ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Deliverable 6.7

Report on academic and scientific dissemination & events

Disclaimer: This deliverable has not yet been approved by the European Commission and should be seen as draft!

Author(s): Joep van den Broeke (KWR)

Date: 29/10/2024

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869318

Technical References

Project Acronym	ULTIMATE
Project Title	ULTIMATE: indUstry water-utiLiTy symbIosis for a sMarter wATer society
Project Coordinator	Gerard van den Berg KWR
Project Duration	01.06.2020 – 31.05.2024 (48 months)

Deliverable No.	6.7
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Work Package	WP6
Task	T6.7
Lead beneficiary	KWR
Contributing beneficiary(ies)	ESCI, UNEXE, NTUA, UCRAN, NTNU, UNIVPM, KWB, KWR
Author(s)	Joep van den Broeke (KWR)
Quality Assurance	Gerard van den Berg (KWR)
Due date of deliverable	31-10-2024
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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

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Document history

V	Date	Author(s) /Reviewer(s) (Beneficiary)	Description
0.1	24-10-2024	Joep van den Broeke (KWR)	First draft
0.2	27-10-2024	Gerard van den Berg (KWR)	QA
1.0	28-10-2024	Joep van den Broeke (KWR)	Final version

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Executive Summary

Summary of Deliverable

To maximise the impact of the evidence base ULTIMATE created, an elaborate strategy for exploitation and dissemination was formulated. One element of impact creation by ULTIMATE is to maximise uptake and insights among the scientific and academic community. This is supported by the dissemination of new knowledge through scientific publications and contributions to scientific conferences, including open access publications and papers. A specific task, T6.7 – Academic and Scientific Dissemination & Events, was dedicated to the communication of results to the international scientific community. This deliverable provides on overview of the activities and outputs delivered under this task 6.7.

A total of 21 scientific papers were prepared for publication in peer reviewed journals, of which 10 papers had been accepted for publication by the end of the project (31st October 2024). Of the accepted papers, 9 are published as open access, and at least 8 further open access papers are expected. A large collection of these papers was submitted to a special issue in the journal Water Science and Technology dedicated to industrial symbiosis solutions. In addition to the peer reviewed papers, ULTIMATE provided 29 contributions (presentations and posters) to international scientific conferences. To further support the dissemination of the outcomes to the academic and scientific communities, an ULTIMATE project page was created in the ResearchGate platform, results were publishing by participating organisations (e.g. the online library of KWR) and ULTIMATE organising exchange between research and university partners.

EU Added value

- The activities reported in this deliverable ensured that the novel and innovative results obtained in ULTIMATE by its academic and scientific partners, but also by several private industry partners, were widely disseminated throughout the European and international scientific community. This supports the wider uptake of the technological developments and thus furthers the ambition of furthering Water Smart Industrial Symbiosis.

Policy relevance of the results described

- ULTIMATE, funded under the H2020 programme, participates in the Open Research Data Pilot of the European Commission. As part of this pilot, it committed to the preparation of at least 10 open access contributions to peer reviewed journals and scientific events. This target has been achieved. This shows that open access publication of scientific advances funded by public funds is possible also when these are achieved in close collaboration with private industry. The open access publication of proprietary information from such industries, and their innovations, however, was proven to be unacceptable to these industries as this would damage their economic and competitive position in the market and thus be counterproductive to the objectives of (commercial) exploitation and valorisation of project outcomes by the project partners.

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1. Introduction

In ULTIMATE (indUstry water-utiLiTy symbIosis for a sMarter wATEr society) 28 project partners, and 2 linked third parties, worked together over a period of 53 months to build an evidence base for industrial symbiosis based on real-world, large-scale demonstrations. The project hinged upon the case studies, located in nine different countries across Europe and Israel, in which large demonstrations of symbiosis solutions took place.

The nine large-scale demonstration cases covered the four most important industrial sectors in Europe: Agro-food processing, Beverages, Heavy chemical / petrochemical and Biotech industry. The cases demonstrated technologies for turning wastewater into a resource, recovery, refining and reusing wastewater, and for extracting and exploiting energy and materials contained in industrial wastewater. Figure 1 provides a schematic overview of parties involved in the industrial symbioses, Figure 2 provides a schematic representation of the processes covered by ULTIMATE.

