg/l CaCO3]
DM1 Spring-Fall 2023	CS	FU	Average	7.53	1,573	469	402	1,655
			Max	7.71	9,404	1,450	568	2,348
			Min	7.29	962	50	296	1,201
DM2 Summer-Fall 2023	AS	CMSP	Average	7.94	22,655	10,398	3,637	17,476
			Max	9.18	25,200	12,500	4,373	19,478
			Min	7.66	21,000	8,780	2,542	13,899
DM3 Winter-Spring 2024	AS	FU	Average	8.22	1,186	158	501	2,038
			Max	8.90	1,261	550	688	2,125
			Min	7.90	1,122	15	326	1,925
DM4 Spring 2024	CS	CMSP	Average	7.79	1,130	147	90	676
			Max	7.88	1,162	224	101	700
			Min	7.70	1,080	105	74	660

2.6.3 Challenges

2.6.3.1 Industrial water reuse (T2.6.1)

From a technical point of view, the only criticality that emerged during the tests was the pre-treatment intended to safeguard the ultrafiltration system which, for the purposes of upscaling, should be carefully assessed and sized based on the characteristics of the incoming water, to limit manual cleaning interventions.

More generally, since the technologies installed in this type of system consume non-negligible amounts of energy, the convenience of the application must be carefully assessed, considering also strategic elements such as the qualitative and quantitative stability of the water produced, in addition to the economic aspects.

2.6.3.2 Ammonia recovery (T2.6.2)

Pilot tests on CS technology have highlighted the need:

- to preserve the column with an effective pretreatment to remove solids and carbonates/bicarbonates,

- to prevent the formation of condensation in the air circuit,
- to have an accurate control system to regulate the process and record the main parameters (fundamental to understand and resolve any anomalies).

Furthermore, since it is a relatively complex technology, management must be entrusted to expert personnel and an accurate maintenance plan must be provided, aimed at preventing clogging and encrustations.

Although AS technology has proven to be very robust and capable of treating even very difficult wastewater, to achieve significant ammonia removal yields and contain energy consumption it is necessary to carefully consider the contextual factors that influence both the design and the process (removal yield targets, availability of thermal waste, characteristics of the wastewater to be treated, etc.), to equip the plant with reliable and easy-to-manage measurement and control systems, and to pay particular attention to parameters such as retention time, air flow rate introduced and purged and reintegrated air flow rate, which heavily influence energy consumption and space requirements.

There are no particular challenges for the liquid organic waste and sludge co-digestion, only opportunities for more ergonomic handling of this type of matrix. There is a need to adopt suitable and low energy-intensive thickening treatments.

2.6.4 Lessons learned

2.6.4.1 Industrial water reuse (T2.6.1)

The results showed that the treatment of purified effluents for industrial water reuse can meet both the qualitative and quantitative challenges that the use of freshwater, with its high variability and exposure to the risk of contamination and scarcity, cannot guarantee. The solution proposed for this pilot, which is based on mature and commercially available technologies, is a key solution in these increasingly challenging climate scenarios. Cost may remain a challenge, but since water reuse is one of the most effective ways to mitigate the effects of climate change on water services, it is not only a choice but an opportunity. In addition, it is not a question of increasing energy consumption and costs, but only of relocating and centralising industrially widespread individual treatments.

2.6.4.2 Ammonia recovery (T2.6.2)

The tests carried out with pilot-scale plants have shown a series of advantages and limitations of the two technologies tested, highlighting that the preference for one or the other is strictly linked to the application context:

