iWAYS
innovative water recovery solutions

Decision Support Systems

Sustainable water source assessment framework

[01/12/2023]

Authors:
BUL

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Technical References/

Project Acronym	iWAYS
Project Title	Innovative Water recoverY Solutions through recycling of heat, materials and water across multiple sectors
Project Coordinator	Prof. Luca Montorsi – University of Modena and Reggio Emilia
Scientific and Technical Director	Prof. Hussam Jouhara – Brunel University London
Project Duration	48

Deliverable No.	D 3.7
Dissemination level [1]	PU
Work Package	3
Task	3.4
Lead beneficiary	BUL
Contributing beneficiary(ies)	Atlas-Concorde, Alufluor, Tubacex, EUT, ICRA
Due date of deliverable	30/11/2023
Actual submission date	01/12/2023

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
V0.1	04/10/2023	BUL	Daniel Dias
V0.2	27/11/2023	ALU	Krister Eskilsson
V0.3	27/11/2023	BUL	Hussam Jouhara
V0.4	30/11/2023	EUT	Edgar Rubión
V0.5	01/12/2023	BUL	Daniel Dias

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

V0.6	18/03/2024	BUL	Daniel Dias
V0.7			
V0.8			
V0.9			
V1.0			
V1.1			
V1.2			
V1.3			

Summary

Summary of Deliverable

Deliverable D3.7 describes the Sustainable water source assessment framework, as well as the interactive software developed for aiding stakeholders and decision makers. The decision support (DSS) tools were developed and tested against scenarios in order to observe the potential gains that it can offer over business as usual. Finally, the interactive software was built around the Water-Waste-Energy Nexus (WWE) and extended with the prospective rainwater harvesting tool through Shared Socioeconomic Pathways. The results decree the level of potential water savings, economical gains and trade-offs.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Disclaimer

This publication reflects only the author's view. The Agency and the European Commission are not responsible for any use that may be made of the information it contains.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table of contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table of tables

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table of figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N°958274

Acronyms

ALU	Alufluor
CAPEX	Capital Expenditure
CON	Atlas Concorde
CO_2	Carbon Dioxide
CMIP6	Coupled Model Intercomparison Project 6
DM	Decision Maker
DSS	Decision Support System
EU	European Union
HPCE	Heat Pipe Condenser Economiser
MCDM	Multi-Criteria Decision Making
OPEX	Operational Expenditure
PES	Potential Economic Savings
RCP	Representation Concentration Pathways
RRC	Rooftop runoff coefficient
RWH	Rainwater Harvesting
SSP	Shared Socio-economic pathways
TTI	Tubacex
UKESM1-0-LL	U.K. Earth System Model
WWTP	Wastewater treatment plant

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

1 Introduction

1.1 Background

The expansion of population and industrialisation calls on more sustainable and efficient management of water systems, i.e., sourcing, treating and reusing. This ultimately leads to an increase in complexity and uncertainty which can be credited to climate change, technological evolution and types of water practice. Therefore, informed decision-making is the logical next step through data availability, collection, analysis and synthesis, and a field know as Decision Science and its emerging capabilities in this area, i.e., methods and tools (e.g. multi-criteria decision making (MCDM)), can contribute and deal with the complexity and uncertainties brought on by more information. Employing the best-possible decisions in water management requires a profound understanding of how those systems operate (Blythe et al., 2017; Gittins et al., 2021). Decision Support Systems (DSS) are tools that can simulate and evaluate the impact of decisions or strategies through acquiring prior and current knowledge of the system, and a well-designed and tailored DSS for a water system can prove to be a powerful tool for aiding stakeholders and key decision makers to achieve sustainable water management. Since its early implementations (mid-20th century) and success in increasing efficiency and productivity throughout manufacturing systems (Danishvar et al., 2021), DSS have evolved and borrowed its capabilities from other industries (e.g. retail, telecommunication and transportation).

It is widely accepted that the market uptake and success of the majority of DSS developed across the water sector remains limited (Lu et al., 2001; McIntosh et al., 2011; Mysiak et al., 2005; Newman et al., 2000; Poch et al., 2017; Walling and Vaneeckhaute, 2020; Zasada et al., 2017), possibly related to resistance to integrate robust ICT infrastructures and interoperability standards across industries (European Commission and ICT4Water, 2018). This is mainly due to short-sighted views by the industry in not perceiving the gains that are brought on by digitalisation, as well as resistance to share data and promote transparency. Current digital and DSS tools in the water industry are isolated to specific cases (e.g. maintenance planning, localised treatment plants and demand management).

In agreement with above, the transition to a full digitalisation of industries, specifically in water management, can occur due to the accumulation of human scientific and technical endeavours which is propelled by the 4th generation of industry and thus enabling Industry 4.0 Smart Water Systems (i4 Smart Water). It is generating a shift in the attitude, practices, awareness, transparency and sense of responsibility of management of water systems. Alabi et al. (2019) provides some insight into the implementation of Industry 4.0 methods in the Water Sector, where it will be a holistic integrated multidisciplinary / multisector vehicle with the following principles:

(i) Highly aware of its surrounding (big data);
(ii) Highly observant and analytical (data driven);
(iii) Succinct and intelligent interpreter (situation awareness and visualisation), and;
(iv) **Utilitarian prudent decision-maker (DSS)**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

1.2 Motivation and objectives

1.2.1 Deliverable

The goal of Deliverable 3.6 (D3.7) is to provide a confidential report on the Sustainable water source assessment framework. This corresponds to Task 3.4 – *Sustainable water source assessment framework*, active between M4 – M36 of the project calendar, and reporting at the end of M36. The task was led by Brunel University London (BUL), and the work package 3 (WP3) led by EURECAT. To create context of this task, listed below are WP3's other tasks (five (5) in total):

Task 3.1: Design of sustainable water sourcing as replacement for industrial water;
Task 3.2: Integration of the monitoring solutions;
Task 3.3: Data security, clarity and reliability;
Task 3.4: Sustainable water source assessment framework;
Task 3.5: Water-waste-energy nexus.

According to the Grant Agreement and the objectives of WP3, the goal of WP3 is to utilise the outputs of WP2 and deliver efficient designs of sustainable water sourcing as replacement for industrial water, focusing on:

- Design and implement monitoring and control modus operandi, hardware and the associated software tools, for integrated sustainable water source systems;
- Create a safe, secure and reliable knowledge and data engineering platform to guarantee accurate and representative performance measures of the loops – demonstrated in the form of software application that communicates the key performance indicators of the system;
- **Build the prescriptive models for the optimisation of the loops' performances e.g. operational cost, quality, energy efficiency, and sustainability; subject to technical and environmental constraints – demonstrated by operations research inspired decision support models**;
- Develop the Circular Economy models to demonstrate the circularity and economic merits of the solutions within the water-waste-energy nexus – demonstrated in the form of an interactive software application, serious game, where users will be able to instigate events and visualise the circularity and economic impact on the nexus.

The highlighted bullet point indicates the expected outcome of task 3.4. In order to proceed with the completion of the highlighted bullet point, the Decision Support System (DSS) tool was developed to optimise water sourcing loops. Complementary, a prospective DSS tool was developed to aid decision makers in relation to implementing Rainwater Harvesting Systems regarding Shared Socioeconomic Pathways and projected rainfall data from the Copernicus platform. As mentioned in D3.9, in line with the latter and also developed in D3.9 is demonstrated through an interactive software application and reported here in D3.7 (confidential). This has been implemented for the industrial cases under study and will be extended to as many regions possible in the EU.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

1.2.2 Report objectives

The current deliverable reports on the *Sustainable water source assessment framework*, as well as the interactive software developed for aiding stakeholders and decision makers. Inputs from partners and D2.2, D4.1 and D3.9 were useful to develop the DSS's and the interactive software. The 1st DSS tool was developed and tested against scenarios in order to observe the potential gains that it can offer over business as usual. The 2nd DSS tool presents a prospective take on the implementation of alternative rainwater harvesting (RWH) solutions. Finally, the interactive software was built around the Water-Waste-Energy Nexus (WWE) and allied with the prospective rainwater harvesting system tool to further empower and inform key decision makers and stakeholders regarding their current, and potentially prospective scenarios through the implementation of RWH solutions and through Shared Socioeconomic Pathways. The results decree the level of potential water savings, economical gains and trade-offs. As the final tool, the interactive App is presented.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

1.3 Structure of the report

Following the introduction, description of the use-cases and objective, the deliverable is divided into two main sections: methodology and results & discussion (per case-study). These sections are divided into subsections, in line with the deliverable's objectives:

- Methodology
    - Concept and General Framework;
    - Multi-objective Integer Linear Programming (MOILP) Formulation;
    - Alternative water source prospective DSS assessment tool;
    - Interactive software.
- Results & discussion
    - DSS Framework Applied to Use-Cases;
    - Alternative water source prospective DSS assessment tool applied to Use-Cases;
    - Interactive software.

1.4 Overall description and general concepts

The following three (3) sections describe the three (3) Use-Cases and the general idea behind the water recovery from the steam sources.

The Innovative WAter recoverY Solutions (iWAYS) through recycling of heat, materials and water across multiple sectors is a take on optimising, circularising and increasing overall sustainability for the industrial sector. The approach is to be applied to three distinct industrial sectors with the aim of demonstrating the feasibility and flexibility of the bespoke implementations for vapour / condensate recovery, increased water circularity and thermal energy recovery in the targeted industries. Overall, the iWAYS project is bridging the gaps to closing the loops on water and energy circularity.

1.4.1 Demo case 1 – Ceramics: Atlas Concorde (Ceramiche KEOPE Facility)

The KEOPE facility (Gruppo Atlas Concorde – CON) industrial partner is located in Casalgrande, in the Reggio Emilia region in northern Italy, bordering municipalities such as Castellarano, Modena and Sassuolo. According to the Köppen-Geiger for climate classification, the facility's location is classified as Cfa – humid subtropical climate or mild temperate - frequent thunderstorms.

The facility is a full cycle ceramic company, meaning that it includes the spray drying process for tile manufacturing, therefore promoting the production of a multitude of different ceramic products such as wall and floor ceramics. The ceramic process begins with selecting the raw materials (mainly clays, feldspars, sands, and kaolins) and then mixing them. After this step, continuous milling with the addition of water occurs, therefore resulting in a ceramic suspension, or ceramic slip. Part of the water contained in the slip is removed by exposing it to the spray dryer process, resulting in a product with a moisture content between 5 - 7% to be used in the next process. The resulting vapour / gas from the spray drying process, is lost to the atmosphere through the chimney stack.

The Atlas Concorde Cermiche Keope (CON) facilities employs different types of water in the product manufacturing steps, specifically:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

- Fresh (e.g. wells) or good quality water (e.g. industrial water) is used (D2.2) primarily for the glazing process;
- Treated water from the onsite water treatment plant (onsite WWTP) and freshwater (and other water sources) are also sourced for the grinding process (ceramic milling), and the types of water used depends on the quality of the required slip – D2.2
- Dirty water which is captured and circulated from onsite processes, as well as from sources found offsite the industry from other industries. This water can be used directly in the process of producing the ceramic slip, or in the most part is treated and results in two different types of water: Treated water and sludge water – D2.2. Preference is given to treating the water first and then reusing it.

Overall, the CON facilities do not discharge their generated wastewater to the public sewage line, instead each waste stream is collected into a sludge recovery basin and used in the milling process (e.g. when possible, for darker slips). The water recovered from the milling process is sent to an onsite WWTP to remove pollutants and suspended solids, and reused in the milling process, reducing freshwater consumption when possible. In some cases, treated water quality from the existing WWTP (physical-chemical treatment) is adequate to be reused also in the glazing section, but this is rare.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

1.4.2 Demo case 2 - Chemical – Alufluor

The Alufluor AB (ALU) industrial facility is located in Helsingborg, in the Scania province in southern Sweden. According to the Köppen-Geiger for climate classification, the facility's location is classified as Cfb – oceanic climate – cloudy conditions with precipitation.

ALU is a major actor on a global scale regarding Aluminium Fluoride (AlF_3) production. Generally, AlF_3 is employed as a flux in the primary aluminium production process, as it lowers energy consumptions and consequently reduces overall production costs. However, the production of AlF_3 generates anhydrous hydrofluoric acid / hydrogen fluoride (HF) emissions, which apart from toxic, fluoride (F) precipitates quickly as calcium fluoride (CaF_2) or Barium Fluoride (BaF_2) in the sea.

The exhaust gases contain gaseous fluorine (HF) from producing AlF_3 and is treated by a gas purification scrubber unit to wash and condense the exhaust with clean water in a continuous fashion. A mixture of water and absorbed exhaust gases flows from the scrubber unit to the onsite water treatment plant for purification. Precipitation with lime is added to the acidic water to recover calcium fluoride which is then sold to the construction industry. The treated effluent is discharged into the sea. Even though the scrubber unit is present, exhaust emissions in the form of gaseous fluorine compounds, as well as water vapour are lost through the stack chimney to the environment.

Freshwater is used in the following processes at the ALU facility:

- Production of aluminium fluoride;
- Pure and clean water from the tap is heated to 65° C to wash the centrifuges and reactors;
- Pure and clean water from the tap is used in the scrubber to wash and condense the exhaust gases from process, resulting in an acidic effluent stream.

All water after use is flowed to the onsite water purification plant.

In general, the water treatment scheme of the iWAYS project was evaluated in detail and reported in D2.1 and D2.2, the configuration of ALU facilities, as well as the characteristics of the water to be treated (D2.2) and the specific requirements for the possible re-use requested by ALU itself were considered (D4.2).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

1.4.3 Demo case 3- Steel – Tubacex

The Tubacex Tubos Inoxidables (TTI) industrial park is located in Amurrio, in the Álava province, Basque Country, northern Spain. According to the Köppen-Geiger for climate classification, the industrial park's location is classified as Cfb: oceanic climate – cloudy conditions with precipitation.

TTI is part of the Tubacex Group and a world leader in the production of seamless stainless-steel tubes and high-nickel alloys, as well as both hot and cold finishing of the tubes. Additionally, the manufacturing of tubes for oil and gas (oil country tubular goods – OCTG) extraction and production in critical conditions (offshore deep waters) also takes place at the facility, as well as tubes for heat exchangers, condensers, boilers, refinery piping and equipment, and high-performance tubes that can withstand high and low temperatures, pressures and corrosion.

The TTI chain of industrial processes operates with three independent water circuits (D4.2). Water circuit 1 is connected to industrial processes consisting of (i) pilgering, (ii) degreasing and (iii) rinsing of steel tubes; it has an onsite wastewater treatment system (decantation and LAMIK systems), but still generates on average 50m^3 of wastewater per week. Water circuit 2 is connected to the heat treatment process and does not generate wastewater. Water circuit 3: industrial processes consisting of (i) pickling, (ii) rinsing and (iii) washing of steel tubes. This water circuit 3 already has its own water treatment system implemented allowing to close the loop in terms of water reuse in this circuit and does not generate wastewater.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

1.5 Objective of the document

The objective of this document is to provide a comprehensive report on the Sustainable water source assessment framework and solutions applicable to the Use-Cases. The document includes a description and development of two distinct forms of DSS to aid in decision making regarding planning water management and prospective rainwater harvesting strategies. It covers the development of the concepts for both tools, models, dynamic simulations, and assessment of the results in relation to a defined baseline scenario. Additionally, the development of the interactive software to incorporate the work developed in D3.9 and the DSS tool here (rainwater harvesting) was developed as a form to present the integration of iWAY solutions in industries to different stakeholders. It considers different shared socioeconomic pathways to demonstrate different routes that could be taken depending on climatic conditions and based on the latest information and tools from the Copernicus EU platform.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

2 Methodology

2.1 Concept and General framework

The development of the general framework consists in analysing the commonalities of the industries under study. To perform this step, a high-level understanding of current and potential water flows (e.g. freshwater, alternative water, steam vapour, treated water and discharged water) and mapping end-user water chain was performed (Figure 1). This is defined by the boundary for the system which encapsulates the identified sub-systems or processes part of the general system. Outside of the boundary are the inputs and outputs to the system, which include water supply (e.g. fresh and clean water), and alternative water sources, i.e., water from alternative sources such as rainwater, other industries, or recycled water. It also considers water that is discharged after use (treated first) or lost through processes and in different states (e.g. vapour).

Additionally, water use within the iWAYS project framework considers to capture the requirements of what is proposed in terms of optimising water management.

The next subsections focus on the individual sections of the general framework.

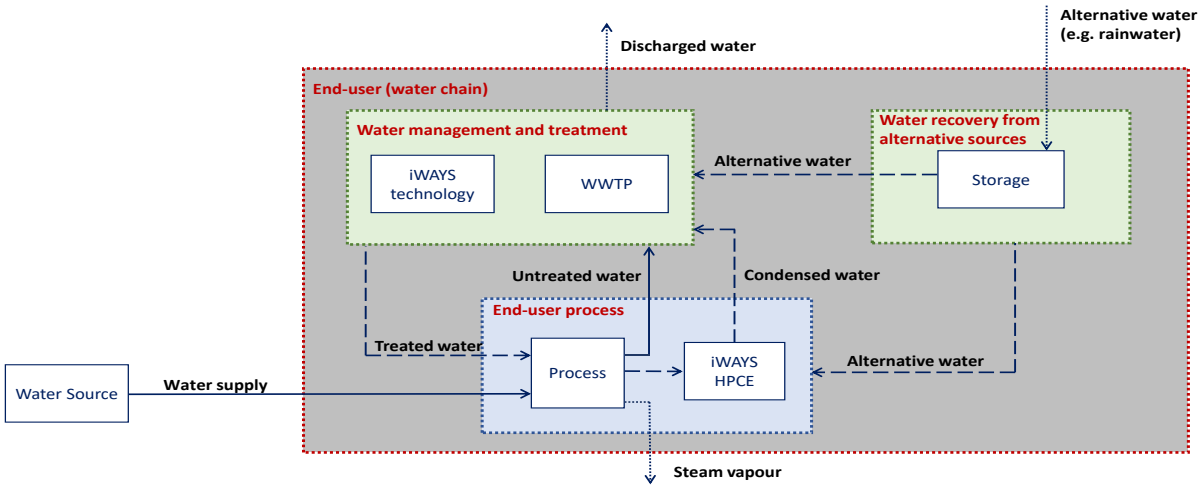


Figure 1 – Concept and General framework for the development of the DSS tool for water sourcing.

2.1.1 End-user

This step includes defining the ***End-User*** (water chain) of the DSS and tracing connections between the different processes that makeup the system. As shown in Figure 1 the general framework highlights, in a general way, the processes of the industries, or potentially are part of the system. The connections between processes and externally to the boundaries can be divided into *solid*, *dashed* and *dotted* lines – solid lines indicate integrated flows of the system and between processes; dashed lines indicate potential connections between the processes and solutions (i.e. iWAYs solutions); and finally, dotted lines specify potential losses or gains from processes, process units and the system externally to the defined boundary region. The next sub-sections describe each process within the end-user.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

2.1.2 End-user process

The ***End-User process*** boundary consists in encapsulating the industrial processes that makeup the industry, with specific focus on the processes that require freshwater (or major consumer of) in their operations. Secondly, the iWAYs technology – the Heat Pipe Condenser Economiser (HPCE) may or may not be included in this boundary as it will be incorporated in the industry to capture a portion of the steam / vapour generated from process activities – this depends on the sourcing options of this water after recovery. The input to the process or sub-processes include freshwater supply, and potentially treated water (recovered) and alternative water. The outputs include any water that requires industrial treatment [i.e. with an onsite industrial wastewater treatment plant (WWTP)], recovered condensate from the HPCE, and steamed vapour that is lost to the environment and not recovered by the HPCE.

2.1.3 Water management and treatment

The ***Water Management and Treatment*** boundary considers the onsite WWTP, including the proposed iWAYs WWTP solution that will enable the recovery of treated wastewater to be reused as a substitute for freshwater sourcing. Inputs to this section are the untreated water from the industrial processes, alternative water from other sources, and condensate recovered by the HPCE. Treated water that is not recirculated and reused in the system is discharged back to the environment or can be sent to other industries and therefore promote industrial symbiosis (note: it does not need to be waste to qualify as an industrial symbiosis practice). As this is out of the scope of the iWAYs project, industrial symbiosis was not considered.

2.1.4 Water recovery from alternative sources

The ***Water Recovery from Alternative Sources*** boundary considers the sourcing of different sources of water that can potentially substitute freshwater. This can be from other industries, or from structures such as Rainwater Harvesting (RWH) systems, desalination processes, etc. Depending on the quality of water that can be used in the *End-user process* boundary, the alternative sources of water can be used directly in the industrial processes, or first treated onsite and then used. Usually, rainwater is of sufficient quality to be used directly in the processes (D.4.1), requiring minimal maintenance to reduce algal persistence, as well as simple filtration options.

2.1.5 Questionnaire

Through bilateral meetings and online chats, an interview was conducted with partners to identify optimisation opportunities in their industrial water circuit and to understand how water is currently sourced. This helps understand if the approach is applicable to the use-case and thus tailor the approach of the DSS to the use-case's reality. The questionnaire was divided into 5 sections:

- Information (identification of: place of interview, interviewers, interviewee's, company, roles in company);
- Questions about current activities and planning;
- Questions about how water sourcing is currently performed for production;
- Open questions (awareness of any short-comings regarding how decisions are made now and what they would like to improve);
- Questions about (historical) data needed to establish a baseline.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

2.2 Multi-objective Integer Linear Programming (MOILP) Formulation

2.2.1 Background

A Multi-Objective Optimisation (MOO) problem consists in finding solutions that minimise (or maximise) *d* objective functions. In such cases, typically there is no single solution that simultaneously minimises all objectives. Instead, multiple (Pareto-)optimal solutions exists, where improvement in one objective leads to degradation in other objective(s) when comparing such solutions among each other. The set of all (Pareto-)optimal solutions is called the Pareto set and its mapping into the objective space, $\mathbb{R}^d$, is called the Pareto front. Typically, the end goal is to find the most preferable solution for the Decision Maker (DM). However, that depends on his/her preferences and frequently that information is not know upfront. In such cases, one option is to enumerate all (Pareto-)optimal solutions or a subset of such solutions to present to the DM (see, e.g. K. Miettinen, 1998 for more information on this approach).

When all objective functions and problem constraints are expressed as linear functions the problem, and all problem variables only admit integer values, and thus the problem is called a Multi-objective Integer Linear Programming (MOILP) problem. In this project, the water sourcing problem is formulated as a MOILP, and it is assumed that no preference information is known, and therefore, the goal is to enumerate (a subset of) the optimal solutions.

The approach also considers the integration of an onsite water treatment process (generalised), as well as an extension to aid in planning product production activities.

2.3 Alternative water source prospective DSS assessment tool

A prospective assessment DSS tool for implementing Rainwater Harvesting (RWH) solutions was designed and developed. The tool allows for DM to consider the implementation and/or step-wise expansion of an RWH solution tailored to their region. The following subsections detail the development of the prospective DSS tool for sustainable sourcing of rainwater.

2.3.1 Concept and framework

The concept and framework behind the development of the prospective DSS tool for sustainable sourcing of rainwater covers points that enable strategies and solutions to be employ when an industry contemplates the integration of an RWH system. As climate change, global warming and droughts will play a crucial part in employing RWH solutions in the near-future, especially for water intensive industrial sectors, a medium- to long-term strategy is essential, and before any initial investments are conducted, scenario projections and simulations is considered good practice in the decision-making process. Figure 2 presents the proposed concept, framework, and methodologies, composed of three sections and respective integrated processes / requirements. The requirements for the framework are divided into three (3) sections:

- Information on the region, industry, water miscellaneous and current catchment solutions of the ***Industry***;
- Information regarding ***Rainwater*** in the region / area and;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

- Input data in the form of ***Prospective Scenarios*** based on the use of Coupled Model Intercomparison Project Phase 6 (CMIP6) model results for average monthly rainfall estimates from 2030 to 2050 horizons framed by the use of IPCC Shared Socioeconomic Pathway (SSP) narratives (O´Neil et al., 2016).

Modelling the RWH system considering the three sections enables to assess the results on the potentiality, feasibility and optimal strategy for RWH implementation or expansion. Each section and processes are explained in subsequent subsections.