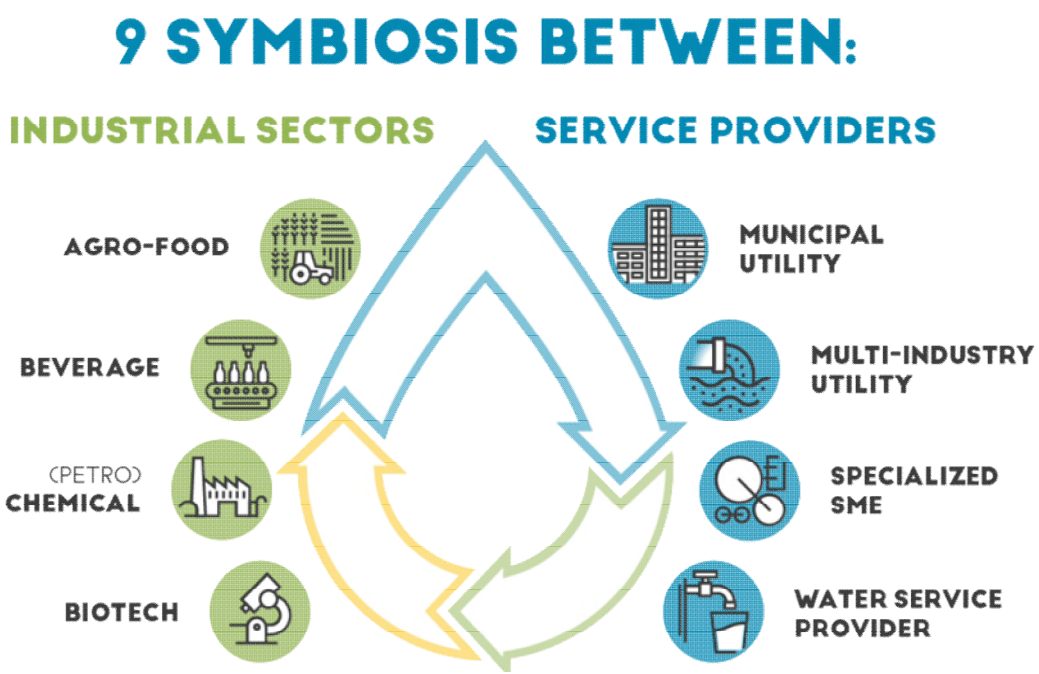

Figure 1 - Overview of ULTIMATE project main components

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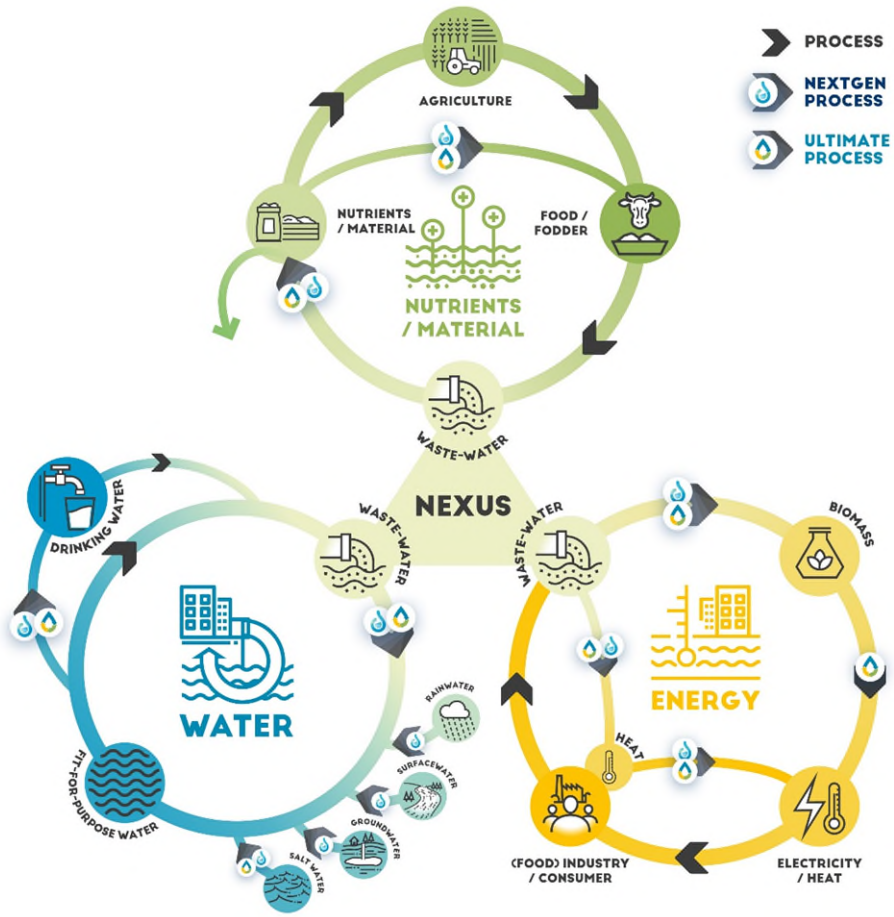

Figure 2 - Schematic overview of the processes covered by ULTIMATE

To maximise the impact of the evidence base ULTIMATE created, an elaborate strategy for exploitation and dissemination was formulated consisting of, amongst others, the following components:

- **Assessing market en synergy opportunities for WSIS**
- **ULTIMATE outputs and exploitation routes**
- **Individual partner exploitation strategies**
- **Foster implementation and replication of ULTIMATE**
- **Creation of spin-offs**
- **Business ecosystem for new WSIS**
- **Novel business models**

These elements were detailed in the plan for exploitation and dissemination of project results (D5.3). One element of impact creation by ULTIMATE is to maximise uptake and insights among the scientific and academic community. This is supported by the dissemination of new knowledge through scientific publications and contributions to scientific conferences, including open access publications and papers. A specific task, T6.7 – Academic and Scientific Dissemination & Events, was dedicated to the communication of results to the international scientific community. This deliverable provides on overview of the activities and outputs delivered under this task 6.7.

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2. Academic and Scientific Dissemination & Events

Maximising the impact of project results and findings in the academic and scientific community was the objective connected to Task 6.7 - Academic and scientific dissemination & events. To support maximum access to these results, ULTIMATE supported the EC Open Access Strategy Obligations by participating in the Open Research Data Pilot (ORD Pilot). This constated primarily the use of the OpenAIRE e-infrastructure for open scholarly communication, in particular the Zenodo platform, to disseminate scientific outputs, and the publication of scientific (peer reviewed) papers in open access journals as much as possible. A target was set to produce 10 or more open access publications and conference proceedings over the course of the project.

Open science was further supported by publication of open data sets according to the FAIR (Findability, Accessibility, Interoperability, Reusability) principles. A detailed overview of the datasets published is provided in D7.7 (Data Management Plan – updated (2nd).

An overview of the publications prepared and published is provided in section 2.1, an overview of the contributions to scientific conferences is provided in section 2.2.

Dissemination to the academic and scientific community were further supported through the following actions:

- **An ULTIMATE project page was created in the ResearchGate platform. However, the project function in ResearchGate was discontinued in 2023[1] and the page is no longer accessible.**
- **Publishing of results by participating organisations (e.g. the online library of KWR, https://library.kwrwater.nl, see figure 3).**
- **Organising exchange between research and university partners (see section 2.3)**