- The AS is characterized by its remarkable construction and management simplicity, combined with great versatility and robustness which allow it to also treat wastewater containing very high concentrations of solids and alkalinity (carbonates and bicarbonates). Having to heat the wastewater in the stripping reactor, the need to operate with rather long retention times and to purge part of the stripping air, reintegrating it with fresh air, require the availability of large quantities of thermal energy, as well as non-negligible spaces. Naturally, this quantity is mainly linked to the ammonia removal yields to be achieved, to the characteristics of the wastewater and at the temperature of both the wastewater and the introduced air.
- CS technology allows to reach removal efficiencies close to 100%, by heating the clarified wastewater only for the short passage time in the column and by blowing it in a closed circuit, without significant purge or top-ups. Compared to AS, this entails a significant limitation of energy consumption and space. However, CS is not a suitable system for stripping very concentrated wastewater, which for AS, on the other hand, do not represent a problem. In fact, CS is a relatively sophisticated technology, which requires careful pre-treatment of the

wastewater to eliminate both solids and alkalinity, thus avoiding clogging and scaling inside the column. Unlike the AS, which as mentioned above can carry out the stripping by exploiting only the heating of the wastewater, in the CS the presence of a chemical-physical pre-treatment implies a systematic use of various reagents and the production of a sludge which must find a suitable destination. The relative complexity of the CS is evident both in the construction and management phases, with the need to have more qualified personnel than the AS and to regularly carry out cleaning and pickling of the stripping section.

3 Impacts

3.1 Alicante

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
10	Anaerobic Co-digestion (D2.2)	EI 6	Considering the energy consumption in Rincón de León WWTP and the increased biogas production by means of co-digestion, the capacity of such technology to achieve the expected impact mainly depends on the waste availability and the digesters capacity. Different scenarios can be found in D2.2 describing how they would achieve the quantified percentages of the EI 6.	21% / 36% / 59% Numbers estimated according to results obtained at pilot scale
13	Microturbine (D2.3)	EI 6	Considering the energy consumption in Monte Orgegia WWTP and the annual energy production of the turbine, the energy recovery is not highly impactful.	1%
9	CEVAP (D2.10)	EI 7	According to the mass balance and the ammonia concentration in the target stream characterized in D2.10, the recovery capacity of the CEVAP is of 40% due to ammonia losses.	41% Numbers estimated according to results obtained at pilot scale
8	Selective electrodialysis + Electro chlorination (D2.9)	EI 8	The selective electrodialysis capable of recovering minerals from the RO brines (i.e. Magnesium and Calcium) as divalent ions in water that could be fit for reuse.	83% Numbers estimated according to results obtained at pilot scale
		EI 9	The selective electrodialysis unit evaluated at pilot scale was able to recover around 93% of the monovalent ions (Na^+ and Cl^-) from the RO brine. The softening stage prior to the electro chlorination unit removed approximately 20% of their concentration. This leads to a recovery capacity of 71% of salt (i.e. NaCl).	71%* Numbers estimated according to results obtained at pilot scale

3.2 Bodø

Technology		Contributed to Expected impact		
#	**Description (Deliverable)**	**Number**	**Explanation**	**Quantification (if applicable)**
14, 15	IoT sensors for infiltration detection and Smart water meters for leak detection (D2.4)	EI2	Improved water efficiency: Average consumption in the pilot area: 100 m^3/year per household. Assumed consumption in Bodø: 140 m^3/year per household.	71,4% difference in water consumption in the pilot area compared to the average assumed consumption 40m^3/year less per household on average within the pilot area compared to the average assumed consumption
12	Water-smart small-scale energy production from small wastewater treatment plants (D2.5)	EI6	Energy Recovery: The feasibility study found that Bodø had an insufficient amount of sludge, thus the study was expanded to include additional sludge from the surrounding area. In this case scenario 100% of sludge produced in Bodø would be converted into energy.	
		EI9	Recovery of heat for de-icing purposes: T2.2.2.'s analysis has calculated the total heat generated and consumed throughout biogas production of 5 alternative methods. However, due to insufficient sludge amounts in the Bodø region, the location assumed in the study would not have needed heat for de-icing purposes. However, the heat could be used for other purposes in this scenario.	
		EI12	Support transition to a more circular economy at different scales and different social conditions: The biogas feasibility study provided Bodø, a city with lower population density and limited spending power, with valuable insights into how new circular technological solutions can be implemented effectively, considering the city's specific challenges and resources.	

