Deliverable 1.1

Assessment of baseline conditions for all case studies

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

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Date: 31/05/2021

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.	1.1
Dissemination level [1]	PU
Work Package	1
Task	All tasks in WP1
Lead beneficiary	KWB
Contributing beneficiary(ies)	EUT, UNIVPM, KWR, UCRAIN, AQUALIA, GTG TECH, SUEZ RR; KALUND, NOVO, GSR
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Quality Assurance	Sandra Casas Garriga, Christos Makropoulos, Gerard van den Berg
Due date of deliverable	May, 31st 2021
Actual submission date	May, 31st 2021

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
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Document history

V	Date	Author(s) /Reviewer(s) (Beneficiary)	Description
0.1	23rd April	A. Kleyböcker (KWB), C. Bruni (UNIVPM), A. Naves Arnaldos (EUT)	First version to be submitted to the case study leaders
0.2	30th April	Case study leaders	Reviewed version: each CS leader reviewed the paragraph of his own case study
0.3	5th May	A. Kleyböcker (KWB), C. Bruni (UNIVPM), A. Naves Arnaldos (EUT)	Feedback of the CS leaders addressed
0.4	9th May	Christian Remy (KWB)	Internal review of the whole document
0.5	14th May	A. Kleyböcker (KWB), C. Bruni (UNIVPM), A. Naves Arnaldos (EUT)	Feedback of internal reviewer addressed
0.6	18th May	Christos Makropoulos (KWR)	External review of the whole document
0.7	20th May	A. Kleyböcker (KWB), C. Bruni (UNIVPM), A. Naves Arnaldos (EUT)	Feedback of the external review addressed
0.8	27th May	Sandra Casas Garriga (EUT), Gerard van den Berg (KWR)	Quality control
1	31th May	A. Kleyböcker (KWB), C. Bruni (UNIVPM), A. Naves Arnaldos (EUT)	Feedback of quality control addressed → final document

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Executive Summary

Summary of Deliverable

Ultimate aims to establish and foster water smart industrial symbiosis by implementing circular economy solutions for water, material and energy recovery. The circular economy solutions shall create a win-win situation for both the water sector and the industry. In nine case studies the water sector forms those symbiosis with companies from the agro-food, beverage, petrochemical, chemical and biotech industry.

Objective of the deliverable and links to other deliverables

This deliverable describes the symbiosis in detail and the situation in the case studies before the start of Ultimate. A special focus is put on the technological units which were already in place before Ultimate and the available flow streams as resources for the new Ultimate solutions.

Relevant data of those flow streams were collected in the frame of this deliverable to describe the baseline conditions that existed before the start of Ultimate. They will be used as a basis to quantify the improvements of the case study due to the implementation of the Ultimate circular economy solutions. The results will be presented in the deliverables *D1.3 –D1.5 New approaches and best practices for closing the water, energy and material cycles within symbiosis cluster.*

Furthermore, other work packages (WP), specifically WP2 and WP5, will need those data for their life cycle assessments in *D2.2 LCA, cost and risk assessment for WSIS* and their KPI tool in *D2.5 A KPI Tool for WSIS Performance Assessment* as well as for assessing starting conditions and requirements for other potential replication sites in *D5.6 Three Ultimate WSIS Integrated Assessments*, respectively.

The data were collected via excel templates from the case studies. The time period of the presented data comprises usually one full year of operation. The most important data are presented in the paragraphs *Detailed description of the technological solution before Ultimate*. In the subsequent paragraph *Baseline Conditions,* those and additional data are presented in more detail showing average, minimum and maximum values for each parameter as well as standard deviations. As an outlook for the expected results from Ultimate, the Ultimate solutions are briefly presented and the planned key performance indicators, which will be used in the upcoming technological deliverables (*D1.3-D1.5*) to evaluate the performance of the Ultimate solutions are displayed.

Results

The baseline data of the nine case studies showed for all of them high potentials for the implementation of circular economy solutions. Especially the cooperation of the industry with the water sector creates a win-win situation for both enabling the implementation of the Ultimate solutions. Tab. 1 gives an overview of the different types of resources and their potential for the implementation of recovery technologies for water, energy and material.

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- Water recovery

All types of wastewater ranging from municipal wastewater characterised by the occurrence of pathogenic organisms up to wastewater from the petro(chemical) industry with high sulphur and metal concentrations to biotech, beverage and food industry can be used to recover water. Those wastewaters can be technically treated until drinking water quality is reached. However, in Europe it is very difficult to use the reclaimed water for direct potable reuse as the main sources for drinking water production are surface water and groundwater. Thus, almost all case studies consider only agricultural irrigation, water supply for cooling towers or for cleaning purposes as reuse options.

Especially in coastal regions, the intrusion of saltwater in coastal aquifers and sewer systems increases the chloride concentration in the water and thus, render (salty) water unsuitable for irrigation. Therefore, to avoid irrigation with salty water, an early warning system will be developed and implemented to take immediate action during salinity peaks. As suitable measures, flow splitting and equalisation of the secondary effluent as well as the potential use of other waters are considered.

Tab. 1 Ultimate case studies and symbiosis with their resources for circular economy concepts regarding water, energy and material (WWTP: wastewater treatment plant; SME: small and medium enterprise providing water services; WRP: water reclamation plant)

Case study	Water Smart Industrial Symbiosis	Resources	Closing the cycles of WATER, ENERGY, MATERIAL		
			WATER	ENERGY	MATERIAL
CS1 Tarragona (ES)	**Internal symbiosis within multi-industry utility**: municipal and industrial WWTP & urban WRP	Municipal wastewater and industrial wastewater from the petrochemical complex	✓		
CS2 Nieuw Prinsenland (NL)	**Internal symbiosis within cooperative**: greenhouses & water treatment facility	Drain water from greenhouses; residual and geothermal heat	✓	✓	✓
CS3 Rosignano (IT)	**Municipal utility, multi-industry utility & SME**: Sewer system, municipal WWTP, WRP	Municipal wastewater mixed with seawater due to an undesired intrusion of the seawater; byproducts from industry for reuse in water treatment	✓		✓
CS4 Nafplio (EL)	**Industrial utility & SME:** industrial WWTP	Wastewater from fruit processing industry	✓		✓
CS5 Lleida (ES)	**Municipal utility & multi-industry utility**: industrial WWTP & municipal WWTP	Wastewater from brewery & municipal wastewater	✓	✓	✓
CS6 Karmiel/ Shafdan (IL)	**Municipal utility & two SMEs**: two municipal WWTPs & WRP	Wastewater from olive oil production, slaughter-houses and wineries & municipal wastewater		✓	✓

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CS7 Tain (UK)	**Distillery, water company, & SME**: industrial WWTP	Wastewater from whiskey distillery	✓	✓	✓
CS8 Chem. Platform Roussillion (FR)	**Internal symbiosis within multi-industry utility**: industrial WWTP	Wastewater from chemical industry		✓	✓
CS9 Kalundborg (DK)	**Municipal utility & multi-industry utility**: municipal WWTP & industrial WWTP	Wastewater from pharma & biotech industry and municipal wastewater	✓	✓	✓

- Energy recovery

Especially the wastewaters from olive oil production and the distillery contain very high COD concentrations with 120 g/L and 38 g/L, respectively and thus, are very well suited for an anaerobic treatment to produce biogas. Also the brewery wastewater as well as the mix of municipal wastewater with olive mill wastewater are still in a suitable range for an anaerobic treatment even though their concentrations are much lower and range between 2 and 4 g/L.

The biogas can further be used to produce electricity and heat via a solid oxide fuel cell. Hereby, the efficiency of the solid oxide fuel cell is expected to be 1.5-times more efficient than a combined heat and power unit.

For heat recovery temperatures of wastewaters between 23 °C and 70 °C are considered and they are found in the biotech and chemical industry, respectively.

- **Material recovery**

Wastewaters from fruit processing and from olive oil processing plants contain valuable polyphenols and are suited for the recovery of this high value added product.
Regarding the recovery of nutrients, the ammonium concentration of anaerobically treated distillery wastewater is promising for ammonia recovery and its further processing to a fertiliser as ammonium sulphate. The nutrient composition of drain water from greenhouses is very suitable as a basis to design a fertilising mixture or product for the greenhouses.

Flue gas washing water resulting from the chemical industry contains enough sulphur and metals such as copper, zinc, nickel and chromium suggesting their recovery. The wastewater from the biotech and pharma industry is also characterised by a sufficient sulphur concentration. In addition, its acetic acid concentration is also high enough to consider its recovery.

- Reduction of energy and chemicals consumption in plant operation

In wastewater treatment, to avoid fouling processes of the membranes in anaerobic reactors, an early warning system will be tested in order to save energy due to an optimised operation of the membranes.

For two neighbouring wastewater treatments plants, a joint control system will be implemented in order to save energy and chemicals due to a predicted demand driven oxygen supply and due to the change from a chemical phosphorus removal system to

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an enhanced biological phosphorus removal, respectively. Here the requirement is that the wastewater treatment plants are connected to each other and that the wastewaters can be treated together.

Exploitation and Outlook

The presented data that refer to the starting conditions of the case studies will be further used and presented in the technology evidence base (*D1.6 Technology Evidence Base concept and integration* and *D1.7 Technology Evidence Base final version*). This technology evidence base will provide valuable information for investors in such technologies, for operators and engineers as well as for policy and decision makers, who can use them to define future strategies for boosting industrial symbiosis. It will be free accessible via the project homepage. After the end of the Ultimate project, it will be hosted by Water Europe.

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Abbreviations

AAT	Advanced Anaerobic Technology
AD	Anaerobic Digestion
AOP	Advanced Oxidation Process
BOD	Biological Oxygen Demand
CE	Circular Economy
CFU	Colony-Forming Unit
COD	Chemical Oxygen Demand
CTG	Cross-cutting Technology Group
ELSAR^{TM}	Electrostimulated Anaerobic Reactor
GAC	Granular Activated Carbon
HT-ATES	High-Temperature Aquifer Thermal Energy Storage
IEX	Ion exchanger
iWWTP	Industrial Wastewater Treatment Plant
KPI	Key Performance Indicator
nZLD	Near Zero Liquid Discharge
OMW	Olive Mill Wastewater
PAC	Powdered Activated Carbon
PPP	Public Private Partnership
RO	Reverse Osmosis
SAT	Soil Aquifer Treatment
SBP	Small Bioreactor Platform
SCWE	Subcritical Water Extraction
SME	Small and Medium-sized Enterprises
TOC	Total Organic Carbon
UF	Ultrafiltration
WP	Work Package
WWTP	Wastewater Treatment Plant
WRP	Water Reclamation Plant
WWRP	Wastewater Reuse Plant

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1. Objectives and methodology

Work package (WP) 1 aims to demonstrate the feasibility of innovative technological solutions in order to foster circular economy in the water sector. Therefore, so called water smart industrial symbiosis between the industrial sector and service providers lead to a mutual advantage of both via a synergetic cooperation. In those symbioses demonstrated at nine case studies, the water, material and energy cycles are closed also, considering the nexus between the three cycles. WP1 will provide the necessary data to assess the benefits of the technologies (WP2) and the evidence to convince stakeholders of these benefits (WP3), while overcoming the social and governance barriers and creating new business models to promote the implementation of those solutions (WP5 & WP6).

This deliverable presents the situation before Ultimate including relevant data of the different flow streams serving as a resource for the new Ultimate solutions. Hereby, for each case study, the already existing symbiosis between the water sector and the industrial sector is explained and presented together with the detailed description of the technological system before Ultimate started. The relevant parameters referring to that system are presented in detail as baseline conditions. Based on those conditions the need and the potential for the innovative technologies to be implemented in the frame of Ultimate are concluded together with the description of the extension and/or intensifying of the symbioses that are necessary to implement the Ultimate solutions. As an outlook for the expected results from Ultimate, the Ultimate solutions are briefly presented and the planned key performance indicators, which will be used in the upcoming technological deliverables (D1.3-D1.5) to evaluate the performance of the Ultimate solutions are displayed.

The data describing the baseline conditions of each case study will be used in the course of the project as a basis to quantify the improvements of the case study after the implementation of the Ultimate circular economy solutions. Furthermore, WP2 will need those data for the evaluation of the circular economy solutions for example by using life cycle assessments or key performance indicators (KPIs).

For WP5, the starting conditions of each case study will be very interesting, since they want to find replications sites which should provide similar conditions in order to successfully implement similar concepts.

The baseline conditions have been obtained through interviews and systematic data collection through templates, which have been adapted for each site considering its particularities.

Based on these general aspects, specific KPIs and parameters for each site have been compiled in spreadsheets, gathering technical data from at least a complete year of monitoring. The spreadsheets collected have been complemented with information from the living documents describing the symbioses, the sites and the technical solutions that were already in place before the start of the project. This information has been compiled, assessed and summarised in this deliverable.

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Two types of KPIs were chosen: case study-specific KPIs aim to quantitatively showcase the impact of the circular economy solutions while technology-specific KPIs shall show, how efficient a technology is and may enable a comparison to similar technologies. For the KPIs, based on the first suggestions of the case studies, the CTG leaders proposed additional KPIs in order to be consistent for the whole work package. For each case study, the collection of KPIs was listed in a PowerPoint presentation. Those were presented, send back to the case study and, when necessary, were discussed with the case study partners. The final version of the KPIs was confirmed by the case study partners and is presented in this document. However, KPIs might change during the project, if the partners feel that additional KPIs might be of interest or better fit the demonstration character of the cases.

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2. Assessment of baseline conditions for all case studies

Ultimate aims to promote, establish and extend water smart industrial symbiosis between service providers from the water sector and the industrial sector. In the Ultimate case studies, the industrial sector consists of the agro-food, beverage, petrochemical, chemical and biotech industry. As service providers in the water sector, municipal utilities, multi-industry utilities, specialised small and medium enterprises and water service providers are involved. The nine case studies are located in different European countries and Israel. There, innovative technologies are developed, demonstrated and optimised to create a win-win situation for both, the industrial and the water sector (Fig. 1).

Fig. 1 Ultimate case studies

The following chapters provide a detailed description of the case studies and their baseline conditions before Ultimate started. Furthermore, the technological objectives are described and specific KPIs for innovative technologies are presented.

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2.1. CS1 Tarragona (Spain)

2.1.1. General description of the case study and site

The Petrochemical Complex of Tarragona (Spain) is an industrial area that groups several companies related to the chemical and oil fields (Fig. 2). This complex started its operation in 1971, with the construction of the first refinery, and since then its activity has progressively grown until being considered one of the most important of this type in Catalonia, Spain and southern Europe. The more than 30 companies that form this complex, from which we can highlight companies like Repsol (chemical, petroleum and gas), Bayer, BASF, ERCROS, Cepsa, Bic or The Dow Chemical Company, are mainly focused on the production of chlorine, alkaline salts, oxygen gas, fertilisers, insecticides, fuels, plastics and synthetic essences.

Fig. 2 Petrochemical complex of Tarragona

Aguas Industriales de Tarragona Sociedad Anónima (AITASA) is a private company founded in 1965 to supply water to industries, mainly the chemical industries that were then being stablished in the Tarragona complex. AITASA supplies water for industrial and drinking uses to the complex from groundwater and reclaimed water production.
In order to meet its water demands in both the industry and households, Tarragona's region has traditionally relied on water transfers from the Ebro River via a system that was built back in 1989. However, the increasing water demand from the industry outpaced the system's capacity, which led to the implementation of a reclamation plant to feed industrial water only and to avoid consuming resources of the drinking water production.

Since 2012, AITASA operates the Water Reclamation Plant (WRP) of Camp de Tarragona producing water for boilers and cooling towers (Fig. 3). This locally available additional water supply replaces surface water supplies that were transferred from the Ebro River some years ago for the use at the petrochemical park. As a result, an equivalent volume of surface water is available for urban water supply in the coastal areas of Tarragona province. By developing this new and locally available water supply source, industrial growth in a water scarce region has been supported, while promoting local industry's sustainability.

Currently, a construction of an industrial wastewater treatment plant (iWWTP) is taking place (expected to be commissioned in December 2021) to treat industrial wastewater from the different companies of the complex.

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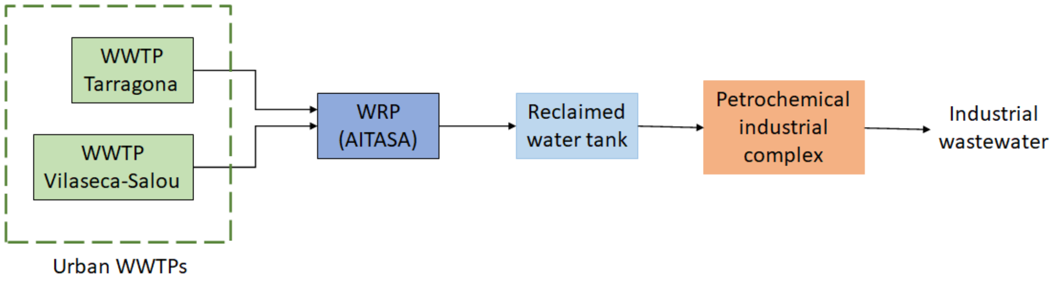

Fig. 3 Scheme of the pre-existing system and the partners of the symbiosis before the start of Ultimate

2.1.2. Detailed description of the technological solutions before Ultimate

The Tarragona and Vilaseca-Salou wastewater treatment plants (WWTPs) were interconnected by a 4-km pipeline to ensure that the WRP can be supplied with enough secondary effluent from either or both WWTPs. Secondary effluent undergoes a basic reclamation process at the WRP (1021 m^3/h average inlet flow rate), consisting of a ballasted clarification step, followed by disc filtration, multimedia filtration and sand filtration. The effluent undergoes an advanced reclamation process including a two-pass RO treatment processes and disinfection, using ultra-violet light and chlorine, before it enters the reclaimed water distribution system (Fig. 4).

Furthermore, chemical reagents such as coagulant, flocculant and antiscaling are added to enhance the plant performance.

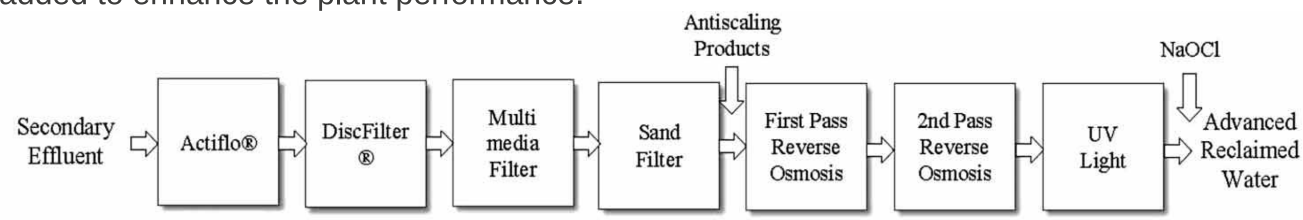

Fig. 4 AITASA WRP process diagram

Cooling water supply has been one of the main expected uses of reclaimed water produced at the Camp de Tarragona WRP. Reclaimed water for cooling towers supply had to meet the quality requirements established by the Spanish reclaimed water regulations (RD 1620/2007) and also the operational specifications applicable to the cooling water systems considered, like concentration limits for ammonia, phosphates, 5-day biochemical oxygen demand (BOD5), total organic carbon (TOC), chemical oxygen demand (COD), electrical conductivity, chloride, sulphate, calcium and alkalinity. One of the parameters most restrictive is ammonia, that is removed in the reverse osmosis process (970 m^3/h average inlet flow rate to this unit), achieving a removal effectiveness higher than 97%. For the rest of the parameters, the removal effectiveness after WRP treatment is 98.6% conductivity, 71.6% COD, 82.4% sulphate, 99.1% total alkalinity and 96.2% orthophosphate.

The daily energy consumption of these facilities (WRP) is 27080 kWh.

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On the other hand, in order to meet future water requirements (BREF limits), an industrial wastewater treatment plant (iWWTP) will be commissioned by the end of 2021 to polish the aggregated wastewater from the petrochemical complex with an average water flow rate of 1348 m^3/h. The technology train to be implemented in these new facilities will be:

- Dissolved air flotation
- Biological membranes reactor
- Granular activated carbon

It is assumed that 1.01 m^3/h sludge (value from design) will be produced as waste.