[1] https://www.researchgate.net/researchgate-updates/retiring-projects

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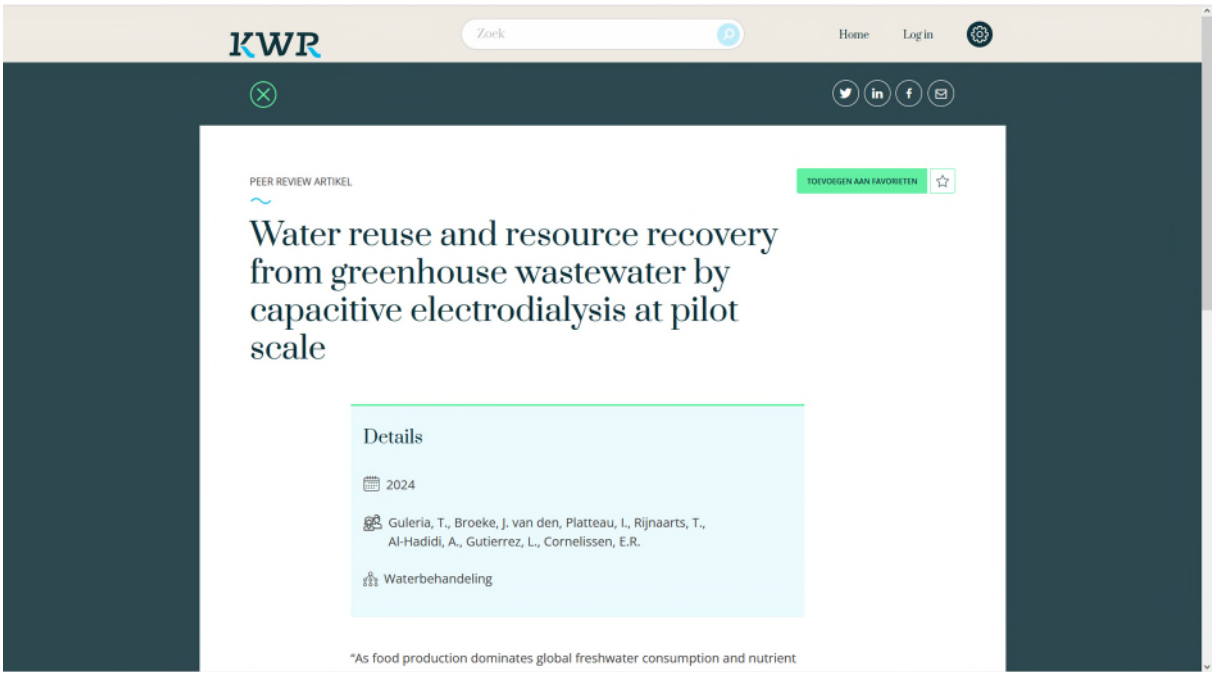

Figure 3 - Open access publication republished through the online library of KWR.

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2.1. Publications

A total of 21 papers were prepared by the ULTIMATE partners for publication in peer reviewed journals. A total of 10 papers were accepted for publication by the end of the project (31st October 2024), a further 11 papers have been submitted and are in the process of being reviewed. Of the accepted papers, 9 are published as open access, of the 11 submitted papers the 8 papers under review for the special issue of Water Science and Technology will be open access once accepted. The overview below provides details about the published papers and a list of titles and affiliations for the submitted papers.

2.1.1. Published papers

Journal: Environmental Research
Reference: Environmental Research, 2021, Volume 196, 110367
Title: Catchment-wide validated assessment of combined sewer overflows (CSOs) in a mediterranean coastal area and possible disinfection methods to mitigate microbial contamination
Authors: P. Crocetti, A.L. Eusebi, C. Bruni, E. Marinelli, G. Darvini, C. Bernardo Carini, C. Bollettini, V. Recanati, Ç. Akyol, F. Fatone
Affiliated ULTIMATE partners: NTUA
DOI: https://doi.org/10.1016/j.envres.2020.110367
Zenodo: https://zenodo.org/records/4563985/files/Catchment-wide%20validated%20assessment%20of%20Combined%20Sewer%20Overflows%20(CSOs)%20in%20a%20Mediterranean%20coastal%20area%20and%20possible%20disinfection%20methods%20to%20mitigate%20microbial%20contamination.pdf
Open Access: yes
Altmetrics: Citations 13, Captures 41 (readers: Mendeley 41)

Abstract
The first phase of this study aimed to evaluate the environmental impact of combined sewer overflow (CSO) events originated from 35 spillways on the Rio Vallescura catchment (Central Italy) and to understand their contribution to the deterioration of the coastal bathing water quality. A specific analytical campaign was carried out in the sewer system and a dynamic rainfall-runoff simulation model was developed and integrated with a water quality model and further validated. The simulations led to identify the most critical spills in terms of flow rate and selected pollutant loads (i.e. suspended solids, biochemical oxygen demand, chemical oxygen demand, total Kjeldahl nitrogen, Escherichia coli). Specifically, the E. coli release in the water body due to CSO events represented almost 100% of the different pollutant sources considered. In the second phase, the applicability of various disinfection methods was investigated on the CSOs introduced into the catchment. On site physical (UV) and lab-scale chemical (peracetic acid (PAA), performic acid (PFA), ozone) disinfectant agents were tested on microbial indicators including E. coli and intestinal enterococci. PFA and ozone were more effective on the removal of both bacteria (above 3.5 log units) even at low concentration and with short contact time; whereas, PAA showed a moderate removal efficiency (around 2.5 log units) only for E. coli. The highest removal

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efficiency was achieved in the on-site UV unit and none of the indicator bacteria was detected in the final effluent after the sand filtration and UV treatment. Finally, potential scenarios were developed in comparison to the baseline scenario for the management and treatment of CSOs where a mitigation of E. coli loads from 28% to 73% was achieved on the receiving water body, and a comparative cost assessment of the disinfection methods was provided for in situ treatment of the most critical spillway.

Journal: Frontiers in Chemical Engineering
Reference: Front. Chem. Eng., 14 September 2021
Title: Membrane-Based Processes to Obtain High-Quality Water From Brewery Wastewater
Authors: M.S. Toran, P. Fernndez Labrador, J.F. Ciriza, Y. Asensio, A. Reigersman, J. Arevalo, F. Rogalla, V.M. Monsalvo
Affiliated ULTIMATE partners: Aqualia
DOI: https://doi.org/10.3389/fceng.2021.734233
Zenodo: https://zenodo.org/records/14003139
Open Access: Yes
Altmetrics: 3.1K views, 599 downloads, 9 citations, attention score 1, Mentioned by Twitter 2, Readers on Mendeley: 20

Abstract
Water reuse is a safe and often the least energy-intensive method of providing water from non-conventional sources in water stressed regions. Although public perception can be a challenge, water reuse is gaining acceptance. Recent advances in membrane technology allow for reclamation of wastewater through the production of high-quality treated water, including potable reuse. This study takes an in-depth evaluation of a combination of membrane-based tertiary processes for its application in reuse of brewery wastewater, and is one of the few studies that evaluates long-term membrane performance at the pilot-scale. Two different advanced tertiary treatment trains were tested with secondary wastewater from a brewery wastewater treatment plant (A) ultrafiltration (UF) and reverse osmosis (RO), and (B) ozonation, coagulation, microfiltration with ceramic membranes (MF) and RO. Three specific criteria were used for membrane comparison: 1) pilot plant optimisation to identify ideal operating conditions, 2) Clean-In-Place (CIP) procedures to restore permeability, and 3) final water quality obtained. Both UF and Micro-Filtration membranes were operated at increasing fluxes, filtration intervals and alternating phases of backwash (BW) and chemically enhanced backwash (CEB) to control fouling. Operation of polymeric UF membranes was optimized at a flux of 25–30 LMH with 15–20 min of filtration time to obtain longer production periods and avoid frequent CIP membrane cleaning procedures. Combination of ozone and coagulation with ceramic MF membranes resulted in high flux values up to 120 LMH with CEB:BW ratios of 1:4 to 1:10. Coagulation doses of 3–6 ppm were required to deal with the high concentrations of polyphenols (coagulation inhibitors) in the feed, but higher concentrations led to increasing fouling resistance of the MF membrane. Varying the ozone concentration stepwise from 0 to 25 mg/L had no noticeable effect on coagulation. The most effective cleaning strategy was found to be a combination of 2000 mg/L NaOCl followed by 5% HCl which enabled to recover permeability up to 400 LMH·bar^{-1}. Both polymeric UF