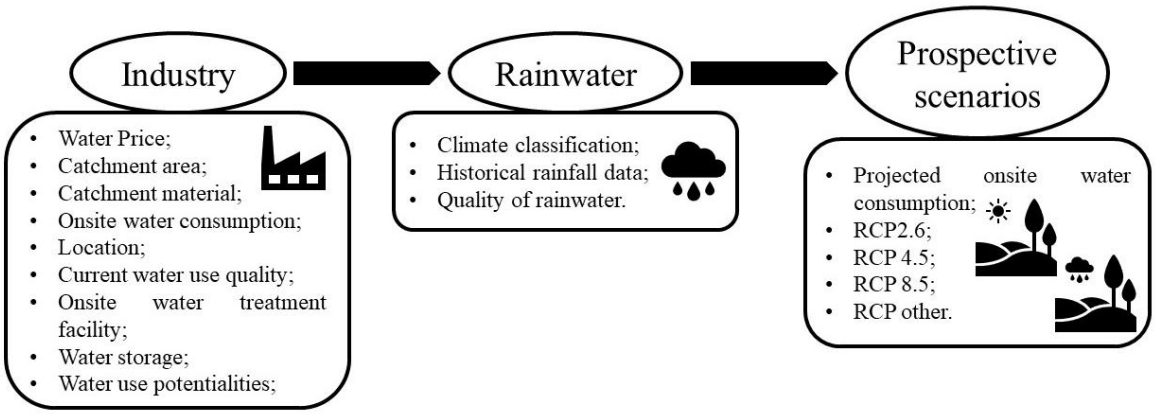


Figure 2 – Concept and General framework for the development of the DSS tool for RWH strategies.

2.3.1.1 Industry

The first step of the framework involves defining the information regarding the Industrial sector, i.e. to identify specific characteristics of the targeted industry in terms of miscellaneous water information as well as complementary information regarding the location of the industrial site. A large portion of the information can be obtained directly from the industrial site operators, stakeholders and through online tools – Table 1.

Table 1 – Industry step of the RWH DSS tool framework.

Parameter	Description	Unit
Water Price	*The price currently paid for sourcing freshwater.*	*€ / m^3*
Catchment Area	*The size of the potential catchment area.*	*m^2*
Catchment Material	*The material employed in the catchment area.*	-
Onsite Water Consumption	*Current and past industrial freshwater consumption – historical data.*	*m^3 / year*
Geographical Location	*Exact location, including details of the region and country.*	-
Current Water Quality	*The current quality of the used freshwater source(s) - laboratory analyses.*	-
Onsite Water Treatment	*Presence of an onsite water treatment facility.*	-
Water Storage Tanks	*The presence or not of water storage tanks.*	*m^3*
Water Use Potentialities	*Identification of all the different types of water uses / water circuits.*	-

Collecting this information allows to assess the requirements of the industry in terms of freshwater use, current available areas that can be allocated for RWH, available infrastructures, and quality requirements in order to facilitate the implementation of an RWH system tailored to the industrial context. Additionally, it allows to calculate current and project future freshwater consumption rates and monetary saving.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

The catchment area can be in the form of a rooftop or other structure for harvesting rainwater (e.g. photovoltaic panels that serve as car ports and provide shading), while the material (most of the EU industries employ are either concrete or metal / iron material), shape and design employed for the catchment area can potentially affect the quantity of rainwater harvested – climate conditions also play a role in this matter. This can be characterised by the Rooftop Runoff Coefficient (RRC):

- During shorter and smaller rainfall events when atmospheric conditions such as wind, sunshine and subsequent evapotranspiration affect harvesting (RRC = 0.7 – 0.9);
- For larger and longer rainfall events, the shape of the catchment area hinders the RRC value less – increasing the minimum value (RRC = 0.8 – 0.9).

For industrial parks, rooftops can provide the most advantageous and ideal catchment surface for RWH, and most industrial parks have large rooftop surface areas – advantageous because the catchment area is already freely available.

Current and past freshwater consumption datasets indicate the annual freshwater requirements and trends of the industry – allowing to project potential future freshwater consumption tendencies. The identification of water uses potentialities of all the different types of water uses / water circuits in place at the industry (industrial process, cleaning/maintenance, sanitation, gardening, etc.) and to identify the potential use of the harvested rainwater. Additionally, if there exists alternative grey water circuits, or reinjection points in the industrial processes, or if other uses are already in place.

The presence of an onsite water treatment facility can be employed to treat the harvested rainwater if necessary – alternatively the onsite treatment system can be extended to accommodate solutions to treat harvested rainwater. In some cases, the harvested rainwater quality is good enough to be used directly in the industrial processes. If available, the water quality of the freshwater source(s) should be characterised in order to evaluate the feasibility of directly employing harvested rainwater in a process. The parameters to monitor should be decided on by each industry, and compared with the quality of the harvested rainwater to determine if treatment is required.

2.3.1.2 Rainwater

The second step of the framework consists in gathering information for the ***Rainwater*** section of the framework in order to characterise the local climate, historical precipitation and rainwater quality – Table 2. A characterisation of past and present precipitation and potential RWH applied to the use-cases in greater detail can be found in D4.1 and D3.9. Here only the results will be presented.

Table 2 – Rainwater step of the RWH DSS tool framework.

Parameter	Description
Climate Classification	*Climate classification of the region is determined by the geolocation in the first step.*
Historical Rainfall	*Historical rainfall data.*
Quality	*Quality of harvested rainwater.*

The climate can be classified based on its geolocation – first section step of the framework. The Köppen climate classification is a good means of retrieving high level information for comparison with historical and current data. This classification system informs on the type of climate group of the region, including seasonal precipitation and heat level trends through a 3-letter cataloguing process. The information can be presented to interested parties such as stakeholders, as it provides a comprehensive and easy form of conveying climate information.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Historical rainfall data ought to be retrieved from verified sources such as Copernicus or the European Climate Assessment and Dataset (ECA&D). Statistical analysis and metrics of historical data will determine, as a preliminary assessment, if the volume of harvested rainwater captured by the current catchment area is economically attractive. Monthly average precipitation values are recommended after statistically treating historical data – D4.1.

Sampling and characterising rainwater as runoff from the catchment area is also recommended, but not during the first precipitation events as to allow the catchment area to be cleansed – first-flush – alternatively rainwater can be sampled directly and characterised. As with the freshwater sampling and characterisation, the targeted constituents should be decided by the industry. The quality of the rainwater will determine if it can be directly used, which industrial processes can receive it, and if additional treatment steps are required (indirect use – industrial step of the framework) – D4.1.

2.3.1.3 Prospective Scenarios

To estimate probable future annual precipitation at each of the regions, the Intergovernmental Panel on Climate Change (IPCC) framework of the Shared Socioeconomic Pathways (SSPs) was considered, which also facilitates the exploitation of Coupled Model Intercomparison Project phase 6 (CMIP6) results. These results provide estimates of monthly average rainfall over the whole EU territory until the year 2100 and are publicly available in the Copernicus Climate Change Service datastore. These narratives interlink levels of CO_2 concentration, socioeconomic advancement trajectories, and collectively agreed-upon policy presumptions, providing a solid foundation for complex scenario simulations, and designed at the global level in a consistent manner. The convergence of SSPs and the Representative Concentration Pathways (RCPs) produces a comprehensive matrix, where anthropogenic pressures on the climate system can be described. Beyond this foundational nexus, an additional layer of complexity emerges as shared policy assumptions are integrated into the RCPs / SSPs matrix, thereby paving the way for the contemplation of meticulously crafted policy-driven mitigation scenarios (Kriegler et al., 2014; O'Neill et al., 2017).

The monthly rainfall estimates result from the UKESM1-0-LL model for the scenarios that are considered significant. Specifically, the study was framed considering the different pathways as shown in Table 3.

Table 3 – Prospective scenario step of the RWH DSS tool framework.

SSP	RCP	Description
1	2.6	Characterised by its sustainable development-oriented paradigm, often referred to as the "Green Society".
2	4.5	Considered the current path or trajectory the world is taking / Business as Usual (BAU) trajectory.
5	8.5	Representative of a development pathway heavily reliant on fossil fuels, eliminating "green" technologies.

In addition to the identified scenarios in Table 3, industries are expected to present an increase in freshwater consumption in the future due to an increase in activities and overall demand. This can be projected based on previous yearly operations and an annual increase (%) in freshwater requirements can be hypothesised. It also assumes that freshwater consumption is not capped, though this can be introduced as a limiting factor if the industry foresees this. These projections do not consider potential drastic changes in production trends and / or external factors impacting production and water consumption (political, economic or technological disruptive events) which are inferred linearly for the sake of simplification.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

However, the disruption to production observed across the EU and the world by the COVID-19 pandemic was considered to project future industrial water consumption.

2.3.1.4 Model parameters

Collecting data from the industries also includes collecting historical freshwater consumption data, which can contemplate as many years possible or necessary. Additionally, abnormal years were included in the analysis, as these represent potential disruptions to normal operation, i.e. the year 2020 which saw a decline in overall world production of consumables and materials due to the COVID-19 pandemic. These events will potentially occur in the coming years, more frequently, and possibly with greater impacts, resulting in greater disruption in productions and affecting overall industrial consumption – as was proven by the data. Therefore, the year 2020 was included in the analysis to quantify freshwater consumption. The model parameters can be seen in Table 4.

Table 4 – Model parameter inputs for the RWH DSS tool.

Parameter	Unit	Description
AAGR	%	Average Annual Growth Rate (AAGR) represents the mean increase in water consumption. It is a linear measurement which is calculated considering the arithmetic mean from historical data and used to project future consumption.
Max consumption	m^3 / year	The maximum consumption of freshwater observed from historical data. This is considered the starting point for freshwater requirement.
Area	m^2	The initial catchment area that will be employed to harvest rainwater.
RRC	%	The Rooftop Runoff Coefficient which is used to stipulate the potential efficiency of the harvest area for collecting rainwater.
Treatment efficiency (TE)	%	If harvested rainwater undergoes some form of treatment, this is quantified through this parameter. If no treatment is required, then this parameter is considered 100%.
FWR	%	Percentage of freshwater requirements covered by the RWH solution.

2.3.1.5 Model equations

2.3.1.5.1 Average Annual Growth Rate (AAGR)

To calculate the potential increase in freshwater consumption by the industries, the Average Annual Growth Rate (AAGR) method was used. The AAGR helps determine long-term trends and the ratio informs on an average increase or decrease of consumption. Usually applied in finance, it was adapted to determine the growth rate of freshwater consumption for each industry based on historical freshwater consumption data.

Equation 15 and Equation 16 are used to calculate the Average Annual Growth Rate (*AAGR - %*).

$$AAGR = \frac{WCGR_A + WCGR_B + \cdots + WCGR_n}{N} \quad (15)$$

$$WCGR_n = \frac{Previous\ yearly\ freshwater\ consumption}{Current\ yearly\ freshwater\ consumption} - 1 \quad (16)$$

Where, $WCGR_N$ is the water consumption growth rate relating to period n (n is between the water consumption of previous and following year), and N the number of years.

2.3.1.5.2 Potential industry freshwater requirements

To forecast potential industry freshwater requirements (*PIFWR – m^3*) for the industrial sites, Equation 17 was devised which considers previous annual consumption and the AAGR which was calculated based on historical freshwater consumption data.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

$$PIFWR = PYC \times (1 + AAGR) \quad (17)$$

Where, *PYC* is the previous year consumption (m^3) and *AAGR* the Average Annual Growth Rate (%). It is possible to cap the maximum freshwater consumption rate by considering that if the PIFWR > maximum freshwater requirements of the industry, then that value is considered and not the newly calculated one which is greater. Additionally, freshwater consumption can also be capped considering a year for basis (e.g. 2040 no more increase in freshwater consumption by the industry).

2.3.1.5.3 Potential rainwater harvested

To determine the volume of potential rainwater that can be harvested, Equation 18 was developed. The equation considers the RRC value, total annual rainfall, the harvest area, treatment efficiency of the water treatment plant, and the first-flush practice, therefore modelling the process in terms of volume regarding harvested rainwater.

$$Q = (RRC \times R \times A \times TE \times 0.001) - (N \times FF) \quad (18)$$

Where Q is the potential volume of harvested rainwater (m^3 / year), *RRC* is the rooftop (or harvest area) runoff coefficient (- or %) – sub-section 2.3.1.1, R is the total rainfall (mm / time), and A is the catchment area (m^2), TE is the treatment efficiency (%), *FF* is the first-flush volume (m^3) and *N* the number of first-flushes performed in a year.

During the drier seasons of the year, the surface area is a natural collection surface for dust, leaves, twigs, dead insects, animal faeces, and other residues. The first flush (*FF*) practice can potentially reduce contamination of storage tanks or avoid / reduce any downstream treatment, and hence costs associated – therefore it is considered a good practice. The *FF* considers the first harvested volumes of rainfall to be diverted from the storage tank or direct use in the industrial processes, and is calculated based on the harvest area (for every 92.903 m^2 of harvest area, 37.8541 litres should be discharged - Texas Water Development Board, 2005). *FF* can be calculated using Equation 19.

$$FF = A \times FF_V/1000 \quad (19)$$

where *FF* is the total volume of the first-flush (m^3), A is the catchment area (m^2), and FF_V is the volume of water discharged per area (normalised = 0.41 l / m^2) (Texas Water Development Board, 2005).

2.3.1.5.4 Potential harvest area

The tool allows to project the harvest area required depending on the volume of freshwater that is to be substituted by the RWH solution, the volume of harvestable rainwater with the current harvest area, and the percentage of freshwater to be substituted with the RWH solution. Equation 20 calculates the potential harvest area required for the different SSP / RCP scenarios, and is based on the prospective volumes of rainwater that can be potentially harvested against the prospective freshwater consumption.

$$HA_{RCP} = \max(PYHA; ((area \times PIFWR_{RCP}/VHRA) \times FWR)) \quad (20)$$

Where the Harvest Area for an RCP scenario (HA_{RCP} – m^2) is the area required to harvest the volume of rainwater to cover freshwater needs, stipulated by the DM, decided by comparing two conditions where the maximum satisfies the output requirements. The first condition is the previous year's harvest area (*PYHA* – m^2). This is compared with the second condition of the equation, which calculates the potential harvesting area required to cover the newly calculated freshwater needs. It considers the initial catchment area (*Area* – m^2), the potential industry

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

freshwater requirements for the selected scenario ($PIFWR_{RCP}$ – m^3), the volume of rainwater harvested with the initial area ($VRWA$ – m^3), and percentage of freshwater requirements covered by the RWH solution (FWR - %).

To calculate the volume of harvestable rainwater (Equation 18) with the new HA, the DM should consider the area that was calculated in Equation 6.

2.4 Interactive software

The iWAYS (RWH + Water-Waste-Energy (WWE)) application has been designed and coded in the National instrument LabVIEW package 2017. It considers the work developed in D3.9 and the Rainwater Harvesting DSS tool developed and reported in this deliverable (section 2.3).

2.4.1 Background

LabVIEW, which is short for Laboratory Virtual Instrument Engineering Workbench, is a programming environment to create programs using a graphical notation (connecting functional nodes via wires through which data flows); in this regard, it differs from traditional programming languages like C, C++, or Java, in which you program with text.

Using the very powerful graphical programming language that many LabVIEW users affectionately call "G" (for graphical), LabVIEW can increase in productivity by orders of magnitude. LabVIEW is specifically designed to take measurements, analyse data, and present results to the user. Also, because LabVIEW has such a versatile graphical user interface and is easy to program with, it is also ideal for simulations, presentation of ideas, general programming, or even teaching basic programming concepts.

LabVIEW's extensive libraries of functions and subroutines help with most programming tasks, without the fuss of pointers, memory allocation, and other arcane programming problems found in conventional programming languages. LabVIEW also contains application-specific libraries of Code for Data Acquisition (DAQ), General Purpose Interface Bus (GPIB), and serial instrument control, data analysis, data presentation, data storage, and communication over the Internet. The Analysis Library contains a multitude of useful functions, including signal generation, signal processing, filters, windows, statistics, regression, linear algebra, and array arithmetic. Because of LabVIEW's graphical nature, it is inherently a data presentation package. Output appears in any form users desire, i.e., charts, graphs, and user-defined graphics which are just a fraction of available output options.

2.4.2 Framework and development

The framework was based on the work developed in D3.9 – nexus modelling. It has been structured according to Figure 3 – Location and structure characterisation, Figure 4 – Water characterisation, Figure 5 – Energy characterisation and Figure 6 – Emissions characterisation. Figure 3 is characterised by the location of the industrial case and what onsite structures are available. Additionally, the prospective RWH solution proposed in section 2.3 of this deliverable is also included in this Figure 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

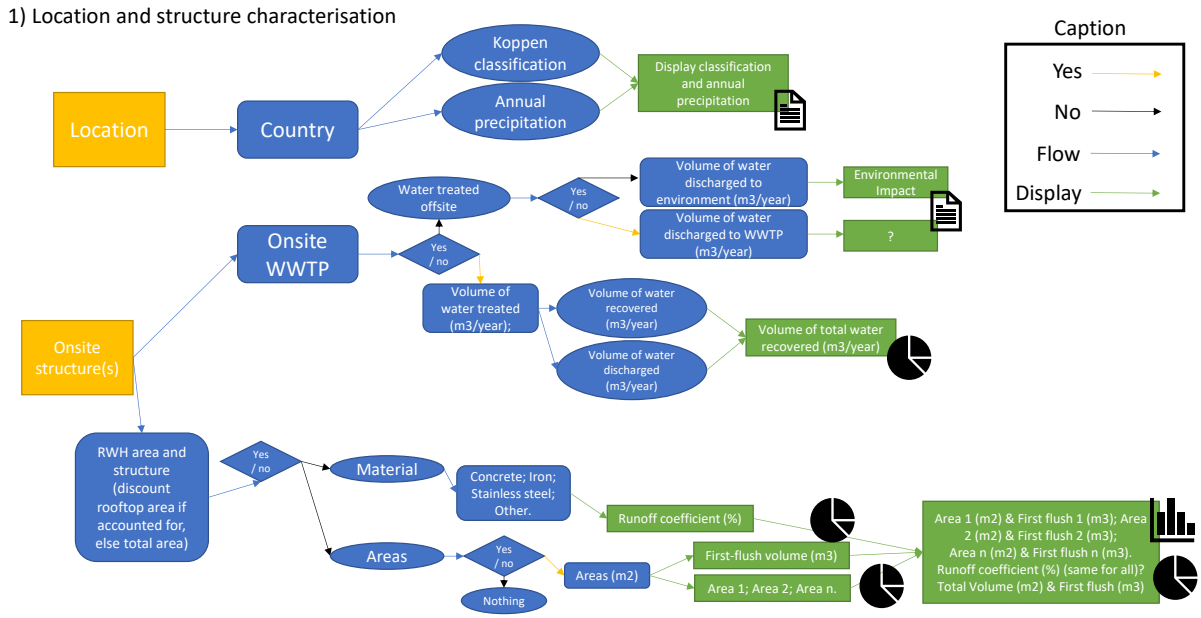


Figure 3 – Location and structure characterisation for interactive software.

Figure 4 presents the Water characterisation of the industrial site, what is used, how much is used, and from where it is used. Additionally, already implemented alternative sources are also considered (e.g. RWH or desalination).

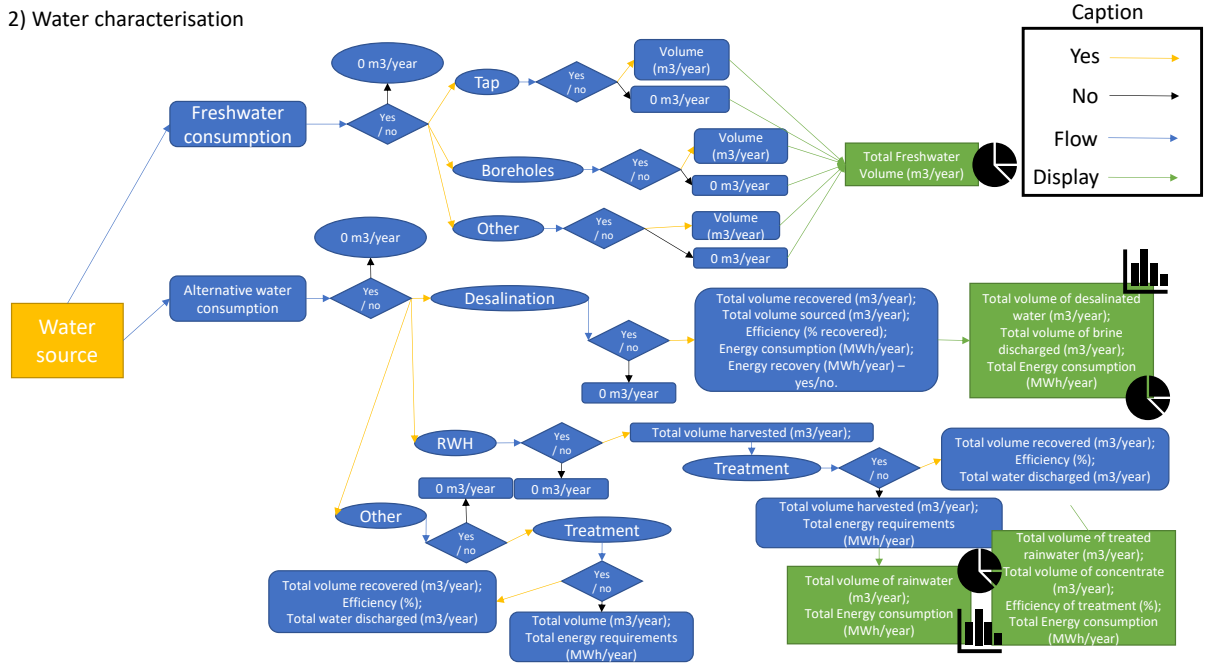


Figure 5 considers the sourcing of energy of the industrial site, renewable and non-renewable sources. This can be used to calculate the CO_2 footprint of the plant and renewable energy contribution.

Figure 4 – Water characterisation for interactive software.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

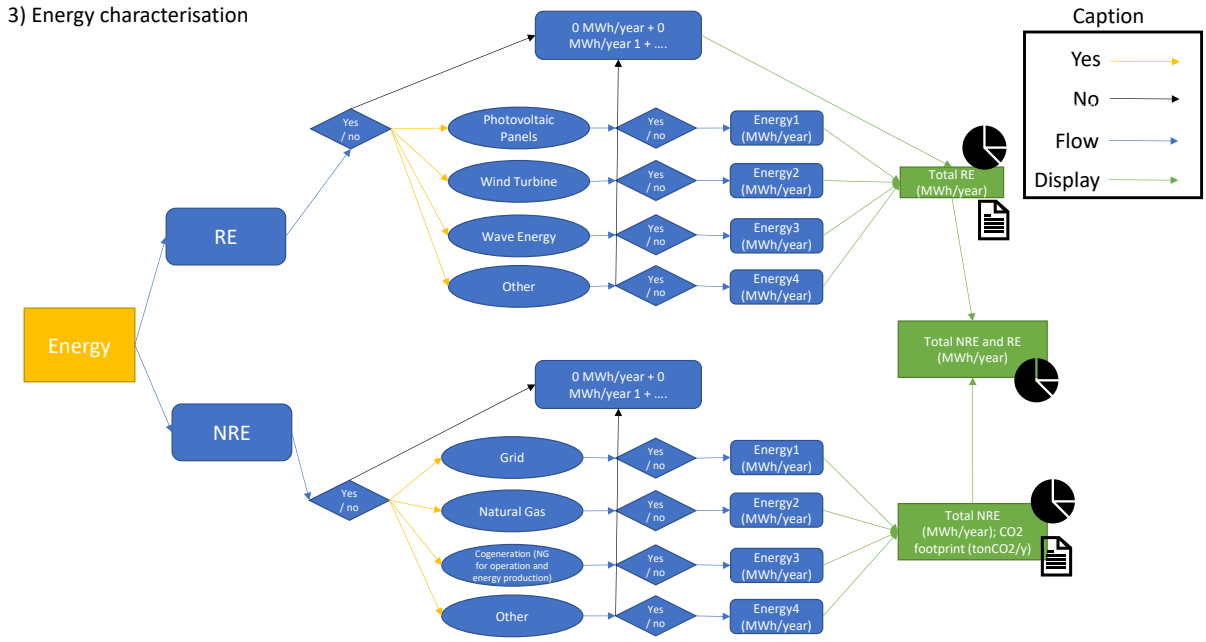


Figure 5 – Energy characterisation for interactive software.

Finally, Figure 6 considers the waste emissions in the form of vapour and/or gases, how this is emitted to the environment and the choice to include one of the three heat pipe condenser economisers (HPCE) to recover condensate and energy from the vapour gases.