3.3 East Frisia

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
6	Combined treatment of vapour condensate & milk/whey permeate for reuse in dairy industry (D2.3)	EI1	Reduced ground water abstraction	400,000 m^3/year
		EI4	Less wastewater produced as condensates will be reused instead of being subjected to wastewater treatment.	400,000 m^3/year
		EI11	Growth of companies with high water demand is expected to be limited by drinking water supply in East Frisia. Water reuse is expected to overcome this limitation/competitive disadvantage.	
		EI13	Enhanced water security by reduction of dependence on local drinking water supplier.	400,000 m^3/year
		EI14	Reduced risk of further future, climate change-related limitations of ground water abstraction.	
		EI15	Increased awareness for water as a limited resource among all participating stakeholders.	

3.4 Flanders

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
2, 3	Demonstration of effluent reuse and treatment of off-spec raw water with reverse osmosis (D2.6)	EI1	We have demonstrated the feasibility of CCRO at a small scale and for a short period of time. CCRO at the site would in full-scale be designed to produce 20,000 m3 permeate/day with high water recovery of 90 up to 95%. A conventional RO system would operate at a maximum of 75 to 80% water recovery. The freshwater requirement for RO is therefore around 26700 m3 to meet this goal versus 22200 m3 for CCRO. This implies a potential freshwater reduction of 16,8 % while producing a very high standard of water quality.	The demonstrated reduction in freshwater uptake is estimated to be around 17%.
		EI3	Reclamation plant is designed to produce maximum 5,000 m^3 permeate/day. Considered restrictions on the availability of effluent the total potential volume of effluent reuse is	15% reduction in freshwater uptake (total drink water production in the

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
			estimated at 1,55 Mm^3 permeate/year out of this demonstration.	Blankaert 10 Mm^3/year).
		EI4	The total volume of wastewater treated at Woumen is 3,5 to 4 Mm^3/year. The demonstrated potential volume reuse at the site is 1,55 Mm^3/year of RO permeate. With an RO installation with 75-80% recovery, this amounts to 2 Mm^3/year of raw effluent redirected for reuse. In perspective of the region Flanders, the total amount of treated effluent is about 800 Mm^3/year (depending on weather conditions). Part of it is required for maintaining ecological waterflows in rivers and streams or is unsuitable for reuse. According to a study from prof. Patrick Willems, 100 Mm^3/year is available for reuse for all kind of applications (industry, drinking water, etc.). 3 Mm^3/year (3%) is already reused for drinking water purposes at Aquaduin. Two future cases are being concretely planned (one already in construction phase) that will apply the demonstrated technology. It is estimated that these two have a potential of 1 Mm^3/year (1%). Additional cases for industrial reuse are already in place are concretely planned in the near future. They are not taken into account in this evaluation, but they are also covered by the 100Mm3/year of available effluent.	50% potential for effluent reuse for drinking water purpose demonstrated on a local scale. 2% potential demonstrated on a regional scale. 3% reuse was already in place. 1% additional potential soon. An additional significant share (not quantified) for other applications
		EI8	RO technology generates concentrate streams (brine) within which materials can be recovered. This was however not investigated within the scope of the B-WaterSmart project. Since demonstration revealed a lot of potential, a research project has been set up in collaboration with Ghent University to elaborate scenarios for concentrate stream treatment and valorisation.	