2.1.3. Baseline conditions

Tab. 2 shows the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

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Tab. 2 CS1: Baseline conditions of water related parameters

BASELINE - CURRENT SYSTEM							
Parameter			**Units**	**Mean value**	**Standard deviation**	**Frequency and no. of measurements**	**Comments**
Water yield of the system	**Current system**	WRP inlet water flow rate	m^3/h	1021	704	Daily 1/1-5/4/2021	
		WRP outlet water flow rate	m^3/h	646	108		
		iWWTP inlet water flow rate	m^3/h	1348	Design value (nominal)		
		iWWTP outlet water flow rate	m^3/h	1348			
		Advanced RO inlet water flow rate	m^3/h	970	133	Daily 1/1-5/4/2021	
		Advanced RO outlet water flow rate	m^3/h	646	79		
Water quality	**WRP inlet (Reclamation plant)**	pH	upH	7,8	0,1	1/2/2021-31/3/2021 (Monday-Friday)	
		Temperature	ºC	18,2	1		
		Conductivity	µS/cm	2150	222,2		
		Redox potential	mV	217,8	18,1		
		Turbidity	NTU	10,7	8		
		MSS	mg/L	20,7	12,1		
		DQO	mg O_2/L	52,9	18,8		
		Total alkalinity	ºFr	31,7	2,7		
		Dissolved oxygen	mg O_2/L	8,7	0,6		
		Ammonium	mg NH_4-N/L	35,9	5,3		
		Total chlorine	mg Cl_2/L	0,2	0,1		
		Monochloramines	mg Cl_2/L	0,1	0		
		Sulphate	mg/L	227,6	54,3		
		Orthophosphate	mg P_2O_5/L	1,3	0,8		
Water quality	**WRP outlet (Reclamation plant)**	pH	upH	5,6	0,3	1/2/2021-31/3/2021 (Monday-Friday)	
		Temperature	ºC	18,7	1		
		Conductivity	µS/cm	30,7	15,7		
		Redox potential	mV	688,8	30,4		
		Turbidity	NTU	0,2	0,1		
		MSS	mg/L	0	0		
		DQO	mg O_2/L	15	0		
		Total alkalinity	ºFr	0,3	0,2		
		Dissolved oxygen	mg O_2/L	9,4	0,3		
		Ammonium	mg NH_4-N/L	0,9	0,4		
		Total chlorine	mg Cl_2/L	1,9	1,3		
		Monochloramines	mg Cl_2/L	0,5	0,6		
		Sulphate	mg/L	40	0		
		Orthophosphate	mg P_2O_5/L	0,05	0		

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BASLINE-CURRENT SYSTEM						
Parameter			Units	Mean value	Standard deviation	Frequency and no. of measurements
Water quality	Advanced RO inlet	pH	upH	7,1	0,3	1/2/2021-31/3/2021 (Monday-Friday)
		Temperature	ºC	18,4	0,9	
		Conductivity	µS/cm	2221,2	279	
		Redox potential	mV	504,3	47,1	
		Turbidity	NTU	0,8	0,1	
		MSS	mg/L	7,9	2,5	
		DQO	mg O_2/L	23,8	5,2	
		Total alkalinity	ºFr	20,4	3,1	
		Dissolved oxygen	mg O_2/L	9,2	0,3	
		Ammonium	mg NH_4-N/L	34	5,4	
		Total chlorine	mg Cl_2/L	2,6	1,4	
		Monochloramines	mg Cl_2/L	0,4	0,2	
		Sulphate	mg/L	218,2	53,4	
		Orthophosphate	mg P_2O_5/L	0,1	0	
		Iron	mg/L	0,1	0,1	
		Aluminium	mg/L	0,04	0	
Water quality	Advanced RO outlet (=WRP outlet)	pH	upH	5,6	0,3	1/2/2021-31/3/2021 (Monday-Friday)
		Temperature	ºC	18,7	1	
		Conductivity	µS/cm	30,7	15,7	
		Redox potential	mV	688,8	30,4	
		Turbidity	NTU	0,2	0,1	
		MSS	mg/L	0	0	
		DQO	mg O_2/L	15	0	
		Total alkalinity	ºFr	0,3	0,2	
		Dissolved oxygen	mg O_2/L	9,4	0,3	
		Ammonium	mg NH_4-N/L	0,9	0,4	
		Total chlorine	mg Cl_2/L	1,9	1,3	
		Monochloramines	mg Cl_2/L	0,5	0,6	
		Sulphate	mg/L	40	0	
		Orthophosphate	mg P_2O_5/L	0,05	0	

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BASELINE - CURRENT SYSTEM							
Parameter			Units	Mean value	Standard deviation	Frequency and no. of measurements	Comments
Water quality	iWWTP inlet (industrial plant)	pH	upH	7,5			Design value (nominal)
		Conductivity	µS/cm	12091			
		MSS	mg/L	82			
		Hydrocarbons	mg/L	2,5			
		DBO_5	mg/L	89			
		DQO	mg/L	237			
		TOC	mg/L	79			
		Chromium	µg/L	10			
		Copper	µg/L	21			
		Nickel	µg/L	30			
		Zinc	µg/L	464			
		Lead	µg/L	11			
		Cadmium	µg/L	4			
		Mercury	µg/L	1,6			
		Chloride	mg/L	3120			
		Total nitrogen	mg/L	36			
		Nitrogen inorganic	mg/L	8			
		Total phosphorus	mg/L	3			
		Benzene	mg/L	75			
		AOX	mg/L	2,1			
	iWWTP outlet (Industrial plant)	MSS	mg/L	1			Calculated design value (nominal)
		Hydrocarbons	mg/L	0,1			
		DQO	mg/L	50,5			
		TOC	mg/L	17			
		Chromium	µg/L	5			
		Copper	µg/L	10,5			
		Nickel	µg/L	28,5			
		Zinc	µg/L	138			
		Lead	µg/L	8,8			
		Cadmium	µg/L	3,2			
		Mercury	µg/L	0,2			
		Total nitrogen	mg/L	16			
		Nitrogen inorganic	mg/L	3,6			
		Total phosphorus	mg/L	1,5			
		Benzene	mg/L	41			
		AOX	mg/L	0,7			

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BASELINE - CURRENT SYSTEM							
Parameter			**Units**	**Mean value**	**Standard deviation**	**Frequency and no. of measurements**	**Comments**
Energy consumption	**Current system (WRP)**	Whole system	kWh/day	27080		Daily 1/1-5/4/2021	
Reagents required	**Current system (WRP)**	Coagulant (pre-treatmemt)	kg/L	1,36	Established dosage flow rates (2021)		PAX-14
		Flocculent (pre-treatment)	g/L	1,5			HYDREX 6171 (0,15%)
		Organic coagulant (filtration)	kg/L	1,05			HYDREX 3495 (10%)
		Antiscaling (Reverse Osmosis)	kg/L	1,11			HYDREX 4106
		Reclaimed water (outlet)	kg/L	1,242			Sodium hypochlorite (15%
Waste produced	**iWWTP**	Sludge from iWWTP	m^3/h	1,01	Designed value (nominal)		

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2.1.4. Objectives of the Ultimate solutions

CS1 aims to extend the water synergies already implemented in the complex by increasing water availability for future demands with new reclaimed water production from the industrial WWTP. The aim of CS1 is to further close the loop of water in the complex, reclaiming water from the future iWWTP with near ZLD systems and optimising the current urban WRP so to maximise its water production and diminish the energy consumption. Thus, CS1 will also aim at reducing energy consumption of the current urban WRP while maximising its recovery.

New near zero liquid discharge (nZLD) treatment system

A new nZLD treatment coupling advanced reverse osmosis and membrane distillation for reclaiming water from the industrial WWTP will be demonstrated at pilot scale to obtain a new industrial water source for the complex.

Ammonia removal via a zeolite adsorption-based technology

Additionally, new low-cost treatments based on zeolite adsorption for the removal of ammonia from the current urban WRP will be demonstrated to diminish the current reclaimed water production costs and increase the water yield of the system. Those possible zeolite treatments will be studied at bench-scale and the most economical and technically feasible will be implemented at pilot-scale

Concept study for fit-for-purpose water

The symbiosis between the industry with 30 companies and the industrially owned multi-utility will foster the integration of the industrial reclaimed water production into fit-for-purpose water production for covering the local industrial demand. Therefore, a concept study will be conducted to study the future uses of the reclaimed water.

2.1.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 3 will be determined during the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 3 Specific KPIs in CS1 and parameters to be determine

Topic	Objectives	Specific KPIs
Water	Fit-for-purpose water reclamation from WWTP effluent and water reuse. Ammonia removal with a low-cost technology	- Water yield - Water quality - Specific energy consumption - Reagents and materials required - Waste produced

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2.2. CS2 Nieuw Prinsenland (Netherlands)

2.2.1. General description of the case study and site

Coöperatieve Tuinbouw Water Zuivering de Vlot is a wastewater treatment facility located at ‘s-Gravenzande treating 160 hectares (60 companies) of drain water from greenhouses mainly growing ornamental crops (Fig. 5). By exploring water and nutrient reuse opportunities for their facility, they are optimising their system for internal symbiosis within their own facility and external symbiosis with neighbouring greenhouses and industries.

Fig. 5 De Vlot wastewater treatment plant facility

2.2.2. Detailed description of the technological solutions before Ultimate

The current system treats drain water from 60 greenhouses (160 ha) and has a capacity for a flow rate of 60 m^3/h (Fig. 6). However, the normal flowrate is usually around 40 m^3/h. The inlet water stream from the greenhouses is water with a high salt content (2.14 mS/cm) and contains pathogens (34 CFU/L E. Coli, 29 CFU/mL coliforms, 71000 CFU/mL, aerobic colony bacteria, 120 CFU/mL molds/yeast, 240 CFU/mL Enteriobacteriaceae). The process steps are shown in Fig. 6 and as follows:

- Pre-filtration by vibrating and rotating filters: suspended solids removal
- Coagulation in sedimentation buffers: P removal.
- Sand filtration with glycerol dosage: N removal, achieving effectiveness higher than 28% for ammonia removal and 5% for nitrate. Initially, a target of 75% nitrogen removal was established with the addition of glycerol, however the

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dosage of glycerol was stopped prematurely due to a contamination of the slow sand filter.

- Activated carbon: crop protection agent removal

The current status at De Vlot is that they cannot handle this capacity yet. The sedimentation tanks are working. The sand filters are giving problems which they hope to tackle if they use gravity for the pass instead of a vacuum. Also, backwashing helped for a few hours, however, the system is not designed for backwashing so the pump capacity is not sufficient for a good backwash for all three filters. The pressure is too low to reach the furthest filter. Only after the sand filter is working, they will start with the activated carbon to remove plant protection agents first.

The wastewater stream from the greenhouse is currently discharged to the sewer, although it contains high concentrations of nutrients (worth up to 3.5 €/m³) and also represents value for the water itself (0.6 €/m³). In 2027, greenhouses in the Netherlands will need to remove all crop-protection agents and nutrients from their wastewater, before it can be discharged. Therefore, it is really interesting to have the possibility to use this re-water and its resources for greenhouse irrigation.

Greenhouses require energy for heating during winter periods. Currently, they are being heated with fossil energies. The use of more sustainable energy sources for heating greenhouses is being explored, amongst others driven by the target of climate neutral horticulture by 2040, as laid down in the horticulture agreement (Tuinbouwakkoord). Currently, in several areas in the Netherlands, fossil free heating of greenhouses is prepared by using a geothermal source. To make optimal use of the residual heat supply, there needs to be a balance in demand and supply. The amount of geothermal heat available is fairly constant throughout the year, as geothermal wells are ideally operated under stable conditions, at a stable capacity. Therefore, they cannot rapidly adjust to changes in heat demand.

In greenhouse areas there are high peak demands during cold periods. Therefore, balancing demand and supply by storing excess heat produced in times of low demand (summer) and using it to supplement the supply capacity in times of high demand (winter time) would allow for optimising of the design of the geothermal plants. A high temperature aquifer thermal energy storage (HT-ATES) is a possible solution to store the excess heat produced during the summer months (Fig. 7).

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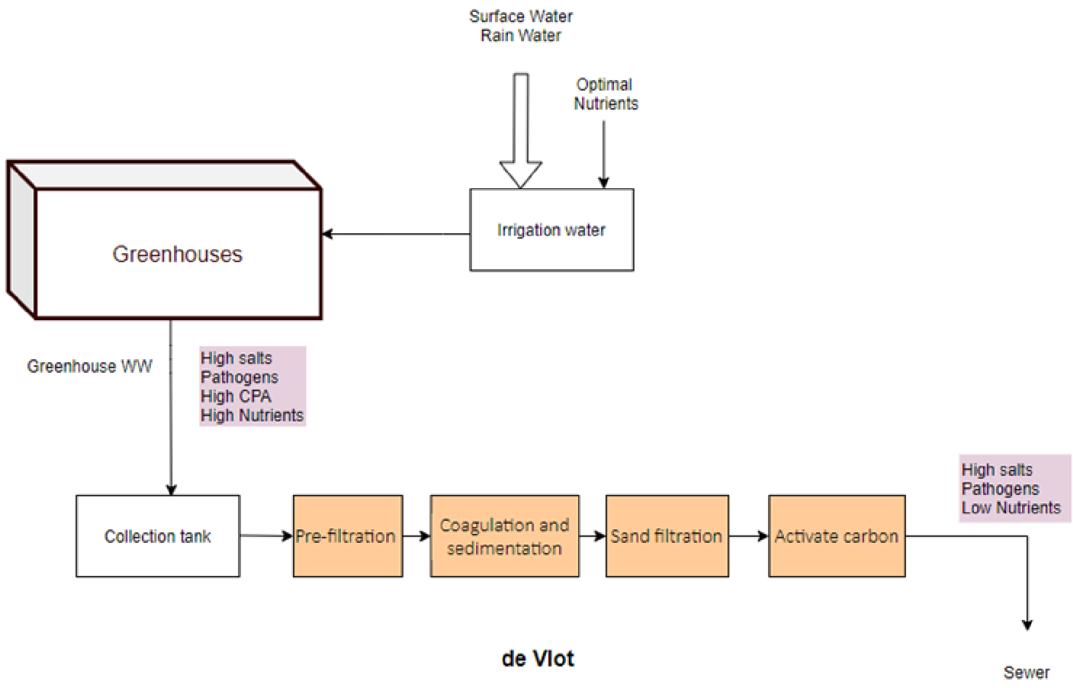

Fig. 6 CS2 process diagramme of the pre-existing system

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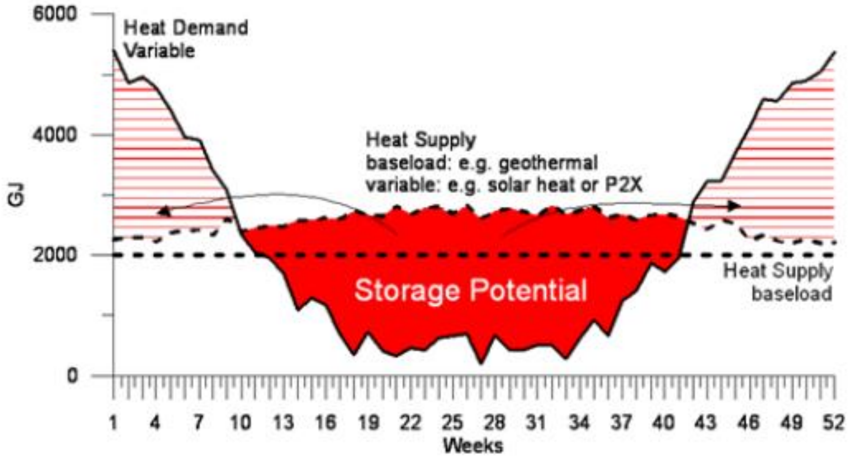

Fig. 7 Heat supply vs demand across the year (source: Hartog, N., M. Bloemendal, E. Slingerland and W. A. van (2017). "Duurzame warmte gaat ondergronds." VV+ sept-okt 17)

2.2.3. Baseline conditions

Tab. 4 and Tab. 5 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

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Tab. 4 CS2: Baseline conditions of water related parameters

BASELINE - CURRENT SYSTEM							
Parameter			Units	Mean value 2020	Standard deviation	Frequency and no, of measurements	Comments
Water yield of the system	Current system	Rainfall climatology of the area	mm/year	937,74	88,04	Monthly, 35 stations for region 7	Based on specific location of the site rainfall can range from 875 -1125 mm/year. Source: https://www.knmi.nl/nederland-nu/klimatologie/gegevens/monv, https://cdn.knmi.nl/knmi/map/page/klimatologie/gegevens/monv/jonv_2020.pdf. Data given in CS2 data excel
		Volume of water recovered *vs* rainfall	m^3/year				NA
		Water inlet flow rate	m^3/h	40	_	_	As specified by the water operator at de Vlot, The maximum capacity is 60 m^3/h
		Water outlet flow rate	m^3/h	20 - 40	_	_	As specified by the water operator at de Vlot. Currently, the system is having operational issues, The planned value is 40 m^3/h so that they can have (nearly permanently) 1 street in maintenance if required
Water quality	Current system	COD	mg O_2 /L				Currently not measured
		BOD (influent de Vlot)	mg O_2 /L	3,45	1,51	Weekly, 11	Measurements started in September 2020
		BOD (effluent street A)	mg O_2 /L	4,25	2,5	Weekly, 5 -11	Measurements started in September 2020
		pH (influent de Vlot)	upH	7,32	0,16	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		pH (effluent street A)	upH	7,22	0,11	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		EC (influent de Vlot)	mS/cm	2,14	0,43	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		EC (effluent street A)	mS/cm	2,17	0,24	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		TSS	mg/L				Currently not measured
		Turbidity	NTU				Currently not measured
		N, Kjeldahl	mg /L				Currently not measured
		Ammonium (influent de Vlot)	mg /L	1,94	1,21	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		Ammonium (effluent street A)	mg /L	<1,4	0	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		Total nitrogen	mg /L				Currently not measured
		Total phosphorus	mg /L				Currently not measured
		Nitrate (influent de Vlot)	mg /L	50,1	18,07	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		Nitrate (effluent street A)	mg /L	47,28	13,53	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
		Phosphate (PO_4-P)(influent de Vlot)	mg /L	3,81	1,6	Weekly, 5 -11	Measurements started in September 2020
		Phosphate (PO_4-P) (effluent street A)	mg /L	1,21	0,7	Weekly, 5 -11	Measurements started in September 2020
		TOC (influent de Vlot)	mg /L	18,53	2,23	Weekly, 5 -11	Measurements started in September 2020
		TOC (effluent street A)	mg /L	14,43	2,23	Weekly, 5 -11	Measurements started in September 2020
		E. Coli concentration (influent de Vlot)	CFU/mL	34	_	1	Only 1 measurement on 29th March 2021
		E. Coli concentration (effluent street A)	CFU/mL	<1	_	1	Only 1 measurement on 29th March 2021
		Coliforms (influent de Vlot)	CFU/mL	29	_	1	Only 1 measurement on 29th March 2021
		Coliforms (effluent street A)	CFU/mL	<4	_	1	Only 1 measurement on 29th March 2021
		Aerobic colony count bacteria (influent de Vlot)	CFU/mL	71000	_	1	Only 1 measurement on 29th March 2021
		Aerobic colony count bacteria (effluent street A)	CFU/mL	8500	_	1	Only 1 measurement on 29th March 2021
		Molds / yeasts (influent de Vlot)	CFU/mL	120	_	1	Only 1 measurement on 29th March 2021
		Molds / yeasts (effluent street A)	CFU/mL	1200	_	1	Only 1 measurement on 29th March 2021
		Enterobacteriaceae (influent de Vlot)	CFU/mL	240	_	1	Only 1 measurement on 29th March 2021
		Enterobacteriaceae (effluent street A)	CFU/mL	<4	_	1	Only 1 measurement on 29th March 2021
		Salmonella (influent de Vlot)	/25mL	NA	_	1	Only 1 measurement on 29th March 2021
		Salmonella (effluent street A)	/25mL	NA	_	1	Only 1 measurement on 29th March 2021

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BASELINE - CURRENT SYSTEM							
Parameter			Units	Mean value 2020	Standard deviation	Frequency and no, of measurements	Comments
Energy consumption	Current system	Whole system	kWh/m³	0,5	-	1	Based on information from the operator at de Vlot
Reagents required	Current system	Coagulant	g/m³	70	-	1	Iron Chloride with 40%, consumption at 75% removal of phosphates; based on infromation from the operator at de Vlot
		Glyserol	mL/m³	115	-	1	Estimated glyserol consumption at 75% nitrogen removal. This target was not achieved, because the dosage of glyserol was stopped prematurely due to contamination of the slow sand filter.
		Hydrogen peroxide	g/m³	3	-	1	Hydrogen peroxide 35% weekly (= 23 kg) per slow sand filter to keep the sand bed open longer
		Active carbon	g/m³	75	-	1	Active carbon NRS 0.5-2.5 consumption as it stands now, looking at the latest analyzes, we can now assume a lifespan of 10,000 bed volumes, that number is quite low, in the forecasts we have assumed 20,000 bed volumes, when changing AK after 10,000 bed volumes, we consume 75g per m³.
Waste produced	Current system	Trilfilter sludge	m³/year	40	-	1	20 micron filter, solid, mainly organic material as sludge
		Doekfilter	m³/year	12	-	1	40-50 micron filter
		Sedimentaion silos sludge	m³/year	15	-	1	Sludge from sedimentation silos will have to be dewatered, a rough estimate is 15 M³ of solid material per year
		Slow sand filltration sludge layer	m³/year	35	-	1	Dirty sand, top layer from the slow sand silos, estimate is now 4 cm skimmed off 4 cm per year, which is 36 M³ of polluted sand per year
		Activated carbon	m³/year	20	-	1	Active carbon can be regenerated in a pool
		Post denitrification sludge	g/m³	100	-	1	As it looks now, it will be denitrified after ACF, we assume that this sludge can be discharged into the sewage system

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Tab. 5 CS2: Baseline conditions of material related parameters

BASELINE - current system								
	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
Greenhouse waste-water	Flow	m^3/d	40	-	-	-	-	As specified by the water operator at de Vlot, The maximum capacity is 60 m^3/h
	pH (influent de Vlot)		7,32	7,00	7,70	0,16	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	pH (effluent street A)		7,22	7,00	7,40	0,11	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Conductivity (influent de Vlot)	µS/cm	2,14	1,10	3,40	0,43	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Conductivity (effluent street A)	µS/cm	2,17	1,80	2,70	0,24	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Ammonia (NH_4-N) (influent de Vlot)	mg/L	0,14	0,10	0,50	0,09	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Ammonia (NH_4-N) (effluent street A)	mg/L	0,01	0,10	0,10	0	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Nitrites (NO_2-N)	mg/L						Not currently measured
	Nitrates (NO_3-N) (influent de Vlot)	mg/L	50,1	9,8	91	18,07	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Nitrates (NO_3-N) (effluent street A)	mg/L	47,28	29,4	75,6	13,53	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Total Phosphorus (TP)	mg/L						Not currently measured
	Phosphate (PO_4-P) (influent de Vlot)	mg/L	3,81	1,85	9,91	1,6	Weekly, 5 -11	Measurements started in September 2020
	Phosphate (PO_4-P) (effluent street A)	mg/L	1,21	0,77	3,09	0,7	Weekly, 5 -11	Measurements started in September 2020
	Potassium (influent de Vlot)	mg/L	71,45	46,90	113,36	19,47	Weekly, 5 -11	Measurements started in September 2020
	Potassium (effluent street A)	mg/L	73,97	58,63	105,53	12,91	Weekly, 5 -11	Measurements started in September 2020
	Calcium (influent de Vlot)	mg/L	190,56	140,24	332,58	48,38	Weekly, 5 -11	Measurements started in September 2020
	Calcium (effluent street A)	mg/L	197,27	168,29	260,45	23,49	Weekly, 5 -11	Measurements started in September 2020
	Sulfur (influent de Vlot)	mg/L	74,52	43,27	144,24	22,97	Weekly, 5 -11	Measurements started in September 2020
	Sulfur (effluent street A)	mg/L	81,27	61,3	111,78	12,11	Weekly, 5 -11	Measurements started in September 2020
	Chemical oxygen demand (COD)	mg/L						Not currently measured
	Bioloogical oxygen demand (BOD_5) (influent de Vlot)	mg/L	3,45	3	8	1,51	Weekly, 11	Measurements started in September 2020
	Bioloogical oxygen demand (BOD_5)	mg/L	4,25	3	8	2,5	Weekly, 5	Measurements started in September 2020
	Total suspended solid concentration (TSS) (effluent street A)	mg/L						Not currently measured
	Turbidity	NTU						Not currently measured

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BASELINE - current system								
	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
Greenhouse waste-water	E. Coli concentration (influent de Vlot)	CFU/mL	34	_	_	_	1	Only 1 measurement on 29th March 2021
	E. Coli concentration (effluent street A)	CFU/mL	<1	_	_	_	1	Only 1 measurement on 29th March 2021
	Sodium (influent de Vlot)	mg /L	138,77	57,5	246,1	41,7	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Sodium (effluent street A)	mg /L	160,12	133,4	200,1	20,08	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Magnesium (influent de Vlot)	mg /L	49,55	36,45	89,91	12,23	Weekly, 5 -11	Measurements started in September 2020
	Magnesium (effluent street A)	mg /L	51,96	43,74	70,46	6,98	Weekly, 5 -11	Measurements started in September 2020
	Silicone (influent de Vlot)	mg /L	12,32	8,42	19,65	2,75	Weekly, 5 -11	Measurements started in September 2020
	Silicone (effluent street A)	mg /L	12,31	11,23	14,04	1,42	Weekly, 5 -11	Measurements started in September 2020
	Chloride (influent de Vlot)	mg /L	228,38	81,53	428,94	75,75	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Chloride (effluent street A)	mg /L	267,78	216,24	350,95	37,87	Bi-weekly, 25	Measurements from 2007 onward and after 2020 are given in the CS 2 data excel
	Bicarbonate (influent de Vlot)	mg /L	369,85	274,59	506,46	66,88	Weekly, 5 -11	Measurements started in September 2020
	Bicarbonate (effluent street A)	mg /L	359,55	317,3	421,03	32,62	Weekly, 5 -11	Measurements started in September 2020
	Iron (influent de Vlot)	μg /L	421,36	83,77	1022,05	206,86	Weekly, 5 -11	Measurements started in September 2020
	Iron (effluent street A)	μg /L	220,39	67,02	804,24	264,4	Weekly, 5 -11	Measurements started in September 2020
	Manganese (influent de Vlot)	μg /L	312,24	10,98	928,48	199,24	Weekly, 5 -11	Measurements started in September 2020
	Manganese (effluent street A)	μg /L	237,93	82,41	313,15	59,23	Weekly, 5 -11	Measurements started in September 2020
	Zinc (influent de Vlot)	μg /L	261,16	19,61	1765,26	549,75	Weekly, 5 -11	Measurements started in September 2020
	Zinc (effluent street A)	μg /L	38,73	19,61	78,45	15,21	Weekly, 5 -11	Measurements started in September 2020
	Boron (influent de Vlot)	μg /L	261,42	1,08	421,59	107,46	Weekly, 5 -11	Measurements started in September 2020
	Boron (effluent street A)	μg /L	315,15	270,25	421,59	38,43	Weekly, 5 -11	Measurements started in September 2020
	Copper (influent de Vlot)	μg /L	13,49	6,35	31,77	7,4	Weekly, 5 -11	Measurements started in September 2020
	Copper (effluent street A)	μg /L	14,18	12,71	25,42	3,81	Weekly, 5 -11	Measurements started in September 2020
	Molybdenum (influent de Vlot)	μg /L	23,03	11,51	68,11	12,54	Weekly, 5 -11	Measurements started in September 2020
	Molybdenum (effluent street A)	μg /L	25,61	17,26	47,97	8,18	Weekly, 5 -11	Measurements started in September 2020
	TOC (influent de Vlot)	mg /L	18,53	16	22	2,23	Weekly, 5	Measurements started in September 2020
	TOC (effluent street A)	mg /L	14,43	11	17	2,23	Weekly, 5	Measurements started in September 2020

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2.2.4. Objectives of the Ultimate solutions

CS2 aims to close the loops of water, energy and material. In ULTIMATE, the symbiosis is extended in two ways:

1) De Vlot has ambitions to reach zero liquid discharge and provide symbiotic internal and potentially external reuse of water and nutrients from greenhouse drain water (approx. 10% discharge). In this setup, recycling would be provided internally for the greenhouses in the summer and in the winter months the excess recovered water and nutrients can be reused in nearby industries or a central water bank. Re-use of this water for irrigation is hampered by the risk of introducing salinity and plant diseases upon recycling of this water. ULTIMATE will improve and demonstrate the functionality of advanced wastewater treatment for reliable removal of salinity and plant pathogens via electrochemical and disinfection treatment technologies.