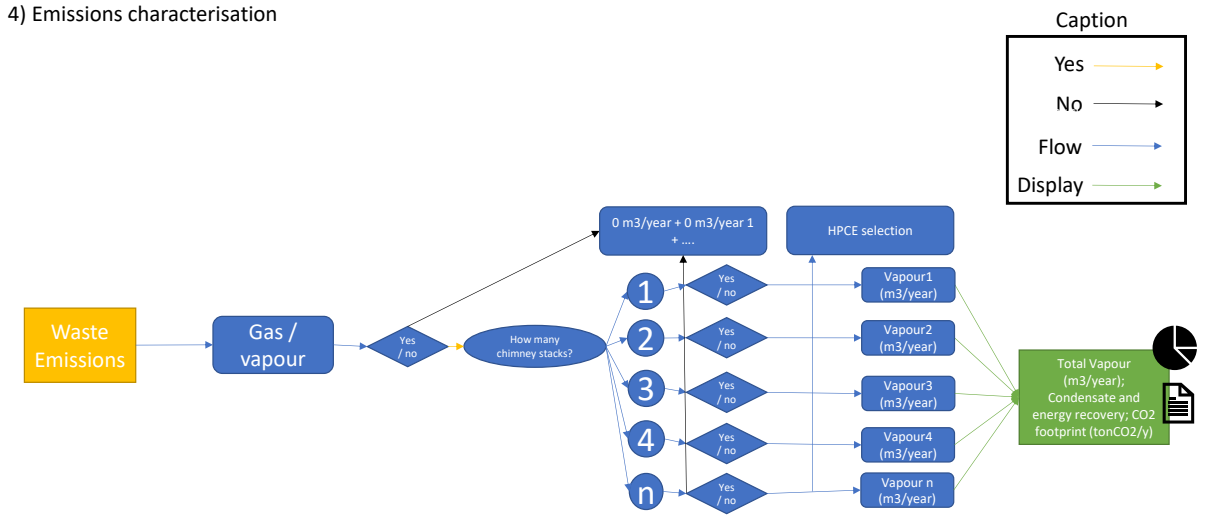


Figure 6 – Emissions characterisation for interactive software.

All models have been developed and presented in D3.9 and in this deliverable. All economic information and performance of the selected solutions as well and will be expanded.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3 Results and Discussion

3.1 DSS Framework Applied to Use-Cases

The following section consists in tailoring the developed framework to the specificities of each industrial use-case. The application of the approach requires that each use-case be analysed on how the current procedure on sourcing varied water sources is performed in order to identify optimisation opportunities in each industrial water circuit. Once identified, the DSS solution can be tailored to the use-case and decision-making can be driven on preferences and criteria.

3.1.1 Ceramics – Atlas Concorde (Ceramiche KEOPE Facility)

3.1.1.1 Optimisation opportunity: Water sourcing process description

The Atlas Concorde (CON) is a full cycle ceramic company, therefore promoting the production of a multitude of different ceramic products such as wall and floor ceramics. The industrial facility sources different types of water for its activities, presenting a form of circular water flows and industrial symbiosis, as purified water is attained from treating dirty water from other industries located in the vicinity (and also internally recycled). However, the majority of sourced water still remains freshwater. No water is discharged from the facility.

As stands, the CON facility sources various types of water: Well 1 and 2, and the Industrial Aqueduct (considered the freshwater sources), Dirty Water (from other industries and internally recycled), Sludge Water (from the onsite WWTP), and Purified Water (also from the onsite WWTP) – Figure 7. More information on the quality of these sources can be found in D2.2. From an interview conducted with the industrial partners on the 13/02/2023, water is sourced for the production of three different types of products in the milling activities:

- **White products**: preference is given to using purified and then freshwater in the mixture;
- **Grey products**: preference is given to the other types of water, i.e. dirty water, sludge water, with purified and freshwater being the last option;
- **Black products**: preference is given to using sludge water, then dirty water and then freshwater.

Water is sourced based on the best available option at the time and planning is generally done on a weekly basis, however it can be updated on a daily basis to accommodate new orders – there is a specific plan every day. The number of production cycles varies and is based on orders. No predictive software or optimisation techniques are used and a “recipe” is followed based on the different mixtures. A group of people will perform the decision-making process and planning for production. The planning of production logistics does not depend on the available water sources, it will always focus on what source is available at the time for production, and this is performed by one person (i.e. DM). Production batches are fully completed before passing on to the production of other batch qualities (i.e. products). When sourcing the water for the production phase, the DM decides on which water source to employ based on the conductivity value (i.e., mineral salt) of the water sources. The threshold of which water to source (based on conductivity and availability) for which products is defined by the DM and based on online measurement of each water source. The rule-of-thumb is to use as much dirty and / or sludge water as possible and when possible, while not considering the criteria to reduce energy or chemical use. An example of a batch production for white product consists in first using all the water in the purified water tank, as well as treatment of the dirty water to produce purified water, and only then if more water is required will freshwater be

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°958274

sourced. Dirty water is mainly sourced from internal recycling of water from the milling section (~80%), with the remaining ~20% received three times a week from external sources.

From the open questions part of the questionnaire, it was established that the operators would like to improve on producing less dirty water, while using more purified / freshwater in the milling sector. This does consider the objective of the DSS to reduce freshwater sourcing and maximise the use of other sources, additionally, they would find it interesting and useful in the decision-making process energy and chemical consumption minimisation (which is essentially from the KEOPE onsite WWTP, including pumping). To increase the use of purified water would mean treating more dirty water, which would also produce more sludge water and thus not resolve or optimise the current process of sourcing water. The Keope was modelled considering a black box and rates approach, as well as from the experience of the operators – D3.9. It is considered to recover 75% purified water and 25% sludge water. Additionally, partners are open to alternative sources of water sourcing, such as rainwater harvesting.

Regarding historical data for daily, monthly and yearly planning is available, however the partners could not share this information with the consortium. Moreover, historical data regarding the amount of slip produced and the volume and quality of water sourced for each production cycle did not exist.

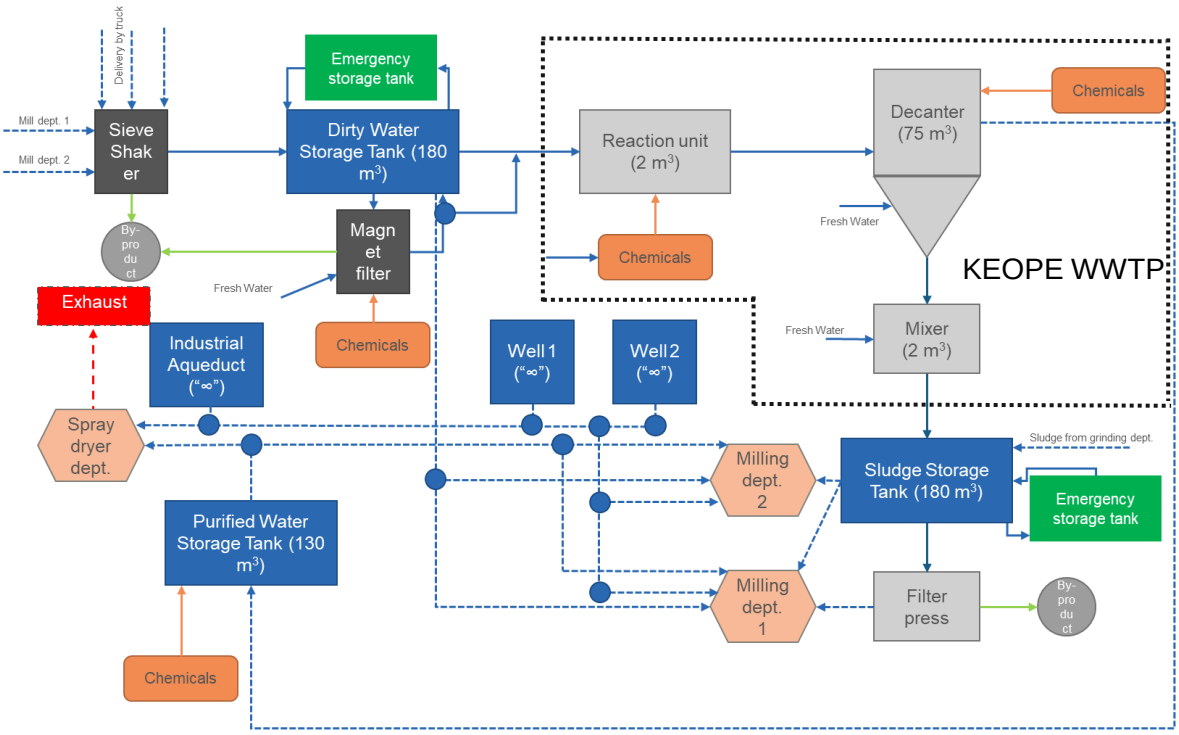


Figure 7 – Overview of the CON water sourcing scheme.

Analysing the current setup of how water is sourced (Figure 7, D2.2., D4.1 and D3.9) and the feedback from partners (questionnaire), this setup presents itself with interesting optimisation solutions and in line with the proposed general framework.

3.1.1.2 MODSS with no water treatment plant

This section focuses on the application of the Multi-Objective Decision Support System (MODSS) tool considering the problem described in Section 2.2.2.2. This first approach considers that the water treatment plant (from herein known as Keope), is not considered in the optimisation exercise. This can be considered as directly sourcing the water for the mixture

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

process in the milling activities from the sources, therefore it reflects what is available in each of the tanks. The iWAYS solutions are not considered.

As mentioned in Section 3.1.1.1, the CON system employs six (6) different sources of water, each with varying qualities (D2.2). In Figure 7, water sources from Well 1 and 2, as well as from the Industrial Aqueduct are considered freshwater sources. The water is used by the milling department, and the water has to respect the requirements set by the departments to be used. The milling department is the main consumer of water in the industry and uses the water for milling the product and then is sent to the spray dryer for drying. Sourcing the different water includes energy requirements for pumping the water to the department and chemicals for treating dirty water.

For the MODSS tool to run, the following information is required:

- First the tool needs to know what is in the sources, i.e., available volume of water and quality of the water. Here we have chosen a few metals (5) to define the quality of the water sources. These are real values from the monitoring campaign (D2.2. – except for the volume). This was chosen because historical operational data regarding water sourcing was not available, however, any parameter can be used to define the water quality, and the number of parameters can be large.
- The end user defines what are the limits for the parameters (which is then used to calculate the total load) that were selected and the volume of water that is required for the end-product. Again, the parameters can be whatever the end-user wants to use to limit the sourcing of water from the different sources.

Table 5 presents the parameters and concentrations of the water from their respective sources, as well as the available volumes (theoretical). Table 6 presents the End-User requirements to satisfy the product quality – the limit for which the product can have to guarantee it is graded accordingly (i.e., black, grey or white).

Table 5 – Parameters of for each water source and respective concentration.

Parameter / source	Unit	Well 1	Well 2	Ind. Aq.	Purified W.	Dirty W.	Sludge W.
Al	g/m^3	0.0035	0.002	0.17	2.3	540	1320
Sb		0.0002	0.0002	0.0003	0.0026	0.025	0.03
As		0.0001	0.0001	0.0002	0.0072	0.15	0.3
Ba		0.0269	0.039	0.07	13	569	1170
Cd		0.0001	0.0001	0.0001	0.0001	0.012	0.03
Volume available	m^3	1000	1000	1000	40	180	70

Table 6 – End-User requirements to satisfy the final product quality.

Parameter / source	Unit	End-user requirements
Al	g/m^3	≤ 10 000
Sb		≤ 0.01
As		≤ 0.1
Ba		≤ 50
Cd		≤ 0.03
Volume required	m^3	100

The next step consists in selecting what criteria does the DM want to minimise (or maximise).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

For the current example, the following 2 criteria (problem definition) were considered:

- Minimise freshwater sourcing;
- Minimise the amount of pollutant in the product (load – defined by parameter(s)).

Figure 8 presents the results from the scenario considering directly sourcing the water from the sources (no water treatment).

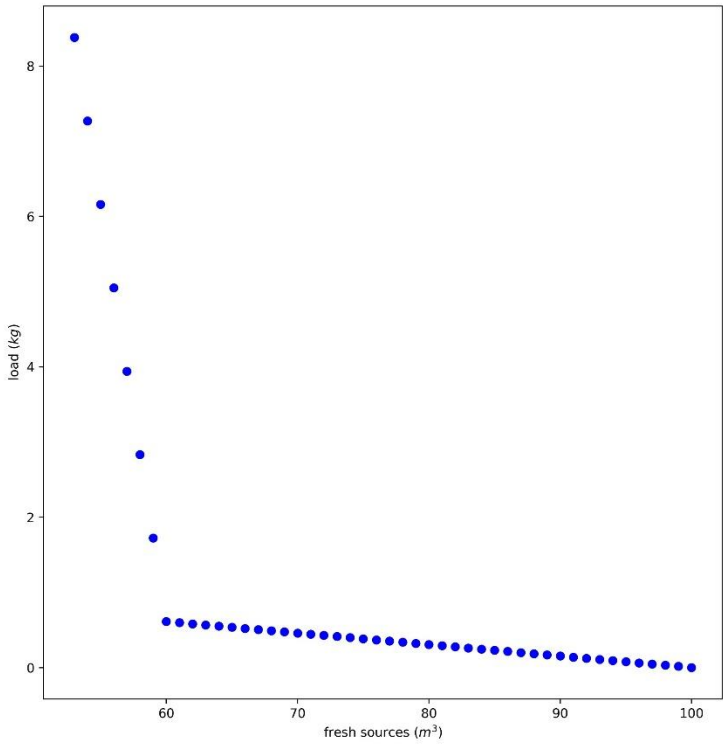


Figure 8 – Pareto front for Problem 2.2.2.2 – two criteria.

Each blue dot in Figure 8 represents the mapping to objective space of a solution for the product defined in Table 6. A total of 48 Pareto-optimal solutions were computed to display to the DM. If the DM has a set of preferences regarding the optimal solution, he/she may express those preferences to help guide the search process towards the most preferable optimal solution.

The results for the scenario without the Keope result in 48 Pareto-optimal solutions, where a maximum of 8.38 kg of pollutants can be in the final product, or a minimum of 0.1 kg can be in the final product. This is the trade-off for reducing freshwater use in the products and increasing dirty water use. In the leftmost solutions, all the available volume from the purified water tank is used while this will decrease as the solutions are presented from left to right. Therefore, the MODSS maximises the use of purified water in the leftmost solution and then moves on to the other sources of water that are available (mixing volumes from the different sources). An example of an output, in text format, can be seen in Table 10.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table 7 – Output of the Pareto-optimal solutions for sourcing the different sources of water. Problem 2.2.2.2.

Minimise fresh sources	Minimise total load	Well 1	Well 2	Ind. Aq.	Dirty W.	Sludge W.	Purified W.
m^3	kg	m^3	m^3	m^3	m^3	m^3	m^3
53	8.37834	53	0	0	7	0	40
54	7.26918	54	0	0	6	0	40
55	6.16003	55	0	0	5	0	40
56	5.05087	56	0	0	4	0	40
57	3.94171	57	0	0	3	0	40
58	2.83256	58	0	0	2	0	40
59	1.7234	59	0	0	1	0	40

Additionally, it is possible to consider three criteria for optimising the water sourcing regarding the same product requirements as above (Table 6):

- Minimise freshwater sourcing;
- Minimise the amount of pollutant in the product (load – defined by parameter(s));
- Minimise energy requirements.

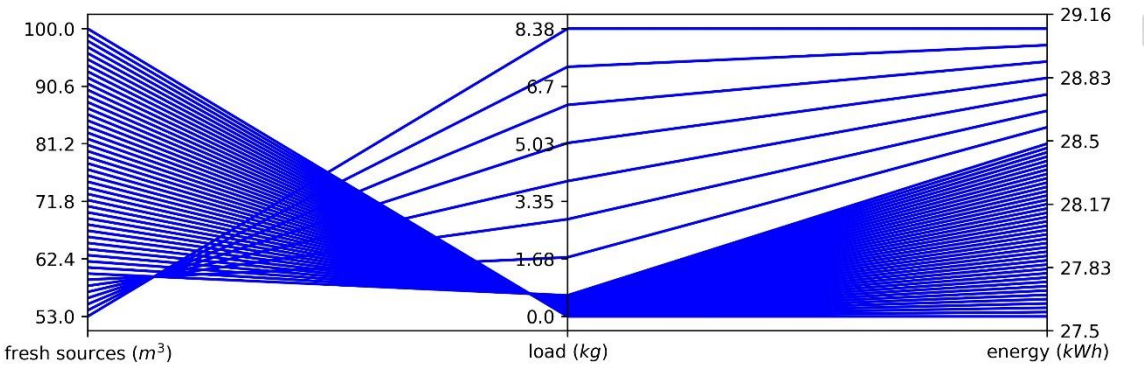


Figure 9 – Pareto front for Problem 2.2.2.2 – three criteria – different pathways.

Figure 9 presents the potential pathways and end results regarding the MODSS tool regarding three criteria. Depending on the Pareto-optimal solution that is taken, there are implicit benefits and trade-offs that need to be weighed by the DM. Using fewer fresh sources of water in the production implies higher loading rates. However, it increases the circularity and potentially the sustainability of the industrial site and product in terms of water footprint.

3.1.1.3 MODSS with water treatment plant

This section focuses on the application of the MODSS tool considering the problem described in Section 2.2.2.3. This approach considers that Keope is included in the optimisation exercise. This can be considered as indirectly sourcing the water for the mixture process from the different sources in the milling process, therefore it reflects what is available in each of the tanks, as well as a variable volume for the purified and sludge water tanks. The proposed iWAYS solutions are not considered.

As mentioned previously, CON employs six (6) different sources of water, each with varying qualities (D2.2). In Figure 7, water from Well 1 and 2, as well as from the Industrial Aqueduct are considered freshwater sources. The water has to respect the requirements set by the departments to be used (Table 6), in this case by the milling department. This department is the main consumer of water in the industrial site and uses the water for milling the product

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

before sending it to the spray dryer for drying. Sourcing the different water includes energy requirements for pumping the water to the departments. The criteria (2), considerations, and information in Table 5 and Table 6 from Section 3.1.1.2 are the same for the solving the Problem 2.2.2.3.

Figure 10 presents the results from the scenario that includes direct sourcing of the water from the different sources as well as indirect sourcing resulting from the incorporation of the Keope water treatment plant (Figure 7).

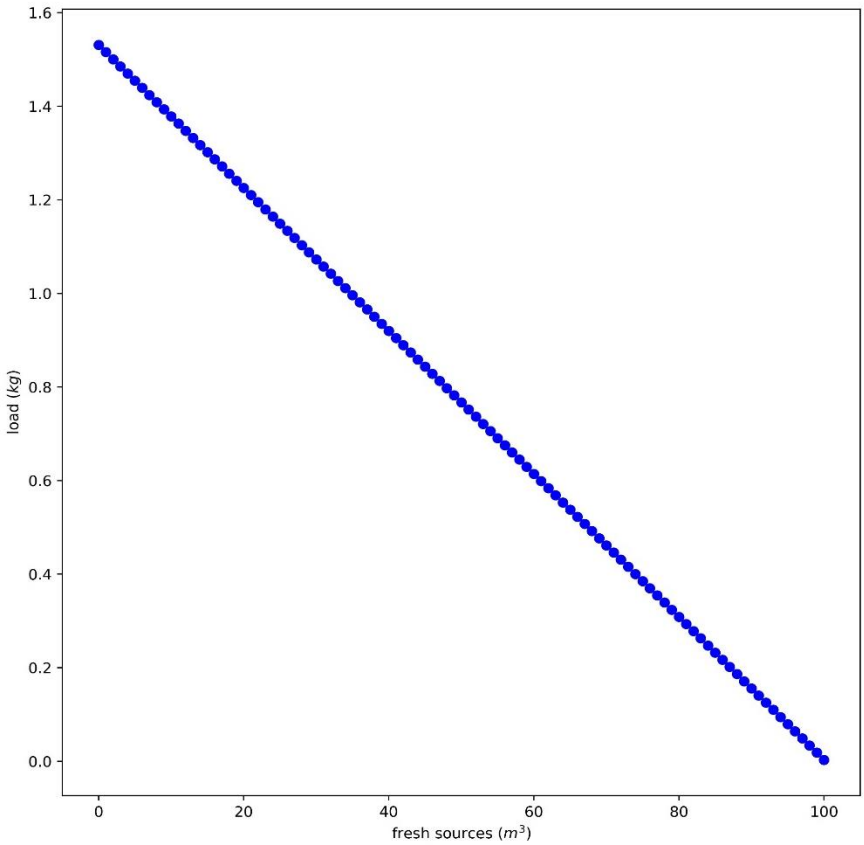


Figure 10 – Pareto front for Problem 2.2.2.3 – two criteria.

Figure 10 presents the Pareto front, i.e., the mapping into objective space of 101 Pareto-optimal solutions, when the Keope water treatment plant is considered. These solutions have an additional variable (X7) representing the amount of water treated in Keope (Figure 7 and Table 8). The treated water from the dirty water tank (X7) results in water being added to the purified water tank (X6). Therefore, if we look to solution 1, it indicates that 100 m^3 of treated water (X6) is used for the product and that 80 m^3 of dirty water is treated (X7 – Keope). Hence, the 100 m^3 include the 40 m^3 initially available in the purified water tank plus the 60m^3 that are added to the tank and that result from treating the 80 m^3 in Keope (the remaining 20 m^3 goes to the sludge tank). Additionally, it is clear that the use of additional water treated in Keope increases the quality of the water regarding metals content. In Pareto-optimal solutions mapping to points towards the right-hand side of the figure sourcing water from Keope decreases and increases the use of what is available in the treated water tank in combination with the freshwater.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table 8 – Output of the Pareto-optimal solutions for sourcing the different sources of water. Problem 2.2.2.3.

Minimise fresh sources	Minimise total load	Well 1	Well 2	Ind. Aq.	Dirty W.	Sludge W.	Purified W.	Keope
m^3	kg	X1 - m^3	X2 - m^3	X3 - m^3	X4 - m^3	X5 - m^3	X6 - m^3	X7 - m^3
0	1.53099	0	0	0	0	0	100	80
1	1.51571	1	0	0	0	0	99	79
2	1.50043	2	0	0	0	0	98	78
3	1.48516	3	0	0	0	0	97	76
4	1.46988	4	0	0	0	0	96	75
5	1.4546	5	0	0	0	0	95	74

More Pareto-optimal solutions are produced for this scenario as considering Keope allows the existence of solutions that use less than 53 m^3 from fresh sources comparatively with the solutions in Section 3.1.1.2. Moreover, the load of pollutant in the final product in such solutions decreases and only from 53 m^3 of freshwater are the results the identical (Figure 11).

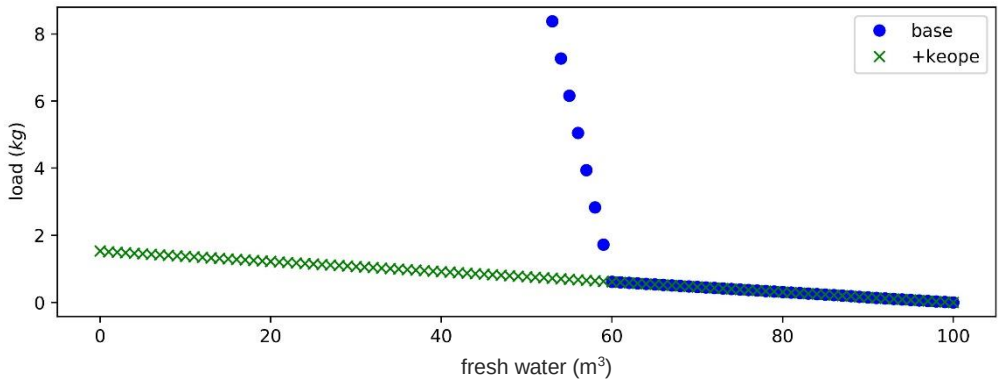


Figure 11 – Comparison between the Pareto fronts for Problems 2.2.2.2 and 2.2.2.3 – two criteria.

As previously performed for Section 3.1.1.2, three criteria for optimising the water sourcing regarding the same product requirements as above was considered (Figure 12):

- Minimise freshwater sourcing;
- Minimise the amount of pollutant in the product (load – defined by parameter(s));
- Minimise energy requirements.