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
		EI10	The Flemish Environmental Authorities launched in 2022 a call on WWTP effluent reuse. 5 projects were granted. Technologies demonstrated in this project are in focus for implementation. In 2024 www.aquamarkt.be came online. This is an initiative of Aquafin to stimulate and facilitate water reuse. The reuse potential of WWTP effluent is visualized and reuse dossiers are made public.15 dossiers concerning effluent were already assigned. 2 dossiers concerning effluent are under investigation.	
		EI11, EI12	Establishing regional circularity in the water system, contributing to ensuring water for all. Based on positive results of CCRO in Woumen, CCRO can be integrated in future treatment plants within Flanders (e.g., CCRO is considered as option in new water production plant De Ganzepoot, while effluent reuse is under consideration in Woumen (B-Watersmart), Aalst (Deeper Blue), Limburg (Blue Future Limburg). Waterleau (company that provided the technology) has used the developed demonstration already for other end-users, indicating a strong interest for replication on other sites and for other purposes.	
		EI13	There is a strong drive to improve water security for Flanders in the future, and several regional and national initiatives have been started to work towards a more robust and circular water system. Regulations on effluent reuse are needed for the successful implementation of circular solutions. Discussions have been started based on Q&A out of this project and subsequent projects (e.g., concentrate treatment). Furthermore, governance and business models for shared solutions are required, involving multiple stakeholders across sectors.	

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
		EI15	Findings suggest that both scenarios contribute to a more robust drinking water production in the region, offering alternative water sources to supplement the existing supply, which greatly contribute to a more robust and climate proof smart drinking water supply.	
5	Stormwater reuse for agriculture (D2.7)	EI1	The buffer basin holds 1,400 m³ of stormwater from an area upstream of about 3 ha for use in nearby agricultural fields (4 ha).	
		EI3	During the demonstration 50.000 m³ of run-off water was collected in four months, which would mean 150.000 m³/y. Extremely wet weather conditions during the complete demonstration period result in a strong overestimation of the amount of run-off collected. The wet weather conditions resulted in abnormally high ground water tables and no solid estimation of the reuse potential can be made based on this testing method.	
		EI10	The potential of smart control of flood prevention infrastructure is recognised by the Flemish government. In 2022, they assigned 5 M€ Blue Deal financing to Aquafin to make water available for agriculture in the project Restwater. This project focuses now on adapting stormwater infrastructure to be compliant with smart control systems to contain the water for agricultural purposes, similar to the case in Mechelen. In 2024 www.aquamarkt.be came online. This is an initiative of Aquafin to stimulate and facilitate water reuse. The reuse potential of buffer basins is visualized, and reuse dossiers are made public. One dossier concerning collected run-off is under investigation. WaterProof, funded by the Flemish Blue Deal in 2021, applies the smart buffer control system on a flood prevention basin at an Industrial site.	

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
		EI11, EI12	Increasing circularity by water reuse, building connections between stakeholders (city, farmers), supporting groundwater recharge and protection of ecosystems. Demonstration will be transferred to Pidpa for exploitation after the project ends. Commercial use of the stormwater management system is not expected. However, the developed knowledge and experience may be used by the project partners Aquafin, VITO and Proefstation voor de Groenteteelt for replicating parts of the system at other locations. The control algorithm will be used by VITO as add-on to its existing tools for ground- and surface water monitoring and modelling, provided as a consulting service for all kinds of water managers. This will allow VITO to provide additional consulting for stormwater basin management and irrigation systems	
		EI13	There is a strong drive to improve water security for Flanders in the future, and several regional and national initiatives have been started to work towards a more robust and circular water system. Regulations on effluent reuse are needed for the successful implementation of circular solutions. Furthermore, governance and business models for shared solutions are required, involving multiple stakeholders across sectors.	
		EI15	The stormwater buffer basin has demonstrated the potential reuse of relatively large volumes of water for both with a groundwater recharge and irrigation function.	