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and ceramic MF membranes produced effluents that fulfil the limits of the national regulatory framework for reuse in industrial services (RD 1620/2007). Coupling to the RO units in both tertiary trains led to further water polishing and an improved treated water quality.

Journal: ACS Sustainable Chemistry & Engineering
Reference: ACS Sustainable Chem. Eng. 2021, 9, 30, 9970–9987
Title: Targeted Bio-Based Volatile Fatty Acid Production from Waste Streams through Anaerobic Fermentation: Link between Process Parameters and Operating Scale
Authors: C. Bruni, A. Foglia, A.L. Eusebi*, N. Frison, Ç. Akyol, F. Fatone
Affiliated ULTIMATE partners: UNIVPM
DOI: https://doi.org/10.1021/acssuschemeng.1c02195
Zenodo: no
Open Access: no
Altmetrics: 1291 views, 11 citations

Abstract
Anaerobic processes are proven to have much more environmental and economic benefits than conventional aerobic treatment systems, offering sustainable energy and valuable biochemicals. In recent years, bio-based volatile fatty acid (VFA) production has come into prominence as more value is derived before ending up with other final products. This paper presents a critical review of the research studies on bio-based VFA production from different waste streams (i.e., industrial sludge/waste, organic fraction of municipal solid waste/food waste, municipal wastewater/sludge, combined streams) through anaerobic fermentation. Fundamentals and decisive process parameters (i.e., pH, temperature, retention time, organic loading rate) are reviewed, and their correlations with VFA yields are critically discussed based on 178 cases (156 lab- and 22 pilot-scale). The picture we provided clearly demonstrates that process parameters should be clearly defined and optimized according to the type of waste streams which may have a significant impact on downstream processes in most cases.

Journal: Entropy
Reference: Entropy 2023, 25(1), 4
Title: Resource Recovery and the Sherwood Plot
Authors: G. Karakatsanis, C. Makropoulos
Affiliated ULTIMATE partners: NTUA
DOI: https://doi.org/10.3390/e25010004
Zenodo: https://zenodo.org/records/14000655
Open Access: yes
Altmetrics: 2142 views, 4 citations

Abstract
Our work analyzes the biophysical and economic foundations of the Sherwood Plot (SP). In general, the SP depicts the theoretical relationship between the cost of recovering a target material or an identified Value Added Compound (VAC) from a waste matrix and its dilution in the waste matrix; specifically suggesting that the

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recovery cost is reverse proportional to the VACs dilution in it. We further utilize the SP as a scientifically consistent and economically coherent analytical framework for measuring resource recovery performance. Initially, we analyze the SPs fundamental physical properties, as well as its many potential economic extensions. Specifically, we substantiate the relation between a VACs Entropy, Dilution and Recovery Cost. On these grounds we present the SPs remarkable and numerous economic properties that make it consistent to its physical foundations; thus integrating concisely its physical and economic aspects and postulate a generalized SP function. We further test econometrically the validity of an SP based on both deterministic and stochastic real data from a small-scale industrial unit of polyphenols' recovery from natural fruit juice production residual wastewater. In turn, based on the fusion of our theoretical argumentation and empirical findings we dive into the epistemological extensions of the SP. Specifically, we study how the recovery cost structure at the single industry level is revealed by the SP and can be useful for postulating cost structure ontologies. Cost ontologies are in turn useful as a diagnostic of the formation process of VAC recovery markets as well as their structure and concentration, defining the industrial shares when many industries operate in the recovery of the same VAC.

Journal: Journal of Environmental Chemical Engineering
Reference: J. Env. Chem. Eng., Volume 12, Issue 2, April 2024, 112222
Title: Conductive adsorbents enhance phenol removal from wastewater by direct interspecies electron transfer "DIET"-based anaerobic biodegradation process
Authors: S. Shimshoni, K. Baransi-Karkaby, K. Yanuka-Golub, H.Azaizeh, M. Hassanin, I. Sabbah
Affiliated ULTIMATE partners: GSR
DOI: https://doi.org/10.1016/j.jece.2024.112222
Zenodo: https://zenodo.org/records/14002358
Open Access: yes
Altmetrics: 9 views, 3 citations

Abstract
This study examined the hybrid adsorption and anaerobic biodegradation processes of phenol by using activated carbon cloth (CC) to stimulate direct interspecies electron transfer (DIET). Phenol biodegradation was tested over three sequential runs using 100 mL lab-scale bioreactors and compared with two different types of CC and granular activated carbons (GAC). The addition of the carbon adsorbents to the bioreactors significantly accelerated the methane production rate. This high rate of methane production was also accompanied by the complete removal of phenol, and a high COD(s) removal rate of about 95%, compared to 43.68% and 48.65% in the control sets in the first and second runs, respectively. The enhancement of the phenol biodegradation is attributed to the synergy of the adsorption and biodegradation processes. An initial adsorption stage has contributed to a significant and rapid reduction of phenol, leading to a lower inhibition effect of phenol, followed by anaerobic biodegradation of the adsorbed phenol stimulated by the DIET process. Specifically, the optimal concentration for Single Weave carbon cloth (CCSW) of 1.6 g L^{-1} promoted both the DIET and the adsorption processes. Microbial community composition analysis revealed that CCSW facilitated the growth of syntrophic bacterial groups (Rikenellae, Syntrophorhabdaceae, Gracilibacteraceae, and DTU014), and

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archaea (Methanosaetaceae and Methanoregulaceae), previously reported as key players in the DIET processes to promote phenol degradation. To the best of our knowledge, this is the first work that demonstrates the contribution of CC to stimulate DIET mechanism of anaerobic biodegradation synergistically combined with adsorption process for enhanced phenol removal.