2) To provide alternative energy sources for greenhouse heating. Because the initiative for utilization of residual heat from the chemical complex Moerdijk is stopped, there is no possibility for HT-ATES in Nieuw Prinsenland. Therefore, the demonstration of the high-temperature aquifer thermal energy storage system (HT-ATES) system will be carried out in another greenhouse-area. Currently, in several other areas in the Netherlands, fossil free heating of greenhouses is prepared by using residual heat or a geothermal source. For both sources of heat, HT-ATES is used to balance demand and supply. The combination of a geothermal system and HT-ATES will allow for optimal utilisation of the available heat and also cost effectively and carbon free supply of peak demand. ULTIMATE will develop and demonstrate a cost-effective method to identify and characterise suitable aquifers for HT-ATES, by combining the drilling of a geothermal well with logging and screening of potential HT-ATES aquifers. In that way, geohydrological risk aspects are mitigated, without the need of a separate test drilling. ULTIMATE will also prepare further implementation by establishing a preliminary design of the well and an integration plan for the total heating system.

Optimising water reclamation from agro-food industries

The main aim of this task is to facilitate the reuse of drain water from greenhouses with a view on optimising the water reclamation. To do so, an extensive analysis of the treated wastewater will be conducted. Then, an adequate treatment will be determined supported by a quantitative microbial risk assessment (WP2), so that pathogen-free water will be supplied for irrigation in the greenhouses.

In order to validate a reliable way of removing plant diseases from the water, the reuse of this water will be investigated on pilot scale in a demo-greenhouse.
Finally, a full-scale treatment plant for water will be designed based on the previous results and the ones of the economic analysis (WP2).

High Temperature Aquifer thermal energy storage and recovery

To improve the use of the residual heat and the economic viability of this heat supply system, it is considered to store the residual heat in the deeper brackish-saline groundwater system for its late recovery and use. This would allow a maximisation of reuse, as surplus heat can be stored (summer) and recovered when the capacity of the residual heat supply alone is insufficient (winter). For storage, a high-temperature

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aquifer thermal energy storage (HT-ATES) solution is proposed. In such an HT-ATES, a pair of groundwater wells in one aquifer is used to pump groundwater up from the first well, increase its temperature with a heat exchanger and the residual heat, and then inject the water in the second well to store it in the ATES.

Because HT-ATES is not a proven solution yet, it is important to work on several demonstrations to learn how to overcome uncertainties in technical, financial, and regulatory fields as well as to build trust with developers to apply such solutions in the field. Therefore, the ULTIMATE showcase is linked to another greenhouse-area, where an ongoing development towards fossil-free heating can be combined with the preparatory work for HT-ATES-solutions.

For the analysis and the selection of a suitable aquifer via hydrogeological evaluation, a (combination of) method(s) for logging and screening of possible suitable layers while drilling of a geothermal well is assessed, selected and applied. It is expected that the developed approach can be extended to other HT-ATES solutions in order to cost-effectively mitigate geohydrological risk aspects. The demonstration is dependent on the possible combinations with a planned drilling of the geothermal well in a greenhouse area. At this moment, there are several opportunities, planned drillings are in 2021 or 2022.

To demonstrate the HT-ATES solution for greenhouses, the potential for this technology is investigated. This task includes a cost-benefit analysis based on the expected recovery efficiency of the ATES, which will be determined using model calculations of the heat storage (e.g., different sizes, configurations, storage efficiency).

Recovery of nutrients from greenhouse wastewater
As salinity and pathogens will be removed with advanced treatment, the reclaimed greenhouse wastewater will still contain valuable nutrients. The effects of this nutrient composition in the reused water on plant growth and health (e.g., Na/K ratio) will be assessed in test beddings in the demo-greenhouse.

To achieve an optimum nutrient balance and prevent the accumulation of specific minerals in a future ZLD system, strategies for mixing the recovered nutrient-rich water with clean water and/or concentrated nutrient solutions will be assessed.
Finally, an economic analysis of potential cost savings by using recovered nutrients will be performed in WP2.

2.2.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 6 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve

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as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 6 Specific KPIs in CS2 related parameters and scales

Topic	Objectives	Specific KPIs
Water	Optimising water reclamation from agro-food industries	- Water yield - Water quality - Specific energy consumption - Reagents and materials required - Waste produced
Energy	High temperature aquifer thermal energy storage and recovery	- To be defined
Material	Recovery of nutrients from greenhouse wastewater	- Material recovery rate related to the influent load to the WWTP - Recovery efficiency

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2.3. CS3 Rosignano (Italy)

2.3.1. General description of the case study and site

The ARETUSA Consortium has been established in 2001 and associates an urban water utility (ASA Azienda Servizi Ambientali Spa) in PPP with industry (Solvay Chimica Italia Spa) and technology provider (TME Termomeccanica Ecologia Spa). Thanks to ARETUSA water reclamation facility, Solvay replaces high-quality groundwater with fit-for-purpose treated municipal wastewater for industrial use, while groundwater is more exploited for drinking water production to serve the coastal areas. Up to 3.8 Mio. m^3 per year of treated municipal wastewater is already reused by the industrial partner Solvay, freeing up Solvay private industrial wells for drinking water use. Currently, the Solvay plant has highly expanded both in terms of production and variety, which further increases the water demand. The plant produces sodium carbonate, sodium bicarbonate (also for pharmaceutical use), calcium chloride, chlorine, hydrochloric acid, chloromethane, plastic materials, peracetic acid and hydrogen peroxide.

The ARETUSA water reclamation facility was designed to treat the secondary effluent coming from the two municipal Wastewater Treatment Plants (WWTP) of Cecina and Rosignano by chemical, physical, and biological processes in order to reach the quality requirements of Solvay. The scheme of the ARETUSA symbiosis is represented in Fig. 8.

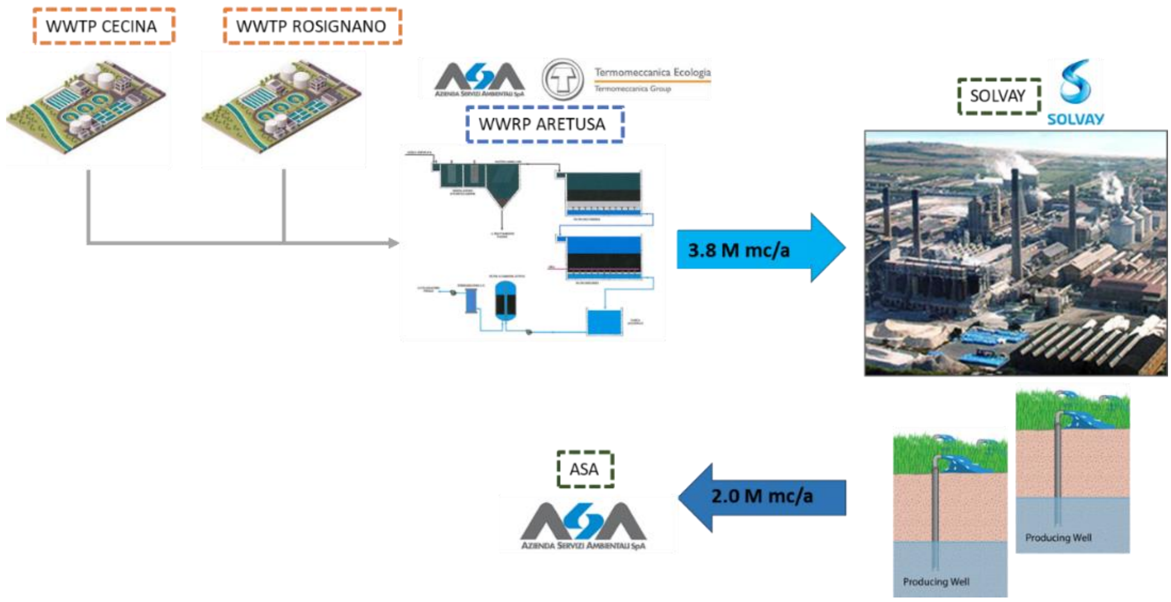

Fig. 8 CS3 Symbiosis

The catchments of Cecina and Rosignano WWTPs are impacted by currently unpredicted and relevant seawater intrusion that increases the chloride up to levels higher than acceptable and agreed by the contract in force among the ARETUSA partners. In addition, other parameters (e.g., surfactants and COD) can irregularly and unpredictably exceed the quality standard required for industrial reuse in Solvay. The successful results of ULTIMATE will be integrated in the definitive and executive design and implemented in full scale for real long-term operation. Three million euros

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investments to revamp, upgrade and digitalize the reclamation plant and system are currently envisaged by ARETUSA PPP.

2.3.2. Detailed description of the technological solutions before Ultimate

In 2019 and 2020, the ARETUSA water reclamation plant treated around 12785±855 m^3/d of secondary effluents from Cecina and Rosignano Marittimo WWTPs. The influent to ARETUSA had a pH about 7.5 and concentrations of COD of 35±15 mg/L, TSS of 13.5±4 mg/L and nutrients of about 15±5.5 mgN/L and 2.7±1.2 mgP/L. The electrical conductivity was on average 2406 µS/cm, with peaks up to 2979 µS/cm. The design flow scheme (Fig. 9) is composed by the following operation units: equalisation, coagulation-flocculation, lamella clarification, sand filtration, bio-filtration, activated carbon adsorption (GAC) and UV disinfection. After the equalisation unit, the flow stream is split in two treatment lines. The coagulation-flocculation unit is not operated by relevant chemical dosage, while in the past 140 t per year of aluminium polychloride, and 12 t per year of polyelectrolyte were used. Within the ULTIMATE project, innovative materials (i.e., by-products from local factories and industries) will be tested as coagulant/flocculant in full scale trials. Currently, even the bio-filtration and the activated carbon are not used. Finally, the disinfection phase is performed by UV lamps.

The final effluent shows how the current treatment train is not able to achieve relevant COD removal, which final average concentration ranges at 23±12 mg/L. The treatment has no effect on the electrical conductivity and the chloride concentration which are at 2320±483 µS/cm and 493±79 mg/L, respectively. The produced sludge is collected, treated and disposed together with the waste activated sludge of Rosignano WWTP.

Finally, the electrical energy consumption of the plant is around 0.5 kWh/m^3.

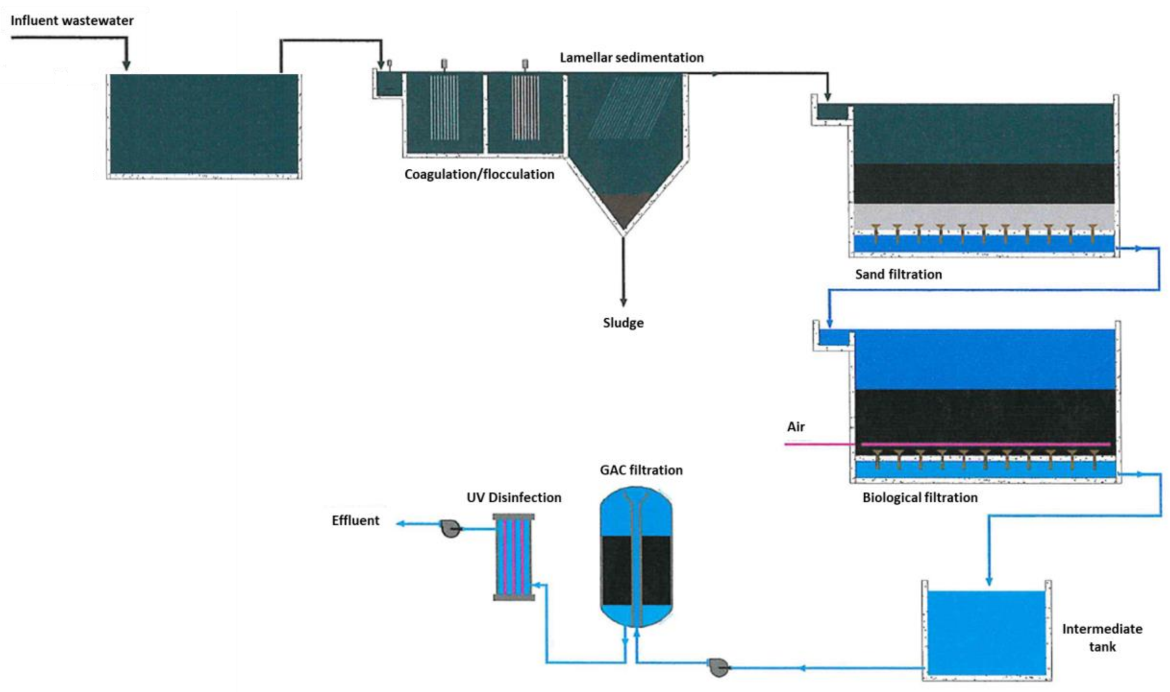

Fig. 9 Treatment train of ARETUSA

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Different by-products are available from local industries operating in a potential circular territorial cluster where ASA is managing urban water services:

1) Organoclay-sludge is a by-product that is generated by Laviosa industry, based in Livorno, from the purification process of bentonite in water-based solution. After passing the centrifuge and the grit, the remaining compounds that are not dispersed, are not further processed. This by-product is therefore a material poor in bentonite, but rich in other silicates.

2) Sodium carbonate and sodium bicarbonate are by-products that are collected during the maintenance and cleaning operations of the Solvay plants (based in Rosignano) and do not meet the required standard. In particular, these materials usually include high quality sodium carbonate and sodium bicarbonate, which is mixed with gross particles (e.g. screws, pieces of wood), traces of oil or simple fine materials (dust).

3) Hydrochar produced by hydrothermal carbonisation of lignocellulosic biomass and/or sewage sludge, which was planned to be used for sewage management in Toscana (decision currently under discussion). This is the output of the HTC process where lignocellulosic biomass and/or sewage sludge is treated at about 200 °C and around 20 bar. Under these conditions, the organic fraction contained in the sludge and/or biomass is carbonised. The water contained in the sludge and/or biomass is recovered and further treated, while the carbonised solids are dried and pelletised to obtain the final product which is an organic lignite, which can be activated to obtain renewable activated carbon.

4) Alum and/or iron sludge are a waste material generated in massive quantities from drinking water treatment plants that use aluminium and/or iron salts as a coagulant. Alum and/or iron sludge are among the most extensive by-products generated by the water industries globally and projected to increase with the global demand of drinking water. Alum and/or iron sludge were investigated for the removal of several contaminants, for instance, phosphorus, copper, zinc, and lead from wastewater, for the manufacturing of building and construction materials such as concrete and cement mortars, in constructed wetlands, and in geotechnical applications such as road pavements and subgrades, landfill covers, and soil improvement methods. However, finding new beneficial uses for WTSs generated in huge amounts worldwide is still a challenge for scientists. Other solutions are the evaluation the impact of aging of ferric- rich drinking water sludge (DWS) on its reactivity and capacity for sulphide removal in sewers and phosphate removal in downstream wastewater treatment plants. The ALU Circles initiative (https://www.alliedwaters.com/project/alucircles/) is addressing the challenge to convert the alum sludge from one-off use of material into a sustainable solution, such as upcycling or recycling, at a lower cost. ULTIMATE will explore water-smart symbiotic solutions to regionally optimise the material flows. Uses within the domain of water and wastewater treatment services will be prioritised, but also other possible uses will be tested to finally deliver a regional masterplan for alum and/or iron sludge use.

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2.3.3. Baseline conditions

Tab. 7 to Tab. 9 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

Tab. 7 CS3: Baseline conditions of water related parameters

BASELINE - CURRENT SYSTEM							
Parameter			**Units**	**Mean value 2020**	**Standard deviation**	**Frequency and no. of measurements**	**Comments**
Water yield of the system	**Current system**	Rainfall climatology of the area	mm/y	899.5	-	77 rainy days/y	1) 980.2 mm/y from Cecina rain gauge and 818.8 mm/y from Rosignano rain gage 2) 78 days of rain in Cecina and 76 in Rosignano
		WWRP water inlet flow rate	m^3/h	531	114	Daily data from Jan2020 to Dec2020	
		WWRP water outlet flow rate	m^3/h	410	38	Daily data from Apr2020 to Dec2020	
Water quality	**WWRP inlet**	COD	mg O_2 /L	36	15	10 samples from Rosignano and 13 from Cecina during 2020	The influent of Aretusa WWRP is composed of the effluent coming from Cecina and Rosignano WWTPs
		BOD_5	mg O_2 /L	6.4	5.1	10 samples from Rosignano and 13 from Cecina during 2020	
		pH	pH	7.5	0.2	10 samples from Rosignano and 14 from Cecina during 2020	
		CE	µS/cm	2406	241	10 samples from Rosignano and 12 from Cecina during 2020	
		TSS	mg/L	13.5	4.1	10 samples from Rosignano and 13 from Cecina during 2020	
		Total nitrogen (TN)	mg N/L	15	5.5	10 samples from Rosignano and 11 from Cecina during 2020	
		Ammonium (NH_4-N)	mg N/L	3.1	4.9	10 samples from Rosignano and 13 from Cecina during 2020	
		Nitrite (NO_2-N)	mg/L	0.4	0.3	10 samples from Rosignano and 14 from Cecina during 2020	
		Nitrate (NO_3-N)	mg/L	12	3.3	10 samples from Rosignano and 13 from Cecina during 2020	
		Total phosphorus (TP)	mg P/L	2.7	1.2	10 samples from Rosignano and 13 from Cecina during 2020	
		Phosphate (PO_4-P)	mg P/L	6		1 sample from Rosignano and 2 from Cecina in 2021	
		Chloride	mg/L	497	61	10 samples from Rosignano and 11 from Cecina during 2020	
		Sulfate	mg/L	144		1 sample from Rosignano and 2 from Cecina in 2021	
		Sodium	mg/L	245		1 sample from Rosignano and 2 from Cecina in 2021	
		Potassium	mg/L	15		1 sample from Rosignano and 2 from Cecina in 2021	
		Magnesium	mg/L	50		1 sample from Rosignano and 2 from Cecina in 2021	
		Calcium	mg/L	159		1 sample from Rosignano and 2 from Cecina in 2021	

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BASELINE - CURRENT SYSTEM							
Parameter			**Units**	**Mean value 2020**	**Standard deviation**	**Frequency and no. of measurements**	**Comments**
Water quality	**WWRP outlet**	COD	mg O_2 /L	23	12	48 samples during year 2020	
		pH	pH	7.3	0.16	14 samples between 2016 and 2020	
		CE	mS/cm	2320	483	20 samples during year 2020	
		TSS	mg/L	10		21 samples during year 2020	
		Ammonium (NH_4-N)	mg N/L	1.4	1.7	48 samples during year 2020	
		Nitrite (NO_2-N)	mg/L	0.077	0.06	1 sample in 2016, 1 sample in 2019 and 3 samples in 202	
		Nitrate (NO_3-N)	mg/L	13.05	3.7	1 sample in 2019 and 3 samples in 2020	
		Total phosphorus (TP)	mg P /L	2.7		2 samples in 2020	
		Phosphate (PO_4-P)	mgP/L	6.3		2 samples in 2020	
		Chloride	mg/L	493	79	21 samples during year 2020	
		Sulfate	mg/L	160		2 samples in 2020	
		Magnesium	mg/L	49.4		2 samples in 2020	
		Calcium	mg/L	122		2 samples in 2020	
Energy consumption	**Current system**	Whole system	kWh/m^3	0.500		Energy consumption in 2020	
Reagents required	**Current system**	Coagulant	kg/y	140000			At the moment no reagent is used in Aretusa Plant, data refers to when reagents were dosed in the system. The coagulant that was used is Aluminum Polychride
			g/m^3	30			
		Flocculant	kg/y	12000			At the moment no reagent is used in Aretusa Plant, data refers to when reagents were dosed in the system. The flocculant that was used is Polyelectrolyte
			g/m^3	3			

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Tab. 8 CS3: Baseline conditions related with material recovery