The MODSS in this case considers using in some of the Pareto-optimal solutions dirty water directly in the product, resulting in higher loads (8.96 kg) when compared with the direct sourcing option (8.38 kg). The trade-off is to use none to much less freshwater in the product. There are more Pareto-optimal solutions available for the DM to choose from, therefore preferences should be considered in order to present less Pareto-optimal solutions to the DM and in agreement with what is expected as an output.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

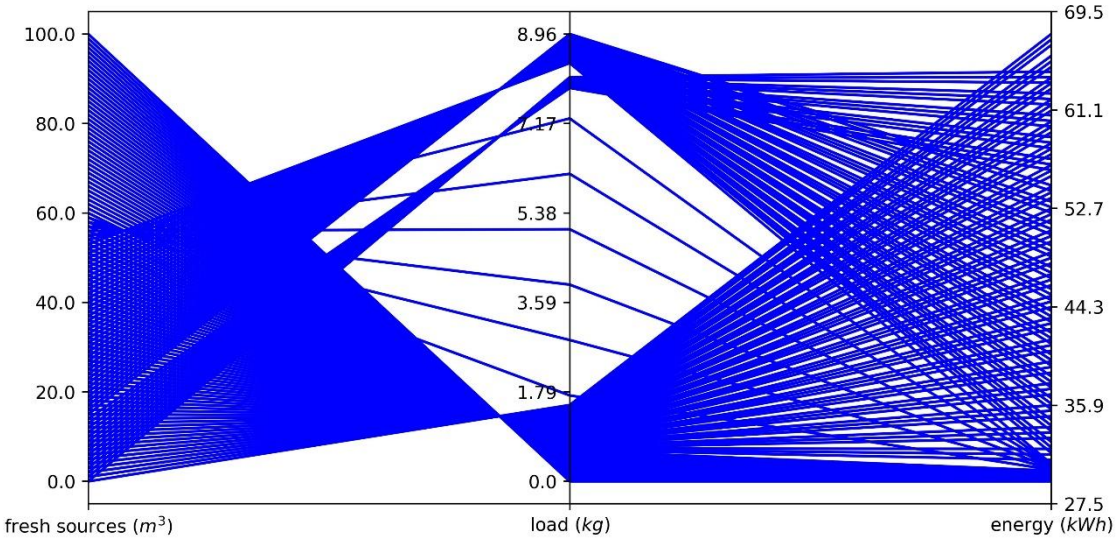


Figure 12 – Pareto front for Problem 2.2.2.3 – three criteria – different pathways.

3.1.1.4 MODSS with water treatment plant and daily or weekly planning

Finally, this section focuses on extending the MODSS tool described in 2.2.2.3, as defined in Section 2.2.2.5. This third approach includes both direct and indirect water sourcing, extending the solution by considering daily or weekly planning in the optimisation exercise. By optimising activity planning, i.e., optimising the order in which the products are produced, it is possible to optimise water sourcing, energy consumption, load in the final product, and so on. The criteria selected by the DM should be tailored to the industries preferences and thus reflect on the potential benefits and trade-offs, but for the current exercise we have considered two criteria (problem definition):

- Minimise freshwater sourcing;
- Minimise energy requirements.

To add a third criteria would potentially require a different solver tool, unlike the one used here (PolySCIP), as it may struggle to enumerate all Pareto-optimal solutions in a reasonable amount of time due to the large search space and/or the possible large number of Pareto-optimal solutions. A workaround, will highly depend on the DM, therefore, in terms of good practice, only a small amount of (diverse) Pareto-optimal solutions should be shown to the DM, either for him/her to select one, or for him/her to learn about the (location of the) Pareto front and be able to express preferences to further refine the search.

The concentrations of the parameters in each source are the same (Table 5), however to make the problem more interesting for this scenario, volumes of the dirty, sludge and treated water varied – two scenarios (3.1 and 3.2) as shown in Table 9. In Table 10, Table 11 and Table 12, unlike for the previous two problems in Sections 3.1.1.2 and 3.1.1.3, are three (3) products and their maximum concentration per parameter, classified as white, grey and black, respectively. The values, for the sake of simplicity, are fictitious, and can be defined by the End-user.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table 9 – volumes of water in the different sources. Two scenarios are considered.

Parameter / source	Unit	Well 1	Well 2	Ind. Aq.	Purified W.	Dirty W.	Sludge W.
Volume scenario 3.1	m^3	1000	1000	1000	50	14	8
Volume scenario 3.2	m^3	1000	1000	1000	50	5	10

Table 10 – White product definition (theoretical).

Type of product	Parameter / source	Unit	End-user requirements
White	Al	g/m^3	≤ 10 000
	Sb		≤ 0.01
	As		≤ 0.1
	Ba		≤ 50
	Cd		≤ 0.03
	Volume required	m^3	14

Table 11 – Grey product definition (theoretical).

Type of product	Parameter / source	Unit	End-user requirements
Grey	Al	g/m^3	≤ 800 000
	Sb		≤ 0.1
	As		≤ 20
	Ba		≤ 600
	Cd		≤ 30
	Volume required	m^3	24

Table 12 – Black product definition (theoretical).

Type of product	Parameter / source	Unit	End-user requirements
Black	Al	g/m^3	≤ 1000 000
	Sb		≤ 1
	As		≤ 10
	Ba		≤ 5000
	Cd		≤ 3
	Volume required	m^3	30

Figure 13 and Figure 14 presents the results for these scenarios for weekly/daily planning of the production of three products, while directly and indirectly sourcing the water from the different sources (Figure 7).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

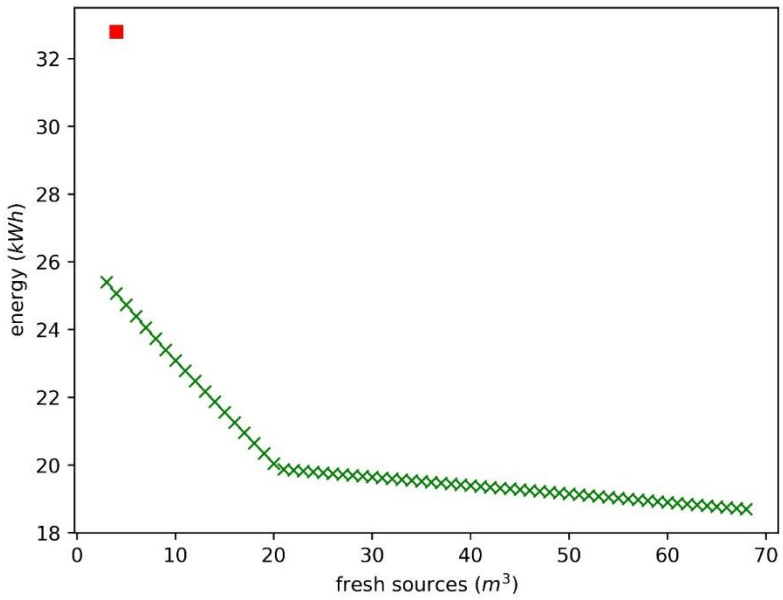


Figure 13 –Pareto front for Problem 2.2.2.5 – scenario 3.1 – two criteria.

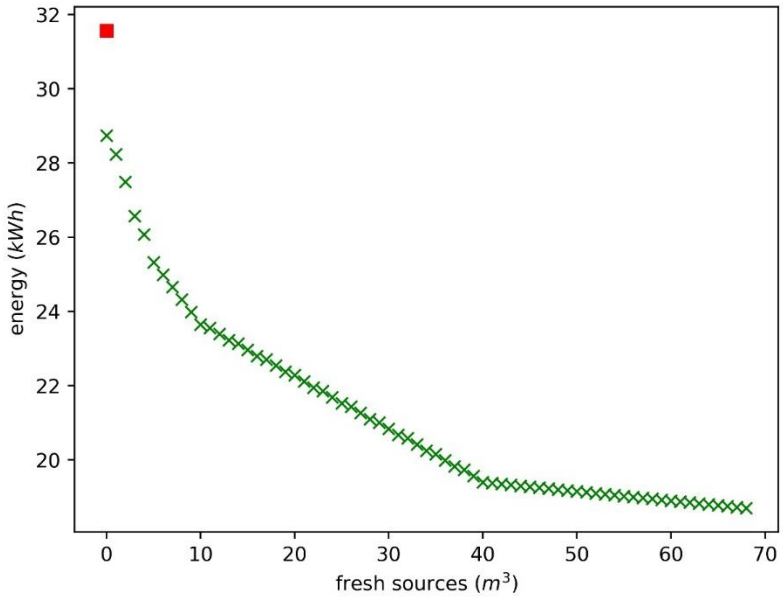


Figure 14 – Pareto front for Problem 2.2.2.5 – scenario 3.2 – two criteria.

Analysing Figure 13 and Figure 14 above presents the Pareto fronts (i.e., the mapping of all Pareto-optimal solutions into objective space) for both scenarios 3.1 and 3.2, respectively. It is interesting to observe that the shape of the front (green crosses) changes due to the different volumes of available water, and therefore the procedure for sourcing the water from the different sources is affected. The red square in Figure 13 and Figure 14 indicates the baseline scenario, i.e., how sourcing and production of the products is currently done by the industrial partner (first the white product, then the grey product and then the black product) based on the information obtained from the questionnaire described in Section 3.1.1.1. In both cases, the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

baseline scenario performs worse than the proposed optimal solutions in terms of energy consumption (Figure 13: ~25 kWh vs ~33 kWh; Figure 14: ~ 29 kWh vs ~32 kWh), a potential reduction of ~24% and ~9% from 3 batches, respectively. Other Pareto-optimal solutions are available to decrease energy consumption at the expense of increasing freshwater in the mixture. This will depend on the preference of the DM, however, with this exercise, the objective is to show that the DSS tool can present better solutions than that potentially practiced by the industry.

Table 13 and Table 14 presents some of the different production orders for each Pareto-optimal solution that the products can be produced depending on which solution has been chosen. In these tables, solutions are numbered in ascending order of the value of the first objective (fresh sources), i.e., solution 1 is related to the leftmost point in the figures, whereas solutions 66 and 69 refer to the rightmost points in the figures.

Table 13 – Sequence of product production - Scenario 3.1.

Solutions for scenario 3.1	First	Second	Third
1	1	2	3
2	3	2	1
3	2	3	1
4	3	2	1
5	1	2	3
6	1	3	2
7	3	2	1
…	…	…	…
66	1	3	2

Table 14 – Sequence of product production - Scenario 3.2.

Solutions for scenario 3.2	First	Second	Third
1	1	2	3
2	3	1	2
3	1	2	3
4	1	3	2
5	2	1	3
6	3	1	2
7	3	1	2
…	…	…	…
69	1	3	2

Comparing both tables, it is possible to conclude that the order of production of the products may change based on the volume of water available in each tank. Again, this is to optimise the sourcing of water, objectively reducing the overall amount of freshwater and increasing the sourcing of water from the other alternative sources. This implies that the order can be different, and it does matter, considering the following example: imagine there is 0 m^3 of purified water and 180 m^3 of sludge water (tank is full), however the DM wants to favour purified water in the products. This will be restricted as treating more water in Keope would lead to exceeding the volume capacity of the sludge tank. Therefore, first it would be necessary to use sludge water to produce a low-grade quality product, i.e., black or grey to ensure that there is enough volume available in the tank to receive the sludge water produced from treating the dirty water, while recovering purified water.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3.1.2 Chemical – Alufluor AB

3.1.2.1 Optimisation opportunity: Water sourcing process description

As mentioned in section 1.3.2, the resulting exhaust gases (contains HF) from AlF_3 production enter a scrubber unit to be washed, partially removed and condensed with a continuous flow of clean water (~7.0 – 10 m^3 / h). However, remaining exhaust vapour gases still escapes through the stack chimney and lost to the environment. This is where the iWAYS solution Heat Pipe Condenser Economiser (HPCE) contributes – WP2 – to condense and recover the highly acidic vapour. Two HPCE's are to be installed, one before the scrubber unit and one after the scrubber unit (before the chimney stack). The condensate recovered from both HPCE's will be treated by the onsite WWTP and a portion of the effluent will be treated by the iWAYS wastewater treatment plant (WWTP – WP4). The iWAYS WWTP can operate without receiving the condensate from the HPCE's, as it will receive the effluent from the onsite WWTP which treats effluent from the scrubber unit and from other processes of the industrial system.

The recovered and treated effluent will be recirculated and reused in the scrubber unit for treating the corrosive exhaust vapour gases, therefore covering freshwater requirements and consumption of the scrubber unit. The iWAYS solution will reduce the amount of exhaust vapour gas discharged in the environment and increase the overall water and resource circularity of the Alufluor (ALU AB) industry. Analysing the industrial site considering the current MODSS tool, it was possible to identify:

- One (1) source of water (freshwater) – no other sources available;
- Continuous flow;
- Aluminium fluoride products;
- iWAYS solution promotes an alternative source for the scrubber unit (continuous flow).

As only one (1) source of water is used in the industry, continuous flow, and the iWAYS solution does not produce a new source of water for product production (used exclusively for the scrubber process), no optimisation opportunities were identified to apply the MODSS tool.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3.1.3 Steel – Tubacex

3.1.3.1 Optimisation opportunity: Water sourcing process description

As mentioned in section 1.3.3, as part of TTI's production, freshwater is used to cool down the hot parts that exit from the 3 gas ovens (process B – see Grant Agreement (GA)), with no recovery of heat or steam (i.e. condensate). The proposed solution for the Heat Pipe Condenser Economiser (HPCE) – WP2 – will not recover condensed vapour due to the specificities of the location where it will be installed – its prime focus will be on thermal heat recovery and the latent heat of the steam will be used to preheat the liquid that feeds the evaporator equipment in the WWTP from process A (see GA). This will allow to reduce the energy and gas requirements for the degreasing tanks and evaporator equipment. The iWAYS wastewater treatment plant proposes to treat the sludge produced in water circuit 1, which is independent from the activities and solutions proposed by the HPCE for exclusively energy recovery. The objective is to reduce freshwater consumption and sludge disposal through transport with this solution, resulting in economic savings, among others, for the industry as mentioned in D4.1:

i) quality posing challenges for standard treatment processes (receiving the mineral greases and solvent from the above describes industrial processes);
ii) high environmental footprint in its current state having a high energetic cost and GHG emission in its treatment (the wastewater is transported by a third party for incineration);
iii) high economical value (80 euros per m^3 transported).

Analysing the industrial site considering the current MODSS tool, it was possible to identify:

- Water circuits (1 source): 1st generates 50 m^3 of wastewater/week; 2nd closed heat treatment process; 3rd already closed loop (no wastewater generation) – mainly freshwater;
- Continuous and batch flow;
- Inox tubing;
- IWAYS solution will create one source of alternative water.

There are three water circuits in the industry, where each use one (1) source of water and two of the circuits are closed. The iWAYS water treatment solution targets the first circuit, however, the recovered water will be reused in the same circuit, reducing freshwater requirements, therefore no optimisation opportunities were identified to apply the MODSS tool.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3.2 Alternative water source prospective DSS assessment tool applied to Use-Cases

The next sections demonstrate how to apply the model that was developed to assess alternative rainwater harvesting solutions for each industry's reality. The framework and methodologies were applied to the three different use-cases which are located in very different regions across the EU, therefore resulting in very different results in terms of precipitation, freshwater consumption, and characteristics of the freshwater and rainwater. Sampling freshwater and rainwater was conducted by each industrial partner, following specific analytical standards (D2.2 and D4.1 for more information). Other information was collected directly from the industrial partners through online meetings or through correspondence. Each use-case will be analysed in separate sections.

3.2.1 Ceramics – Atlas Concorde (Ceramiche KEOPE Facility)

3.2.1.1 Characterising the Industry and rainwater

Table 15 summarises the information gathered for step 1 and step 2 of the framework. The methodologies employed for characterising the water samples are those that are already in place by the industry (D2.2), while other methodologies for characterising the catchment area, freshwater consumption, etc, can be found in D2.2, D3.9, and D4.1.

Analysing data recovered for the CON industrial site, it is possible to infer that harvested rainwater can be used directly in CON's processes, therefore requiring no treatment as the analysed variables present lower values than the freshwater source (Table 15, D2.2 and D4.1) – Specific Electroconductivity (SEC) of the rainwater is much lower than of freshwater. This potentially implies that 100% of the harvested rainwater is recoverable (not accounting for RRC) and therefore no generation of waste (not accounting for the first-flush). Even if treatment was required, the fact that there is an onsite water treatment facility can reduce initial capital expenditure (CAPEX), however at the expense of operational expenditure (OPEX), that will potentially reduce the volume of recovered freshwater and increase chemical and energy requirements. There are onsite storage tanks that can be used, and the harvestable area for rainwater is the current rooftop area. Other information in Table 15 will be relevant in subsequent sections.

Table 15 – Information gathered for step 1 and step 2 of the RWH DSS tool framework for CON.

Step	Parameter	Input
INDUSTRY	*Location*	Casalgrande, Reggio Emilia, Italy (N 44 34.945, E 10 45.433).
	Onsite water treatment facility	Yes, to treat dirty water and obtain purified water through a precipitation and separation techniques; Nanofiltration and Ultrafiltration units.
	Catchment material	Rooftop – concrete and galvanised iron sheet.
	Catchment area	Rooftop area = 63 000 m^2.
	Freshwater quality	Freshwater: COD = 10 mg/l; TSS = 4 mg/l; pH = 7.2; SEC = 1277 µS/cm; TN = 6.7 mg/l; Ca = 250 mg/l. (D2.2)
	Freshwater consumption	Average = 96 066 m^3 / year.
	Water Storage	Potentially. At least 100 m^3 tanks or greater.
	Freshwater price	1.05 €/m^3
RAINWATER	*Climate*	Köppen-Geiger: Cfa – humid subtropical. No significant precipitation difference between seasons. No dry months in the summer. Average rainfall = 582.81 mm / year[1].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

	Rainwater quality	COD = 9.0 mg/l; TSS < 4.0 mg/l; pH = 7.1; SEC = 75 µS/cm; TN < 5.0 mg/l; Ca = 12.2 mg/l; Hardness 3.2 French degrees (D4.1).
	Historical data	Copernicus or ECA&D[1].

[1]Klein Tank, 2002.

3.2.1.2 Historical rainwater data: quick scan potentialities on harvesting and economic savings

Historical rainwater data collection and characterisation can be the first step to conduct in any project related with RWH (not accounting for available harvesting area), because without rain there is no possibility to harvest it. Therefore, an initial estimate of how much rainwater is potentially harvestable considering just the current harvest area and the rainfall volume was performed through the following scenario: 100% of the rainfall is recoverable and reused (nothing lost) – however it is possible to reduce its volume to reflect potential treatment processes, evapotranspiration, etc. Even a range can be considered for worst case scenario (low rainwater recovery and harvest material not adequate, e.g., 50% rainwater recoverable). This type of quick scan can be presented to stakeholders before conducting a full assessment in order to give an idea of the potential behind the current harvest area at the industry. Table 16 presents the potentially harvestable volumes of rainwater for CON based on historical data (Table 15) downloaded from ECA&D. This was calculated using Equation 18 but not considering the part for first-flush.

Table 16 – Potentially harvestable volumes of rainwater and economic savings for CON.

Volume (m^3/y)	Potential economic savings – PES (€/y)	Cumulative PES (€): 2023 - 2050	Comment
40 930	42 977	1 160 919	European Climate Assessment & Dataset – average cumulative rainfall 583 mm / year: RCC and TE = 100%; A = 63 000 m^2 - Table 15.

The current structure, i.e., rooftop harvest area available at the CON industrial park has the potential to recover 40 930 m^3 of water a year on average, accounting for ~ 43% of current freshwater requirements and potential annual savings of 42 977 €. The initial quick scan indicates that rainwater harvesting with the current setup is feasible and can potentially cover up to nearly 50% of current freshwater needs. However, as it would be expected, industries are prone to increase in production, especially when there is a demand, therefore resulting also in increases in freshwater requirements.

3.2.1.3 Expected and projected industrial freshwater consumption

To determine the volume of freshwater required in the future, by means of linear determination to maintain simplicity (other methods may be employed), Equation 15 and 16 calculate the freshwater consumption from historical freshwater consumption data, which can go back as far as possible. Additionally, abnormal years were included in the analysis, as these represent potential disruptions to normal operation, i.e. the year 2020 which saw a decline in overall world production of consumables and raw materials due to the COVID-19 pandemic. These events will potentially occur in the coming years, more frequently, and possibly with greater impacts, resulting in greater disruption in productions and affecting overall industrial consumption – as was proven by the data here – therefore the year 2020 was included in the analysis for freshwater consumption. Table 17 presents the percentages of increase and decrease from historical data supplied from the CON partners. The data for freshwater consumption covers 2018 to 2021.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table 17 – Percentages of increase and decrease of freshwater consumption at CON.

Years	Annual increase / decrease in fresh water consumption – %	Expected / projected water consumption increase per year (AAGR) – %	*Expected water consumption increase – %: 2023 –		
			2030	2040	2050
2018 – 2019	2.71	2.75	28	67	119
2019 – 2020	-12.74				
2020 – 2021	18.28				

*Over current consumption

On average, for the period under analysis, it is possible to conclude that freshwater consumption increased 2.75%. It is possible to also notice the impact the sanitary pandemic had on the industry between 2019 and 2020, with a steep decrease in freshwater consumption occurring. The following year saw an increase and potential recovery as production proceeded to recovery from the crisis. By the year 2030, it is expected that freshwater consumption increases by 28% given the current trend. By 2040 it would have more than doubled percentage wise, and by 2050, freshwater requirements would be more than double, in volume, of 2023 (119% increase). This is projected in Figure 15.

It is possible to cap projected freshwater consumption, adding restrictions to the models to define the maximum expected freshwater consumption, and therefore project which year the capped consumption value will be reached.

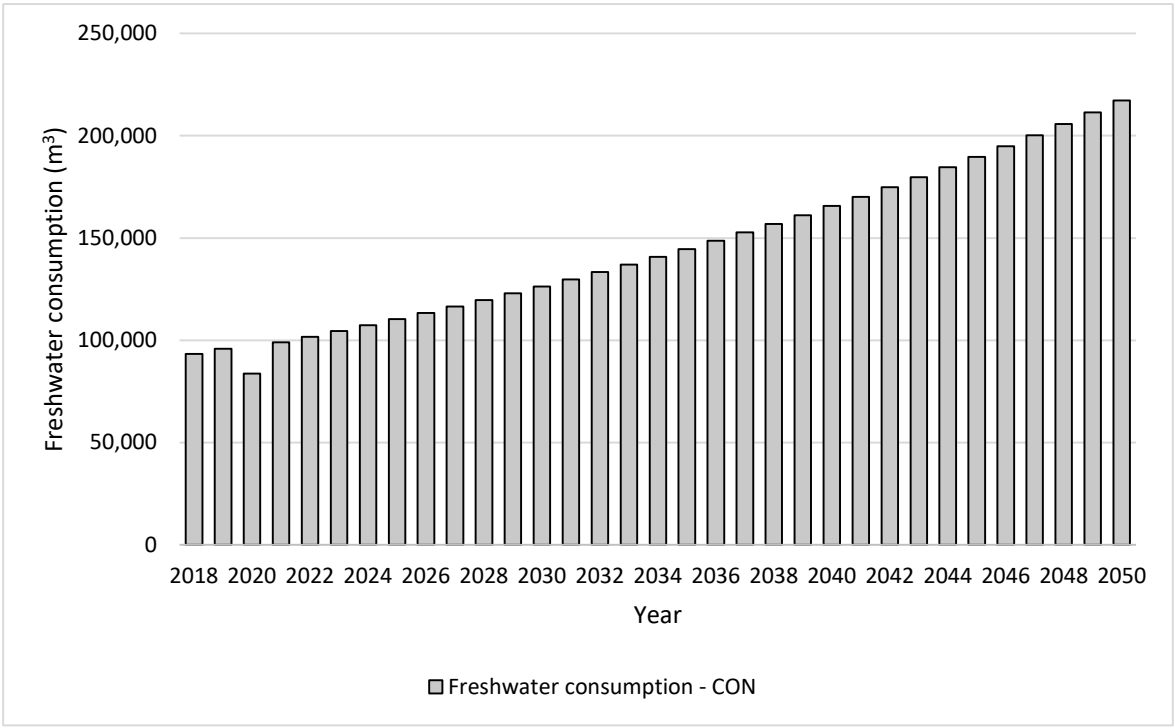


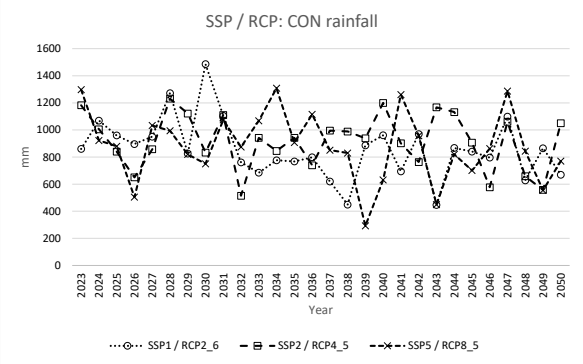
Figure 15 – CON projected freshwater consumption until 2050.