Journal: Desalination
Reference: Desal. 583 (2024) 117669
Title: Water reuse and resource recovery from greenhouse wastewater by capacitive electrodialysis at pilot scale
Authors: T. Guleria, J. van den Broeke, I. Platteau, T. Rijnaarts, A. Alhadidi, L. Gutierrez, E. Cornelissen
Affiliated ULTIMATE partners: KWR
DOI: https://doi.org/10.1016/j.desal.2024.117669
Zenodo: https://zenodo.org/records/14002781
Open Access: yes
Altmetrics: 14 readers

Abstract:
As food production dominates global freshwater consumption and nutrient discharge regulation tightens, the performance of novel technologies at applied scale needs to be studied to optimize water use and minimize environmental impact. Water reuse and the nutrient recovery from greenhouse wastewater were assessed utilizing one-pass capacitive electrodialysis (CED) at a pilot scale (19.32 m2 membrane area, 1–4 m3/day capacity), employing carbon-based electrodes. CED was optimized for key parameters, including applied voltage, cross-flow velocity, staging, water recovery, and varying feed concentrations. High-quality greenhouse irrigation water (conductivity<0.2 mS/cm and Na+ < 0.1 mmol/L) was produced, meeting specified guidelines. Na+ was retained less compared to Ca2+ and Mg2+ (86 % ± 4 %, 97 % ± 2 %, and 98 % ± 3 % removal, respectively) and nutrients concentration factors for K+, NO3− and PO43− reached up to 2.3 (596 ± 5 mg/L), 2.7 (1330 ± 20 mg/L), and 1.9 (130 ± 2 mg/L), respectively. There was no significant improvement in ion removal for all feed compositions beyond 12 V and 80 % water recovery. CED's specific energy consumption (SEC) with optimized parameters was 4-fold lower than the modeled RO system, and lower than previous electrodialysis studies. The highest SEC obtained was 0.24 kWh/m3. These findings suggest that CED is a promising technology for the greenhouse horticulture sector, aiding the move toward zero liquid discharge.

Journal: Frontiers in Chemical Engineering
Reference: Front. Chem. Eng., 06 June 2024
Title: Matchmaking for industrial symbiosis: a digital tool for the identification, quantification and optimisation of symbiotic potential in industrial ecosystems
Authors: C. Makropoulos, N.-A. Kritikos, C. Pantazis
Affiliated ULTIMATE partners: NTUA
DOI: https://doi.org/10.3389/fceng.2024.1363888
Zenodo: https://zenodo.org/records/14003130
Open Access: yes

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Altmetrics: 527 views, 890 downloads, 14 readers, Mentioned by twitter 1, readers on Mendeley 7

Abstract
Effective waste management is crucial for sustainable industrial operations. This paper introduces a state-of-the-art digital tool designed for the circular economy. Primarily it pinpoints and quantifies symbiotic possibilities between industries with liquid waste streams, emphasising the most lucrative inter-industry connections. In practice, the tool takes in data such as waste stream volumes, material concentrations within these streams, market prices of materials, and industries' raw material consumption rates. Utilising these, its algorithm identifies and assesses the most profitable material exchanges among the specified industries. This assessment considers the market value of materials and the costs associated with recovering those materials from liquid waste streams. One of the major challenges, the estimation of recovery costs, is addressed using an innovative Sherwood plot analysis. This analysis draws a correlation between a material's recovery cost and its concentration within a liquid medium. The tool's output provides a detailed list of potential transactions complemented by illustrative graphs that detail mass flows, profit margins, and environmental advantages for each industry. Collectively, these details offer insights both for individual industries and the industrial ecosystem as a whole. One of the tool's most significant revelations is its ability to uncover potential "bridges" linking industrial waste streams to resource needs, unearthing previously unnoticed economic and ecological gains. By calculating economic and environmental benefits of "waste" reuse, this tool offers a compelling rationale for the adoption of industrial symbiosis. Ultimately, it uncovers the transformative potential of aligning industrial activities with a balance that fosters both economic growth and ecological responsibility.

Journal: Resources
Reference: Resources 2024, 13, 65
Title: Chemical Leasing (Ch.L.) and the Sherwood Plot
Authors: G. Karakatsanis, C. Makropoulos
Affiliated ULTIMATE partners: NTUA
DOI: https://doi.org/10.3390/resources13050065
Zenodo: https://zenodo.org/records/14000747
Open Access: yes
Altmetrics: -

Abstract
Although the Circular Economy (CE) has made remarkable technological progress by offering a wide range of alternative engineering solutions, an obstacle for its large-scale commercialization is nested in the adoption of those business and financial models that accurately depict the value generated from resource recovery. Recovering a resource from a waste matrix conserves natural reserves in situ by reducing demand for virgin resources, as well as conserving environmental carrying capacities by reducing waste discharges. The standard business model for resource recovery is Industrial Symbiosis (IS), where industries organize in clusters and allocate the process of waste matrices to achieve the recovery of a valuable resource at an optimal cost. Our work develops a coherent microeconomic architecture of Chemical Leasing

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(Ch.L.) contracts within the analytical framework of the Sherwood Plot (SP) for recovering a Value-Added Compound (VAC) from a wastewater matrix. The SP depicts the relationship between the VAC's dilution in the wastewater matrix and its cost of recovery. ChL is engineered on the SP as a financial contract, motivating industrial synergies for delivering the VAC at the target dilution level at the market's minimum cost and with mutual profits. In this context, we develop a ChL market typology where information completeness on which industry is most cost-efficient in recovering a VAC at every dilution level determines market dominance via a Kullback–Leibler Divergence (DKL) metric. In turn, we model how payoffs are allocated between industries via three ChL contract pricing systems, their profitability limits, and their fitting potential by market type. Finally, we discuss the emerging applications of ChL financial engineering in relation to three vital pillars of resource recovery and natural capital conservation.