BASELINE - current system									
	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
Influent to the WWRP	**Flowrate**	m^3/d	12785	921	32029	855	Daily data from Jan2020 to Jan2021	
	pH		7.5	7.3	8	0.2	10 samples from Rosignano and 14 from Cecina during 2020	The influent of Aretusa WWRP is composed of the effluent coming from Cecina and Rosignano WWTPs
	Conductivity	µS/cm	2406	2169	2979	241	10 samples from Rosignano and 12 from Cecina during 2020	
	Chemical oxygen demand (COD)	mg/L	35	19	71	15	10 samples from Rosignano and 13 from Cecina during 2020	
	Ammonium (NH_4-N)	mgN/L	2.8	0.4	14.8	4.4	10 samples from Rosignano and 13 from Cecina during 2020	
	Nitrite (NO_2-N)	mgN/L	0.4	0.1	19	0.3	10 samples from Rosignano and 14 from Cecina during 2020	
	Nitrate (NO_3-N)	mgN/L	12	8	17	3	10 samples from Rosignano and 13 from Cecina during 2020	
	Total phosphorus (TP)	mgP/L	3	1	4	1	10 samples from Rosignano and 13 from Cecina during 2020	
	Phosphate (PO_4-P)	mgP/L	6				1 sample from Rosignano and 2 from Cecina in 2021	
	Total suspended solid (TSS)	mg/L	14	10	22	4	10 samples from Rosignano and 13 from Cecina during 2020	
	Chlorides	mg/L	487	373	582	61	10 samples from Rosignano and 11 from Cecina during 2020	
	Sodium	mg/L	245				1 sample from Rosignano and 2 from Cecina in 2021	
	Calcium	mg/L	159				1 sample from Rosignano and 2 from Cecina in 2021	
	Magnesium	mg/L	50				1 sample from Rosignano and 2 from Cecina in 2021	
	Sulphate	mg/L	144				1 sample from Rosignano and 2 from Cecina in 2021	
	Potassium	mg/L	15				1 sample from Rosignano and 2 from Cecina in 2021	

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BASELINE - current system								
	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
Effluent to the WWRP	Flowrate	m^3/d	9812	5284	11300	855	Daily data from Apr2020 to Jan2021	
	pH		7.58	7.3	7.9	0.16	14 samples between 2019 and 2020	
	Conductivity	µS/cm	2320	1498	3740	483	19 samples in 2020	
	Chemical oxygen demand (COD)	mg/L	23	12	98	12	48 samples in 2020	
	Ammonium (NH_4-N)	mgN/L	1.07	0.39	6.38	1.35	48 samples in 2020	
	Nitrite (NO_2-N)	mgN/L	0.077	0.02	0.16	0.06	1 sample in 2016, 1 sample in 2019 and 3 samples in 2020	
	Nitrate (NO_3-N)	mgN/L	13.05	8	17	4	1 sample in 2019 and 3 samples in 2020	
	Total phosphorus (TP)	mgP/L	2.7	2	4	1	2 samples in 2020	
	Phosphate (PO_4-P)	mgP/L	6.3	1	12		2 samples in 2020	
	Total suspended solid (TSS)	mg/L	10	10	10	0	13 samples in 2020	
	Chlorides concentration	mg/L	493	358	637	79	21 samples in 2020	
	Calcium	mg/L	122	116	128		2 samples in 2020	
	Magnesium	mg/L	49.4	49	50		2 samples in 2020	
	Sulphate concentration	mg/L	160	159	161		2 samples in 2020	
	E. Coli	FCU/100ml	57	0	530	141	17 samples in 2020	
Coagulation and flocculation unit	Volume of the tank 1: coagulation	m^3	5.73					
	Volume of the tank 2: flocculation	m^3	73					
	Volume of the tank 3: flocculation	m^3	72					
	Coagulant_type		Aluminum Polychride					At the moment no reagent is used in Aretusa Plant, data refers to when reagents were dosed in the system. The coagulant that was used is Aluminum Polychride
	Coagulant_quantity	kg/y	140000					
	Flocculant_type		Polyelectrolyte					At the moment no reagent is used in Aretusa Plant, data refers to when reagents were dosed in the system. The flocculant that was used is Polyelectrolyte
	Flocculant_quantity	kg/y	12000					
Disinfection unit (UV)	Number of lamps	-	3					
	Clean lamp intensity	W/m^2	115					
	Contact time	s	3-4					
	Lamp housing volumes	L	170					

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Tab. 9 CS3: By-products available

	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
BASELINE - current system								
By-products	ORGANOCLAY SLUDGE produced by Laviosa industry							
	Quantity available	t/y	600					Data from the technical sheet of the by-product shared by Laviosa industry
	Zeolites	%	33					
	Calcite	%	28					
	Plagioclase	%	15					
	Quartz	%	10					
	Mica	%	8					
	k-feldspar	%	6					
	Humidity	%	35					
	Na_2O	%	1.8					
	MgO	%	0.86					
	Al_2O_3	%	11.75					
	S_iO_2	%	59.05					
	P_2O_5	%	0.35					
	K_2O	%	2.76					
	CaO	%	9.85					
	TiO_2	%	0.3					
	MnO	%	0.4					
	Fe_2O_3	%	1.22					
	SODIUM CARBONATE produced by Solvay industry							
	Particle size	µm	< 125 (60-70 %)					
	Molecular weight	g/mol	106					
	pH	-	11.2-11.3					11.2 (4 g/L) (25 °C); 11.3 (10 g/L) (25 °C)
	Bulk density	kg/dm^3	0.5-0.6					
	Relative density	-	2.53					at 20°C
	Solubility	g/L	71-212.5					72 g/L at 0°C, 212.5 g/L at 20°C
	SODIUM BI-CARBONATE produced by Solvay industry							
	Molecular weight	g/mol	84.01					
	pH	-	8.4-8.6					8.4 (8,4 g/L), 8.6 (52 g/L)
	Bulk density	kg/dm^3	0.5-1.3					
	Relative density	-	2.21-2.23					at 20°C
	Solubility	g/L	69-165					70 g/L at 0°C, 93 g/L at 20°C, 165 g/L at 60°C

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BASELINE - current system								
	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
By-products	HYDROCHAR produced by hydrotermal carbonization of municipal sludge							
	C	Weight %	55					Results of the SEM analysis performed on one sample of Hydrochar. Characteristics of the material can vary depending on on the type of biomass from which they are produced
	O	Weight %	30					
	Mg	Weight %	0.91					
	Al	Weight %	1.82					
	Si	Weight %	2.77					
	P	Weight %	3.13					
	S	Weight %	0.67					
	K	Weight %	0.46					
	Ca	Weight %	5.68					
	Ti	Weight %	0.33					
	Fe	Weight %	0.82					
	Cu	Weight %	0.21					
	Nitrogen content	%	1-3					
	Lower calorific value (LCV)	MJ/kg	> 19					
	Alum sludge							
	pH	-	7-8.8					Characterization from: K.B. Dassanayake, G.Y. Jayasinghe, A. Surapaneni, C. Hetherington, 2015. *"A review on alum sludge reuse with special reference to agricultural applications and future challenges".* Waste Management.
	EC	dS/m	0.36-1.66					
	Sand	%	60.4-69					
	Clay	%	14-16.6					
	Silt	%	17-23					
	Total carbon	g/kg	127-188					
	Organic matter	g/kg	63-144					
	Total nitrogen (TN)	g/kg	4-4.8					
	Ammonium (NH_4-N)	g/kg	0.022-0.263					
	Nitrate (NO_3-N)	g/kg	0.035-0.298					
	Total phosphorus (TP)	g/kg	3.13-35					
	Al	g/kg	27-153					
	Fe	g/kg	4.87-37					
	Ca	g/kg	2.2-11.7					
	Mg	g/kg	2.4-7.9					
	Mn	g/kg	0.8-2.99					
	Zn	mg/kg	53.3-160					
	Cu	mg/kg	35-624					
	Ni	mg/kg	10.9-60					
	Pb	mg/kg	2.5-69					
	Cr	mg/kg	19.1-81					
	Cd	mg/kg	0.12					
	Hg	mg/kg	0.02-0.46					
	Cl^-	mg/kg	15.89-16.41					
	SO_4^{2-}	mg/kg	8.57-9.73					

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2.3.4. Objectives of the Ultimate solutions

CS3 aims to close the loops for water and material. Therefore, the symbiotic relationship, already defined by a PPP, between Utility (ASA), technology provider (TME) and industry (Solvay) is extended to optimise the quality and quantity of treated water increasing the technical, economic and environmental sustainability of industrial reuse, in a local circular economy background. The technological solutions of Ultimate will comprise in detail:

Monitoring, modelling, and control system to avoid high chloride concentrations in reuse water

A real-time data driven monitoring and process control system for seawater intrusion and infiltration in the subcatchment and sewers sub-system will be established to overcome salinity peaks in the influent to the WWRP. Therefore, flow splitting and equalisation of the secondary WWTP effluents will be tested. An early warning system for the intrusion of seawater and salinity management will be developed, using a model-based approach with hydrometeorological forecasts combined with hydrogeological data to predict saltwater intrusions and impacts from sea spray. To allow for water reuse during periods of very high salinity, the potential for others water uses outside of Solvay will be screened regarding the highest admissible chloride content. These potential uses will be integrated in a data-driven matchmaking platform for water reuse.

Use of by-products of local industries for wastewater treatment

This task will demonstrate the potential to reuse by-products of Solvay and other local industries for water treatment.

1. Bentonite and other mineral by-products will be used as alternative coagulants and/or adsorbent.
2. A pilot scale adsorption system will be tested with alternative GAC.
3. Residual hydrogen peroxide and peracetic acid will be tested in order to improve disinfection.
4. The possibility to re-use the chemical (alum/ferric) sludge from coagulation/flocculation in the WWRP will be analysed and potential users will (potentially) be identified via the Alu Circles initiative.

2.3.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 10 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

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Tab. 10 Specific KPIs in CS3

Topic	Objectives	Specific KPIs
Water	Chloride and other key parameters concentration in Aretusa's effluent in line with the requirements for reuse in Solvay industry and/or for other potential reuses	- Reduction of salinity at inlet of WRP vs baseline. - Physicochemical parameters (conductivity) at the WRP in different scenarios.
Material	Bentonite and other by-products use in the existing WWRP	- Adsorption capacity compared to commercially available materials - Reduced waste production
	Test of alternative GAC	- Adsorption capacity compared to commercially available materials - Reduced waste production
	Use of residual by-products for improving disinfection	- Pathogens or other pollutants removal efficiency - Reduced waste production

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2.4. CS4 Nafplio (Greece)

2.4.1. General description of the case study and site

The eastern Peloponnese is one of the most productive regions in Greece in terms of citrus fruit (it is to be highlighted that Greece is the third largest producer of citrus fruit in the EU).

Alberta S.A. (Fig. 10) is a Greek fruit processing industry and specialises in the production of fruit juice concentrates, fruit purees s/s and concentrates, clarified juice concentrates, NFC juices as well as tailor made products and blends, since 1981. It produces juices not only by fruits but also by vegetables like carrots and red beets. Its main fruit juices come from citrus fruits (oranges, lemons, grapefruits and mandarins), pome fruits (apples, pears), stone fruits (peaches, apricots), pomegranates, chokeberries, grapes, carrots, red beets.

Fig. 10 Alberta S.A. facilities

Particularly in the Argolida area, where the Ultimate demo will take place, there is an increasing water demand for irrigation purposes that along with the high-water consumption of the fruit processing industry is putting under a great pressure the regional aquifer. This is due to the fact that most water comes from irrigation wells, which are often not legal.

However, the groundwater quality is rather poor, with high conductivity (around 3000 µS/cm) as a result of over-irrigation and subsequent intrusion of the sea into the aquifer. The most common treatment method is reverse osmosis which involves increased energy consumption and maintenance costs. In addition to this, it must be said that the wastewater treatment rises the overall water usage cost, as all industrial waste is collected by the municipal biological treatment unit at a cost of 0.43 €/m^3 for BOD<1000 mg/L and COD <1500 mg/L and daily limit of BOD = 738 kg/day distributed in at least 18 h.

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With a view on reducing the overall cost of disposing wastewater to the municipal biological treatment and meet the effluent criteria, all sizeable fruit processing plants of the area have their own primary biological unit. However, the primary treatment unit needs to be periodically stopped, due to the seasonality of the fruit processing industry. This procedure increases operational costs as it is necessary to restart the unit when needed. No symbiosis among stakeholders of the area is established at this point enabling water reuse or recovery of any valuable resource.

2.4.2. Detailed description of the technological solutions before Ultimate

Alberta S.A has a primary biological treatment unit of about 20 m^3/h capacity to meet the effluent criteria as well as to reduce the cost of disposing wastewater to the municipal WWTP (Fig. 11). This process is mainly focused on the removal of organic matter, achieving removal of effectiveness higher than 50% (COD concentration in the outlet stream <1000 mg O_2/L). Currently, inlet and outlet water streams are not monitored regularly.

During the high production period (usually during citrus production from November until March and grape/pomegranate production from August to October), the amount of wastewater treatment is about 3500 m^3/d. During all the other months the amount is about 500 m^3/d.

Fig. 11 Alberta water system before Ultimate

2.4.3. Baseline conditions

Tab. 11 and Tab. 12 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

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Tab. 11 CS4: Baseline conditions of water related parameters

BASELINE - CURRENT SYSTEM									
Parameter			Units	Summer mean value 2020	Standard deviation	Frequency and no. of measurements	Winter mean value 2020	Standard deviation	Frequency and no. of measurements
Water yield of the system	Current system	Rainfall climatology of the area	mm/year or $L/m^2/year$	17.3 mm/y		every month	61,3	every month	
	WWTP	WWTP inlet water flow rate	m^3/h	8	±5		15	±5	
Water quality	WWTP inlet	COD	$mg\ O_2/L$	2000	±500		5500	±1000	1 sample/everyday
		BOD_5	$mg\ O_2$ /L	1000	±200		2500	±500	1 sample/everyweek
		pH	upH	5,5	±1,0		5,5	±1,0	1 sample/everyday
		CE	mS/cm	3000	±200				
		Turbidity	NTU	100	±30				
	WWTP outlet	COD	$mg\ O_2$ /L	<1000			<1000		1 sample/everyday
		BOD_5	$mg\ O_2$ /L	<500			<500		1 sample/everyweek
		pH	upH	7,5	±0,5		7,5	±0,5	1 sample/everyday
		TSS	mg/L	<500			<500		
		Total phosphorus	mg P/L	<10			<10		1 sample/everyweek
		Total nitrogen	mg N/L	<20			<20		1 sample/everyweek
Energy consumption	Current system	Whole system	kWh/month	8000	±2000		10000	±2000	every month

Tab. 12 CS4: Baseline conditions of material related parameters

BASELINE - current system					
	Parameter	Unit	Mean	Min	Max
Influent to WWTP	pH	upH	3,50	3	4
	Conductivity	µS/cm	2000	1000	3000
	Chemical oxygen demand (COD)	mg/L	160000	20000	300000
	Biological oxygen demand (BOD_5)	mg/L	45000	30000	60000

2.4.4. Objectives of the Ultimate solutions

CS4 aims to close the loops of water and material. Ultimate's main aim in CS4 is to extend and reinforce the symbiotic relationship of Alberta and the fruit processing sector with the water service provider by reducing the freshwater demand and its production costs (which implies reducing the cost of the primary treatment and the cost related to the high COD of the wastewater), giving products an added value (functional foods) and finally generating revenues from the possible exploitation of the extracted value-added compounds. Additionally, this processing plant will lead to a reduction on the cost of water usage, and the municipal biological treatment unit will process better quality water, thus enabling it not to put so much strain on its operation.

The aim after the implementation of the pilot wastewater treatment process is to achieve lower organic burden in the final effluent, compliant to limits specified by the local water management authority either for disposal to the local final treatment unit, either for irrigation or for reuse in the production procedure of Alberta S.A.

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Reuse of fruit processing wastewater
In order to foster the reuse of the fruit processing wastewater, a pilot plant for antioxidants recovery and water reclamation will be constructed.
Depending on the value-added compounds and the pollutants in the wastewater, the pilot plant will comprise of filtration, adsorption /extraction, AOP units and a small bioreactor platform (SBP).

The SBP consists of macro-capsules with a microfiltration membrane serving as a physical barrier. The filtration step will separate the coarse particles and suspended solids by one or more filtration steps. This way, the wastewater stream will be clarified and will have a lower organic load, which will enable a deeper penetration of UV radiation so that the AOP will be more effective and that the amount of energy required for the process will be reduced.

The oxidative degradation of organic pollutants will be by means of hydroxyl radicals produced by the effect of UV radiation on catalysts (such as TiO_2, a semiconducting solid), or other materials such as hydrogen peroxide and ozone. This step is particularly important in case of the presence of:
1. Low biodegradability compounds as they are not effectively removed by biological treatment, or toxic materials.
2. Toxic compounds that kill the biological treatment microorganisms.
3. Predator organisms that feed on the biological treatment microorganisms.
In order to enhance the performance of the AOP, the AOP is combined with a biological treatment, which in this case turns out to be a bioreactor that will only operate if deemed necessary. The combination of these two systems can lead to a significant reduction on time and cost of the processing of this wastewater, and to an increase of the process' efficiency. This SBP is a form of biological treatment in capsules, which means that microorganisms are encapsulated in porous material. This allows for reduction of the cost of the treatment and may even render further biological treatment unnecessary.

The pilot plant will be implemented upstream prior to the primary biological treatment of the manufacturing plant, and different hybrid-setups of the technological units in the pilot plant will be demonstrated aiming for the necessary fit-for-purpose qualities for irrigation or washing purposes.

Recovery of high added-value compounds (antioxidants)
For the recovery of antioxidants from fruit processing wastewater, a hybrid adsorption - subcritical water extraction (SCWE) pilot unit will be designed and employed. After the adsorption of the antioxidants on a selective material (e.g., resins), the high added-value compounds will be extracted by means of subcritical water extraction, i.e. pressurized water at an elevated temperature, though below its critical point.

Water was chosen due to its lack of toxicity compared to organic solvents. Exploiting its non-ideal properties, i.e. as its temperature rises, its permittivity, viscosity and

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surface tension decrease, while its diffusion rate increases, enabling the extraction of polar substances with high solubility in water, under ambient conditions at lower temperatures, whereas the moderately polar compounds require a less polar medium, which is induced by high temperature.

Several trials will be conducted to determine the suitable temperature and pressure conditions and the most efficient and suitable adsorption material.
In addition to this, the possibility to use recovered products for upgrading primary products such as fruit juice will be analysed mainly by tasting them (for example, too high temperature may lead to bitterness).

2.4.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 12 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 13 Specific KPIs in CS4 related parameters and scales

Topic	Objectives	Specific KPIs
Water	Reuse of fruit processing wastewater	- Water yield - Water quality - Energy consumption
Material	Recovery of the high-added value compounds (antioxidants)	- Material recovery rate related to the influent load to the WWTP - Recovery efficiency of the certain unit - Purity of the recovered material

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2.5. CS5 Lleida (Spain)

2.5.1. General description of the case study and site

In Lleida, the water smart industrial symbiosis exists since 2009 and interlinks the Mahou San Miguel (MSM) brewery with a multinational utility Aqualia as well as the local municipal utility of Lleida and the Catalan Water Agency.

The brewery has its own wastewater treatment plant. However, up to now, there is no water reclaimed and no energy recovered. Mahou San Miguel desires to reduce its water consumption by 10% by 2025, which shall be facilitated by the Ultimate solution for water reclamation. In addition, energy shall be recovered in the form of biogas and be converted as efficiently as possible to electricity and heat. According to preliminary estimations, the surplus electricity produced by the proposed Ultimate solution might supply a significant fraction of the thermal energy and electricity needs amounting to 3% and 30%, respectively. The carbon footprint shall be also reduced due to Mahou San Miguel´s commitment to green energy and self-sufficiency.

Even though the excess sludge is thickened, tried and composted, there might be other interesting options to reuse the valuable nutrients in the sludge. Those shall be explored and evaluated in the Ultimate project.

2.5.2. Detailed description of the technological solutions before Ultimate

Before the start of Ultimate, there were no CE approaches for water, energy and materials implemented at the wastewater treatment plant of the brewery. Here, around 1350 m³/d of wastewater are treated via the conventional activated sludge process (Fig. 12). The yearly COD, nitrogen and phosphorus loads are 2130 t COD/a, 32 t N/a and 6 t P/a, respectively.

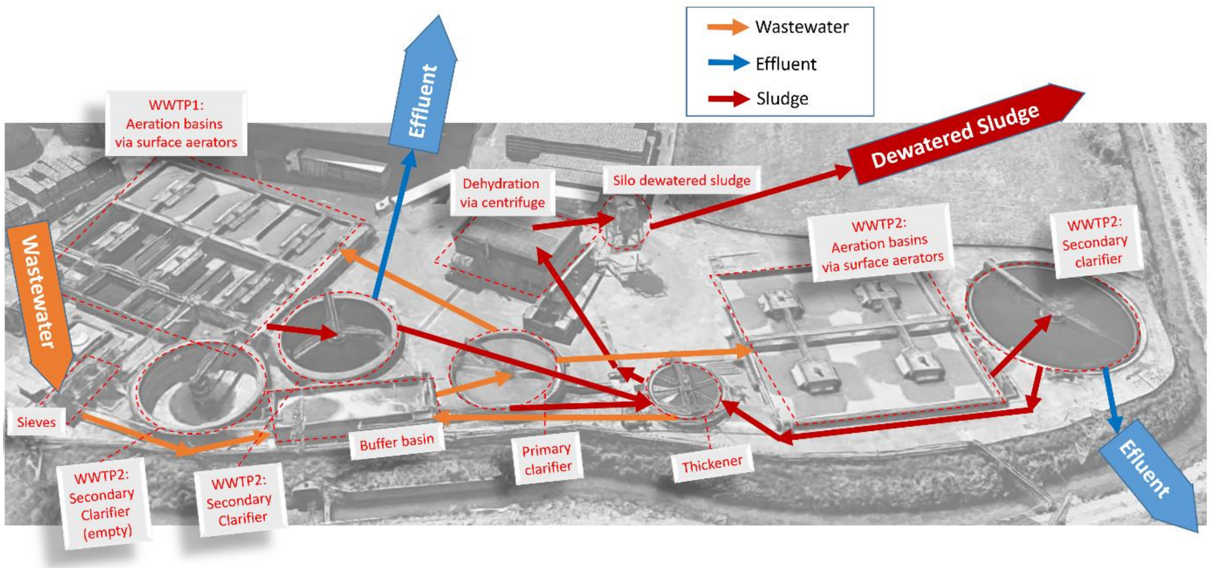

Fig. 12 Pre-existing system in Lleida at the start of Ultimate

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On average, 98% of the COD is biodegraded aerobically to CO_2 and converted into biomass. Therefore, 90% of the nitrogen are used by the microorganisms to grow. The phosphorus is only partially removed by approximately 30% due to its microbial uptake for growth. The effluent from the secondary clarifier enters the municipal sewer system and the biosolids are disposed to an external sludge management. Around 9.4 t of dried sludge are daily produced and sent to a composting plant.

So far, there is no energy production integrated in the brewery WWTP. Even though the COD load is high enough to implement anaerobic treatment technologies and to produce biogas.

The nearby municipal WWTP digests its excess and primary sludge via mesophilic digestion with an organic loading rate of around 1.4 kg VS/(m^3*d). Thus, the municipal WWTP produces on average 1,181,600 Nm^3 biogas per year with a methane content of around 60%. The combined heat and power plant generates 1.53 GWh/a of electricity and 1.87 GWh/a of heat.