3.2.1.4 Projected rainfall simulation considering the Representative Concentration Pathway (RCP)

Projecting rainfall can either be obtained from average annual precipitation averages, as that performed in the quick scan procedure to present to interested stakeholders, or it can be attained considering the Copernicus Climate Data Store to simulate and project monthly average rainfalls following different pathways (RCP). In this section the average monthly expected rainfall for each SSP/RCP pathway from 2023 to 2050 is presented in Figure 16

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

regarding the CON industrial site region. With this dataset, it is possible to calculate the volumes of harvestable rainwater with the current identified harvest area (Table 15) and to what extent can it substitute freshwater sourcing considering: minimal treatment is required (90% recovered), RRC = 90%, the harvesting area remains intact, and at least two first-flushes are performed per year (Figure 17).



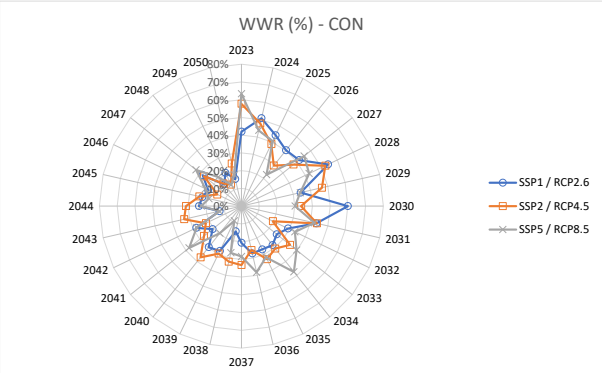
SSP	RCP	Description
1	2.6	Characterised by its sustainable development-oriented paradigm, often referred to as the "Green Society".
2	4.5	Considered the current path or trajectory the world is taking / Business as Usual (BAU) trajectory.
5	8.5	Emblematic of a development pathway heavily reliant on fossil fuels, eliminating "green" technologies.

Figure 16 – Average monthly expected rainfall for each SSP/RCP pathway from 2023 to 2050 at the CON industrial site.

To translate this information regarding the impact on freshwater reduction requirements, the Water Withdrawal Reduction (WWR) Indicator was selected because it demonstrates the volume of water from alternative sources that can cover freshwater requirements. The WWR can be calculated following Equation 21.

$$WWR(\%) = (TWC - TFC)/TWC \quad (21)$$

Where, *TWC* (m^3/year) is the observed or projected total water consumption, and *TFC* (m^3/year) is the observed or projected total freshwater consumption. Now, if we simulate the volume of harvestable rainwater and freshwater consumption at and by the industry, respectively, from 2023 – 2050 (not capping consumption), we are able to project the % in water withdrawal reduction of the industry, and thus the substitution of freshwater with rainwater – Figure 17.



Baseline scenario:
- Harvest area static (current – Table 15);
- Treatment efficiency: *90%* (harvested rainwater treatment);
- RRC = *90%*;

Figure 17 – Potential WWR for the CON industrial site considering the Baseline scenario.

In potential economic savings (PES), not including any CAPEX or OPEX – though for the current industrial case, most of the infrastructure is already available and little to no investment is foreseen compared to installing a system with nothing available. OPEX on the other side should also be minimal, reflecting only on pumping (i.e. energy) and associated maintenance costs. Therefore, Table 18, presents the PES for the baseline scenario for 2023 – 2050.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table 18 – Potential economic savings (PES) for the Baseline scenario CON.

Baseline CON: Potential Economic Savings (PES): € (2023 – 2050)		
SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
1 285 048	1 376 503	1 320 149

3.2.1.5 Dynamic harvest area to accompany projected freshwater requirements and rainfall: SSP / RCP scenarios

In order to enable decision support in decision-making, in regard to its feasibility and implementation and expantion requirements of an RWH system, a tool was developed based on the Equations in section 2.3.1 which allows to perform an incremental and dynamic simulation of the harvest area to implement and / or expand, in relation to how much the stakeholder / DM wishes to substitute freshwater requirements with rainwater. In other words, the DSS tool allows for the DM to decide on how much freshwater would they like to substitute with, i.e. the freshwater requirements (FWR), harvested rainwater. This DSS tool allows to foresee how the harvestable area increases in size to accommodate the step-wise implementation of the RWH solution, while influenced by the different SSP / RCP scenarios.

Figure 18 presents the results for a first scenario regarding dynamic rainfall and consumption input, and thus simulating the required harvestable area to accommodate the criterion of the decision maker for substituting freshwater with rainwater – contributing to a more sustainable and circular economy. **Scenario 1** is the same as the baseline (3.2.1.4), however, a new parameter is added to the model – freshwater reduction (FWR). For the purpose here, it has been considered to be 100% (the DM wants to cover 100% of total freshwater requirements with rainwater at the CON industrial site). Freshwater consumption is not capped, and will continue to increase to its projected value (Figure 15).

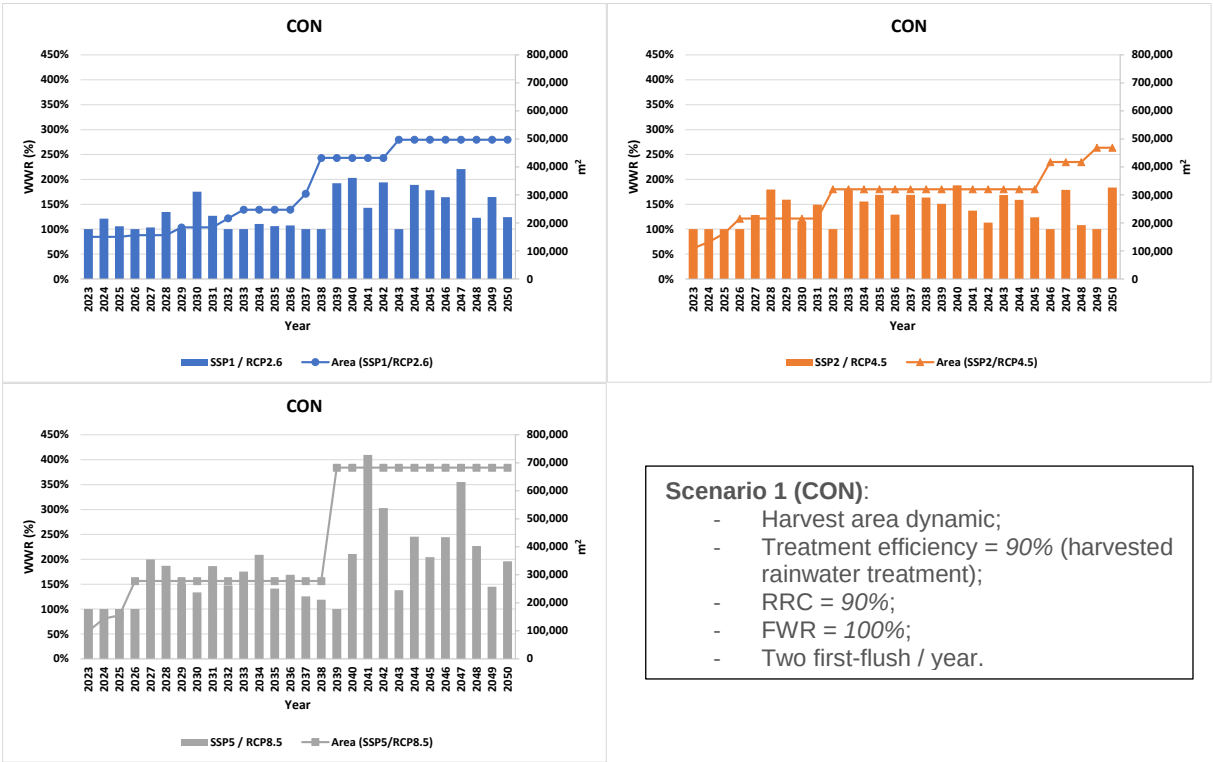


Figure 18 – Scenario 1 regarding dynamic rainfall and consumption input, and resulting harvestable area for CON industrial site.

Analysing Figure 18 it is possible to obtain two types of information:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

- The WWR indicates how much of the harvested rainwater can cover freshwater requirements every year, with a minimum of 100% as this was defined by the DM / stakeholder – values of FWR greater than 100% indicate that the volume of rainwater recovered and treated is greater than the projected volume of freshwater required by the industry – therefore surplus;
- The other piece of information advises on the potential harvest area, in step-wise fashion, that is required to achieve the corresponding WWR value for the same year. The catchment area will progressively increase over the years as freshwater requirements for each industrial site also increases and varying precipitation events.

To quantify the potential savings of covering 100% of freshwater needs with harvested rainwater, the PES is shown in

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table 19, and excludes CAPEX and OPEX. The difference between savings for scenario 1 and the baseline can be compared, however the implementation of the RWH system for scenario 1 will have higher costs. A work around this would be to include carports that combine photovoltaic panels (PV) which can generate energy to supply energy to the industrial facility when the sun is out, and harvest rainwater during precipitation events, all while providing shade and protection to cars.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Table 19 – Potential economic savings (PES) for the Scenario 1 CON.

Scenario 1 CON: Potential Economic Savings (PES): € (2023 – 2050)		
SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
6 332 391	6 388 217	8 673 773

Figure 19 and Figure 20 proposes two other scenarios, while Table 20 compares the potential economic savings of the scenarios:

- **Scenario 2**: treatment efficiency of 90%, RRC of 90%, and FWR of 50%, the rest of the parameters are the same;
- **Scenario 3**: treatment efficiency of 90%, RCC of 90 %, FWR of 50%, and freshwater requirements capped in 2035.

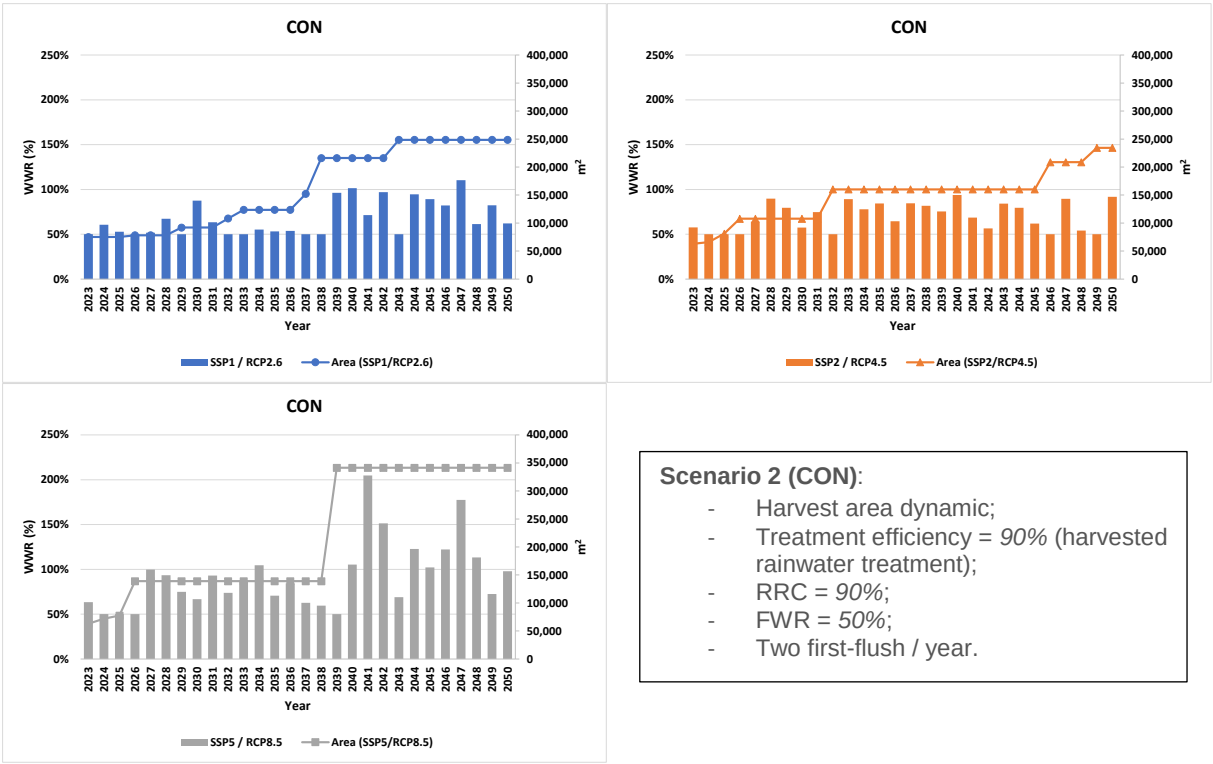
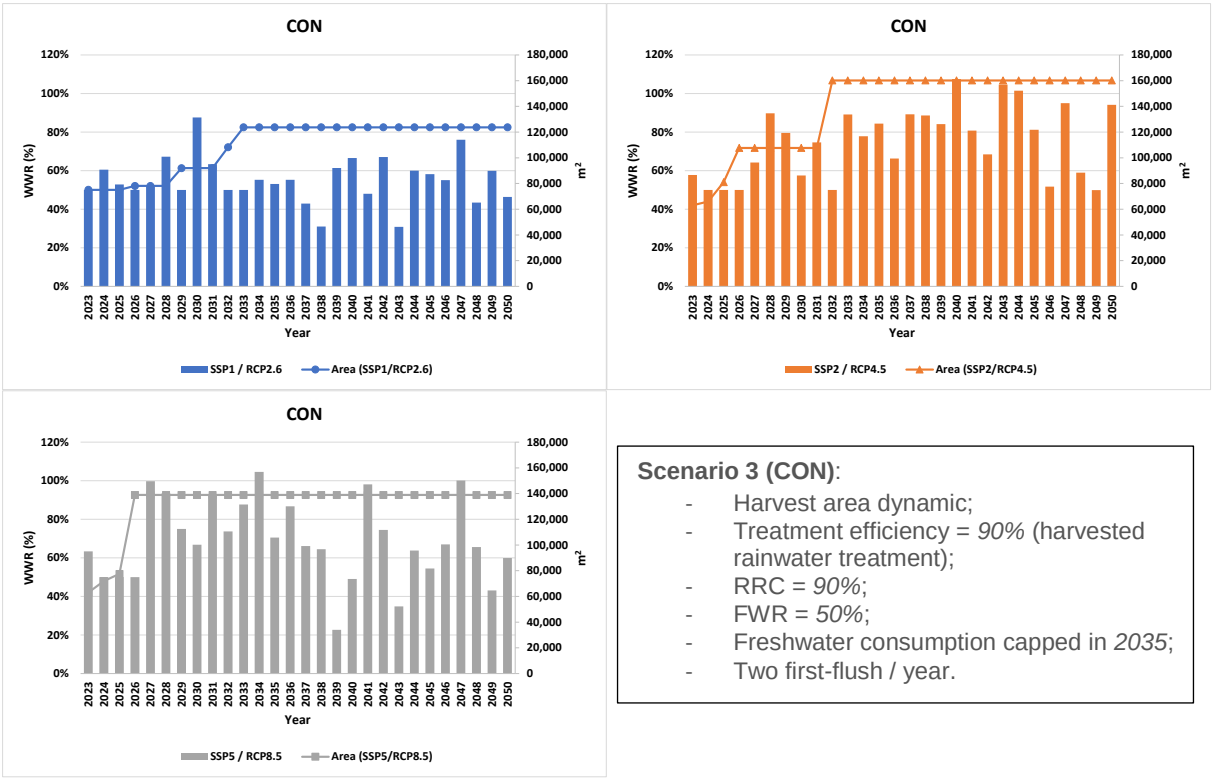


Figure 19 – Scenario 2 regarding dynamic rainfall and consumption input, and resulting harvestable area for CON industrial site.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274



Scenario 3 (CON):

- Harvest area dynamic;
- Treatment efficiency = *90%* (harvested rainwater treatment);
- RRC = *90%*;
- FWR = *50%*;
- Freshwater consumption capped in *2035*;
- Two first-flush / year.

Figure 20 – Scenario 3 regarding dynamic rainfall and consumption input, and resulting harvestable area for CON industrial site.

Table 20 – Potential economic savings (PES) for the all scenarios – comparison – CON.

Scenario baseline, 1, 2 and 3 CON: Potential Economic Savings (PES): € (2023 – 2050)			
Scenario	SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
Baseline	1 285 048	1 376 503	1 320 149
1	6 332 391	6 388 217	8 673 773
2	3 166 195	3 202 575	4 351 523
3	2 180 811	3 006 473	2 729 400

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3.2.2 Aluminium fluoride – Alufluor (ALU)

3.2.2.1 Characterising the Industry and rainwater

As with the previous industrial site, a characterisation and collection of information for the Industry and Rainwater steps was conducted and summarised in Table 21. The methodologies employed for characterising the water samples are those that are already in place by the industry (D2.2 and D4.1), while other methodologies for characterising the catchment area, freshwater consumption, etc, can be found in D2.2, D3.9, and D4.1.

Analysing data recovered for the ALU industrial site, it is possible to conjecture that harvested rainwater cannot be used directly in ALU's processes, as the Ca concentration is above the minimal requirements, and therefore requiring treatment (Table 21 and D4.1) to avoid scaling and other negative effects on the equipment over time. This potentially implies that not all of the harvested rainwater is recoverable (not accounting for RRC) and therefore some generation of waste (not accounting for the first-flush) is expected. The treatment of the rainwater could be performed by the onsite water treatment facility to reduce initial capital expenditure (CAPEX), however at the expense of operational expenditure (OPEX), that will potentially increase chemical and energy requirements. There are no onsite storage tanks that can be used, therefore further investments would be required, and the harvestable area for rainwater is the current rooftop area – smallest size out of all industries analysed here. Other information in Table 21 will be relevant in subsequent sections.

Table 21 – Information gathered for step 1 and step 2 of the RWH DSS tool framework for ALU.

Step	Parameter	Input
INDUSTRY	*Location*	Helsingborg, Scania, Sweden (N 56 00.453, E 12 43.154).
	Onsite water treatment facility	Yes, used to treat the effluent from the industrial processes through precipitation and separations techniques; Sand filter and softner units.
	Catchment material	Rooftop – concrete and corrugated metal sheet.
	Catchment area	Rooftop area = 5 360 m^2.
	Freshwater quality	Freshwater: TSS < 1 mg/l; F < 90 mg/l; Al < 5 mg/l; Ca < 1 mg/l.
	Freshwater consumption	Average = 174 884 m^3 / year.
	Water Storage	No. Would potentially need to be constructed or bought.
	Freshwater price	1.09 €/m^3
RAINWATER	*Climate*	Köppen-Geiger: Cfb – temperate oceanic climate or subtropical highland climate. No significant precipitation difference between seasons. Average rainfall = 664 mm / year[1].
	Rainwater quality	TOC = 1.7 mg/l; SEC = 86.7 µS/cm; TN < 3.0 mg/l; F < 2.0 mg/l; Al < 1.0 mg/l; Ca < 4.0 mg/l
	Historical data	Copernicus or ECA&D[1].

[1]Klein Tank, 2002.

3.2.2.2 Historical rainwater data: quick scan potentialities on harvesting and economic savings

Historical rainwater data collection and characterisation can be the first step to conduct in any RWH project (not only the available harvesting area), because without rain there is no possibility to harvest it. Consequently, an initial estimate of potential rainwater volume considering just the current harvest area and precipitation events is performed bearing in mind (scenario): 100% of the rainfall recovered and reused (nothing lost) – however it is possible to reduce its volume through modelling to reflect potential treatment processes, evapotranspiration, wind, etc. The quick scan regarding feasibility can be presented to stakeholders beforehand conducting a full assessment in order to give an idea of the potential behind the RWH potential at the industry. Table 22 presents the potentially harvestable

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

volumes of rainwater for ALU (Table 21) collected from ECA&D. This was calculated using Equation 4 but not considering the part for first-flush.

Table 22 – Potentially harvestable volumes of rainwater and economic savings for ALU.

Volume (m^3/y)	Potential economic savings – PES (€/y)	Cumulative PES (€): 2023 - 2050	Comment
3 602	3 926	106 002	European Climate Assessment & Dataset – average cumulative rainfall 664 mm / year: RCC and TE = 100%; A = 5 360 m^2 -Table 21.

The current structure, i.e., rooftop harvest area available at the ALU industrial park has the potential to harvest only 3 602 m^3 / y, potentially ~ 2% of current freshwater requirements and annual savings of 3 926 €. The initial quick scan indicates that rainwater harvesting with the current setup is not feasible as it can potentially only cover up to 2% of current freshwater needs. This is very much attributed to the small harvesting area currently available, and high-water consumption by the industrial site. And if projections to increase freshwater consumption verify, then a larger area would be required, or alternatively another form of sourcing water, i.e., desalination plants – ALU has the advantage of locating itself near the sea, and an initial investment would be required to cope with around 480 m^3 / d of desalinated water, which is not expected to increase over time.

3.2.2.3 Expected and projected industrial freshwater consumption

To project the freshwater consumption in the future, by means of linear determination to maintain simplicity (other methods may be employed), Equation 15 and 16 were used to calculate the potential freshwater consumption from historical freshwater consumption data. Additionally, abnormal years were included in the analysis, as these represent potential disruptions to normal operation. For example, the year 2020 saw a decline in overall world production of consumables and materials due to the COVID-19 pandemic. These events will potentially occur in the coming years, more frequently, and possibly with greater impacts, resulting in greater disruption in productions and affecting overall industrial consumption. Therefore, the year 2020 was included in the analysis for freshwater consumption. Table 23 presents the percentages of increase and decrease from historical data supplied from the ALU partners. The data for freshwater consumption covers 2016 to 2021.

Table 23 – Percentages of increase and decrease of freshwater consumption at ALU.

Years	Annual increase / decrease in fresh water consumption – %	Expected / projected water consumption increase per year (AAGR) – %	*Expected water consumption increase – %: 2023 –		
			2030	2040	2050
2016 – 2017	10.13	3.20	25	70	133
2017 – 2018	10.78				
2018 – 2019	1.67				
2019 – 2020	-2.91				
2020 – 2021	-3.70				

*Over current consumption

On average, it is possible to observe that freshwater consumption increases 3.20% on an annual basis. The past few years have seen a dip in consumption, potentially due to the disruption brought on by the pandemic, and still felt from 2020 onwards. Projecting consumption, it is possible to see that by the year 2030 freshwater consumption is expected to increase by 25%. By 2040 it would be 70%, and by 2050, freshwater requirements would be more than double, in volume, of 2023 (133% increase). This is projected in Figure 21.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

These are theoretical values, and therefore it is expected that freshwater consumption should be capped given also the capacity of the industrial process. This is also possible in the model, adding restrictions to define the maximum expected freshwater consumption, and therefore project which year the capped consumption value will be reached. After chatting with the ALU partners, it was concluded that the future freshwater consumption of the facility would not surpass its current consumption rate. This exercise here was performed as form of completeness for the framework.