Journal: Water Science and Technology
Reference: Water Sci. Technol., accepted
Title: Towards circular greenhouse wastewater reuse: Advancements in cation exchange membranes for selective Na+/K+ separation using electrodialysis systems
Authors: T. Guleria; J. van den Broeke; R. Adam; L. Gutierrez; T. Rijnaarts; K. Verbeken; N. De Geyter; X. Tian; E. Cornelissen
Affiliated ULTIMATE partners: KWR
DOI: to be determined
Zenodo: to be added once published
Open Access: yes
Altmetrics: -

Abstract
Driven by the growing need for alternative water sources and forthcoming stringent nutrient discharge regulations, there is growing interest in developing selective membrane solutions to facilitate circular greenhouse wastewater reuse (as emphasized in the EU H2020 ULTIMATE project). For electrodialysis systems, sodium (Na^+) over potassium (K^+) selective membranes are essential to achieve minimal liquid discharge. This study addresses the challenge of developing selective, efficient, and scalable Na+/K+ cation exchange membranes. State-of-the-art CEM developments were reviewed and the functionalization of commercial membranes with crown ethers was identified as a promising approach. Two crown ether-modified membranes (15-crown-5 (15C5) and 18-crown-6 (18C6)) were developed, characterized, and tested in equimolar and greenhouse wastewater binary feed ratios. While the results demonstrated low overall selectivity, the 15C5 modified membrane showed a marginal enhancement in K^+ selectivity, suggesting the need for further optimization. The study concludes with recommendations for the future development of Na^+/K^+ selective membranes, highlighting the potential of machine learning approaches to expedite progress. This research provides a foundational step towards practical and scalable Na+/K+ ion separation solutions, for achieving minimal liquid discharge in greenhouse horticulture.

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Journal: Water Science and Technology
Reference: Water Sci. Technol., accepted with revisions
Title: Supporting Decision-making for Industrial Symbioses using a Hybrid Modelling Approach and its Application to Wastewater Treatment
Authors: Chen, O., Mustafee, N., Evans, B., Khoury, M., Vamvakeridou-Lyroudia, L., Chen, A., Djordjević, S., Savić, D.
Affiliated ULTIMATE partners: UNEXE
DOI: to be determined
Zenodo: to be added once published
Open Access: yes
Altmetrics: -

Abstract
Industrial Symbiosis (InSym) leverages the proximity of entities to gain a competitive advantage through collective strategies. Within the Circular Economy, this involves the circular exchange and reuse of water, energy, and resources amongst participating businesses, enhancing resource valorisation in the manufacturing process. However, InSym, as a distinctive business model, requires collaboration amongst multiple stakeholders working towards a shared goal, posing inherent challenges. Operations Research (OR), particularly computer modelling and simulation techniques, can mitigate InSym implementation risks by informing decision-making through experimental approaches. This paper discusses a hybrid modelling framework to support InSym decision making. The framework employs four OR techniques: agent-based simulation, discrete-event simulation, system dynamics, and multiple criteria decision analysis. It assesses collective treatment strategies for olive mill wastewater, addressing challenges such as scattered locations of small-scale olive mills, seasonal wastewater discharge, and high organic loading. The hybrid model tests innovative approaches for collective wastewater treatment and resource reclamation, demonstrating the novelty of this framework in evaluating scenarios regarding the distribution level of collective treatment. Our work aids decision-making at operational, tactical, and strategic levels of the proposed government policy on wastewater discharge, transforming the economy-environment dilemma into a win-win situation for olive oil businesses and local authorities.

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2.1.2. Submitted papers – under review

ULTIMATE has agreed with Water Science and Technology that contributions will be included in a special issue. The below papers were submitted for this special issue. Two papers (Gulera et al. and Chen et al., Water Sci. Technol., accepted) mentioned above will also be included in this special issue.

Submitted papers:

Asensio, Y., Giménez-Lorang A., Conzelmann, L., Kleyböcker, A., Remy, C., Vera-Domingo, R., Ciriza, J., Ortiz, J., Llorente, M., Esteve-Nuñez, A., Tejedor Sanz, S., Tomás Ortiz, X., Hernández Ibañez, N., Rogalla, F., Monsalvo, V. (Submitted). Unveiling the techno-economic and life cycle analysis of a microbial electrochemical fluidized bed reactor (ME-FBR) operated on a brewery wastewater treatment plant. Water, Science and Technology

Jährig, Jeannette, Kleyböcker, Anne, Kraus, Fabian, Rodenkam-Melchiorsen, Line, Milter, Hasse, Thisgaard, Preben, Vredenbregt, Leo, Miehe, Ulf (Submitted). Performance and life cycle assessment of different pre-treatments for reverse osmosis to enable water reuse.

Schütz, Jan, Kleyböcker, Anne, Bendix Larsen, Sille, Kristensen, Malene, Remy, Christian, Miehe, Ulf (Submitted) Modelling and set-point definition for the development of a joint control system of two interconnected wastewater treatment plants and its application in practice.

Szelag, B., Ciuccoli, N., Gonzalez Camejo, J., Giansanti, C., Kiczko, A., Eusebi, A., Palermo, C., Fatone, F. (submitted) Infiltration modelling coupled to digital tools to avoid high saline concentrations in reclaimed water: Application in coastal Central Italy.

Bizani, E., Christophoridis, C., Touloupi, M., Iosifidis, D. (submitted) Polyphenol extraction from industrial water by-products: ULTIMATE project fruit processing industry case study

Baransi Karkaby, K., Hassanin; M., Raanan-Kiperwas, H., Massalha, N., Sabbah, I. (submitted) Methane production from anaerobic pre-treatment of municipal wastewater combined with olive mill wastewater – Demonstration study
Vautherin, R., Métivier, H., Reguer, A., Benbelkacem, H. (submitted) Use of a numerical model to evaluate the efficiency of SO2 absorption by sodium sulfite in packed and spray column.

Perkis. A., Mansilla, W., Glotzbach, R., Munaretto, S., Rubini, A., Gervasio, I., Argo, A. (submitted) Stakeholder engagement to increase impact of water technology case studies.

Khoury, M., Evans, B., Guleria, T., Van Den Broeke, J., Vamvakeridou-Lyroudia, L., Chen, O., Mustafee, N., Chen, A., Djordjevic, S., Savic, D. (submitted). Towards the Development of an Online Platform for an Industry Metabolic Pathway

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Other submitted papers

Journal: Journal of Cleaner Production
Title: Investigating the Feasibility of New Business Models for the Circular Economy of Water: A Simulation Study of a Mobile Rental Wastewater Treatment Service
Authors: O. Chen, N. Mustafee, B. Evans, M. Khoury, L. Vamvakeridou-Lyroudia, A. Chen, S. Djordjević, D. Savić
Affiliated ULTIMATE partners: UNEXE

Journal: Journal of the Operational Research Society
Title: A Decision-making Framework for the Valorisation of the Water Cycle through Industrial Symbioses
Authors: O. Chen, N. Mustafee, B. Evans, M. Khoury, M., J. van den Broeke, T. Guleria, L. Vamvakeridou-Lyroudia, A. Chen, S. Djordjevic, D. Savic
Affiliated ULTIMATE partners: UNEXE

One paper has been submitted to the social science research network (SSRN) and is available as preprint (not peer reviewed) and is available under abstract number 4994428 (https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4994428)

Gritti, M.C., Brozou, Z., Jefferson, B.. Pidou, M. Impact of Transition Metals and Humic Acids on Ammonia Vacuum Thermal Stripping.