3.5 Lisbon

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
1	Water reclamation protocol for potable water reuse in beverage industry (D2.8)	EI1 EI3 EI4	The demonstration of multi-barrier treatment schemes for potable water reuse has significantly enhanced water supply safety for the beverage industry and other potable and non-potable uses. By harnessing non-freshwater sources, this demonstration has provided a climate-independent and constant water source, increasing resilience to climate change and mitigating the effects of water scarcity. This advancement supports sustainable water consumption and promotes a circular economy, reducing the environmental footprint and dependency on freshwater resources. Expected impacts therefore include a decreased use of freshwater resources (EI 1) and an increased water reuse (EI 3, 4).	Not applicable. This technology is not foreseen to be implemented until the local water scarcity increase justifies it.
		EI11	As it supports the use of a more resilient water source, TP1 is expected to increase the competitiveness of artisanal beer production and of water-similar industries (e.g. soft-drink production). In addition, the technology provider (Moinhos Água e Ambiente, Lda) has gained data, experience, competences and visibility which may promote its activity in this or in other less demanding applications in Portugal or abroad.	Not applicable, as above. Furthermore, the brewers and the technology provider are not project partners.
		EI12 EI14 EI15 EI17	The successful demonstration has not only shown the feasibility of these technologies but also aims to stimulate a change in public perception and increase awareness and acceptance of water reuse. Presenting to society artisanal beer produced with reclaimed water contributes to the public awareness on water scarcity and the public engagement and acceptance on water reuse. The dissemination of results through national and international platforms has engaged a wide range of stakeholders, fostering a deeper understanding and acceptance of these innovative solutions and supporting transition to a more circular economy (EI 12). This engagement	Not applicable, as above. Special contribution to EI 17a – TP1 was showcased as a successful technical enabler in the Policy Brief on "Accelerating water smartness by successfully implementing the EU Water

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
			encourages broader adoption and integration into water management practices, influencing policy and regulatory frameworks on water reuse (EI 17a), circular economy (EI 17c) and climate change (EI 17g), and further amplifying the project's positive impacts on water sustainability and resilience to climate change (EI 14) and on achieving SDGs 6, 11, 12, 13 (EI 15a,b,c,d). This dissemination is expected to continue beyond the end of the project, ensuring ongoing awareness and adoption of these technologies.	Reuse Regulation (2020/741)".

3.6 Venice

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
4	Compact combinatory treatment technologies for industrial water reuse (D2.12)	EI3	The high quality demonstrated for industrial reuse could allow an increase from the current 0.9% to 33% by 2029. However, as it is more appropriate to identify a more definitive upscaling limit (for a stable and long-term investment scenario), the value of freshwater substitution with treated wastewater could be over 70-80% by 2040.	33% (2029) 80% (2040)
		EI4	Restricting the assessment to the industrial target 2029 and considering the expected agricultural valorisation of effluents, there is also a contribution to EI4. In this case, the current 0.9% could increase to 18% and over 40% by 2029 and 2040 respectively. The boost to water reuse is very high in both areas, but for agricultural valorisation the Water Reuse Strategic Platform DSS (#16) developed under B-WaterSmart plays a relevant leverage role.	18% (2029) 45% (2040)
11	Ammonia recovery from concentrated WWTP streams (D2.13)	EI6	Assuming the EI7 targets, net energy savings form N-Recovery account for 25% and 70% of the regional potential energy saving (about 9 GWh/year), by 2029 and 2040 respectively. This by	25% (2029) 91% (2040)

Technology		Contributed to Expected impact		
#	Description (Deliverable)	Number	Explanation	Quantification (if applicable)
			considering the stripping consumption and the savings from both the Haber-Bosh process and the WWTP oxidative consumptions avoided. The potential diversion of the liquid organic waste (LOW) stream in the WWTP, from the biological oxidative line to anaerobic digestion would result in further energy savings of about 19 GWh/year if Fusina plant first (by 2029) and the 100% of the regional WWTPs anaerobic digestion after (by 2040), decide to implement the diversion of the management of LOW. The exploitation of potential for energy saving would be in this case of 25% and 100% by 2029 and 2040 respectively. Coupling the data, it could be obtained an exploitation of total saving potential (about 28 GWh/year) of 25% and 91% by 2029 and 2040 respectively.	
		EI7 Nutrient recovery out of potential	Using an average stripping yield of 90% for the typical centrate of anaerobic sludge digestion in our territory and considering the current regional potential for nitrogen recovery (430 tonnes/year N), the potential exploitation could increase from the current 0% to 25% and 70% by 2029 and 2040 respectively. This if, Fusina plant first and the 70% of the regional WWTPs anaerobic digestion after, decide to implement the recovery. This in turns will depend on a combination of assessments to be made, including at a regulatory level, where a related more defined regulatory framework is needed.	25% (2029) 70% (2040)

4 Summary

Given all the challenges (e.g., pandemic related, global electronic component shortage) the fact that all technologies were able to reach and complete the demonstration phase is remarkable. This shows the robustness of the technologies (reflected in the common TRLs of at least 7) as well as the flexibility of usage with sufficient contingency planning. This is a first main lesson that a thorough risk assessment and management approach with an early contingency planning mechanism enable technology advancement and testing.