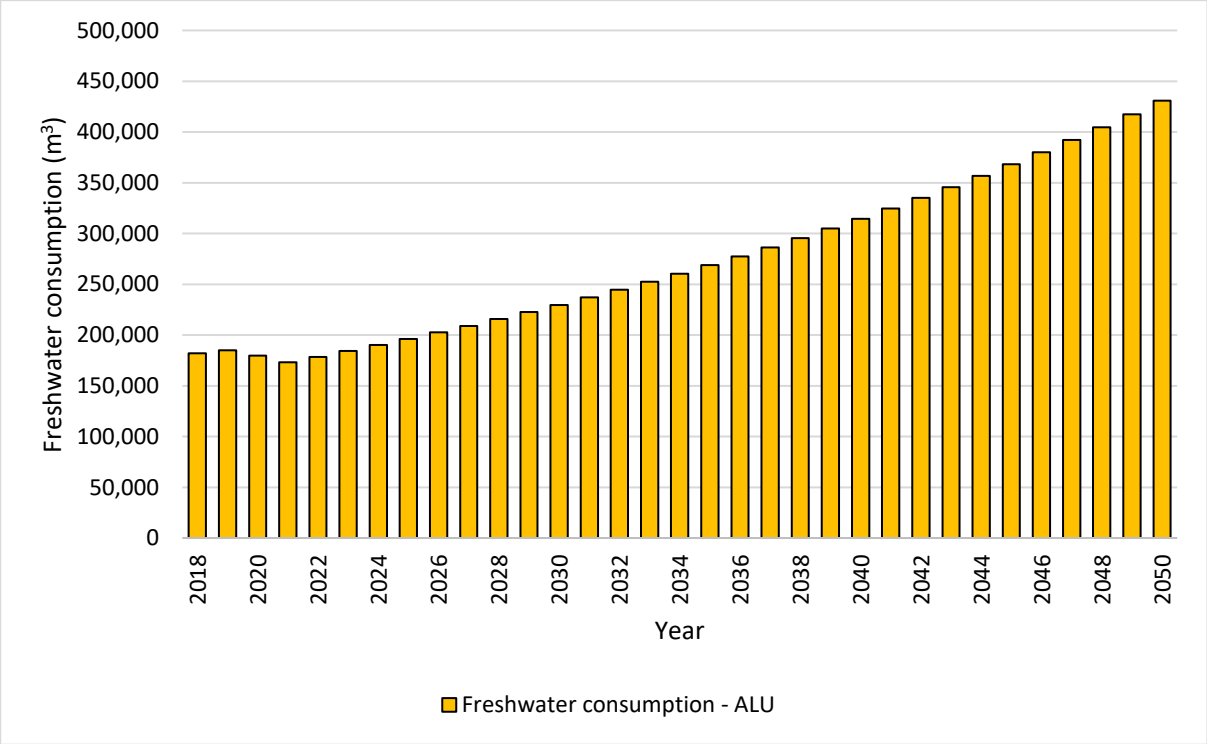
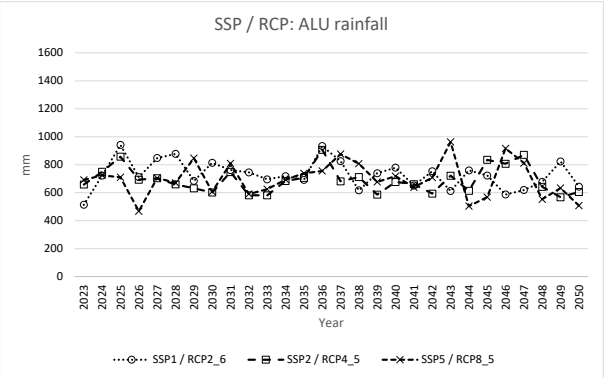


Figure 21 – ALU projected freshwater consumption until 2050.

3.2.2.4 Projected rainfall simulation considering the Representative Concentration Pathway (RCP)

Characterising rainfall can either be performed from annual precipitation averages, as performed in the quick scan procedure, or it can be developed considering the Copernicus Climate Data Store to simulate and project monthly average rainfalls following three different pathways (SSP / RCP). Here, the average monthly expected rainfall for each SSP/RCP pathway from 2023 to 2050 is presented in Figure 22 for the industrial site region.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

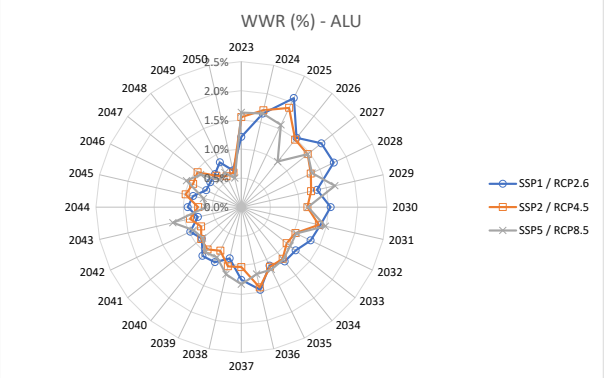


SSP	RCP	Description
1	2.6	Characterised by its sustainable development-oriented paradigm, often referred to as the "Green Society".
2	4.5	Considered the current path or trajectory the world is taking / Business as Usual (BAU) trajectory.
5	8.5	Emblematic of a development pathway heavily reliant on fossil fuels, eliminating "green" technologies.

Figure 22 – Average monthly expected rainfall for each SSP/RCP pathway from 2023 to 2050 at the ALU industrial site.

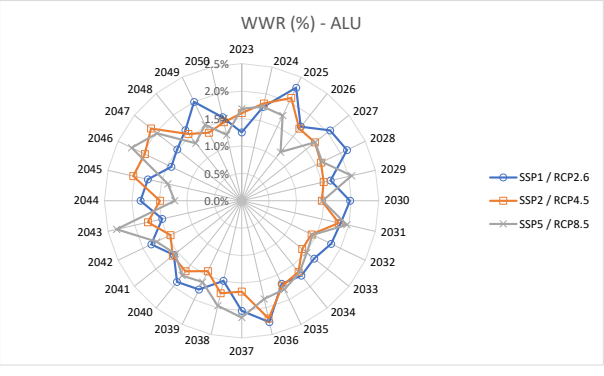
From this dataset, it is possible to calculate the potential volumes of harvestable rainwater with the current identified harvest area (Table 21) and to what extent can it substitute freshwater sourcing considering: treatment required (90% recovered), RRC = 90%, the harvesting area remains intact, and at least two first-flushes are performed per year (Figure 23). The WWR can be calculated following Equation 21.

Now, by simulating the volume of harvestable rainwater and freshwater consumption at and by the industry, respectively, from 2023 – 2050 (not capping and capping consumption), the projected % in water withdrawal reduction of the industry is obtained, and thus the substitution of freshwater with rainwater – Figure 23.



Baseline scenario (increase in freshwater Consumption):

- Harvest area static (current – Table 21);
- Treatment efficiency: 90% (harvested Rainwater treatment);
- RRC = 90%;
- Two first-flush per year.



Baseline scenario (no increase in freshwater Consumption):

- Harvest area static (current – Table 18);
- Treatment efficiency: 90% (harvested
- Rainwater treatment);
- RRC = 90%;
- Two first-flush per year.

Figure 23 – Potential WWR for the ALU industrial site considering the Baseline scenario.

Considering potential economic savings (PES), not including CAPEX or OPEX – though for the current industrial case, most of the infrastructure is already available and little to no investment is foreseen compared to installing a system with nothing available. OPEX on the other side should also be minimal, reflecting only on pumping (i.e. energy), treatment and

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

associated maintenance costs. Table 24 presents the PES for the baseline scenario for 2023 – 2050.

Table 24 – Potential economic savings (PES) for the Baseline scenario ALU.

Baseline ALU: Potential Economic Savings (PES): € (2023 – 2050)		
SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
96 736	91 364	92 238

3.2.2.5 Dynamic harvest area to accompany projected freshwater requirements and rainfall: SSP / RCP scenarios

To enable decision support in decision-making, a tool was developed based on the Equations in section 2.3.1 which allows to perform an incremental and dynamic simulation of the harvest area to implement and / or expand, in relation to how much the stakeholder / DM wishes to substitute freshwater requirements with rainwater. This approach allows to evaluate the feasibility and implementation and expansion requirements of an RWH system. In other words, the tool allows for the DM to choose how much freshwater would they like to substitute with, i.e., the freshwater requirements (FWR), with harvested rainwater. This tool allows to foresee how the harvestable area increases in size to accommodate the step-wise implementation for harvesting rainwater volumes, influenced by the different SSP / RCP scenarios.

Figure 24 presents the results for a scenario regarding dynamic rainfall and consumption input, and thus simulating the required harvestable area to accommodate the criteria established by the decision maker to substitute freshwater with rainwater, therefore contributing to a more sustainable and circular economy. **Scenario 1** is the same as the baseline scenario (3.4.2.4), with the addition of a new parameter – freshwater reduction (FWR). Here, it is considered to be 100% (the decision-maker wants to cover 100% of total freshwater requirements with rainwater at the ALU industrial site). Freshwater consumption production has not been capped in the first section, and will continue to increase to its projected value, while the second part considers that it has been capped to its current consumption rate (Figure 21).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

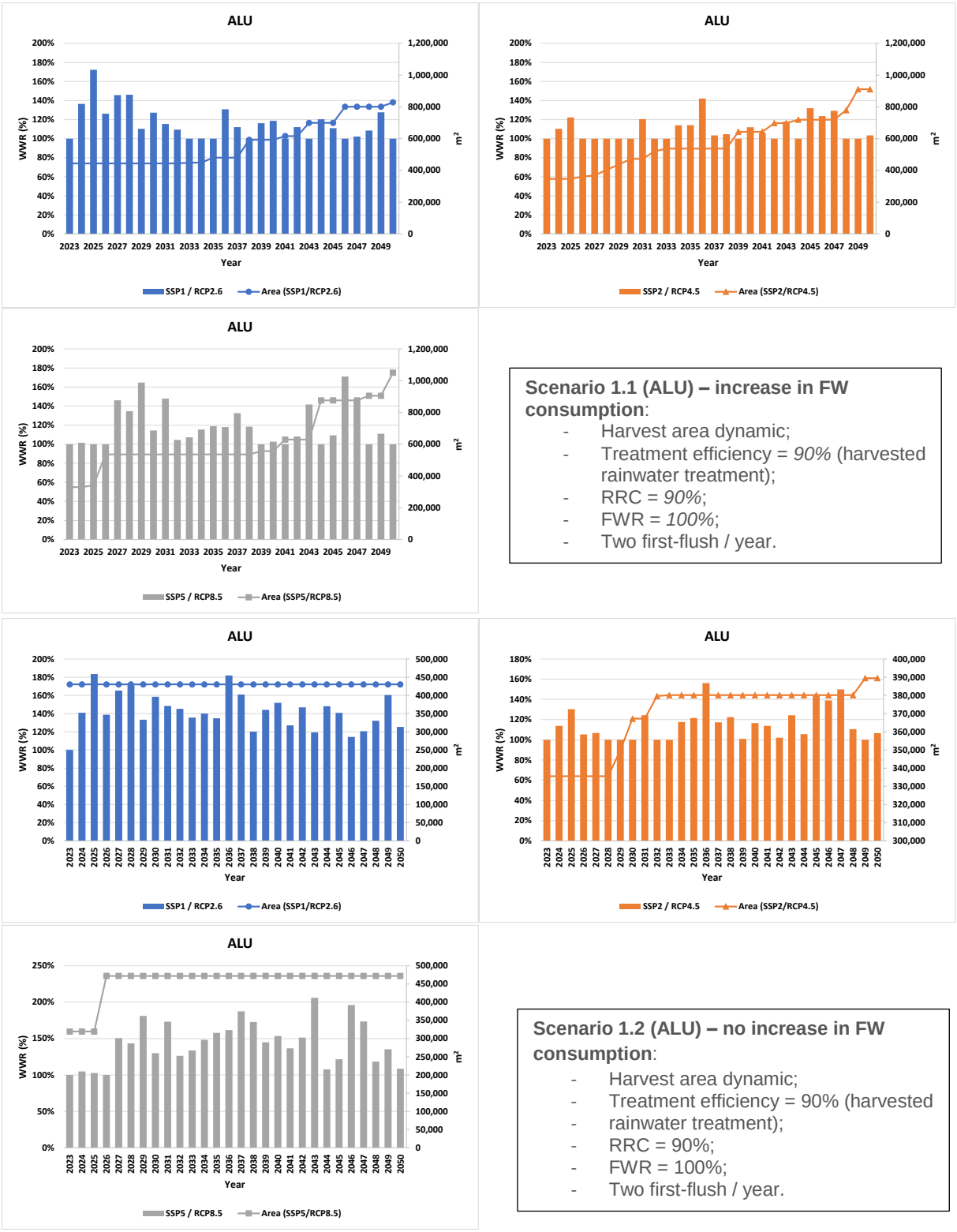


Figure 24 – Scenario 1 regarding dynamic rainfall and consumption input, and resulting harvestable area for ALU industrial site.

By analysing the information in Figure 21:

- The WWR indicates how much of the harvested rainwater can cover freshwater requirements every year, with a minimum of 100% as this was defined by the decision-maker / stakeholder – values of FWR greater than 100% indicate that the volume of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

rainwater recovered and treated is greater than the projected volume of freshwater required by the industry – surplus;

- The potential harvest area, in a step-wise fashion, required to achieve the corresponding WWR value for a given year. The catchment area will progressively increase over the years as the freshwater requirements for each industrial site also increases and varying precipitation events.

PES indicates potential savings of covering 100% freshwater with harvested rainwater (Table 25), and excludes CAPEX and OPEX. CAPEX for the current scenario has the potential of being high, as the increase in harvest area required for the scenario are massive compared to the baseline. The difference between savings for this scenario and the baseline are not even comparable, as the industry consumes high volumes of water, however the development of the RWH system will have costs – especially considering that the harvest area in 2050 would be between 828 371 m^2 and 1 049 948 m^2. A work around this would be to include carports that combine photovoltaic panels (PV) which can generate energy to run the industrial facility when the sun is out, and harvest rainwater during precipitation events, all while providing shade and protection to cars. Even though there is high savings for implementing the system, it would require a feasibility study and comparison between alternative water sourcing technologies, such as desalination processes to ensure the sustainability of the alternative water sourcing solution.

Table 25 – Potential economic savings (PES) for the Scenario 1 ALU.

Scenario 1 and 1.1 ALU: Potential Economic Savings (PES): € (2023 – 2050)			
Scenario	SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
1.1	10 130 323	9 735 026	10 511 700
1.2	7 764 231	6 286 669	7 840 719

In line with the previous industrial case, Figure 25 and Figure 26 proposes two other scenarios, while Table 26 compares the potential economic savings of the scenarios:

- **Scenario 2**: treatment efficiency of 90%, RRC of 90%, and FWR of 50%, the rest of the parameters are the same (increase and no increase in freshwater (FW) consumption);
- **Scenario 3**: treatment efficiency of 90%, RCC of 90 %, FWR of 50%, and freshwater requirements capped in 2035.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

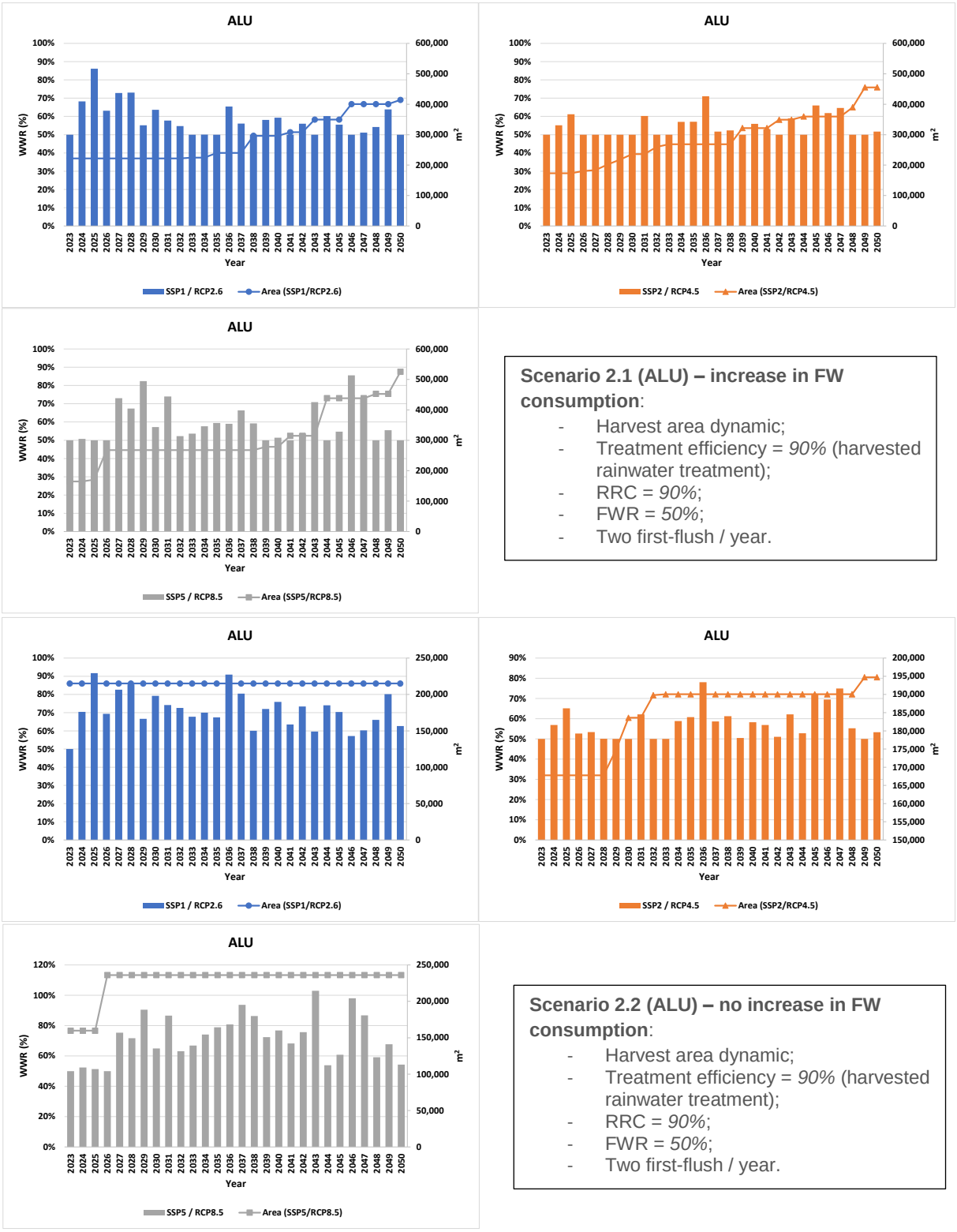
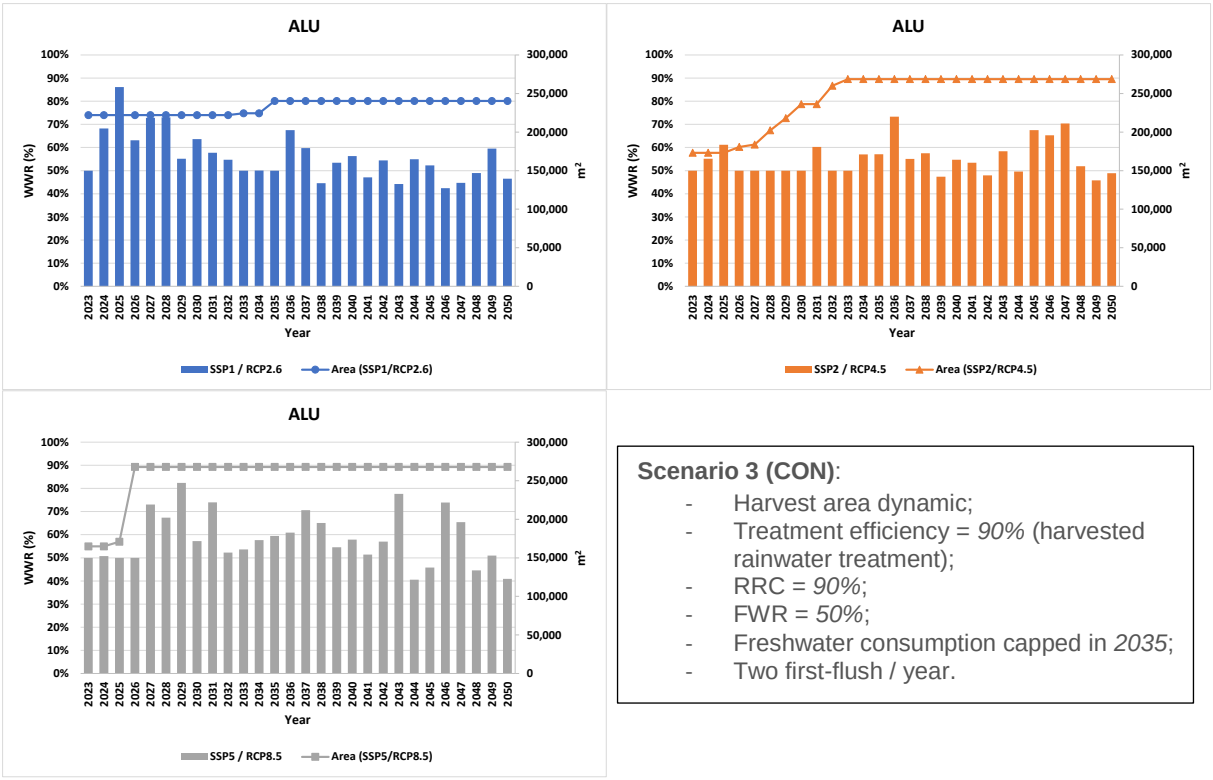


Figure 25 – Scenario 2 regarding dynamic rainfall and consumption input, and resulting harvestable area for ALU industrial site.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274



Scenario 3 (CON):

- Harvest area dynamic;
- Treatment efficiency = *90%* (harvested rainwater treatment);
- RRC = *90%*;
- FWR = *50%*;
- Freshwater consumption capped in *2035*;
- Two first-flush / year.

Figure 26 – Scenario 3 regarding dynamic rainfall and consumption input, and resulting harvestable area for ALU industrial site.

Table 26 – Potential economic savings (PES) for the all scenarios – comparison – ALU.

Scenario baseline, 1, 2 and 3 ALU: Potential Economic Savings (PES): € (2023 – 2050)			
Scenario	SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
Baseline	96 736	91 364	92 238
1.1	10 130 323	9 735 026	10 511 700
1.2	7 764 231	6 286 669	7 840 719
2.1	5 065 162	4 867 513	5 255 850
2.2	3 882 116	3 143 335	3 920 359
3	4 193 264	4 172 103	4 419 227

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3.2.3 Tubacex Tubos Inoxidables – Tubacex (TTI)

3.2.3.1 Characterising the Industry and rainwater

As with the previous two industrial site, the collection and characterisation of information was performed for the Industry and Rainwater steps – Table 27. The methodologies employed for characterising the water samples are those that are already in place by the industry (D2.2 and D4.1), while other methodologies for characterising the catchment area, freshwater consumption, etc, can be found in D2.2, D3.9, and D4.1.

Analysing the data for the TTI industrial site, it is possible to propose that the harvested rainwater can and cannot be used directly in TTI's processes. It can be used in the circuits were recycled water is currently being employed, and cannot for freshwater, even though by a slight margin, as the Ca and TSS are slightly higher in the rainwater compared to freshwater, therefore requiring treatment (Table 27 and D4.1) to avoid negative effects on the equipment and products. This potentially implies that not all of the harvested rainwater is recoverable (not accounting for RRC) and therefore some waste is generated (not accounting for the first-flush). Rainwater treatment can be performed by the onsite water treatment facility to reduce initial capital expenditure (CAPEX), however at the expense of operational expenditure (OPEX), that will potentially increase energy requirements. There are no onsite storage tanks that can be used, therefore further investments would be required, and the harvestable area for rainwater is the current rooftop area – largest size out of all industries analysed here. Other information in Table 27 will be relevant in subsequent sections.

Table 27 – Information gathered for step 1 and step 2 of the RWH DSS tool framework for TTI.

Step	Parameter	Input
INDUSTRY	*Location*	Amurrio, Álava, Basque Country, Spain (N 43 02.225, W 3 00.047).
	Onsite water treatment facility	Yes, for the treatment of two water circuits from processes: i) Sand filter; ii) Series composed of DAF, MD, PNFR.
	Catchment material	Rooftop – concrete and corrugated metal sheet.
	Catchment area	Rooftop area = 72 216 m^2.
	Freshwater quality	Freshwater: TSS < 1 mg/l; F < 90 mg/l; Al < 5 mg/l; Ca < 1 mg/l or Recycled water: COD < 70 mg/l; TSS < 20 mg/l; Cr < 50mg/l.
	Freshwater consumption	Average = 87 694 m^3 / year.
	Water Storage	No. Would potentially need to be constructed.
	Freshwater price	1.60 €/m^3
RAINWATER	*Climate*	Köppen-Geiger: Cfb – temperate oceanic climate or subtropical highland climate. No significant precipitation difference between seasons. Average rainfall = 781 mm / year[1].
	Rainwater quality	TOC < 3.0 mg/l; COD < 30 mg/l ; TSS < 2 mg/l ; SEC = 51.7 µS/cm; TN < 1.0 mg/l; F < 1.0 mg/l; Cr < 6.7 mg/l; Ca < 4.0 mg/l
	Historical data	Copernicus or ECA&D[1].