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2.5.3. Baseline conditions

Tab. 14 to Tab. 18 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

Tab. 14 CS5: Baseline conditions of water related parameters

BASELINE - CURRENT SYSTEM							
Parameter			**Units**	**Mean value 2020**	**Standard deviation**	**Frequency and no. of measurements**	**Comments**
Water yield of the system	**Current system**	Outlet water flow rate (WWTP inlet)	m^3/h	57,0	26,6	Daily	Data from 2019
Water quality	**Influent**	COD	mg O_2 /L	4270	2429	Daily	Data from 2019
		pH	upH	6,5	1,0	Daily	Data from 2019
		CE	mS/cm	2571	628	Daily	Data from 2019
		TSS	mg/L	1558	3052	Daily	Data from 2019
		Ammonium	mg N/L	3	3	Analytical campaign	Data from 2019
		Total phosphorus	mg P/L	11	7	Daily	Data from 2019
		Total nitrogen	mg N/L	64	23	Analytical campaign	Data from 2019
	Effluent (to municipal drain)	COD	mg O_2/L	92	46	Daily	Data from 2019
		BOD_5	mg O_2/L	21	16	Monthly	Data from 2019
		pH	upH	8,6	0,2	Daily	Data from 2019
		CE	mS/cm	2880	240	Daily	Data from 2019
		TSS	mg/L	34	16	Daily	Data from 2019
		Ammonium	mg N/L	<1	<1	Daily	Data from 2019
		Total phosphorus	mg P/L	7,9	5,0	Monthly	Data from 2019
		Total nitrogen	mg N/L	6,2	1,1	Monthly	Data from 2019
Energy consumption	**Current system**	Whole system	kWh/m^3	2,59	0,36	Monthly	WWTP consumption, data from 2019
Reagents required	**Current system**	Flocculant	g/m^3	56	17	Monthly	Polyelectrolyte, data from 2019
Waste produced	**Current system**	Sludge	kg/m^3 collected	6,5	1,08	Monthly	Data from 2019

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For a more detailed characterisation of the effluent of the brewery WWTP, an additional sampling campaign was conducted. The results are shown in Tab. 14.

Tab. 15 CS5: Baseline conditions of water related parameters (brewery WWTP) - additional measuring campaign

BASELINE - CURRENT SYSTEM							
		Parameters	**Units**	**17.11.2020**	**01.12.2020**	**15.12.2020**	**10.02.2021**
Water quality	**Effluent (to municipal drain)**	'Legionella' sp	CFU/1L	n.d.	n.d.	n.d.	n.d.
		Nematode eggs	eggs/10L	n.d.	n.d.	n.d.	n.d.
		'Escherichia coli	CFU/100mL	35000	630	15000	730
		Suspended solids	mg/L	21	50	37	39,5
		Turbidity	UNF	8	14	15	9
		Calcium (total)	mg/L	61	72	52	54
		Chlorides	mg/L	89	78	70	78
		Conductivity at 25ºC	µS/cm	2514	2761	2775	2444
		BOD_5	mg/L	5	14	12	16,5
		COD	mg/L	57	100	117	79,5
		Fluoride	mg/L	0,31	0,26	0,23	0,15
		Magnesium	mg/L	14	16	8	6,8
		Nitrate	mg/L	<5,0	<2,5	<0,5	<0,5
		Ammonia nitrogen	mg/L	<1,0	<1,0	<1,0	1,55
		pH	-	8,3	8,3	8,3	8,35
		Sodium	mg/L	627	650	634	540,5
		Sulfate	mg/L	157	132	56	29,5
		Silicon (SiO_2)	mg/L	38	46	39	15
		Bicarbonates	mg/L HCO_3	1363	1803	1741	1433
		Carbonates	mg/L	98	<20	<20	54
		Potassium	mg/L	10	12	10	13,5
		Boron	mg/L	0,12	<0,050	<0,050	<0,050

Tab. 16 CS5: Baseline conditions of energy related parameters (brewery WWTP)

BASELINE - Current system								
	Parameter	Unit	**Mean**	**Min**	**Max**	**Standard deviation**	**Frequency and number of measurements**	**Comments (e.g. data refer to the years ...)**
	Energy consumption (total plant)	kWh/a	1387853	1080175	1646004	204737	Continuous measurement	Energy consumption is highly affected by the number of line that have worked every year
Excess sludge	**Flowrate**	m^3/d	141	30	232	47	Monthly	Data from 2019
	Total solids content	kg/m^3	15	8	32	4	Daily	Data from 2019
Thickend sludge	**Flowrate**	m^3/d	53	17	90	18	Monthly	Data from 2019
	Total solids content	kg/m^3	30,0	-	-	-		Punctual determination, data from 2019
Dried sludge	**Flowrate**	t/d	9	4	13	2	Monthly	Wet Sludge, data from 2019
	Total solids content	kg TS/kg	0,17	0,14	0,20	0,02	Daily	Every sludge truck , data from 2019

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Tab. 17 CS5: Baseline conditions of energy related parameters (municipal WWTP)

BASELINE - current system								
Parameter		Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
Energy	**Energy production**	kWh/a	1528934	1418864	1671216	97053	Continuous measurement	Electric Energy Production from Cogeneration Engine. Last 5 years considered (2016-2020)
	Energy consumption (total plant)	kWh/a	4506093	4393637	4552889	65293	Continuous measurement	Electric Energy Consumption (Grid+ Cogeneration Engine). Last 5 years considered (2016-2020)
Biogas production	**Organic loading rate**	kg VS/(m^3*d)	1,38	1,29	1,51	0,08	Daily measurement	Last 5 years considered (2016-2020)
	Gas production rate	Nm^3/a	1181597	976861	1273008	120521	Continuous measurement	Last 5 years considered (2016-2020)
	Methane content	Vol. %	60	59	61	0,70	Continuous measurement	Last 5 years considered (2016-2020)
Heat production	**Heat production**	kWh/a	1870955				Not measured	Estimation. To be confirmed

Tab. 18 CS5: Baseline conditions of material related parameters (brewery WWTP)

BASELINE - current system								
Parameter		Unit	Mean	Min	Max	Standard deviation	ency and number of measure	Comments
Influent to WWTP	**Flowrate**	m^3/d	1369	8	3631	639	Continuous measurement	Data from 2019
	Total solids load	kg TS/d	1788	7	9816	1649	Daily	Data from 2019
	Nitrogen load	t/a	32					Calculated with average flow rate and concentration
	Phosphorus load	t/a	6					Calculated with average flow rate and concentration
Dried sludge	**Flowrate**	t/d	9,4	3,5	12,5	2,2	Monthly	Data from 2019
	Total solids content	kg TS/kg	0,17	0,14	0,20	0,02	Daily	Data from 2019

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2.5.4. Objectives of the Ultimate solutions

CS5 aims to close the loops of water, energy and material. The existing symbiosis between the Mahou San Miguel (MSM) brewery, the multinational utility Aqualia as well as the local municipal utility of Lleida and the Catalan Water Agency is expanded to produce water for industrial reuse, thus lowering the consumption of fresh water for industrial purposes, to produce green energy in the form biogas, electricity and heat as well as to recycle the nutrients from brewery wastewater.

Reuse of brewery wastewater for cooling towers

In order to close the water loop, the wastewater from the brewery shall be treated via two different anaerobic technologies. The performance of an anaerobic membrane bioreactor (AnMBR) will be compared to the performance of an electrostimulated anaerobic reactor (ELSAR^{TM}). The resulting effluents of both plants will be post-treated in order to reuse it for cooling towers.

For the optimisation of the AnMBR operation, a new method for online monitoring of membrane fouling will be tested. It will be implemented in the programmable logic controller (PLC) and allow for the maximisation of the reactor performance and the minimisation of chemical consumption for cleaning purposes.

Anaerobic treatment of brewery industry wastewater to recover biogas

The AnMBR and the ELSAR^{TM} will be implemented as pilot plants with 50 m^3/d and 500 m^3/d, respectively. The performance of both reactors will be compared in terms of their methane yields, COD removal efficiencies as well as their energy consumptions. Furthermore, the biogas composition will be determined to calculate the calorific value of the produced gases from both reactors.

Prior to the comparison, the performance of the different reactor types will be optimised via the modification of different parameters such as the organic loading rate, the solid retention time, the gas sparging intensity and the filtration operating mode.

Electricity and heat generation using a solid oxide fuel cell fed with biogas

In order to explore efficient ways to obtain renewable energy from biogas, a solid-oxide fuel cell (SOFC) fed with biogas will deliver electricity and heat. The municipal WWTP of Lleida city is very close to the brewery, produces biogas by means of mesophilic sludge digesters and is also managed by Aqualia. The SOFC will be tested there aiming at producing surplus electricity. Its electricity efficiency is expected to be above 57%. That is 50% higher compared to the usual values from conventional turbines or engines. To the knowledge of the case study partners, there is no similar approach so far. Usually SOFCs are fed with natural gas, not with biogas. Thus, feeding a SOFC with biogas will decrease substantially the carbon footprint of the process. A slight pre-treatment for removing impurities before entering the SOFC is needed.

Recovery of nutrients from treated brewery wastewater

In a concept study, a direct reuse of the nutrient-rich effluents from the anaerobic treatments (AnMBR and ELSAR^{TM}) or from the final effluent will be assessed in comparison to the application of the digested biosolids. The main investigation focuses on the abundance of pathogenic organisms and the concentration of micropollutants

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in the biofertiliser in order to quantify microbial and chemical risks for human health. In summary, the content of the concept study will comprise:

1. Microbial and chemical risk assessment
2. Demand-driven irrigation strategies
3. Evaluation of alternatives for nutrient recovery in wet seasons and for sensitive waters
4. Assessment of different options for fertiliser blending (direct application of digestate to the fields or combination of digestate with co-substrates)

2.5.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 19 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 19 Specific KPIs in CS5

Topic	Objectives	Specific KPIs
Water	Fit-for-purpose water quality of WWTP effluent for certain reuse options such as industrial reuse	- Water yield - Water quality - Specific energy consumption - Reagents and materials required - Produced wastes - Reduction of fresh water through reuse of reclaimed water
Energy	Test of a new online fouling monitoring method for an optimised membrane performance	- Sludge filterability (Resistance after filtrating 20L) - Permeability - Frequency of cleaning procedures
	Comparison of two different digestion systems: AnMBR vs. ELSAR™ for an energy efficient operation	- Methane yield - Removal performance - Specific energy consumption - Substitution of fossil fuels by green energy [%]
	Electricity and heat production via solid-oxide fuel cell from upgraded biogas	- Electricity yield - Electrical efficiency - Heat yield - Thermal efficiency - Substitution of fossil fuels by green energy [%]
	Heat production from upgraded biogas	- Heat yield - Substitution of fossil fuels by green energy [%]
Material	Fertigation strategies	- Nutrient recovery rate related to the influent to the treatment unit [%], - Recovery efficiency [%]

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		- Quality of the secondary fertiliser (in terms of microbial and chemical risks) - Substitution of conventional fertiliser by secondary fertiliser

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2.6. CS6 Karmiel and Shafdan (Israel)

2.6.1. General description of the case study and site

The Symbiosis in Karmiel and Shafdan interconnects 2 SMEs from the agro-food sector with a public wastewater utility, linking an industrial wastewater treatment plant (WWTP) with a municipal WWTP (Fig. 13). The agro-industrial sector includes agriculture, food industry, olive oil mills and water treatment. The symbiosis will enable to protect the current WWTP of Karmiel and Shafdan that are usually exposed to sudden shocks of strong and problematic agro-industrial wastewater (i.e, OMW, Slaughterhouse, winery).

Fig. 13 CS6 Symbiosis

Karmiel municipal WWTP faces problems due to shock loads of olive mill wastewater (OMW) during the harvest period and due to illegal discharges from slaughterhouses in the area. No solution has been found yet for an upstream and on-site wastewater pre-treatment which is technically feasible, economically viable and socially acceptable. Thus, most of this wastewater is discharged without adequate treatment. Shafdan WWTP of Tel Aviv is Israel's largest WWTP (400000 m^3 /d) and collects, treats and reclaims municipal wastewater in this rapidly growing area. Suitable pre-treatment of agro-industrial wastewater at the Shafdan site will enable the continuation of the current nature-based reuse system and supply water for agricultural activity in the Negev desert, even when receiving more industrial wastewater in the future.

2.6.2. Detailed description of the technological solutions before Ultimate

The municipal WWTP in Karmiel includes grit chamber, screener, primary clarifier and activated sludge-based system for carbon, nitrogen and phosphorus removal. The secondary effluent is treated by deep sand filtration to deliver tertiary effluent that is fit for unrestricted irrigation. The produced sludge is anaerobically digested to allow agricultural use, and biogas production, which covers a part of the electricity needs.

The municipal WWTP treats on average 10887145 m^3 per year of wastewater that is characterised by a COD load of 33617 kg/d. During the harvesting period, which lasts

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for around 60 days each year, around 900 m^3/d of OMW is discharged. OMW has a pH of 5.2 and is characterised by high COD and TSS concentrations, equal respectively to 119.5±13 g/L and 14.5±1.2 g/L.

On site, there are an old pilot plant and a demonstration plant (currently operating) able to anaerobically treat the raw wastewater prior to the aerobic biological process. The demonstration plant consists of an Advanced Anaerobic Technology (AAT) developed by AgRobics. The AAT is a "bio-stabilized, polymer-based matrix impregnated with unique anaerobic microorganisms. The matrix has a large surface area and a high capacity that enable the loading of a higher number of microorganisms compared to incumbent wastewater treatment methods. In addition, the matrix provides physical protection for the microorganisms (https://smart-plant.eu/~smartplant/index.php/karmiel). The block diagram of the demonstration plant is represented in Fig. 14.
Right now, the AAT pilot receives 120 m^3/d of wastewater with a COD, TS and TVS loads of 238 kg/d, 97 kg/d and 88 kg/d, respectively. The biogas production rate is 0.3 Nm^3/h with a methane content of 70% on average.

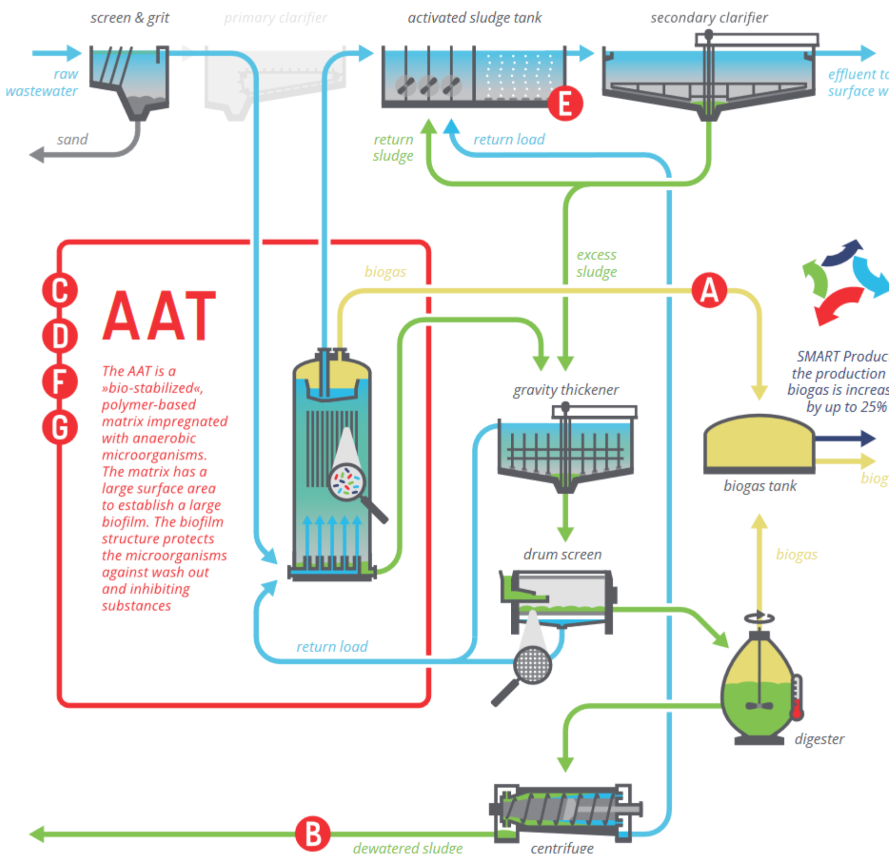

Fig. 14 Block diagram of the ongoing demonstration plant in Karmiel WWTP (https://smart-plant.eu/~smartplant/images/marketing-flyers/SMARTech2a_web.pdf)

The Shafdan WWTP treats a total flowrate of 149 Mio. m^3/a with COD and TS loads equal to 121280 t COD/d and 57125 t TS/d, respectively. The treatment train consists of a conventional activated sludge system with a subsequent thermophilic anaerobic digestion (AD) for the produced sludge. A separate facility provides a soil aquifer

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treatment (SAT) of the wastewater effluent to produce reclaimed water for reuse in agriculture. The influent to the AD is characterised by TS and COD loads equal to 121055 t/a and 228494 t/a, respectively. The unit has an organic loading rate of 2 kg VS/(m^3*d) and a volatile solid degradation rate of 57%. The biogas production is around 3900 Nm^3/h with a methane content of 61%. The effluent has a COD load of 34274 t/a and a TS load of 12105 t/a.

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2.6.3. Baseline conditions

Tab. 20 - Tab. 22 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

Tab. 20 CS6: Baseline conditions of relevant parameters in term of energy recovery in Karmiel

BASELINE - Current system								
	Parameter	**Unit**	**Mean**	**Min**	**Max**	**Standard deviation**	**Frequency and number of measurements**	**Comments (e.g. data refer to the years ...)**
Energy	**Energy production (total plant)**	kWh/a	2341120	2199800	2482440			
	Energy consumption (total plant)	kWh/a	9095442	8684100	9506784			
	Biogas production rate	Nm^3/h	0.30	0.56	0.04			
	Methane content	%	70	60	79			
Influent to WWTP	**Flowrate**	m^3/a	10887145	9956448	11817841			
	COD load	kg/day	33617	31507	35727			
OMW (during harvesting time)	**Flowrate**	m^3/a	54000					The average harvest period is 60 days, 30 Oilve mills=30?, 30 m^3/OM/day
	COD load	kg/a	9180000	3780000	16200000			CODavg= 119.5 Kg/m^3; CODmax= 156, CODmin=93
	Total solids content	kg TS/a	1620000					TS= 30 kg/m^3
	Volatile solids content	% of TS (total solids)	1458000					
Influent to ATT (after mixing of influent WWTP & OMW)	**Flowrate**	m^3/d	120	121	122			Based on the maximal ration of 2/120. the flow rate of the WWTP is 30000 m^3/d.
	COD load	kg/d	237	155	320		Based on real observation of the last two years in Karmiel WWTP	COD of 1.286 kg/m^3 to 2.650 kg/m^3
	Total solids load	kg TS/d	97	75	120			
	Volatile solids content	% of TS (total solids)	88	67	108			
Influent to ATT (if OMW does not occur)	**Flowrate**	m^3/d		120				

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Tab. 21 CS6: Baseline conditions of relevant parameters in term of energy recovery in Shafdan

BASELINE - Current system								
	Parameter	**Unit**	**Mean**	**Min**	**Max**	**Standard deviation**	**Frequency and number of measurements**	**Comments (e.g. data refer to the years ...)**
Energy	**Energy production (total plant)**	kWh/a	56034816				Based on online meters	2020, accumulative value
Energy	**Energy consumption (total plant)**	kWh/a	82408386				Based on online meters	2020, accumulative value
Thermophilic anaerobic digestion (AD)	**Organic loading rate**	kg VS/(m^3*d)	2.09	1.90	2.40	0.16	Based on online meters	2020, Mean, Min and Max values are monthly
Thermophilic anaerobic digestion (AD)	**Biogas production rate**	Nm^3/h	3913	2000	6500	1000	Based on online meters	2020
Thermophilic anaerobic digestion (AD)	**Methane content**	%	60.60	58.90	62.80	1.00	1819 measurements.	2020, based on 1st stage digesters only. Mean, Min and Max values are monthly
Thermophilic anaerobic digestion (AD)	**Methane yield**	Nm^3/(kg VS)	0.87	0.66	1.16	0.14	Based on online meters	2020, based on 1st stage digesters only. The yield is calculated as the ratio of gas flow divided to VS removed. Mean, Min and Max values are monthly
Thermophilic anaerobic digestion (AD)	**Volatile solids degradation rate**	%	57	53	62	3	1714 measurements.	2020, Mean, Min and Max values are monthly
Influent to WWTP	**Flowrate**	m^3/a	149365619				Based on online meters	2020, accumulative value
Influent to WWTP	**COD load**	kg/a	121280000				Based on online meters	2020
Influent to WWTP	**COD load**	kg/m^3	0.812					
Influent to WWTP	**Total solids load**	kg TS/a	57125000				Based on online meters	2020
Influent to WWTP	**Total solids load**	kg/m^3	0.382					
Influent to WWTP	**Volatile solids content**	% of TS (total solids)	87				720 measurements.	2020
Influent to AD (after mixing of influent WWTP & agro-industrial WW)	**Flowrate**	m^3/a	150921511	149987976	151855046			
Influent to AD (after mixing of influent WWTP & agro-industrial WW)	**COD load**	kg/m^3	1.514					COD of the mixture based on 0.5/120
Influent to AD (after mixing of influent WWTP & agro-industrial WW)	**COD load**	kg/a	228494012	227080647	229907377			
Influent to AD (after mixing of influent WWTP & agro-industrial WW)	**Total solids load**	kg TS/a	121055233	93292521	148817945			
Influent to AD (after mixing of influent WWTP & agro-industrial WW)	**Volatile solids content**	% of TS (total solids)	108949710	83963269	133936151			
Effluent from AD	**Flowrate**	m^3/a	150921511	149987976	151855046			
Effluent from AD	**COD load**	kg/a	34274102	34062097	34486107			
Effluent from AD	**Total solids load**	kg TS/a	12105523	9329252	14881795			

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Tab. 22 CS6: Baseline conditions of relevant parameters in term of material recovery in Karmiel

BASELINE - current system								
	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
Olive mill wastewater	Flowrate	m^3/d	54000				Estimation of our previous experince	
	pH		5.2	4.24	6.85	0.1	Sabbah et al., 2004	
	Conductivity	mS/cm	12.2	5	24	0.28	Based on review of Zbakh & Abbassi, 2012, Sabbah et al., 2004 and Rajhi et al., 2018	
	Total Nitrogen (TN)	mgN/L	768	600	950	156	Based on review of Zbakh & Abbassi, 2012	
	Chemical oxygen demand (COD)	mg/L	119500	93000	156000	13300	Based on review of Zbakh & Abbassi, 2012, Sabbah et al., 2004	
	Biological oxygen demand (BOD_5)	mg/L	51400	41300	67000	6640	Based on review of Zbakh & Abbassi, 2012, Sabbah et al., 2004	
	Total suspended solid (TSS)	mg/L	14500			1230	Sabbah et al., 2004	
	Polyphenols	mg/L	5960	1600	10700	3366	Based on review of Zbakh & Abbassi, 2012, Sabbah et al., 2004	

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2.6.4. Objectives of the Ultimate solutions

CS6 aims to close the loops for energy and material. The symbiotic relationship between the SMEs and the public wastewater utility is extended to protect the WWTPs of Karmiel and Shafdan from sudden shocks of agro-industrial wastewater allowing also the recovery of high added value products (polyphenols). Furthermore, the additional produced biogas will be an added value to generate power as renewable energy within the context of circular economy. The technological solutions of Ultimate will comprise in detail:

Biogas production from anaerobic pre-treatment of municipal and/or industrial wastewater in Karmiel

An immobilised high-rate anaerobic system (AAT), as an anaerobic pre-treatment, is planned to be retrofit into the existing WWTP in Karmiel, serving as a barrier for mixed agro-industrial wastewater in the municipal plant, thus protecting the aerobic system against shock loads.