2.2. Contributions to scientific conferences

ULTIMATE partners participated in numerous scientific conferences. The below table provides an overview of the events in which ULTIMATE results were presented in the form or an oral or poster presentation.

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Table 1 - Overview of contributions to scientific conferences.

Partner	Date/period of the event	Event Title	Type of activity	Title of your ULTIMATE intervention	Meeting Place / Remote Meeting
AQUALIA	02 October 2024	NEXO AGUA-ENERGÍA ENERGÍA PARA EL AGUA, AGUA PARA LA ENERGÍA	Presentation	The true value of water: innovation in sustainable energy resources	Madrid, Spain
KWB	8 - 12 September 2024	IWA 2024 Conference on the Design, Operation and Economics of Large Wastewater Treatment Plants	Presentation	Modelling and scenario investigation of two wastewater treatment plants for the development of a predictive joint control system	Budapest, Hungary
KWB	8 - 12 September 2024	IWA 2024 Conference on the Design, Operation and Economics of Large Wastewater Treatment Plants	Presentation	Resource recovery, Full-scale nutrient recovery producing struvite and ammonium sulfate solution	Budapest, Hungary
AQUALIA	24 June 2024	LET2024: 19th IWA Leading Edge Conference on Water and Wastewater Technologies	Poster	Long-term operation of an Electro-Stimulated Anaerobic Reactor (ELSAR®) on Brewery Wastewater	Essen, Germany
KWR	19 - 20 June 2024	7th IWA Regional Membrane Technology Conference	Presentation	Water Reuse and Resource Recovery from Greenhouse Wastewater by Capacitive Electrodialysis at Pilot Scale	Palermo, Italy
GSR	19 - 20 June 2024	International Conference on Wider-Uptake of Water Resource Recovery from Wastewater Treatment 7th IWA – Regional Membrane Technology Conference	Presentation	Conducve adsorbents enhance phenol removal from wastewater by direct interspecies electron transfer "DIET"-based anaerobic biodegradaon process	Palermo, Italy
KWB	25 - 26 October 2023	Aachener Tagung: Wassertechnologie	Presentation	Vergleich verschiedener Membranen als Vorbehandlung für Umkehrosmose bei	Aachen, Germany

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Partner	Date/period of the event	Event Title	Type of activity	Title of your ULTIMATE intervention	Meeting Place / Remote Meeting
				Abwasser mit hohem Anteil an nicht abbaubaren organischen Stoffen	
KWR	9 July 2023	ICOM Membrane Conference	Presentation	Feasibility of Ion Selective Membranes in Electrodialysis for Resource Recovery from Greenhouse Wastewater	Chiba, Japan
AQUALIA	13 - 15 June 2023	XIII INTERNATIONAL CONGRESS AEDYR “Looking to the future”	Presentation	Water treatment and reuse in the agri-food industry	Granada, Spain
GSR	7 – 9 June 2023	WATER Innovation & Circularity Conference (WICC)	Presentation	Carbon cloth stimulates direct interspecies electron transfer for phenol biodegradation	Athens, Greece
UNIVPM	17 - 19 April 2023	ECOMONDO Mexico	Presentation	Innovation actions and urban biorefinery for sustainable wastewater treatment	Guadalajara, Mexico
UNIVPM	17 - 19 April 2023	ECOMONDO Mexico	Presentation	Circular cities and regions, from sustainable finance to green infrastructure	Guadalajara, Mexico
UNIVPM	9 March 2023	Ecoforum Marche	Presentation	I depuratori: impianti per il riutilizzo e l’economia circolare – casi studio italiani di riferimento europeo	Ancona, Italy
GSR	20 - 24 November 2022	Euro Membrane 2022	Presentation	Lab-Scale AnMBR	Sorrento, Italy
X-FLOW	23 - 24 November 2022	18th Aachen Membrane Colloquium (AMK)	Presentation	Capillary nanofiltration membranes; From plant-scale surface water treatment to resource recovery from waste-waters	Aachen, Germany
KWR	22 November 2022	Euro Membrane Conference	Presentation	Feasibility of Ion Selective Membranes in Electrodialysis for Resource Recovery from Greenhouse Wastewater	Sorrento, Italy
KWR	20 September 2022	Melpro Electro-chemical Conference	Presentation	Feasibility of Ion Selective Membranes in Electrodialysis for Resource Recovery from Greenhouse Wastewater	Prague, Czech Republic
UNEXE	13 - 15 September 2022	OR64 Online: 2022 by the Operational Research Society	Presentation	A Hybrid Decision Support System to Facilitate Industrial Symbiosis in the Food Processing Industry	Remote Meeting
UNIVPM	12 - 14 July 2022	ECOMONDO Mexico	Presentation	Ecoinnovaciones financiadas por la UE en	Guadalajara,