[1]Klein Tank, 2002.

3.2.3.2 Historical rainwater data: quick scan potentialities on harvesting and economic savings

Historical rainwater data collection and characterisation can be the first step to conduct in any project related with RWH (not accounting for available harvesting area), because without rain there is no possibility to harvest it. Therefore, an initial estimate of how much rainwater is potentially harvestable with the current harvest area and the rainfall volume is performed considering the following scenario: 100% of the rainfall is recoverable and reused (nothing lost) – however it is possible to reduce its volume through modelling to reflect potential treatment processes, evapotranspiration, etc. Even a range can be considered for worst case scenario (low rainwater recovery %, harvest material not adequate, e.g., RRC = 50%). The quick scan

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

can be presented to stakeholders beforehand, to serve as an enabler for conducting a full assessment of the potential behind the current harvest area at the industry. Table 28 presents the potentially harvestable volumes of rainwater for CON based on historical data (Table 27) retrieved from ECA&D. Equation 18 was used for calculation (excluding first-flush).

Table 28 – Potentially harvestable volumes of rainwater and economic savings for TTI.

Volume (m^3/y)	Potential economic savings – PES (€/y)	Cumulative PES (€): 2023 - 2050	Comment
56 111	89 778	2 424 006	European Climate Assessment & Dataset – average cumulative rainfall 781 mm / year: RCC and TE = 100%; A = 87 694 m^2 -Table 27.

The current rooftop harvest area available at the TTI industrial park has the potential to harvest 56 111 m^3 / y, potentially ~ 50% of current freshwater requirements and corresponding annual savings of 89 778 €. The quick scan indicates that the rainwater harvesting solution with the current setup is feasible as it can potentially cover up to 50% of current freshwater needs. This is attributed to the large harvesting area currently available and also high precipitation in the area.

3.2.3.3 Expected and projected industrial freshwater consumption

As with the previous two industrial cases, freshwater consumption in the future, by means of linear determination to maintain simplicity (other methods may be employed), was determined using Equation 15 and 16. Additionally, abnormal years were included in the analysis, as these represent potential disruptions to normal operation. For example, the year 2020 saw a decline in overall world production of consumables and materials due to the COVID-19 pandemic. These events will potentially occur in the coming years, more frequently, and possibly with greater impacts, resulting in greater disruption in productions and affecting overall industrial consumption. Therefore, the year 2020 was included in the analysis for freshwater consumption. Table 29 presents the percentages of increase and decrease from historical data supplied from the TTI partners. The data for freshwater consumption covers 2013 to 2020.

Table 29 – Percentages of increase and decrease of freshwater consumption at TTI.

Years	Annual increase / decrease in fresh water consumption – %	Expected / projected water consumption increase per year (AAGR) – %	*Expected water consumption increase – %: 2023 –		
			2030	2040	2050
2013 – 2014	19.85	2.33	17	48	86
2014 – 2015	-24.20				
2015 – 2016	15.02				
2016 – 2017	41.67				
2017 – 2018	-1.60				
2018 – 2019	-1.05				
2019 – 2020	-33.38				

*Over current consumption

Average freshwater consumption increases 2.33% per year, based on historical data. The past few years have seen a slight dip and a greater one from 2020, potentially due to the disruption brought on by the pandemic. Foreseeing freshwater consumption trend, the industry in 2030 is expected to consume 17% more than it does in 2023. By 2040 it would be 48%, and by 2050, 86%. This is projected in Figure 27.

These are theoretical values, and therefore it is expected that freshwater consumption should be capped given also the capacity of the industrial process. Restrictions can be added to the model to define the maximum expected freshwater consumption, and therefore project which year the capped consumption value will be reached.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

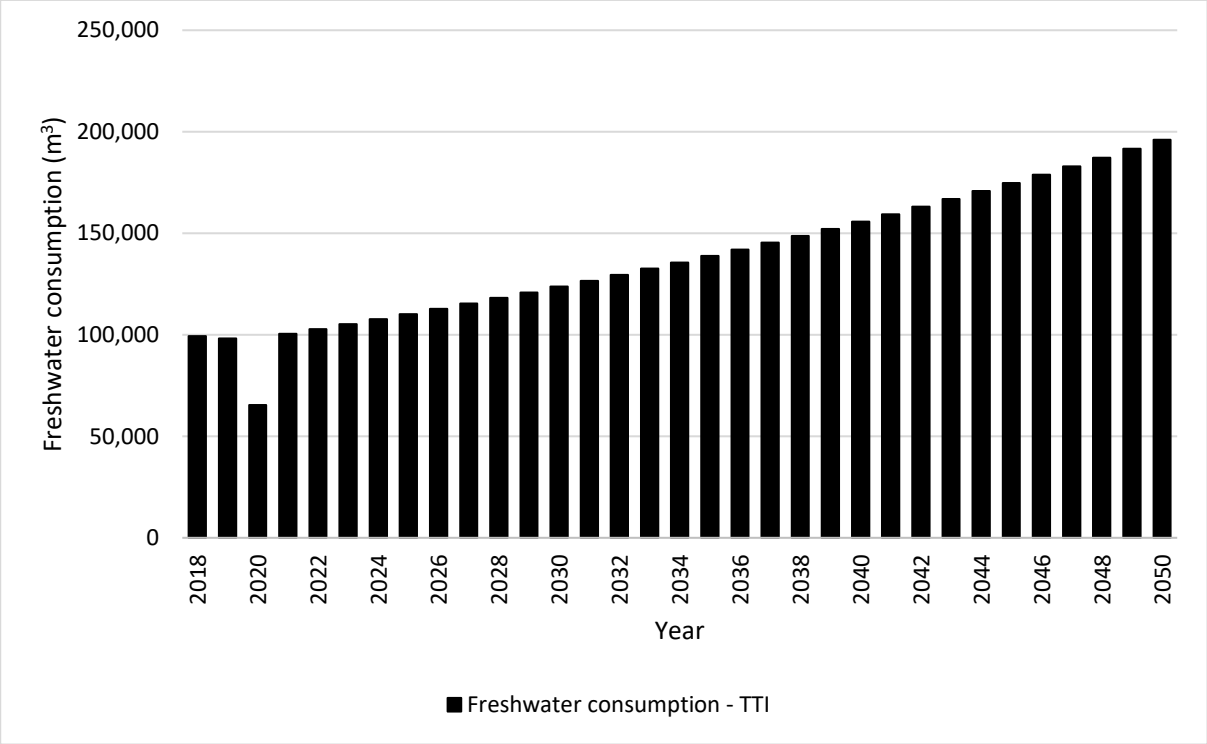
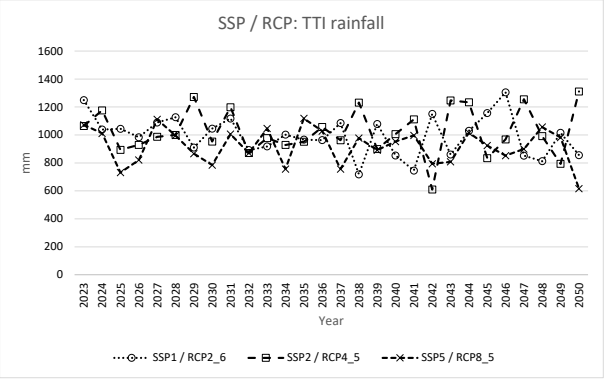


Figure 27 – TTI projected freshwater consumption until 2050.

3.2.3.4 Projected rainfall simulation considering the Representative Concentration Pathway (RCP)

Determining potential rainfall can be performed from annual precipitation averages, as performed in the quick scan procedure, or it can be obtained from the Copernicus Climate Data Store to simulate and project monthly average rainfalls following three different pathways (SSP / RCP). For the current situation, the monthly average rainfall for each SSP/RCP pathway from 2023 to 2050 is presented in Figure 28 for the industrial site region. From this dataset, it is possible to calculate the potential volumes of harvestable rainwater with the currently identified harvest area (Table 27) and determine to what extent can it substitute freshwater sourcing considering: treatment required (90% recovered), RRC = 90%, the harvesting area, and at least two first-flushes are performed per year (Figure 29).



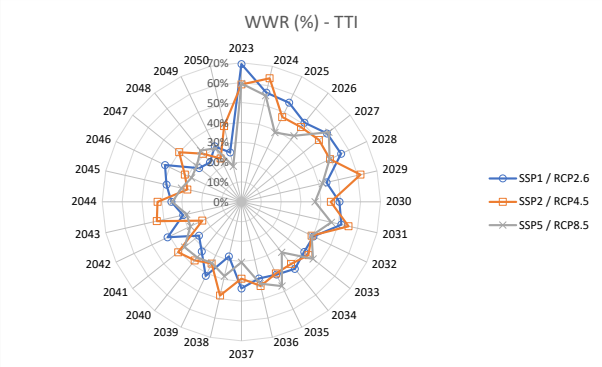
SSP	RCP	Description
1	2.6	Characterised by its sustainable development-oriented paradigm, often referred to as the "Green Society".
2	4.5	Considered the current path or trajectory the world is taking / Business as Usual (BAU) trajectory.
5	8.5	Emblematic of a development pathway heavily reliant on fossil fuels, eliminating "green" technologies.

Figure 28 – Average monthly expected rainfall for each SSP/RCP pathway from 2023 to 2050 at the TTI industrial site.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

To see the impact on reducing freshwater requirements, the Water Withdrawal Reduction (WWR) Indicator was selected and can be calculated following Equation 21.

Simulating the volume of harvestable rainwater and freshwater consumption at and by the industry, respectively, from 2023 – 2050 (not capping consumption), the projected % in water withdrawal reduction of the industry is presented, and consequently freshwater substituted with rainwater – Figure 29.



Baseline scenario:
- Harvest area static (current – Table 27);
- Treatment efficiency: 90% (harvested Rainwater treatment);
- RRC = 90%;
- Two first-flush per year.

Figure 29 – Potential WWR for the TTI industrial site considering the Baseline scenario.

Considering potential economic savings (PES), not including CAPEX or OPEX – most of the infrastructure is readily available and little to no investment is foreseen compared to installing a system with nothing available. OPEX on the other side should also be minimal, reflecting only on pumping (i.e. energy), treatment and associated maintenance costs. Table 30 presents the PES for the baseline scenario for 2023 – 2050.

Table 30 – Potential economic savings (PES) for the Baseline scenario TTI.

Baseline TTI: Potential Economic Savings (PES): € (2023 – 2050)		
SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
2 605 130	2 684 464	2 406 458

3.2.3.5 Dynamic harvest area to accompany projected freshwater requirements and rainfall: SSP / RCP scenarios

To enable decision support, a DSS tool was developed based on the Equations in section 2.3.1 to perform an incremental and dynamic simulation of a rainwater harvest area to implement or expand, considering input from stakeholders / DM on how much they wish to substitute freshwater with rainwater. This approach allows to evaluate the feasibility and implementation (or expanding) requirements of an RWH system. In short, the tool allows for the DM to choose how much freshwater they would like to substitute, i.e., the freshwater requirements (FWR) with harvested rainwater. This tool allows to foresee how the harvestable area increases in size to accommodate the step-wise implementation for harvesting rainwater volumes, influenced by the different SSP / RCP scenarios.

Figure 30 presents the results for a scenario regarding dynamic rainfall and industrial consumption input, and therefore simulating the required harvestable area to accommodate the criteria established by the DM on how much freshwater should be substituted by rainwater – contribution to a more sustainable and circular economy. **Scenario 1** is the same as the baseline scenario (3.4.3.4), with the addition of a new parameter – freshwater reduction (*FWR*). Here, the DM wants to cover 100% of total freshwater requirements with rainwater at the TTI industrial site, therefore *FWR* = 100%. Freshwater consumption production has not been capped, and will continue to increase to its projected value until 2050 (Figure 27).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

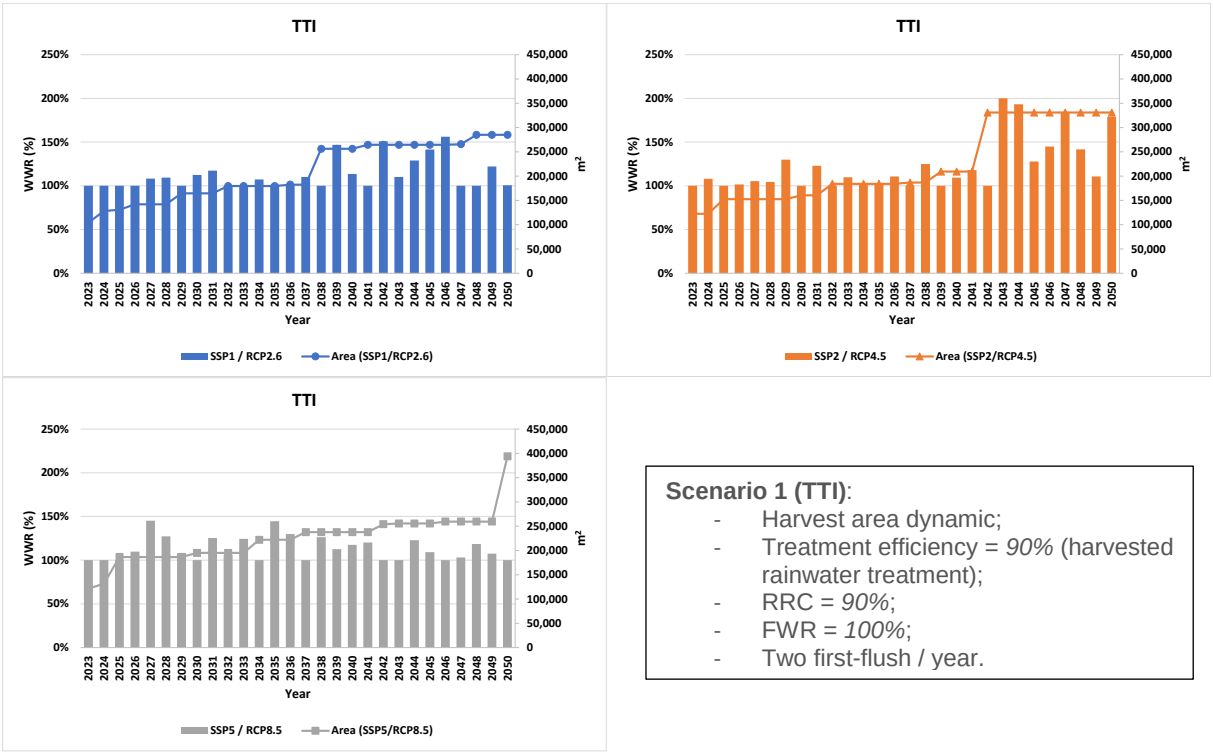


Figure 30 – Scenario 1 regarding dynamic rainfall and consumption input, and resulting harvestable area for TTI industrial site.

Figure 30 conveys the following information:

- The WWR indicates how much of the harvested rainwater can cover freshwater requirements every year, with a minimum of 100%, as this was defined by the decision-maker / stakeholder – values of FWR greater than 100% indicate that the volume of rainwater recovered and treated is greater than the projected volume of freshwater required by the industry – surplus;
- The potential harvest area, in a step-wise fashion, required to achieve the corresponding WWR value for a given year. The catchment area will progressively increase over the years as the freshwater requirements for each industrial site also increases and varying precipitation events.

PES indicates potential savings of covering freshwater with harvested rainwater (Table 31), and excludes CAPEX and OPEX. The difference between savings for this scenario and the baseline can be compared, with the implementation of the RWH system having associated costs – however lower than that projected for the other two previous industrial parks (harvest area in 2050 would be between 284 949 m^2 and 393 606 m^2, depending on the RCP/SSP) – possibly due to the higher precipitation rate and also comparable consumption rate at TTI. The combination of carports with photovoltaic panels (PV), which can generate solar energy to run the industrial facility when the sun is out, and harvest rainwater during precipitation events, is a multifunctional approach to decreasing overall energy and water demand, reflecting on the energy-water nexus, all while providing shade and protection to cars.

Table 31 – Potential economic savings (PES) for the Scenario 1 TTI.

Scenario 1 TTI: Potential Economic Savings (PES): € (2023 – 2050)		
SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
7 420 399	8 252 975	7 366 964

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

In line with the previous industrial cases, Figure 31 and Figure 32 proposes two other scenarios to evaluate, and Table 32 compares the potential economic savings between different scenarios:

- **Scenario 2**: treatment efficiency of 90%, RRC of 90%, and FWR of 50%, the rest of the parameters are the same;
- **Scenario 3**: treatment efficiency of 90%, RCC of 90 %, FWR of 50%, and freshwater requirements capped in 2035.

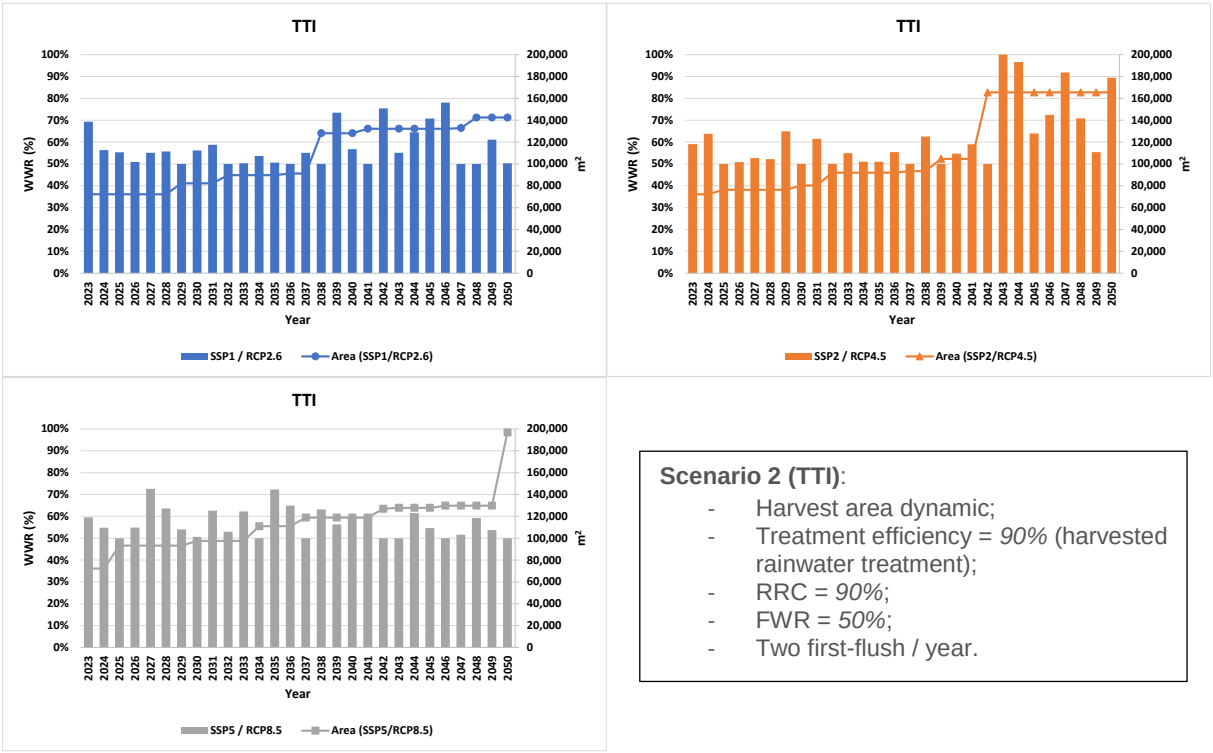
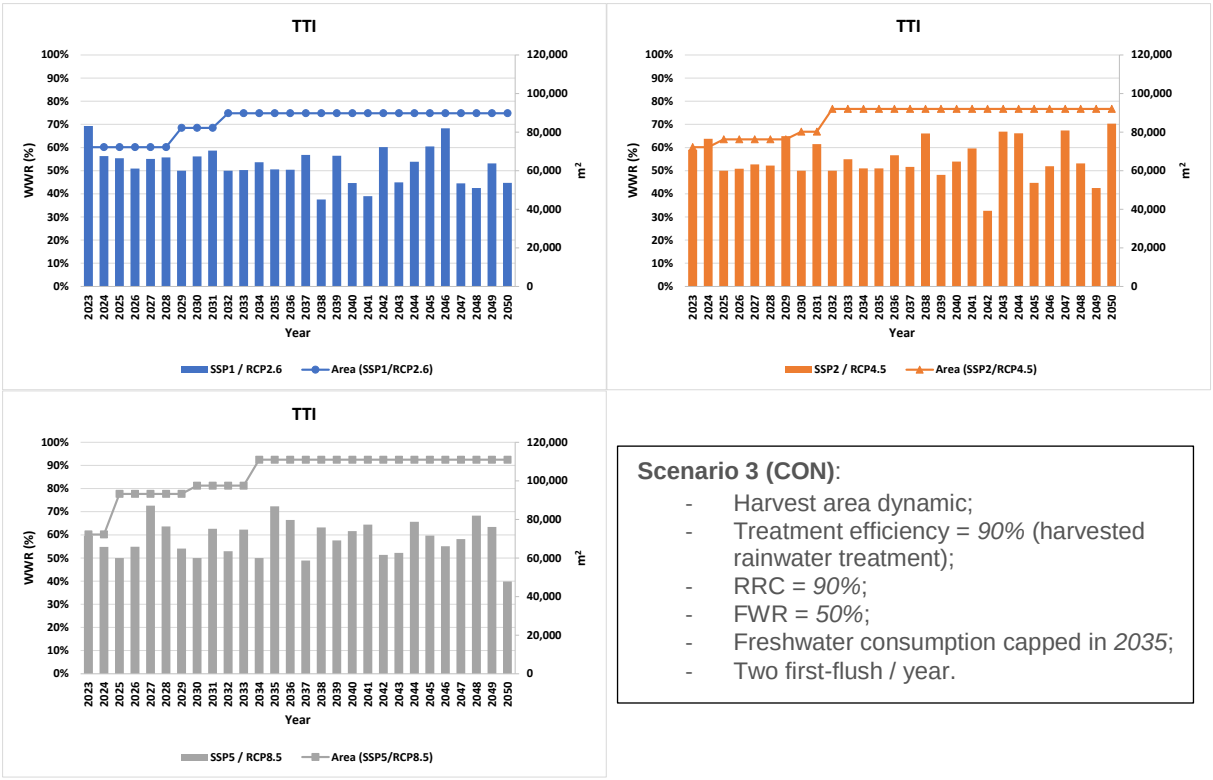


Figure 31 – Scenario 2 regarding dynamic rainfall and consumption input, and resulting harvestable area for TTI industrial site.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274



Scenario 3 (CON):

- Harvest area dynamic;
- Treatment efficiency = *90%* (harvested rainwater treatment);
- RRC = *90%*;
- FWR = *50%*;
- Freshwater consumption capped in *2035*;
- Two first-flush / year.

Figure 32 – Scenario 3 regarding dynamic rainfall and consumption input, and resulting harvestable area for TTI industrial site.

Table 32 – Potential economic savings (PES) for the all scenarios – comparison – TTI.

Scenario baseline, 1, 2 and 3 TTI: Potential Economic Savings (PES): € (2023 – 2050)			
Scenario	SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
Baseline	2 605 130	2 684 464	2 406 458
1	7 420 399	8 252 975	7 366 964
2	3 768 628	4 158 630	3 707 836
3	3 059 693	3 226 793	3 424 057

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3.2.4 Discussion

Results are discussed in this section for all three of the industrial sites and compared between each other. The discussion will follow the same structure as performed for each industrial case, therefore discussing each section. Only reference to previous sections will be inferred.

3.2.4.1 Characterising the Industry and rainwater

Table 15, Table 21 and Table 27 informs on the location of the industries across the different regions in the EU. Two of the industries share the same climate classification according to Köppen-Geiger (ALU and TTI), and therefore it is expected to have similar precipitation volumes. However, over a 100 mm/year more is expected at the Spanish (TTI) site over the Swedish (ALU), and just under 200 mm/year over the Italian (CON) site, therefore TTI presents the best potential to employ an RWH system in terms of precipitation volume. All industrial sites already employ some sort of the onsite water treatment facility, which potentially can be used or adapted to treat rainwater, therefore reducing initial investment costs (reduced CAPEX). It is recommended that the monitoring of selected parameters regarding rainwater be an ongoing task at the industrial sites, therefore ensuring that they meet the industries requirements and treatment efficiencies can be adjusted accordingly – a next step in this direction could be the digitalisation of an RWH system, therefore automating the process.