1. Direct pre-treatment of pure OMW wastewater will be investigated.
2. An existing demo plant will be upgraded, optimised and tested under different scenarios of discharge of OMW or slaughterhouse wastewater at the Karmiel WWTP.
3. The current demo-system will be upgraded and used to examine the proposed technology.
4. A full-scale system will be designed: the alternative process will be based on production of biogas from organic matter of the mainstream that will also lead to the decrease of the energy consumption of the aerobic treatment.

Combining anaerobic biofilm treatment with membrane filtration and activated carbon in Shafdan

To improve biogas production and the effluent water quality, the immobilised biofilm AAT will be combined with membrane filtration and activated carbon at pilot-scale. The pilot at the Shafdan will be used to represent a very large WWTP in order to provide insight into capability of large WWTPs to combine agro-industrial wastewater. The focus at the Shafdan pilot site will be on agro-industrial effluents. The AAT-AnMBR combination shall make the treatment system more flexible, allowing it to better handle drastic changes of wastewater composition, i.e., OMW, winery and dairy effluent, plus domestic wastewater in periods with low industrial wastewater discharge. The addition of activated carbon shall decrease inhibitory effects and membrane fouling when applying high concentrations of polyphenols and tannins from olive oil mills, and thus increase biogas production.

Recovery of polyphenols from olive mill wastewater in Karmiel

After 20 months of pre-trials in lab-scale, a pilot plant system with an adsorption column will be operated to test the removal and recovery of polyphenols from olive mill wastewater (OMW).

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The polyphenol extraction from the OMW is considered a high value product, as olives are rich in polyphenols (range from anywhere between 50 and 5000 mg/kg). The polyphenols will be captured by passing the OMW through an adsorbing resin, then they will be extracted using pressurised hot water in a concentrated form, as a crude extract. The system serves as pre-treatment of OMW (will be designed for 60% reduction in the total phenolic content, measured by a suitable analytical technique (e.g. HPLC or spectrophotometry) before the AAT, to enable resource recovery and improve the performance of downstream systems by removing inhibitory compounds such as polyphenols upstream to the treatment.

2.6.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 23 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 23 Specific KPIs in CS6

Topic	Objective	Specific KPIs
Energy	Reducing the high organic load peaks in WWTP mainstream via an immobilized high-rate anaerobic system (AAT).	- Testing the quality of AAT effluents and biogas production for different scenarios of OMW or slaughterhouse wastewater mixing ratios and retention times. - Methane yield
	Testing the efficacy of combined AAT/ AnMBR and AnMBR / activated carbon for higher biogas production from mixed domestic and low organic load of industrial wastewater	- AAT effluent quality and biogas production will be tested in different scenarios of domestic wastewater mixed with industrial wastewater. - Methane yield
	Showing the success of the implemented circular economy systems	- Substitution of fossil fuels by green energy
Material	Recovery of polyphenols from olive mill wastewater	- Recovery rate related to the influent to the treatment plant - Polyphenols' recovery efficiency - Effluent water quality

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2.7. CS7 Tain (United Kingdom)

2.7.1. General description of the case study and site

For this case study, the symbiosis first interlinks the Glenmorangie whisky distillery and the SME Aquabio which provides circular economy (CE) enabling treatment and reuse solutions. This first started in 2017, with the design and installation by Aquabio of a system for the treatment of the wastewater from the distillery. Indeed, an anaerobic membrane bioreactor (AnMBR) was installed to treat the wastewater generated in the distillery during the whisky making processes and allows to discharge the treated effluent in the local estuary, the Dornoch Firth. However, the Glenmorangie whisky distillery which belongs to the Louis Vuitton Malletier Holdings (LVMH) has a strategy engrained in sustainability and the symbiosis can then also be extended to the local farmers and the local community and environment. Indeed, the Glenmorangie distillery is part of the Dornoch Environmental Enhancement Project which aims to restore Native European oysters and enhance biodiversity in the Dornoch Firth for the benefit of the local environment and community.

As part of Ultimate, Aquabio and Cranfield University (partners in the project) will collaborate with the Glenmorangie distillery and Alpheus, the current operator of the treatment site, (both stakeholders but not beneficiaries) to evaluate options to expand the CE approach at the site. Indeed, the AnMBR effluent provides opportunities for heat recovery, nutrients recovery and finally with further advanced treatment for water recycling within the distillery as outlined in detail in the next paragraph.

2.7.2. Detailed description of the technological solutions before Ultimate

For the treatment of the distillery wastewater, an AnMBR is already installed at the distillery (Fig. 7).

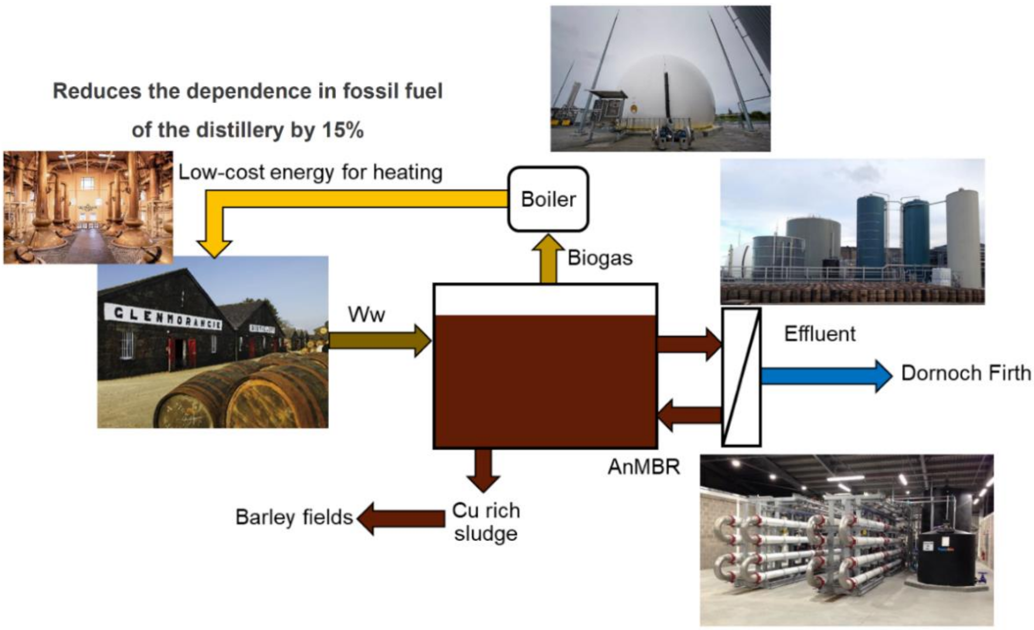

Fig. 15 Pre-existing system in Tain before the start of Ultimate

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On average, the distillery produces daily 322 m^3 of wastewater with a COD load of 10.7 t/d corresponding to an organic loading rate of 4.9 kg COD/(m^3*d) for the AnMBR. In the AnMBR, the COD is biodegraded to biogas with a methane yield of 0.27±0.05 Nm^3 CH_4/(kg COD*m^3). The biogas is converted to heat in a boiler and then reused to heat the stills. Based on the methane content of the raw biogas, the potential for onsite energy production is on average 28.8 MWh/d, however a fraction of the treated biogas can be flared (5% on average daily), depending on the demand on site. Overall, this reduces the dependence in fossil fuels of the distillery by 15%.

The AnMBR is operated in the mesophilic range. Thus, its effluent has a temperature between 35 °C and 40 °C which provides an opportunity for heat recovery.

So far, the effluent from AnMBR flows into the Dornoch Firth still containing quite high concentrations of COD, ammonium and copper with 670 mg/L, 790 mg/L and 0.1 mg/L, respectively. To avoid those emissions to the receiving water, Ultimate aims to recover the ammonia and to further treat and reclaim the water in order to reuse it in the distillery for cleaning purposes for example. Also, the copper-rich digestate is used to enrich barley fields in the region.

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2.7.3. Baseline conditions

Tab. 24 to Tab. 26 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

Tab. 24 CS7: Baseline conditions of water related parameters

BASELINE - CURRENT SYSTEM							
Parameter			**Units**	**Summer mean value**	**Standard deviation**	**Frequency and no. of measurements**	**Comments**
Water yield of the system	**Current system**	Rainfall climatology of the area	mm/year	694			https://www.scottish-places.info/towns/townclimate581.html#:~:text=Rainfall%20in%20Tain%20is%20low,recorded%20in%20a%20typical%20year.
		AnMBR inlet water flow rate	m^3/d	322	50	daily; n=267	21/06-21/09 (years 2018-2020)
		AnMBR outlet water flow rate	m^3/d	325	44	daily; n=206	21/06-21/09 (years 2018-2020)
Water quality	**AnMBR inlet**	COD	$mg\ O_2/L$	33247	5017	1-7 times/week, n=1065	Whole temporal range (not only summer mean) for this and following parameters. Bioreactor feed.
		pH	upH	4,44	0,65	1-7 times/week, n=939	Distillery raw effluent
		TSS	mg/l	8380	1827	0-7 times/week, n=446	Distillery raw effluent
		Ammonium-N	mg/L	39	13	0-7 times/week;n=271	Distillery raw effluent
		Nitrate-N	mg/L	41	24	0-4 times/week;n=206	Distillery raw effluent
		Copper	mg/L	2,62	1,86	0- 7 times/week;n=141	Distillery raw effluent
	AnMBR outlet	COD	$mg\ O_2/L$	673	179	0-5 times/week; n=754	UF permeate
		pH	upH	7,03	0,31	1-7 times/week; n=794	UF permeate
		TSS	mg/L	3,00	2,95	0-7 time/week;n=520	UF permeate
		Turbidity	FNU	14	18	daily; n=1099	UF permeate
		Ammonium-N	mg/L	789	169	0-6 times/week; n=392	UF permeate
		Nitrate-N	mg/L	5,60	1,45	0-3 times/week; n=212	UF permeate
		Copper	mg/L	0,99	0,71	0- 7 times/week;n=271	UF permeate
Energy consumption	**Current system**	Whole system	kWh/m^3	9,0	2,1	daily; n=692	Total energy usage considering whole system (e.g. pre-treatment, dewatering, biogas treatment, etc.)

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Tab. 25 CS7: Baseline conditions of energy related parameters

BASELINE - current system									
Parameter		Unit	Mean	Min	Max	Standard deviation	Frequency and no. of measurements	Comments
Energy	**Energy production at WWTP (biogas, etc.)**	kWh/d	28779	19281	38136	2753	0-5 times/week, n=709	Energy production from AnMBR untreated biogas daily flow. A fraction of the treated biogas can be flared, depending on the conditions on site; the daily average of the flared biogas fraction is 5.17±11% (minimum is 0%, maximum is 97%), n=721.
	Energy consumption of WWTP	kWh/d	2853	1410	4467	537	0-7 times/week; n=692	Total daily energy usage, considering whole system (e.g. pre-treatment, dewatering, biogas treatment, etc.).
Effluent from AnMBR	**Flowrate**	m^3/d	328	250	498	46	daily; n=593	UF permeate
	Temperature	°C	38	20	41	2	daily; n=619	UF permeate
	Methane in raw biogas production rate	Nm^3/d	2886	1934	3825	276	daily; n=709	CH_4 in raw biogas
	Organic loading rate	kg COD/(m^3*d)	4,94	3,06	10,55	1,08	0-5 times/week; n=583	
	Methane content in raw biogas	%	57,69	54,25	62,20	1,22	daily; n=712	
	Methane content in treated biogas	%	58,37	54,10	62,18	1,02	daily; n=708	
	Methane yield	Nm^3/(kg COD)	0,27	0,12	0,35	0,05	0-7 times/week; n=520	CH_4 yield in raw biogas

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Tab. 26 CS7: Baseline conditions of material related parameters

BASELINE - current system								
	Parameter		Unit	Mean	Min	Max	Frequency and no. of measurements	Comments
	AnMBR influent	**Flowrate**	m^3/d	322	250	409	daily; n=754	Bioreactor feed
		pH		4,44	3,30	6,83	1-7 times/week, n=939	Distillery raw effluent
		Ammonium (NH_4-N)	mg/L	39	16	115	0-7 times/week;n=271	Distillery raw effluent
		Nitrate (NO_3-N)	mg/L	41	10	95	0-4 times/week;n=206	Distillery raw effluent
		Phosphate (PO_4-P)	mg/L	289	104	485	0-4 times/week; n=202	Distillery raw effluent
		Chemical oxygen demand (COD)	mg/L	33247	25000	58300	0-7 times/weel; n=1065	Bioreactor feed
		Total suspended solid concentration (TSS)	mg/L	8380	1.800	12.960	0-7 times/weel; n=446	Distillery raw effluent
		Magnesium concentration (Mg)	mg/L	107	42	251	0-3 times/weel; n=171	Distillery raw effluent
	AnMBR effluent	**Flowrate**	m^3/d	328	250	498	daily; n=593	UF permeate
		pH		7,03	6,09	8,04	1-7 times/week; n=794	UF permeate
		Ammonium (NH_4-N)	mg/L	789	327	1394	0-6 times/week; n=392	UF permeate
		Nitrate (NO_3-N)	mg/L	5,60	0,20	13,20	0-3 times/week; n=212	UF permeate
		Phosphate (PO_4-P)	mg/L	236	35	496	0-3 times/week; n=210	UF permeate
		Chemical oxygen demand (COD)	mg/L	673	318	2261	0-5 times/week; n=754	UF permeate
		Total suspended solid concentration (TSS)	mg/L	3,00	0,10	19,80	0-7 times/week; n=520	UF permeate
		Magnesium concentration (Mg)	mg/L	43,0	4,7	90,7	0-1 time/week;n=159	UF permeate
	Produced sludge	**Total solids content**	% (dry solids)	19,4	11,6	23,5	0-7 times/week;n=484	

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2.7.4. Objectives of the Ultimate solutions

CS7 aims to close the loops of water, energy and material. The symbiosis of the Glenmorangie distillery and Alpheus with Aquabio and Cranfield University will be extended to evaluate options to produce water for internal reuse, to recovery heat and nitrogen.

Reverse osmosis treatment of distillery wastewater after AnMBR for internal water reuse

The AnMBR effluent will be further treated by reverse osmosis (RO) membranes to generate high quality water that can be reused within the distillery and partially close the water loop. This will in particular allow to reduce the distillery's fresh water consumption. It is important to note that the recycled water will not be used for the whisky making process where natural water is used but can be reused for other applications such cleaning processes. The work will focus on optimising the operational and treatment performance of the RO unit as well as its integration within the overall treatment train. With preliminary work in the first year at lab and small pilot scale, optimum operational conditions (flux and pressure) will be identified while also investigating fouling formation and control in the system to establish cleaning and maintenance requirements for the membranes. Treatment performance with monitoring of parameters such organics, nutrients, metals and other ions and pathogen indicators will allow to establish the quality achievable for the reuse application and needs for concentrate management. Ultimately, these will also provide an insight in the possible water recovery rate achievable and the savings to be attained. The findings from the preliminary work will be used to design and build a demonstration pilot unit which will be integrated with the other stages (see below) and installed at the site for long term testing.

Heat recovery from treated (AnMBR) distillery wastewater

As stated above, as the AnMBR is operated in the mesophilic range, its effluent has a temperature between 35°C and 40°C which provides an opportunity for heat recovery. The potential to recover heat from the AnMBR effluent will be investigated with in particular the use of heat exchangers. The aim will be to identify possible uses for the recovered heat within the treatment train and/or the distillery process. For example, heat may be required in the ammonia recovery process to either heat the water in the stripping process or dry the product generated such as powdered fertiliser. Alternatively, the heat recovered could be supplemented in the existing heat recovery process to heat the stills in the distillery. Preliminary work will focus on an overall energy balance of the advanced treatment train to establish the optimum use of heat available and provide the necessary information to size and locate the heat exchangers in the demonstration pilot unit.

Recovery of ammonia from distillery wastewater by IEX/packed columns after AnMBR treatment

The AnMBR effluent was shown to contain high levels of ammonia (800 mg N/L on average) which provides an opportunity for recovery. In order to recover the ammonia from the effluent, different systems, including ion exchanger (IEX) and stripping columns, will be investigated during the preliminary work at lab scale. Packed columns are an established technology and have been used to recover ammonia from

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concentrated sources such as sludge liquors but are known to be energy intensive and require a significant space. Alternatively, IEX systems have more recently been demonstrated to be efficient at removing ammonia from water but generally in more diluted sources such as municipal wastewater. In Ultimate, the different technologies will initially be investigated at lab scale to evaluate their potential for this specific application with a particular focus on understanding the impact of key parameters (temperature, pH, etc.) on their performance, the quality of the products generated and ultimately optimum operational conditions for each. The most sustainable technology will be selected for its implementation in the demonstration pilot unit to be tested on site.

2.7.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 27 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 27 Specific KPIs in CS7

Topic	Objectives	Specific KPIs
Water	Production of high quality water from distillery wastewater for cleaning processes	- Water yield - Water quality - Specific energy consumption - Reagents and materials required - Reduction of fresh water through reuse of reclaimed water
Energy	Energy recovery from the biogas generated in the AnMBR	- Methane yield - Substitution of fossil fuels with biogas
	Heat recovery from AnMBR effluent	- Heat transfer efficiency - Substitution of fossil energy due to heat recovery
Material	Comparison of IEX and stripping packed column for ammonia recovery from AnMBR effluent	- Nitrogen recovery rate related to the influent load to the WWTP - Recovery efficiency of the certain unit - Purity of the recovered material - Specific energy and chemicals consumption of the recovery process - Substitution of conventional fertiliser by secondary fertiliser

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2.8. CS8 Chemical Platform of Roussillon (France)

2.8.1. General description of the case study and site

The Roches-Roussillon chemical platform (Fig. 16) exists since 1915 and brings together 15 companies specialised in the chemical industry on the same site, including several giants of the sector such as Seqens, Blue Star, Adisseo and Solvay. SUEZ RR IWS Chemicals operate on this platform two hazardous waste incinerators that treat a significant proportion of the chemical platform waste and a biomass recovery unit that provides 15% of the chemical platform steam requirement.

Fig. 16 The Roches-Roussillon chemical platform

On Roches-Roussillon site, SUEZ RR IWS CHEMICALS activity focuses on three areas:

- Aqueris – High temperature incineration of industrial liquid hazardous waste (aqueous and organic), specialised in:
    - Aqueous waste with strong salt content
    - Sulphurous waste (mercaptan type)
    - Very dangerous waste (cyanide, acetonitrile, etc.)
- Aqueris – Evapo-incineration, for waste with a low pollutant load
- Robin – Hazardous and non-hazardous biomass valorisation, with steam production distributed to the platform industrials.

Among these, the Ultimate project will be involved in the Aqueris application. Over the past five years, the site has developed the ranges of waste received with the treatment of high-sulphur waste. This has resulted in an increase in the amount of sulphates collected in the washing water and then sent without recovery to the treatment plant. Due to environmental constraints (discharge of sulphate in the Rhône must be below 26 g/L and 24 t/d, sulphur dioxide content in the fumes must be lower than 120 mg/Nm^3/30min and 30mg/Nm^3/day), but above all due to the will of SUEZ to convert Aqueris into a material recovery unit, a project is being studied by the Industrial Department of SUEZ RR IWS CHEMICALS for the recovery of sulphur.

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2.8.2. Detailed description of the technological solutions before Ultimate

In Fig. 17 the Aqueris process is represented. Hazardous and non-hazardous liquid wastes are collected to the treatment site by tank wagons (5% of treated waste), tanker trucks (80%) or by pipelines (15%) from two chemistry companies, customers of SUEZ RR IWS CHEMICALS, located on the Roches-Roussillon chemical platform. Depending on their chemical composition, these liquid effluents are selectively stored in 16 tanks before incineration with a capacity of 6600 m^3. A small fraction of these lightly loaded effluents goes through an evaporator-concentrator designed to reduce the water concentration (Aqueris – Evapo-incineration line). The steam condensed after evaporation is sent to the activated sludge WWTP operated by SUEZ WTS. The treated water is discharged into the Rhône River. The concentrates, resulting from evaporation-concentration, are sent to the two incineration units realised in site (Aqueris – High temperature incineration). The largest fraction of wastes is not evaporated-concentrated but sent directly to the two incineration units on site (Aqueris – High temperature incineration line). Each incineration line has one furnace with quenching for cooling flue gas. The gaseous effluents from incineration are washed (950 m^3/d of washing water) to eliminate gases and dust in order to comply with current discharge standards. Each incineration line has:

- Two washing columns, which contain acid and soda, are used for dust and acid gases removal (sulphur dioxide and hydrochloric acid)
- Two electrostatic precipitators in series, for fine dust and metal oxide removal
- One deNox treatment

The washed fumes have a flowrate of 23500±2100 Nm^3_{dry}/h and are characterised by a temperature of 110°C with an estimated sulphur dioxide content of 6 mg/Nm^3 (about 10000 mg/Nm^3 before treatment). The fumes are sent to extraction chimneys with a height of 20 m for dispersion. The water used for fumes washing is sent to a physical-chemical WWTP operated by SUEZ RR IWS CHEMICALS. The first unit of the physical-chemical WWTP allows the cooling of the wastewater through a set of exchangers to reduce the temperature from 86 – 87 °C to 30°C. It should be noted, that the maximum temperature of the water measured in the quencher is 87 °C, while the minimum temperature measured at the inlet of the heat exchangers is 55 °C. The energy contained in this wastewater is entirely lost. The washing water is characterised by a sulphate concentration of 13.2±5 g/L and copper, zinc, nickel and chromium concentrations equal to 0.16±0.2 mg/L, 0.11±0.18 mg/L, 0.18±0.13 mg/L and 0.01 mg/L, respectively. The treatment line of the WWTP includes reactors for coagulation/flocculation, settling tanks, and a sludge dewatering system. The final effluent is discharged into the Rhône River.