If we cluster the technology into three groups based on their main focus, either reuse of water and wastewater (#1-6), recovery of energy and materials from water and wastewater (#7-13), and smart management of water systems and infrastructure with a focus on sensors (#14-15), we can find common themes, synergies and differences.

- The impact and advancements in sensor technology as well as the used algorithms will allow for broader application and transferability to other case studies with similar problems. One of the main challenges and a lesson for future application is regarding the GDPR documentation needed before any smart water meters could be installed. This proved to be more complex than foreseen. Documentation included data processor agreements, risk analysis matrices and homeowner contracts and required a high level of legal and technical expertise from all parties involved. If the data is not used “in-house” this needs to be addressed early on. Also, public participation from an early stage is of highest importance.
- The need for communication with authorities to gain approval for the newly tested technologies was also a shared challenge of all technologies.
- The integration of effluent reuse and high recovery reverse osmosis, and the use of stormwater for agriculture in Flanders significantly enhances the resilience and sustainability of the region’s water supply. Effluent reuse provides a stable water source even during dry periods, mitigating the impact of droughts, while the high recovery reverse osmosis allows for the intake of off-spec surface water during periods of high availability, such as spring and autumn, ensuring year-round water quality and supply. The use of stormwater for agriculture further diversifies water sources, reducing reliance on groundwater and improving overall water system robustness. These solutions support groundwater recharge efforts and address environmental challenges posed by urban infrastructure, such as high levels of pavements and drainage systems. By integrating these approaches, Flanders not only limits groundwater uses but also alters the disadvantages of drainage, aligning with strategic objectives to protect groundwater resources, enhance water quality, and promote sustainable water management practices. This synergy strengthens the water system's resilience against climate variability and urbanisation pressures while delivering broader environmental and socio-economic benefits for the region.
- In contrast to other projects in the B-WaterSmart consortium, LL East Frisia did not focus on the treatment of wastewater, but of residual liquid from a food production process. Cow water that served as raw water is not of hygienic concern and can also be used as a nutritional supplement product in pig fattening. Nearly all the organics contained in cow water are biologically degradable. Removal of trace substances are not of comparable concern as in the reuse of wastewater.
- Potential cross cutting aspects and synergies, intended mainly as potential exchange of experiences following the pilot tests:
    - Technology #4 Combined treatment technologies for industrial water reuse has cross-cutting issues with technology #1 (A reclamation protocol for water reuse in craft beer production). The scope of this treatment is the production of drinkable water, and not

water for general industrial use, but as in #4 a reverse osmosis (RO) is used. Also, in technology #6 (Vapour condensate and milk permeate treatment in dairy industry) the water to be treated and the goal are different than #4 but also in this case the plant includes ultrafiltration and RO. The use of membranes comes with several common challenges like defining suitable backwash protocols or backwash intervals.

- Co-digestion is another common theme throughout several LLs. Technology #11 Ammonia recovery from concentrated WWTP streams has common aspects with #9 (Ammonia recovery from co-anaerobic sludge applying CEVAP), even if the wastewater to be treated and the applied technologies are completely different. The specific line of research of #11 related to liquid organic waste and sludge co-digestion can find some common aspects with #10 (Valorisation of oil and fats and food waste to improve co-digestion performance), although the waste to be co-digested and the general context are quite different. The same goes for #12, Water-smart small-scale energy production from small wastewater treatment plants, which is a feasibility study of anaerobic digestion

B-WaterSmart

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