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Partner	Date/period of the event	Event Title	Type of activity	Title of your ULTIMATE intervention	Meeting Place / Remote Meeting
				el sector del agua	Mexico
UNEXE	4 - 8 July 2022	14th International Conference on Hydroinformatics 2022	Presentation	A hybrid modelling framework for industrial symbiotic water cycle (F-SWC) decision support	Bucharest, Romania
AQUALIA	19 - 22 June 2022	17th IWA World Congress on Anaerobic Digestion	Poster	From Research to Application: Identifying and overcoming barriers to adoption of new AD technology	Ann Arbor, Michigan (USA)
UNEXE	1 – 5 November 2021	Amsterdam International Water Week 2021	Presentation	A Participatory Hybrid Decision Support Framework for Industrial Symbiosis: The Symbiotic Water Cycle Framework (F-SWC)	Amsterdam, Netherlands
AQUALIA	11 - 13 October 2021	IDA 2020 International Water Reuse & Recycling Conference	Presentation	ADVANCED BIO-ELECTROCHEMICAL SYSTEMS AND MEMBRANE-BASED PROCESSES IN SERIES FOR WASTEWATER REUSE IN FOOD & BEVERAGE INDUSTRY	Rome, Italy
KWB	7 October 2021	Aqua Circular Online Conference	Presentation	Keynote: Basics of Circular Economy and Industrial Symbiosis	Remote Meeting
GSR	7 October 2021	Aqua Circular Online Conference	Presentation	Biogas production from anaerobic pre-treatment of municipal and/or food industry wastewater in Karmiel, Israel	Remote Meeting
AQUALIA	13 - 15 September 2021	5th EU-ISMET 2020 European mee-ting of the International Society for Microbial Electrochemistry and Technology	Presentation	Scaling Up of Electro-Stimulated Anaerobic Reactor (ELSARTM) in the industrial wastewater treatment sector	Girona (Spain)
UNEXE	14 – 16 September 2021	International Federation of Operational Research Societies - OR63 Online: Creating A Better Future	Presentation	A Hybrid Simulation Framework for Scenario Forecasting and Decision Support towards Industrial Symbiosis	Remote Meeting

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Partner	Date/period of the event	Event Title	Type of activity	Title of your ULTIMATE intervention	Meeting Place / Remote Meeting
UNEXE	31 August – 2 September 2021	Aqua360	Presentation	A Participatory Hybrid Decision Support Modelling Framework for Industrial Symbiosis	Exeter, UK
UNIVPM	5 - 8 September 2021	4th IWA Resource Recovery Conference	Presentation	Smart Water and Efficient Management in Large Industrial Sites: The Italian Case Study of Aretusa	Remote Meeting

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2.3. Organising exchange between research and university partners

As part of maximising the scientific and academic impact of ULTIMATE, within Task 6.7, the ULTIMATE partners from academia and research and technology organisations (RTO) defined the objective to contextualise ULTIMATE ouputs for, and actively disseminate to, the scientific and academic community. Below is a summary of the actions performed to support this objective.

1. **Ultimate Young Professionals**

KWR initiated the ULTIMATE Young Professionals group. With this group ULTIMATE convened young professionals and early careers, like PhDs, postdocs and early careers, who are actively contributing to ULTIMATE. The aim was to bring about added value of being a part of the project through networking activities with professionals in the same phase of their career. Young professionals activities were organised initially as part of ULTIMATE but at a later stage this was expanded to encompass the young professionals from the CIRSEAU, the cluster consisting of ULTIMATE and its sister projects B-WaterSmart, WATER-MINING, WIDERUPTAKE and REWAISE.

<u>ULTIMATE young professionals activities:</u>

- Kick-off meeting in July 2021
- Private group on LinkedIn created for the ULTIMATE YPs to share news, updates, conferences, etc. of relevance
- Annual Meeting in September 2021
    - YP session
        - Overview of what the YPs are doing, key topic areas, etc.
    - YPs prepared the ULTIMATE social session for the Annual Meeting in September 2021 with the objective of:
        - Have people meet each other and get to know some of the larger group by answering funny questions at random; and
        - Build a sense of community and accountability towards each other and the project.
- Annual Meeting in June 2022
    - Reflection on the YP group (getting the most out of the ULTIMATE YP Group)
        - What has worked
        - What has not worked
        - What we should do more of
    - Talk by Dimitri Iossifidis (GtG) on tips for landing the job you want

<u>CIRSEAU young professionals activities:</u>

- Monthly meeting of the CIRSEAU YP working group
- CIRSEAU YP Meeting in November 2022
    - Presentation of two initiatives
        - Initiative 1: Involving YPs is EU project
        - Initiative 2: Enthusing YPs about the water sector

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- Survey developed and distributed among the sister projects and to broader YP and senior water professionals to about the water sector (opportunities, gaps, challenges, etc.) – The idea was to use this information to the organise a session to discuss the gaps in attracting YPs to the water sector, and what steps need to be taken.
- Conversations held with the IWA European YWP committee on possible alignment (not much success here despite interest from both sides)
- Currently working on a lessons learned and recommendations brief with insights from the CIRSEAU sister projects.

2. Interacting with the academic and scientific community

The academic and RTO partners actively participated in scientific events. Besides individual presentations, as listed in section 2.2, they co-organised several international events or sessions at these events, which convened the scientific community around the topic of WSIS or specific sub-topics addressed by ULTIMATE. Examples of such events (co)organised by the ULTIMATE partners is provided in Table 2.

Table 2 – International scientific events coorganised by ULTIMATE partners.

Event	Dates	Location	(co)organising partners
ECOMONDO The Green Technology Expo - an international trade fair specializing in innovative technologies with associated scientific programme	26 - 29 October 2021, 8 – 11 November 2022, 7 – 10 November, *2023*	Rimini, Italy	UNIVPM
ICT4WATER – a hub for EU-funded research projects on ICT and Water Management	19 Jun 2024 21 June 2023 29 June, 2022	Brussel, Belgium	KWR, UNEXE, NTUA, WE
IWA World Water Congress & Exhibition	11-15 August 2024 11 – 15 September 2022	Montreal, Canada Kopenhagen, Denmark	KWR, UNEXE, UNIVPM, NTUA, WE

3. Discussion and Conclusions

In ULTIMATE partners worked on the building of an evidence base for industrial symbiosis based on real-world, large-scale demonstrations. A range of technologies was developed, demonstrated and validated as part of the project. As part of this work, scientific advances were made, and the partners in ULTIMATE strived to share such advances with the academic and scientific communities to maximise the impact of project results and findings also in these communities. The primary means of communication and dissemination of results to these communities was the preparation of scientific papers and contributions to scientific conferences.

A total of 21 scientific papers were prepared for publication in peer reviewed journals, of which 10 papers had been accepted for publication by the end of the project (31st October 2024). Of the accepted papers, 9 are published as open access, and at least

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8 further open access papers are expected. A collection of these papers was submitted to a special issue in the journal Water Science and Technology dedicated to industrial symbiosis solutions. In addition to the peer reviewed papers, ULTIMATE provided contributions (presentations and posters) to international scientific conferences, and a total of 29 have been presented in Table 1 in this deliverable.

Overall ULTIMATE targeted 10 open access journal and scientific conference papers (as defined in the Grant Agreement). The project has produced a substantially higher amount of open access scientific contributions, which will increase further due to the open access papers still under review that will be published after the finalisation of the project.

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