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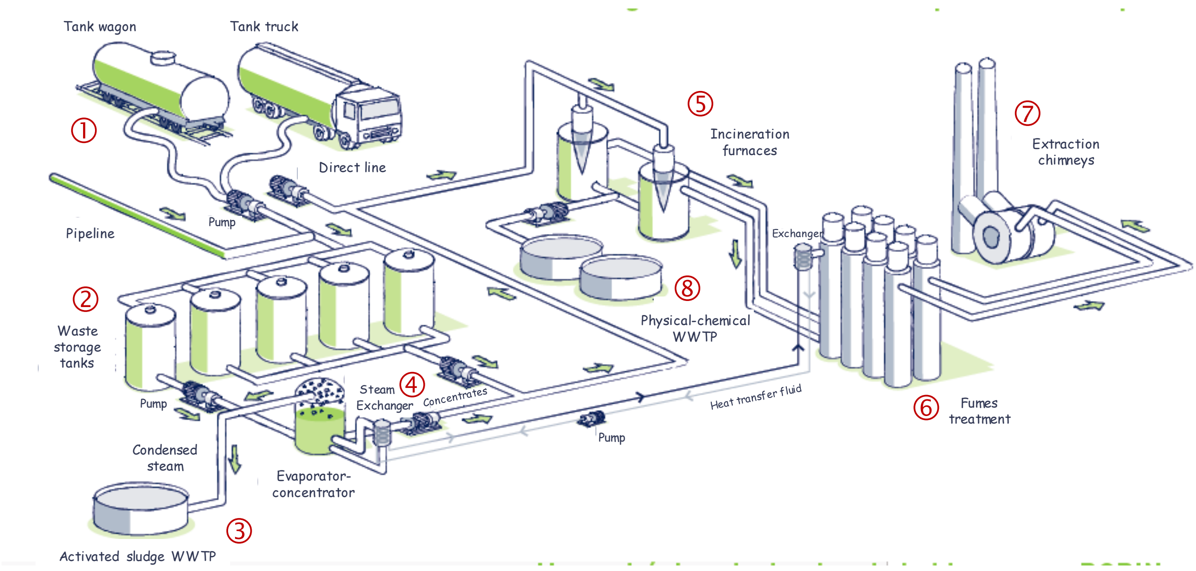

Fig. 17 Aqueris process

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2.8.3. Baseline conditions

Tab. 28-Tab. 29 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

Tab. 28 CS8: Baseline conditions of relevant parameters in term of energy recovery

BASELINE - current system									
	Parameter	Unit	Mean	Min	Max	Standard deviation	Frequency and number of measurements	Comments
Energy	**Energy production at WWTP (biogas, etc.)**	kWh/a	0	0	0			No energy production on site
Washing water	**Flowrate**	m^3/d	950	0	2470	190	Continuous	Based on the analysis of 1 year of data (1 measurement/hour)
Washing water	**Temperature before heat extraction**	°C	68	55	88		Continuous measurement in quench recirculation (before and after heat exchanger placed on quench recirculation) Continuous measurement at WWTP heat exchangers inlet	Between quench and heat exchangers, there are 3 oxidizing tanks and a homogeneization pond. Max: temperature of waste water in quench Mean: temperature of waste water at quench output (a first heat exchanger located on quench recirculation lower temperature from 20°C). Min : temperature measured at heat exchangers inlet on WWTP

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Tab. 29 CS8: Baseline conditions of relevant parameters in term of material recovery

BASELINE - current system								
	Parameter	**Unit**	**Mean**	**Min**	**Max**	**Standard deviation**	**Frequency and number of measurements**	**Comments**
Flue gas of the incineration facility	**Flowrate**	Nm^3_{dry}/h	23500	16300	30300	2100	Continuous	Flowrate measurement only in stack
	Temperature	°C	87.8	74	90		No temperature sensor in the duct of the flue gases to valorize. Measurements carried out in a very punctual way.	
	Sulphur dioxide (SO_2)	mg/Nm^3	10000	0	30000 ?		No measurement. Determine through calculation. Quotation in progress for SO_2 analyzer purchase.	Depends on the amount of sulphur in waste.
	Dust content	mg/m^3	2000		4000		No measurement.	Estimated from emission analyses (stack) and theoretical equipments performance.
	NO_x	mg/m^3	300	0	700		No measurement.	Estimated from emission analyses before DENOX implementation.
	O_2	%	2				Continuous measurement just after basic scrubber.	
	CO_2	%	13	8	19	2	Measurement only in the stack	
	CO	mg/m^3	20	0	50	9	Continuous measurement only on stack.	
	H_2O	%	Saturated					
	HCl		10	0			No measurement	Measurement only on stack. Depends on waste composition.
Effluent feeding the physical chemical WWTP	**Flowrate**	m^3/d	950	0	2470	190	Continuous	Based on the analysis of 1 year of data (1 measurement/hour)
	Temperature	°C	68	55	88		Continuous measurement in quench recirculation (before and after heat exchanger placed on quench recirculation) Continuous measurement at WWTP heat exchangers inlet	Between quench and heat exchangers, there are 3 oxidizing tanks and a homogeneization pond. Max: temperature of waste water in quench Mean: temperature of waste water at quench output (a first heat exchanger located on quench recirculation lower temperature from 20°C). Min : temperature measured at heat exchangers inlet on WWTP
	pH		5	4	6		Continuous measurement of quench recirculation	
	Sulphate	g/L	13.2	1.3	31.8	5	Daily	
	Sulphate load	kg/d	16300	1700	36100	6700	Daily (concentration x Flow rate)	
	Copper (Cu)	mg/L	0.16	0.01	0.70	0.20	Monthly	
	Zinc (Zn)	mg/L	0.11	0.01	0.75	0.18	Monthly	
	Nickel (Ni)	mg/L	0.18	0.02	0.60	0.13	Monthly	
	Chromium (Cr)	mg/L	0.01	0.01	0.02	0.00	Monthly	

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2.8.4. Objectives of the Ultimate solutions

CS8 aims to close the loops of energy and material. The internal symbiotic relationship at the Roches-Roussillon chemical platform is extended to increase the energy and material recovery, improving the operation of the WWTP on site. In particular, the recovery of sulphur, will broaden the chemical spectrum of liquid waste treated on site, while respecting locally defined standards for sulphur released into the Rhône. Furthermore, the symbiosis will expand during the project including possible users of the sulphur extracted among the chemical companies of the platform. The technological solutions of Ultimate will comprise in detail:

Feasibility study for heat recovery from flue gas washing water

During the first step of the WWTP, washing water are cooled from 88 °C to 30 °C, via a set of heat exchangers. The study aims to analyse the potential recovery of this thermal energy: the feasibility to produce electricity and/or steam on-site from hot washing water, for a local use, will be studied during the project.

Sulphur and metals recovery

The recovery of sulphur will be tested for two flows:

1. Flue gas of the incineration facility: a pilot demonstration under real conditions will be implemented with different process steps involving condensation, dust cleaning and scrubbing.
2. Effluent feeding the physical chemical WWTP: lab tests will be conducted (e.g. electrolytic oxidation or natural flocculating agents or chemical precipitation of sulphates).

The recovery of metals (Fe, Si, Cu, Zn, Ni etc.) from the effluent feeding the physical chemical WWTP, will be investigated in a concept study and further refined by physical-chemical modelling (calculation of metal speciation, solubility equilibria, complexation reactions).

2.8.5. Specific key performance indicators (KPIs) of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 30 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 30 Specific KPIs in CS8

Topic	Objectives	Specific KPIs
Energy	Potential recovery of thermal energy	- Feasibility study report including: a technical solution, investment cost and operating cost, recovery form (electricity, steam, heat) and use and energy recovery rate - Reduction of energy consumption - Resulting profits

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Material	Sulphur recovery from flue gas	- Recovery rate of sulphur from the feed of the incinerator - Purity of the sulphur product formed - List of impurities, - Preliminary economic analysis
	Sulphur recovery from effluent feeding the physical chemical WWTP	- Recovery rate of sulphur from mineral and organic waste - Purity of the sulphur product formed - List of impurities, - Preliminary economic analysis
	Metal recovery from effluent feeding the physical chemical WWTP	Report (here, the recovery efficiency and the purity of the recovered material will be considered)

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2.9. CS9 Kalundborg (Denmark)

2.9.1. General description of the case study and site

The Kalundborg Symbiosis Association exists since 1972 and interlinks thirteen private and public companies. The local industrial sector includes petrochemical, light building construction material, food, pharma, biotech, energy and bioenergy as well as waste processing.

Different circular economy approaches for water, energy and materials are already implemented, e.g. the reuse of cooling water for steam production, the reuse of gypsum from exhaust gas cleaning to produce plasterboards, integrated heat management and the transfer between the industries and the district heating network as well as heat recovery from process water for district heating (Fig. 18).

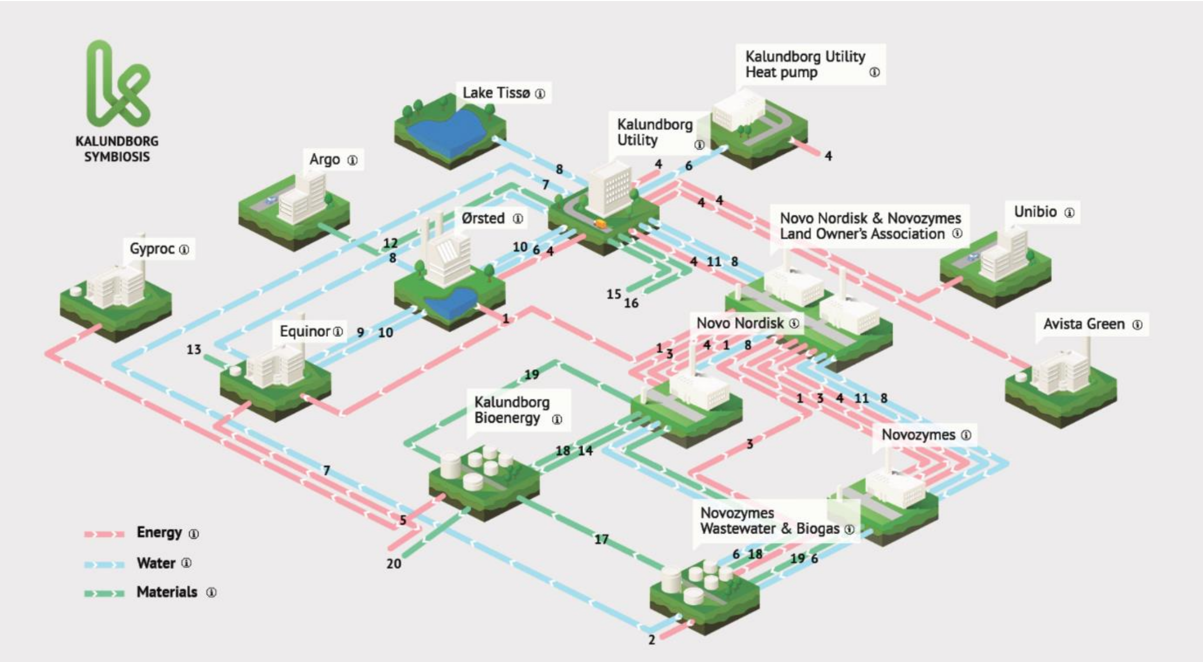

Fig. 18 Kalundborg Symbiosis (source: http://www.symbiosis.dk/en/)

Even though, the Kalundborg Symbiosis already recovers and reuses certain materials, water and energy, there are still options to intensify and extend the circular economy related strategies. One aspect is the treatment of wastewaters which is done by two companies Novozymes and Kalundborg Utility.

Novozymes is a biotechnologically industrial company and owns a multi-utility operating its industrial WWTP. Kalundorg Utility operates the municipal WWTP that receives the effluent from the industrial WWTP.

Ultimate focuses on the optimisation of two WWTPs aiming at developing and implementing a joint control system for both plants, the recovery of the WWTP effluent as fit-for-purpose water and to explore the potential for the recovery of valuable compounds from the industrial wastewater as well as on identifying options to reuse thermal energy recovered from wastewater. Therefore, the symbiotic relationship between Novozymes and Kalundborg utility is extended in the frame of Ultimate to create a win-win situation for both.

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A major challenge for the reuse of water in the production processes of the food, pharma and biotech industries are the Danish and European laws which currently focus more on the water origin than on the water quality. Therefore, Ultimate will bring together relevant stakeholders to support policy and decision makers in order to foster water reuse and circular economy solutions.

2.9.2. Detailed description of the technological solutions before Ultimate

The municipal WWTP treats on average 19300 m³/d. Approximate 51% of the treated wastewater stem from the industrial WWTP, 46% from the municipality and 3% from a nearby power plant. Even though the municipal WWTP treats the pre-treated wastewater from Novozymes, the two WWTPs have both their own process control systems which are not connected to each other.
In the municipal WWTP, only the wastewater from the municipality undergoes a primary treatment (Fig. 19).

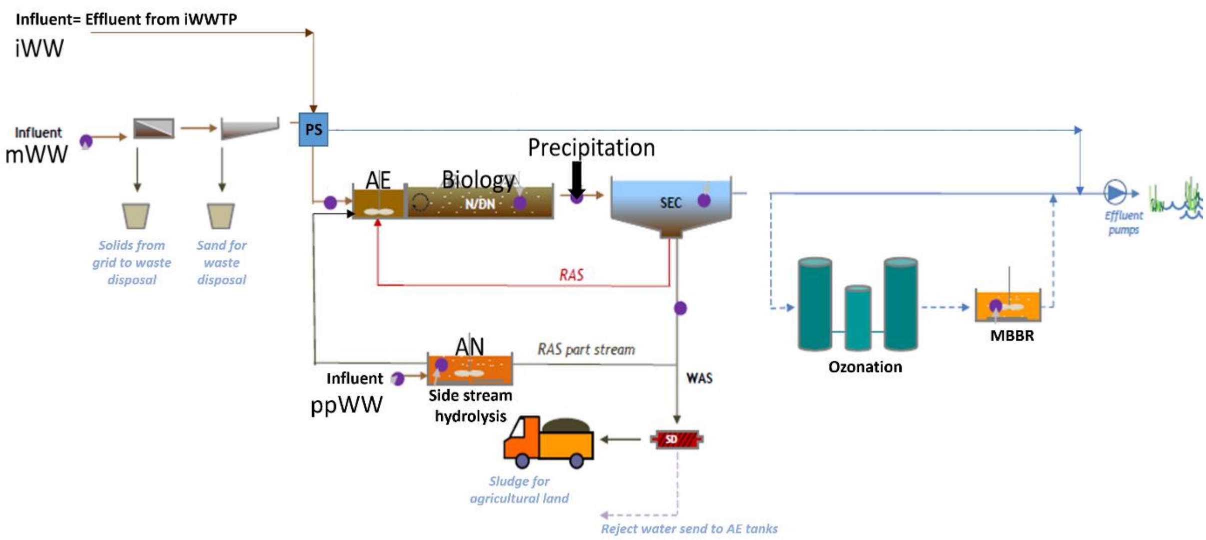

Fig. 19 Scheme of the municipal wastewater treatment plant (iWW: industrial wastewater from Novozymes; mWW: municipal wastewater; ppWW: wastewater from power plant; PS: pumping station; AE: aerobic; AN: anaerobic)

The other wastewater streams from Novozymes and from the power plant enter the municipal WWTP at the secondary treatment step. Here, the carbon is degraded aerobically and the nitrogen is eliminated via nitrification and denitrification in intermittently aerated tanks. The phosphorus is chemically removed. Around 236 t of iron chloride per year are used to precipitate phosphate.
In the case of rain events, when the industrial and the municipal influents exceed the flow rate of 2160 m³/h, the municipal wastewater is directly discharged to the recipient. In 2020, the average rainfall in Kalundborg was 6368 mm/year. This corresponded to direct discharges to the recipient of around 814000 m³/a.
In a side stream, the effluent from the secondary clarifier can be treated via ozonation and a subsequent moving bed bioreactor (MBBR), if required. Currently, it is used to

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reduce xenobiotic compounds. The third treatment step is a good basis for a further water treatment in order to reach a very high water quality as targeted in Ultimate.

The industrial WWTP pre-treats the wastewater resulting from enzyme, insulin and pharmaceutical protein production processes. After a primary clarifier and a pre-acidification tank, the wastewater enters anaerobic internal circulation (IC) tanks (Fig. 20). Each IC consists of two upflow anaerobic sludge blanket (UASB) reactors, whereby one is stacked on the other enabling an internal circulation of gas. Here, soluble organic carbon compounds are biodegraded to biogas with a monthly energy production rate of around 22 GWh. The effluent from the IC tanks undergoes an activated sludge treatment for carbon and nitrogen removal.
The phosphate precipitates due to the addition of polyaluminium chloride (PACl) and is removed in the secondary clarifiers. Around 138 t PACl/month are dosed for coagulation and phosphate precipitation. If the phosphate concentration is still too high, iron chloride is added to the secondary clarifier effluent in the subsequent dissolved air flotation (DAF) plant. The dosing rates of polyaluminium chloride and iron chloride are roughly 477 g/m^3 and 34 g/m^3, respectively. Ultimate aims to reduce those rates. Furthermore, for the inactivation of genetically modified organisms in the sludge, quicklime is used prior to dewatering. Thus, depending on the dosage rate, the concentration of calcium can be so high, that calcium phosphate compounds might precipitate contributing to the phosphorus removal.
The influent as well as the effluent of the industrial WWTP contain valuable nutrients such as sulphur, phosphorus and nitrogen, but also other compounds such as acetic acid, which might be worth to be recovered. In Ultimate, a screening for suitable compounds will be conducted to conceptualise a material recovery scenario.

As already shown in Fig. 18, a heat pump recovers thermal energy from the effluent of the municipal WWTP. The temperature of the effluent varies between 13 °C and 33 °C with an average temperature of 23 °C and thus, the effluent is very well suited for heat recovery. Around 5.3 MWh per year of thermal energy are recovered on average with a coefficient of performance of the heat pump ranging between 3.7 and 4.2. The current supply of the district heating distribution system will not be required anymore on the nearby future. Thus, a new purpose for the thermal energy needs to be found.

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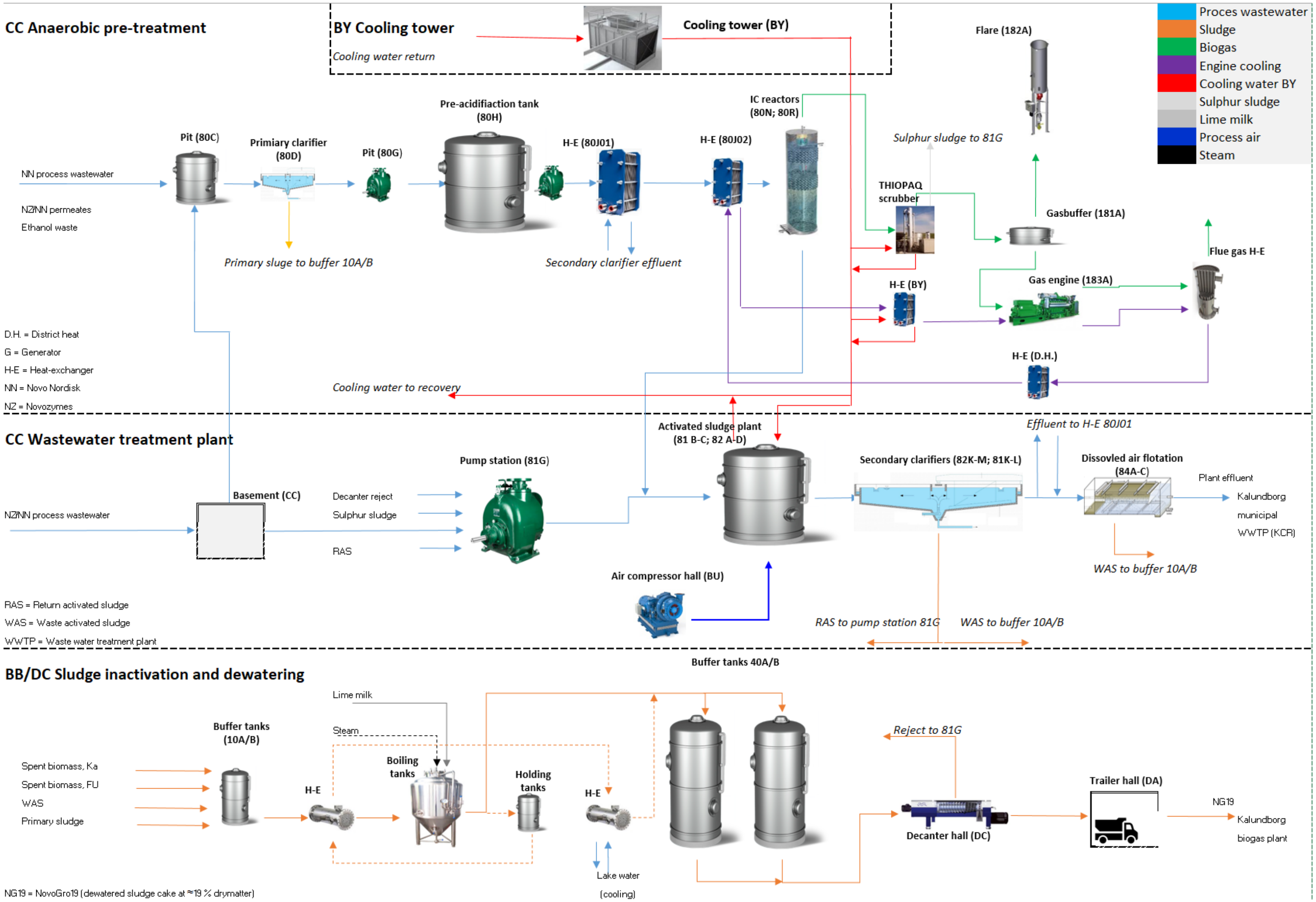

Fig. 20 Scheme of the industrial WWTP

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2.9.3. Baseline conditions

Tab. 31-Tab. 34 show the relevant parameters to describe the baseline conditions that existed before the start of Ultimate. Those data were collected in the frame of this deliverable to make them available to other work packages and to compare them to the results that will be obtained after the implementation of the Ultimate circular economy solutions in order to quantify the improvements.

Tab. 31 CS9: Baseline conditions of water related parameters

BASELINE - CURRENT SYSTEM							
Parameter			**Units**	**Mean value**	**Standard deviation**	**Frequency and no. of measurements**	**Comments**
Water yield of the system	**Current system**	Rainfall climatology of the area	mm/year	6368			Measured at KCR from jan 2020-dec 2020
		Flow rate of iWWTP influent	m^3/d	11215	1761	continuous measurement	2020 data. +/- 7% of deviation is expected which can explain deviation from iWWTP effluent
		Flow rate of iWWTP effluent (iWW from NZ to mWWTP)	m^3/d	10456	1961	continuous measurement	Aug. 2019 - July 2020
		Flowrate of ppWW from power plant to mWWTP	m^3/d	627 744	494 187,2	continuous measurement	Aug. 2019 - July 2020 Aug. 2020 - Feb. 2021
		Flowrate of mWW to mWWTP	m^3/d	9370	3160	calculated	Aug. 2019 - July 2020
		Flowrate of mix of mWW & iWW in mWWTP	m^3/d	19826	5121	continuous measurement	mix of (iWW+mWW): Aug. 2019- July 2020
		Flow rate of mWWTP effluent	m^3/d	19316	4570		Jan 2020 - Dec 2020 flow to recipient without direct discharge from intermidiate pumping station
Water quality	**influent to iWWTP**	COD	mg O_2 /L	1811	274	daily	Activated sludge plant (CAS) filtered (0,45 um) feed including RAS. Possibly, there is some CODs conversion in the cooled automatic samplers (24 h flow proportional samples). Jan-March 2021
		pH	upH	8	0	continuous measurement	iWWTP effluent, assumed to be similar to CAS feed
		TSS	mg/L	1301	753	3 times per week for 1 month	Joint streams to CAS, unfiltered samples on ICP analysis. May 2019 (DTU modelling campaign)
		Total nitrogen	mg N/L	274	85	Daily	Activated sludge plant (CAS) filtered (0,45 um) feed including RAS. Possibly, there is some TNs conversion in the cooled automatic samplers (24 h flow proportional samples). Jan-March 2021
		Ammonium	mg N/L	192	56	3 times per week for 1 month	Joint streams to CAS, unfiltered samples on ICP analysis. May 2019 (DTU modelling campaign)
		Nitrate	mg N/L	13	6	campaign	Joint streams to CAS, unfiltered samples on ICP analysis. May 2019 (DTU modelling campaign)
		Total phosphorus	mg P /L	56	15	3 times per week for 1 month	Joint streams to CAS, unfiltered samples on ICP analysis. May 2019 (DTU modelling campaign)
		Sulfur	mg/L	147	65	3 times per week for 1 month	Joint streams to CAS, unfiltered samples on ICP analysis. May 2019 (DTU modelling campaign)
		Acetic acid	mg/L	116	108	continuous measurement	Anaerobic effluent VFA meassurement (about 63% of the CAS influent). 2020

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BASELINE - CURRENT SYSTEM							
Parameter			Units	Mean value	Standard deviation	Frequency and no. of measurements	Comments
Water quality	iWW (effluent from NZ to mWWTP)	COD	mg O_2 /L	167	64	daily	Aug. 2019 - July 2020
		BOD_5	mg O_2 /L	24		weekly	calculated with COD:BOD=131:19 (2019-2020)
		pH	upH	7,6	0,28	continuous measurement	2019-2020
		TSS	mg/L	43	19	daily	Aug. 2019 - July 2020
		Total nitrogen	mg N/L	18	11	daily	Aug. 2019 - July 2020
		Ammonium	mg N/L	5	2	daily	Aug. 2019 - July 2020
		Nitrate	mg N/L	3	10	daily	Aug. 2019 - July 2020
		Total phosphorus	mg P/L	3	1	daily	Aug. 2019 - July 2020
		Phosphate	mg P/L	2	1	daily	Aug. 2019 - July 2020
		Sulfur	mg/L	524		2-3 times per week	Feb 19-2020 - April 27-2020, we only measured sulphate
	ppWW (from Power Plant to mWWTP)	COD	mg O_2/L	<5		weekly	Aug. 2019 - July 2020
		BOD_5	mg O_2/L	1,7		monthly	Jan. 2018 - Dec. 2018
		pH	upH	5,8	0,6	continuous measurement	Aug. 2020 - Feb. 2021
		TSS	mg/L	27	25	weekly	Aug. 2020 - Feb. 2021
		Total nitrogen	mg N/L	16	34	weekly	Aug. 2020 - Feb. 2021
		Ammonium	mg N/L	1,2	2,3	weekly	Aug. 2020 - Feb. 2021
		Nitrate	mg N/L	7,7	18	weekly	Aug. 2020 - Feb. 2021
		Total phosphorus	mg P/L	0,02		monthly	Jan.2018-Dec.2018
	mWW (from municipality to mWWTP)	COD	mg O_2/L	402	240	daily	Aug. 2019-July 2020
		BOD_5	mg O_2/L	149	89		Estimated via COD/BOD=2,7
		pH	upH	8		continuous measurement	Jan 2020-Dec 2020
		El. Cond.	mS/cm	4,6		continuous measurement	Jan 2020-Dec 2020
		TSS	mg/L	169	71	daily	Aug. 2019-July 2020
		Total nitrogen	mg N/L	38	12	daily	Aug. 2019-July 2020
		Ammonium	mg N/L	24	9	daily	Aug. 2019-July 2020
		Nitrate	mg N/L	2	2	daily	Aug. 2019-July 2020
		Phosphate	mg P/L	3	1	daily	Aug. 2019-July 2020
		Total phosphorus	mg P/L	4	2	daily	Aug. 2019-July 2020
	mix of mWW & iWW (in mWWTP)	COD	mg O_2/L	267	139	daily	Aug. 2019-July 2020
		BOD_5	mg O_2/L	87		monthly	calculated with COD:BOD=208:68 (2019-2020) (we only get BOD samples done by external lab 12 times pr. year)
		T	°C	25	5	continuous measurement	Aug. 2019-July 2020
		pH	upH	8,1	0,53	continuous measurement	Aug. 2019-July 2020
		El. Cond.	mS/cm				Not determined
		TSS	mg/L	129	55		Aug. 2019-July 2020
		Turbidity	NTU				Not determined
		Total nitrogen	mg N/L	26	10		Aug. 2019-July 2020
		Ammonium	mg N/L	11	3		Aug. 2019-July 2020
		Nitrate	mg N/L	3	1		Aug. 2019-July 2020
		Phosphate	mg P/L	3	1		Aug. 2019-July 2020
		Total phosphorus	mg P/L	4	1		Aug. 2019-July 2020
	mWWTP effluent	COD	mg O_2/L	56	17	daily or 3 times a week	Aug. 2019-July 2020
		BOD_5	mg O_2/L	2,98		12 times pr. year	Jan 2020-Dec 2020
		pH	upH	8		continuous measurement	Jan 2020-Dec 2020
		TSS	mg/L	9	5,5	daily or 3 times a week	Aug. 2019-July 2020
		Total nitrogen	mg N/L	7	2	daily or 3 times a week	Aug. 2019-July 2020
		Ammonium	mg N/L	0,79	0,93	daily or 3 times a week	Aug. 2019-July 2020
		Nitrate	mg N/L	2,14	1,08	daily or 3 times a week	Aug. 2019-July 2020
		Phosphate	mg P/L	0,34	0,17	daily or 3 times a week	Aug. 2019-July 2020
		Total phosphorus	mg P/L	0,48	0,22	daily or 3 times a week	Aug. 2019-July 2020

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BASELINE - CURRENT SYSTEM							
Parameter			Units	Mean value	Standard deviation	Frequency and no. of measurements	Comments
Energy consumption	Current system	mWWTP	kWh/m^3	0,56		yearly accounting	jan 2020-dec 2020, The number also includes energy for ozonation, if ozonation is excluded the number is 0,40
		iWWTP	kWh/m^3	4,9		yearly accounting	Plant wide energy use, except cooling towers, diveded by influent flow rate. 2020 data
Reagents required	iWWTP	Polyaluminiumchlorid	g/m^3	477		monthly accounting	PAX-215
		Iron chloride	g/m^3	34		monthly accounting	PIX-113
		Calcium oxide	g/m^3	1380		monthly accounting	96% CaO added to sludge for stabilisation
	mWWTP	Iron chloride	kg	235940		when payed for	PIX 118, total consumption for 2020
Waste produced	Current system	Polluted sand	t/a	260			
		Sludge (collected)	kg/d	3059			Calculated, in 2020 we drove away 3527 t/a

Tab. 32 CS9: Baseline conditions of relevant parameters in terms of the joint control system

BASELINE - Current system - municipal WWTP								
Parameter		Unit	Mean	Min	Max	Standard devi.	Frequency of measurements	Comments (e.g. data refer to the years ...)
	Specific energy consumption (total mWWTP)	kWh/m^3	0,56					Data includes the ozone plant as well, without the energy consumption for the ozone plant the average figure is 0,4
P removal	Yearly P load of mWWTP	t/a	26					Calculated with the mean P concentration and the mean flow rate
	P load resulting from mWW	t/a	14					Calculated with the mean P concentration and the mean flow rate
	P load resulting from iWW(eff)	t/a	11					Calculated with the mean P concentration and the mean flow rate
	P load resulting from ppWW	t/a	0,43					Calculated with the mean P concentration and the mean flow rate
	Massflowrate of iron chloride	t/a	236					PIX 118, total consumption for 2020
Discharge to recipient	Flowrate of direct discharge to recipient	m^3/a	814000				continuous measurement	
	Discharge to recipient as a share of the yearly influent	%	11,5					
Waste activated sludge	Flowrate	m^3/d	161	0	654	128	daily	Aug. 2019 - July 2020
	Total solids content	kg TS/m^3	19	10	27	3	3 times per week	Aug. 2019 - July 2020
	Volatile solids content	% of TS (total solids)	61				12 times per year	Jan. 2020 - Dec. 2020
BASELINE - Current system - industrial WWTP								
Parameter		Unit	Mean	Min	Max	Standard devi.	Frequency of measurements	Comments (e.g. data refer to the years ...)
Energy	Total energy production (total iWWTP)	MWh/month	21956				monthly auditing	2020 data
	Total energy consumption (total iWWTP)	MWh/a	19958				yearly auditing	2020 data
P removal	Yearly P load of iWWTP	t/a	229				3 days per week for 1 month	Joint streams to CAS, unfiltered samples on ICP analysis. May 2019 (DTU modelling campaign)
	Massflowrate of PACl total	kg/month	162854	96638	227445	39232	monthly auditing	2020 data
	Massflowrate of PACl to activated sludge plant	kg/month	137512	84782	189901	33568	-	Added to secondary clarifiers (60% is assumed to be also for minimum coagulation, i.e 0,1 L/m^3 clarifier feed). 2020 data
	Massflowrate of PACl for P removal	kg/month	55005	33913	75960	13427		Estimated via 40% of massflowrate to activated sludge plant. 2020 data
	Massflowrate of iron chloride	kg/month	11768	0	32851	11668	monthly auditing	2020 data

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Tab. 33 CS9: Baseline conditions of relevant parameters regarding heat recovery

BASELINE - current system								
Parameter		Unit	Mean	Min	Max	Standard deviation	Frequency of measurements
Wastewater in contact with heat exchanger	Energy consumption at mWWTP	MWh/a	3961				Measured continuoulsy
	Flowrate	m^3/d	19316	6970	39060	4569	Measured continuoulsy
	Temperature before heat extraction	°C	22,9	13,3	32,5		Measured continuoulsy
Heat pump	Heat pump power input	MW	156	120	203	59	Measured continuoulsy 2019
	Coefficient of performance	-	3,89	3,66	4,24	0,41	Measured continuoulsy 2019
Heat recovery	Heat recoverd & supplied	kWh/a	5330	3266	778870	548435	Measured continuoulsy 2019
	Heat reused on-site?	kWh/a	0	0	0	0	2019

Tab. 34 CS9: Baseline conditions of relevant parameters regarding material recovery

BASELINE - current system								
Parameter		Unit	Mean	Min	Max	Standard deviation	Frequency of measurements	Comments
WW from Novozymes	Flowrate	m^3/d	10456	1125	14467	1961	continuous measurement	Aug. 2019 - July 2020
	pH		7,6	5	11	0,3	continuous measurement	2019-2020
	Acetic acid concentration	mg/L	2200	NA	NA	NA	campaign from 2016	Total concentrations before anaerobic pre treatment (acetate concentration)
	Sulphur concentration	mg/L	480	NA	NA	NA	weekly	sulphate concentration since is the only S form
	Total nitrogen	mg N/L	18	9	175	11	daily	Aug. 2019 - July 2020
	Ammonium	mg N/L	5	2	16	2	daily	Aug. 2019 - July 2020
	Nitrate	mg N/L	3	0	145	10	daily	Aug. 2019 - July 2020
	Total Phosphorus	mg P/L	3	1	7	1	daily	Aug. 2019 - July 2020
	Phosphate	mg P/L	2	0	6	1	daily	Aug. 2019 - July 2020
	Chemical oxygen demand (COD)	mg O_2/L	167	90	546	64	daily	Aug. 2019 - July 2020
	Total suspended solid concentration (TSS)	mg/L	43	14	152	19	daily	Aug. 2019 - July 2020

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2.9.4. Objectives of the Ultimate solutions

CS9 aims to close the loops of water, energy and material. Therefore, the symbiotic relationship between Novozymes and Kalundborg utility is extended to enable the increase in energy efficiency of plant operation and the reduction in chemical consumption. Furthermore, the symbiosis will expand during the project by finding and including the future users of the produced water, the recovered heat and the recycled material. The technological solutions of Ultimate will comprise in detail:

Novel membrane treatment for biotech or biotech and municipal WWTP effluent for water reuse

In order to exploit the potential for water reuse, a treatment train containing a novel tight ultrafiltration membrane will be tested. Therefore, a pilot plant comprising different units will be designed and constructed. The first unit of the treatment train is the novel tight ultrafiltration unit (UF) followed by a reverse osmosis (RO) unit. This will be compared to a commercial UF unit combined with a RO. Different combinations of those units with further treatments such as ozonation and biofiltration and a powder activated carbon (PAC) unit will be implemented at different positions in the WWT systems and will be investigated.

Increase energy efficiency via digitalisation and symbiotic joint operation of two wastewater treatment plants as well as heat recovery

The joint control system will allow for a synergetic wastewater treatment management of both WWTPs. Especially energy shall be saved due to a new predictive controlled nitrogen elimination. Furthermore, the option for a change from chemical phosphorus removal to an enhanced biological phosphorus removal in order to save chemicals will be investigated. Based on the modelling work that will be conducted prior to the implementation of the joint control system, the aim to reduce direct discharges to the recipient during rain events will be tested. Therefore, the industrial WWTP might serve as a buffer for retaining the industrial WW until the flowrate of the municipal WW decreases to a certain threshold.

In the near future, the heat recovery and heat pump installed at the effluent of the municipal WWTP won't be needed anymore for the district heating. Therefore, in a concept study, new purposes for the recovered heat shall be identified. One option might be the pre-heating of the fit-for-purpose water for a potential steam production. In this frame, the water quality requirements have to be considered. Also, the temperature which can be reached via pre-heating of that water for a subsequent steam production shall be determined via the available heat amount from the heat recovery and the heat pump.

Concept study for nutrient and/or high-value product recovery

For the concept study, different components, which are contained in the wastewater from Novozymes will be considered such as acetic acid, sulfur and maybe other valuable compounds. The content of the concept study will comprise:

1. Technological treatment train
2. Economic value of the recovered product
3. Potential for internal usage or the usage by other industries
4. Impact on the operation of the municipal WWTP

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2.9.5. Specific key performance indicators of the Ultimate solutions

The case study specific key performance indicators (KPIs) shown in Tab. 35 will be determined in the course of the project in order to evaluate the improvement of the technological solutions to be developed and implemented in Ultimate. They will serve as a basis for the different assessments to be performed in WP2 such as the life cycle assessments and life cycle costing analyses and for other WPs.

Tab. 35 Specific KPIs in CS9

Topic	Objectives	Specific KPIs
Water	Fit-for-purpose water reclamation from WWTP effluent and water reuse	- Water yield - Water quality - Specific energy consumption - Reagents and materials required - Reduction of fresh water through reuse of reclaimed water
Energy	Higher energy efficiency of the WWTPs due to the joint and synergetic operation of both WWTPs	- Reduction of the specific energy demand of both WWTPs - Reduction in precipitants dosing for chemical phosphorus removal - Less direct wastewater discharges to the recipient during rain events
	Concept study for heat recovery from wastewater (heat pump)	- Coefficient of performance - Substitution of fossil energy due to heat recovery
Material	Concept study for material recovery	- Material recovery rate related to the influent load to the WWTP - Recovery efficiency of the certain unit - Purity of the recovered material

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3. Summary and Conclusions

The assessment of the baseline conditions showed the suitability and the potential of each case study to implement different circular economy solutions via water smart industrial symbiosis. The collected data reveal the starting conditions of our case studies and provide valuable information as a basis to later evaluate the improvements of the case studies due to the implemented Ultimate concepts. Furthermore, the data collected can serve as an orientation for potential replication sites and potential symbiosis to investigate if their sites are suitable for similar concept implementations.

Fig. 21 gives an overview of the options for the Ultimate solutions and their positions in the water, material and energy cycles. Furthermore, the figure highlights the nexus between water, material and energy within concepts of the case studies. Each type of wastewater contains valuable materials such as nutrients, polyphenols, sulphur, acetic acid and metals which are worth being recovered. Wastewaters also carry energy in the form of biomass for biogas production and of thermal energy in the form of heat.

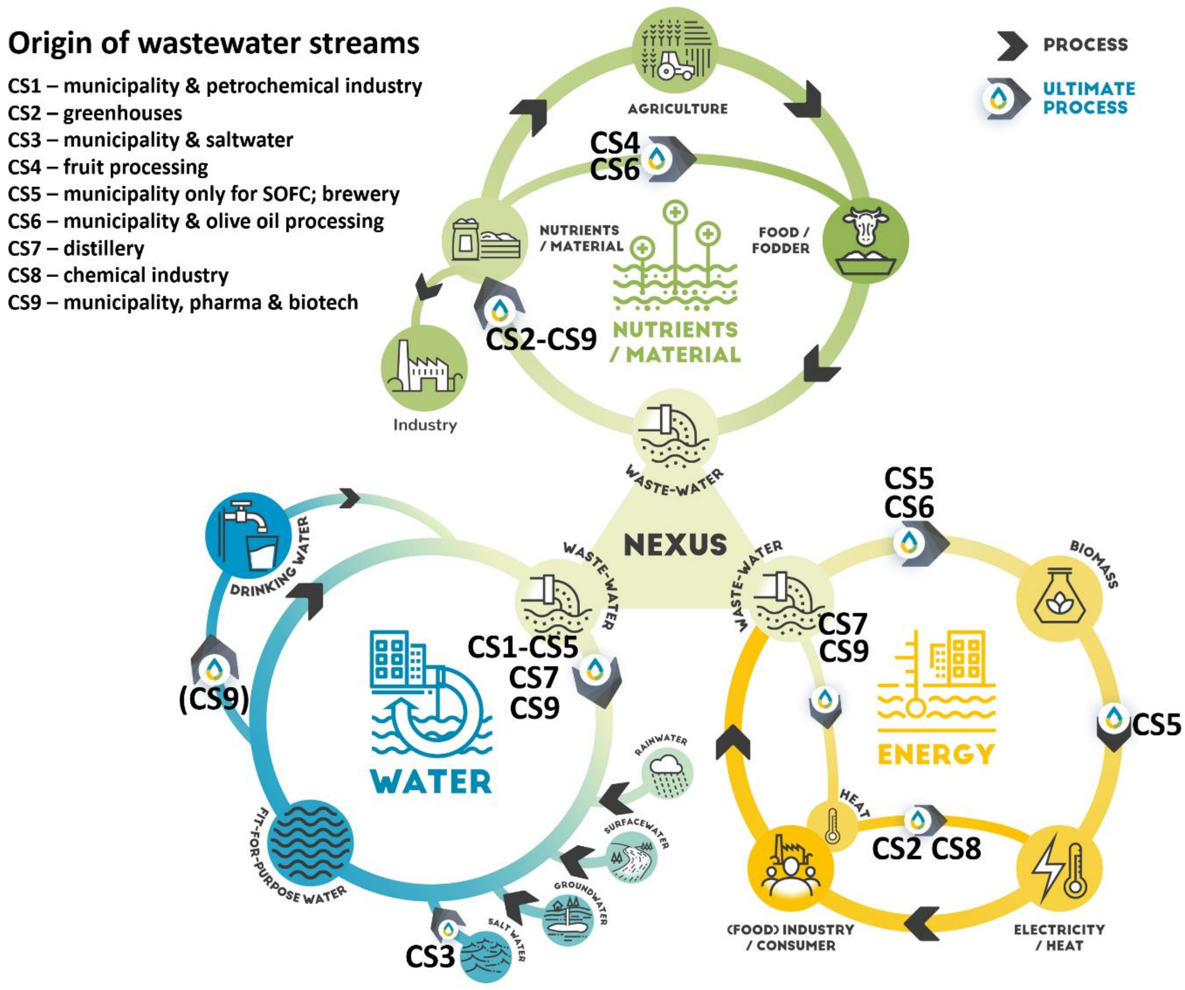

Fig. 21 Overview on the different circular economy solutions in Ultimate referring to each case study.

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Based on the data collection for the baseline assessment, the starting conditions for our case studies are summarised to provide an overview which conditions were met to consider an implementation of those concepts as suitable.

Water recovery

All types of wastewater ranging from municipal wastewater characterised by the occurrence of pathogenic organisms up to wastewater from the petro(chemical) industry with high sulphur and metal concentrations to biotech, beverage and food industry can be used to recover water. Those wastewaters can be technically treated until drinking water quality is reached. However, in Europe it is very difficult to use the reclaimed water for direct potable reuse as the main sources for drinking water production are surface water and groundwater. Thus, almost all case studies consider only agricultural irrigation, water supply for cooling towers or for cleaning purposes as reuse options.

Especially in coastal regions, the intrusion of saltwater in coastal aquifers and sewer systems increases the chloride concentration in the water and thus, render (salty) water unsuitable for irrigation. Therefore, to avoid irrigation with salty water, an early warning system will be developed and implemented to take immediate action during salinity peaks. As suitable measures, flow splitting and equalisation of the secondary effluent as well as the potential use of other waters are considered.

Energy recovery

Especially the wastewaters from olive oil production and the distillery contain very high COD concentrations of 120 g/L and 38 g/L, respectively and thus, are very well suited for an anaerobic treatment to produce biogas. However, also the brewery wastewater with 4200 mg/L as well as the mix of municipal wastewater with olive mill wastewater with 1500 mg/L to 1960 mg/L are still in a suitable range for an anaerobic treatment.

The biogas can further be used to produce electricity and heat via a solid oxide fuel cell. Hereby, the methane content of the chosen biogas is on average 60% and the efficiency of the solid oxide fuel cell is expected to be 1.5-times more efficient than a combined heat and power unit.

For heat recovery temperatures of the wastewaters between 23 °C and 70 °C are considered with flow rates starting at 200 m^3/d up to 19000 m^3/d.

Material recovery

Wastewaters from fruit processing and from olive oil processing plants contain valuable polyphenols and are suited well for the recovery of this high value-added product.

Regarding the recovery of nutrients, the anaerobically treated distillery wastewater with ammonium concentrations of around 800 mg/L will be used for ammonia recovery and its further processing to a fertiliser such as ammonium sulphate. The drain water from the greenhouses contains a nutrient composition of 50 mg/L of nitrate, 2 mg/L of ammonium and 4 mg/L phosphate is assessed as a suitable basis to design a fertilising mixture or product for the greenhouses.

Sulphur recovery is considered for concentrations between 13.2 g/L and 480 mg/L and also the recovery of metals such as copper, zinc, nickel and chromium will be investigated starting with concentrations of 0.16 mg/L, 0.11 mg/L, 0.18 mg/L and 0.01 mg/L, respectively.

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Reduction of energy and chemicals consumption in plant operation
In wastewater treatment, to avoid fouling processes of the membranes in anaerobic reactors, an early warning system will be tested in order to save energy due to an optimised operation of the membranes.

For two neighbouring wastewater treatments plants, a joint control system will be implemented in order to save energy and chemicals due to a predicted demand driven oxygen supply and due to the change from a chemical phosphorus removal system to an enhanced biological phosphorus removal, respectively. Here the requirement is that the wastewater treatment plants are connected to each other and that the wastewaters can be treated together.

Exploitation and Outlook
Also in the frame of the NextGen project (grant agreement no. 776541) further technologies are investigated to close the cycles for water, material and energy. Together with the innovative solutions of Ultimate, they will demonstrate and foster a wide range of exemplary circular economy approaches. Based on the results from both projects, solid evidence on the efficient and sustainable operation of such technologies will be made available to a wide range of stakeholders through a technology evidence base that is currently under development. This technology evidence base will be freely accessible and provide valuable information about circular economy concepts and technologies in operation, useful to investors, operators and engineers as well as to policy and decision makers. After the end of the UItimate project, it will be hosted by Water Europe to ensure its sustainability.

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