All sites employ similar roof structures, either made from concrete and / or galvanised / corrugated metal sheet, therefore reflecting low potential for rainwater loss (RRC = 90%). The freshwater quality of all sites is virtually the same, except for CON which sources its water from underground, therefore higher concentrations are expected. On average, ALU presented itself as the greatest user of freshwater, not employing any form of recycling water in their system, however, water that is discharged into the sea is of high quality and the pollutants removed are sold to the construction market (D3.9). For this water to be reused in the ALU industry, further treatment would be required to match or better freshwater quality (D2.2 and D4.1). Harvested rainwater for CON can be used directly in the processes, as the rainwater quality is better than the freshwater quality currently employed by the industry, while TTI could also directly use the rainwater in their processes, requiring minimal treatment. For ALU, this does not suffice, as additional treatment of rainwater would be required to be used in its processes. Apart from the RWH structure, storage tanks, either underground or aboveground, will be needed to store the harvested rainwater. The volume of the storage tanks should be decided on by the stakeholders / DM, depending on the volume of harvestable rainwater target. Ideally, as for the CON site, they have tanks that can support 100 m^3 or more.

The harvest areas, i.e., rooftops, for CON and TTI are within the same range, while for ALU the rooftop area is relatively small, therefore low harvest volumes are expected for the current size – this in contrast with the high consumption of freshwater that ALU currently practises. This already gives indication that either high precipitation events need to occur at the ALU site for the current harvest area, or that there is a need to increase the catchment area to very large proportions. This hinders on the feasibility of the RWH solution for ALU, and therefore suggestions for alternative forms of sourcing freshwater may be inferred, such as desalination plants – ALU is located very close to the sea. However, this can only be confirmed in the next sections. Therefore, any solution proposed would greatly improve the sustainability of the ALU site. However, investment costs need to be made, and from an initial overview, CON and TTI seem better candidates for installing RWH solutions.

3.2.4.2 Historical rainwater data: quick scan potentialities on harvesting and economic savings

Historical rainwater indicates the potential behind employing an RWH system in the industrial sites, as it identifies trends from past data. Historical data was collected from the European

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Climate Assessment & Dataset (http://www.ecad.eu) (Klein Tank, 2002a) site, statistically treated and an average cumulative precipitation value calculated for each of the sites (D4.1). Savings for the ALU industrial site from 2023 to 2050 are not attractive and might not justify the investment considering the current harvest area (11 €/d saving), as discussed in the previous section. Also, high investment cost to increase the current harvest area to proportions that might enable the RWH solution feasible should be considered and compared with a desalination solution. The more attractive industrial site to install an RWH system, from an economical point-of-view and considering the current available harvest area and annual precipitation, is the TTI industrial site – 246 €/d potential saving. The CON industrial site also presents an interesting potential for installing RWH system with the current harvest area – 118 €/d potential saving.

3.2.4.3 Expected and projected industrial freshwater consumption

Industrial consumption of freshwater is expected to increase until 2050 and beyond, as the demand of commodities is expected to increase with the world population. To ensure that future generations have the right to a sustainable future, sustainable responsibility and accountability should be imbedded in linear processes to ensure that a transition towards a more sustainable management of resources is achieved. One of those resources is water, essential in all sectors regarding anthropogenic activity, and also the natural environment. Therefore, alternative solutions for capturing, using, reusing, treating and restoring and discharging water back to its original conditions in the environment should be part of this plan, and reinforced by the EU.

Growth in water consumption for all the industries was calculated based on previously observed freshwater consumption patterns (linear calculation). When calculating the AAGR for freshwater consumption, abnormal years are crucial to be considered in the analysis, as these represent potential disruptions to normal operation, i.e. COVID-19 pandemic, water shortages, strikes, etc., and the potential for future events, whether from climate change, pandemics, social disruption, sustainability issues, will be more frequently, and possibly with greater impacts. The result from the COVID pandemic is a great lighthouse on this matter as it generated a large disruption in the supply chain and overall raw material consumption by the industrial – verified by the data for water consumption from the industrial sites (Table 17, Table 23 and Table 29). The increase in water consumption presented by the industries demonstrate a steady and conservative growth in overall output. However, this growth can be stopped by the DM at any time as the industrial facility is also limited by its site boundaries and overall production capacity, therefore a foreseen maximum production output is achievable and water consumption can be limited to a maximum value or tangible value within a given timeframe.

3.2.4.4 Projected rainfall simulation considering the Representative Concentration Pathway (RCP)

The Intergovernmental Panel on Climate Change (IPCC) framework of the Shared Socioeconomic Pathways (SSPs) facilitates the exploitation of Coupled Model Intercomparison Project phase 6 (CMIP6) model results. The great outcome of this approach is that it interlinks the levels of CO_2 concentration, socioeconomic advancement trajectories, and collectively agreed-upon policy presumptions, providing a solid foundation for complex scenario simulations, and designed at the global level in a consistent manner. Probably the data base and model used to project the precipitation events will change on a yearly basis, given the advancement of knowledge and also uncertainty regarding climate events. The approach encompasses the convergence of SSPs and the Representative Concentration Pathways (RCPs) in order to produce a comprehensive matrix, that accounts for anthropogenic pressures on the climate system and model outcomes. The UKESM1-0-LL model (https://ukesm.ac.uk/wp-content/uploads/2022/06/UKESM1-0-LL.html) was used to estimate

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

monthly rainfalls for the suggested scenarios from 2023 to 2050, and the study framed within this proposal:

- **SSP1 / RCP2.6** – Characterised by its sustainable development-oriented paradigm, often referred to as the "Green Society";
- **SSP2 / RCP4.5** – Considered the current path or trajectory the world is taking / Business as Usual (BAU) trajectory;
- **SSP5 / RCP8.5** – Representative of a development pathway heavily reliant on fossil fuels, eliminating “green” technologies.

Modelling the different pathways to determine the potential rainfall in each of the different regions for the industrial sites demonstrates how precipitation will be affected by climate change, socioeconomic advancement, and policy presumptions. Through this approach, what stands out is the precipitation amplitude between the pathways for the CON industrial site (as low as 350 mm / year and as high as 1500 mm / year), which indicates variability and uncertainty in precipitation events from year to year. However, the average precipitation values for CON on a yearly basis (Table 33) are relatively high. The ALU industrial site presents the most stable precipitation amplitude until 2050 for all the pathways – less uncertainty is expected / projected regarding precipitation events; however, it presents the lowest average precipitation values for all the pathways. It was expected that ALU would present similar average precipitation values as TTI, both classified as Cfb (Köppen-Geiger), however the TTI average precipitation values are closer to CON (Cfa). The TTI industrial site presents the highest average precipitation values of the three industrial sites.

Comparing the values in Table 33 with the values from historical data (average precipitation), the CON and TTI industrial sites present greater precipitation values following the UKESM1-0-LL model, while ALU historical precipitation records are relatively in line with the projected ones for the different pathways. This indicates that the initial conclusions drawn for the CON and TTI sites regarding historical sites would potentially underestimate the volume of harvestable rainwater, while for ALU this potentially this potentially closer to reality.

Table 33 – Average precipitation values for the industrial sites considering the different pathways and also historical data from ECA&D.

Industrial site	Expected average rainfall (mm/year): 2023 - 2050			Average precipitation (mm/year)
	SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5	ECA&D[1]
CON	858	919	881	583
ALU	731	691	697	664
TTI	995	1025	919	781

[1]Klein Tank, 2002.

In the current scenario (**Baseline**: currently available harvest area; Treatment efficiency = 90%; RRC = 90%; Two first-flush per year), implementing the RWH solution and simulating the different SSP/RCP pathways, on average CON and TTI industrial sites would be able to cover around 30% and 41% of their freshwater needs with harvested rainwater, respectively (Table 34) – considering that SSP2 is in the middle of the other pathways. ALU results indicate that only around 1.03% - 2.0% (not capped and capped to current FW consumption, respectively) of the industries freshwater needs could be covered with rainwater harvesting, possibly due to the lower precipitation comparatively to the other regions, the higher consumption in freshwater, and relatively small size of the catchment area (3.4.2.1). This is reflected in the economical savings from substituting freshwater with harvested rainwater, which are much lower than for CON and TTI (Table 34). Again, from this analysis it is possible to conclude that the ALU industrial park with its current structure, is not sufficient to justify the investment of the RWH solution. It is worth noting that the economic savings considering historical data are in line with those projected by the SSP/RCP.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°958274

Table 34 – Expected volume of rainwater covering freshwater needs for all industrial sites.

Industrial site	Expected volume of rainwater covering freshwater needs (%): 2023 - 2050		
	SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
CON	28	30	29
ALU	1.09	1.03	1.04
TTI	40	41	37

3.2.4.5 Dynamic harvest area to accompany projected freshwater requirements and rainfall: SSP / RCP scenarios

Analysing the scenario results after dynamically simulating RWH area for the substitution of freshwater with rainwater, through progressively incrementing the harvestable area, the following information was gained:

Scenario 1
This is considered the ideal scenario (%), with limited rainwater lost through evapotranspiration and treatment (only surpassed if treatment efficiency = 100% (no treatment required); and RRC = 100%). The bars in the chart that surpass the 100% mark indicate that the amount of rainwater harvested during a given year is enough to satisfy the projected water consumption of the industry (Figure 18, Figure 24 and Figure 30). The surpass can be stored in storage tanks or sold to surrounding industries. To achieve or guarantee that all sites can substitute 100% freshwater for the three different pathways, a progressive increase over the years of the harvest area is required until the horizon date of 2050.

As mentioned previously, the ALU industrial site consumes the most water out of the three industrial parks, has the smallest harvest area, and also the lowest projected precipitation averages out of the three. An increase between 324 260 – 438 594 m^2 from 5 360 m^2 would be required from the start for the ALU site (over 6000% increase). This combination makes the investment less attractive to ALU stakeholders as the site would require to have a plan to expand to an area of at least 500 000 m^2 (e.g. 500x1000 m) in order to cover 100% freshwater requirements by 2038. A work around this would be to include carports that combine photovoltaic panels (PV) which can generate energy to run the industrial facility when the sun is out, and harvest rainwater during precipitation events, all while providing shade and protection to company cars. Observing the results capped for the current consumption, the rooftop area expansion for SSP1 would be the same throughout, guaranteeing the required volume of water for the industrial site. SSP2 presented probably the best strategy for implementing an RWH system if this were the case, and also considering the transition to greener technologies were slow.

Observing TTI's projected RWH solution trajectory, it is possible to conclude that it requires the lowest increase in harvest area compared to the other two industrial sites, therefore possibly the lowest initial investment. The difference between SSP1 and SSP2 pathways is potentially minimal for TTI, while the SSP5 pathway, as an extreme case, implies further invests to harvest rainwater (60 000 m^2 to 110 000 m^2 more than for SSP1 and SSP2). Therefore, if the policy of the EU is to reduce emissions and go a green path, the recommendation would be to follow one or the other pathway solution, possibly inclining towards the SSP1 solution as it presents similar harvest areas as SSP2, and from 2037 its increase in area supports the projected precipitation observed for SSP2. Additionally, SSP1's investment costs should be lower with a similar outcome as SSP2.

CON on the other hand may also require a high initial investment for implementing RWH structure, as it requires also large catchment areas similar to ALU, and from the first year an increase of at least 58% of the harvest area regarding SSP5 (initial harvest area = 63 000m^2). Considering the horizon year, the difference between the catchment areas projected for SSP2 and SSP5 is just under 250 000 m^2 (500x500m), and by observing the data closely, it is

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

possible to conclude that the industrial site region varies the most when comparing the pathways and future precipitation events (projected harvest areas over the years for each pathway is completely different). However, in certain years, the volume of harvested rainwater can potentially surpass the volume of water required for the industrial activities, again requiring storage to be used in subsequent years or sold on the market to surrounding industries. This is observable in 2041, where the volume of harvested rainwater will surpass the volume of freshwater requirements by 300%). Observing the different pathways, the most feasible and balanced approach seems to be the area projected for SSP2, as between 2032 to 2045, the progressively increasing catchment area can cover the requirements projected for SSP1 (year 2037) and SSP5 (year 2038), and from 2039 onwards as SSP1 and SSP5 both present WWR values greater than 100% for their catchment area.

The Potential Economic Savings (PES) – Table 19, Table 25 and Table 31, excluding CAPEX and OPEX, indicates that ALU has the most to gain with the solution, however at the potential expense of major investment costs compared to the other two industrial sites. Regarding CON and TTI, the PES are relatively similar, both presenting high potential savings and requiring less initial invest compared to ALU, therefore the initial investment costs are justifiable. The economic values demonstrate very little variation between the pathways (except for CON, where precipitation is projected to vary more between scenarios). In terms of monetary savings, TTI's ideal pathway would follow the same as previously mentioned – SSP1, as savings are similar and the difference in costs would potentially outweigh the gains. Observing CON's pathways, and also in line with previous comments, SSP2 would suffice as concluded previously, where gains between different strategies (SSP1 and SSP2) are minimal, but investment costs in SSP1 are higher due to the larger harvest area required from the midterm analysis. As mentioned previously, ALU has the potential for greater savings across all pathways, as well as transversally compared to the other industrial sites – this is related to the large consumption of freshwater by the industry – however, the initial investment costs will be higher because ALU requires a large catchment.

Analysing the results from scenario 1 and analysing with the current model parameters, all industrial sites would virtually require an increase of the catchment area on nearly an annual basis. For scenario 1, the greatest monetary savings are expected to be made, at the trade-off of the highest investment costs.

Scenario 2:
This scenario is to observe the changes that can occur it the decision-maker considers reducing the requirement of rainwater to substitute freshwater (from 100% to 50%). Other model parameters remained the same for all industrial case sites. Observing the results from all the industrial sites and comparing them with Scenario 1, it is noticeable that all harvest areas required decreased to essentially half, while the trend for implementing the areas over the years remained the same. This is expected as the other model parameters did not change, therefore the decrease in area is proportional to the substitution of freshwater requirements with the volume of rainwater (50%). Changing the other parameters for other scenarios, i.e., different treatment efficiencies or different harvest area material (RRC's) would further influence the size of the harvest area (potentially increase it) and therefore not reflect a proportional effect. Observing capped FW consumption with the current consumption rate at ALU, it is possible to observe that the harvest area would decrease and that the ideal pathway would b to follow SSP2 as described previously for scenario 1.

In terms of PES, as expected, regarding Scenario 2 for all industrial sites and pathways they are expected to reduce by 50% as only 50% of freshwater is covered by rainwater. This also accounts for surplus volumes of water, which can be stored or sold. Again, if other parameters changed, this saving would not be proportional.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

An example can be seen below for a new Scenario 2.1 (Figure 33 and Table 35). Scenario 2.1 considers a more conservative treatment efficiency for rainwater (70%), the rest remains the same as in Scenario 2.1 in section 3.2.1, 3.2.2 and 3.2.3.

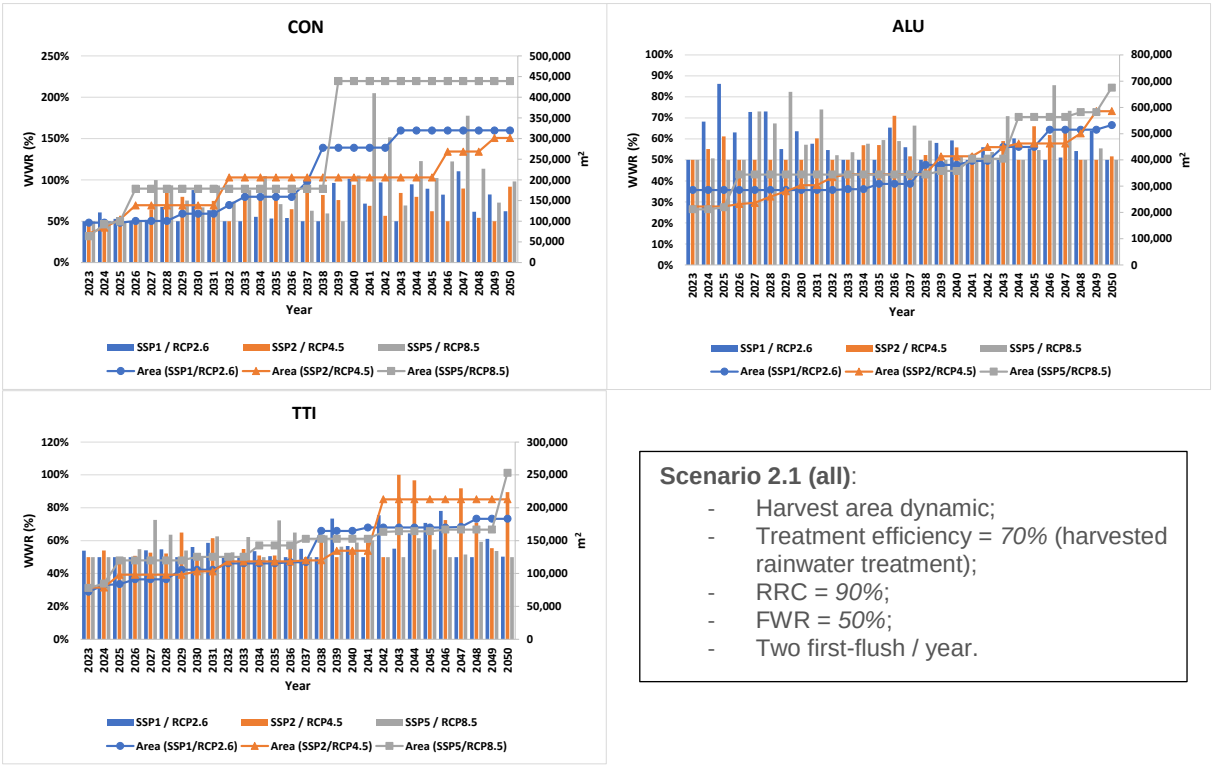


Figure 33 – Scenario 2.1 regarding dynamic rainfall and consumption input, and resulting harvestable area for all industrial site.

Table 35 – Potential economic savings (PES) for the Scenario 2.1 for all industrial sites.

Scenario 2.1: Potential Economic Savings (PES): € (2023 – 2050)			
Industrial site	SSP1 / RCP2.6	SSP2 / RCP4.5	SSP5 / RCP8.5
CON	3 166 812	3 194 727	4 338 961
ALU	5 065 617	4 867 790	5 256 549
TTI	3 716 990	4 126 938	3 683 672

Comparatively, due to the loss of water during the treatment phase, there is less PES observed. However, the increase in circularity is still possible, especially for CON and TTI, as they can source water with less quality for their industrial processes, therefore the discharged water from the treatment line can be reused in the system. In terms of harvest area, for all industrial cases this will increase because there is need to harvest more rainwater to offset the volume of rainwater that is discharged during treatment.

Scenario 3:
The third scenario (Scenario 3) builds on Scenario 2, however, it considers that the DM foresees the maximum water consumption of the industrial site by the year 2035. Observing Figure 20, the maximum harvest area for the CON industrial site will be implemented before reaching the year 2035 – for SSP5 it is expected in 2026. Worth noting is that the harvest area projected for SSP5 is lower than for SSP2, and the lowest projected harvest area is for SSP1 – therefore potentially the harvest area for SSP5 is the better bet for the RWH solution. Comparatively with the other scenarios, the overall harvest area is reduced regarding all social pathways, saving on initial investment costs for the stakeholders, while occasionally the harvested rainwater volume covers the water requirements of the industry, and in certain years

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

it surpasses the requirements of the industry for SSP2 and SSP5. Regarding the ALU industrial site, again the maximum harvest area required regarding SSP5 is implemented before the year 2035 (Figure 26) – however if the consumption is capped, the pathway would follow that of SSP2. For SSP1 this is maintained virtually throughout the proposed period (increasing once in 2035), while for the SSP2 pathway, there is a gradual increase of the harvest area over the years, reaching the maximum required area by 2033. In this analysis, possibly the most balanced approach to implementing an RWH structure would be to follow the SSP2 pathway, which would guarantee SSP1 and virtually achieve the volumes projected by SSP5. Finally, TTI would potentially be the best site to implement an RWH system, as the maximum size of the structure would be under 120 000 m^2 total (already onsite 72 216 m^2 is available for RWH). For SSP1 and SSP2, the harvest areas are virtually the same, therefore the area proposed by these two pathways would possibly be the best option. Again, if the quality of the harvested rainwater is sufficient for the industrial site, then the treatment step could be avoided or reduced, recovering more rainwater and increasing the substitution of freshwater with rainwater. Alternatively, the area for RWH could be reduced, therefore resulting in lower initial investment. To note, that seldomly do the three solutions for the different pathways allow to achieve 100% coverage of water requirements.

In terms of PES, the industrial sites are expected to have the lowest values when compared to the other scenarios, but at the expense of reducing the volume of freshwater to substitute with rainwater, the capping of the amount of water required by the industry, as well as implying lower initial investment costs to setup / extend the current available area for RWH. Scenario 3 is a well-adjusted approach to the RWH solution, as it considers that the industry will one day reach its capacity, therefore lowering investment and balancing return on investment. In fact, in all of the industrial sites, the PES for Scenario 3 are lower, but overall investment costs should also be much lower due to overall harvest area size and similar to sufficient results as Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

3.3 Interactive software

The interactive software integrates the work developed in D3.9 and the RWH tool developed here. The following section presents the graphic interface and options that are available to the end-user. As the Application is an ongoing development, the objective is to present the final version at the last iWAYS conference, were participants can interact with it, and see different benefits and trade-offs from their current and potentially future practices towards a circular and sustainable economy, including economic indicators. All calculations and results for the three use-cases can be seen in D3.9, as well as in this document.

3.3.1.1 Integration of WWE and alternative RWH DSS in the interactive software

Figure 34, Figure 35 and Figure 36 present the graphic user interface of the application. Figure 34 presents the main graphical user interface (GUI), where the country of the industrial site can be selected. At the top are three tabs, which allows the user to navigate between the iWAYs industrial site setup, the relating graphics and the help tab, in order to guide the end-user. After selecting the country in the iWAYS tab, high-level information is displayed regarding the climate classification and annual precipitation following Köppen-Geiger. After this is selected, then different characteristics can be inserted in the Choose the Characterisation menu, which comprises of the Onsite Structure, Energy, Water source and Waste emissions (as detailed in section 2.4). Here it is also possible to detail the model inputs for the RWH solution (current and/or for prospective modelling).

Figure 34 – Graphical user interface (GUI).

Clicking on each of the characterisation buttons brings up another menu that will need the input from the user. Figure 35 presents the popup menu regarding the onsite structure and energy. Figure 36 presents the popup menu regarding Water source and Waste emissions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

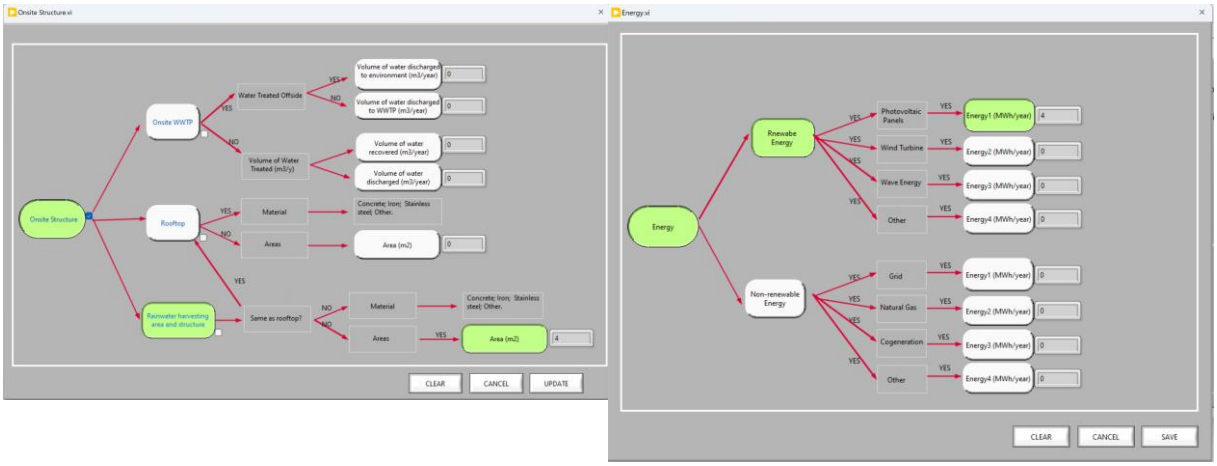


Figure 35 – Popup menu for selecting the constituents of the onsite structure and energy sourcing.

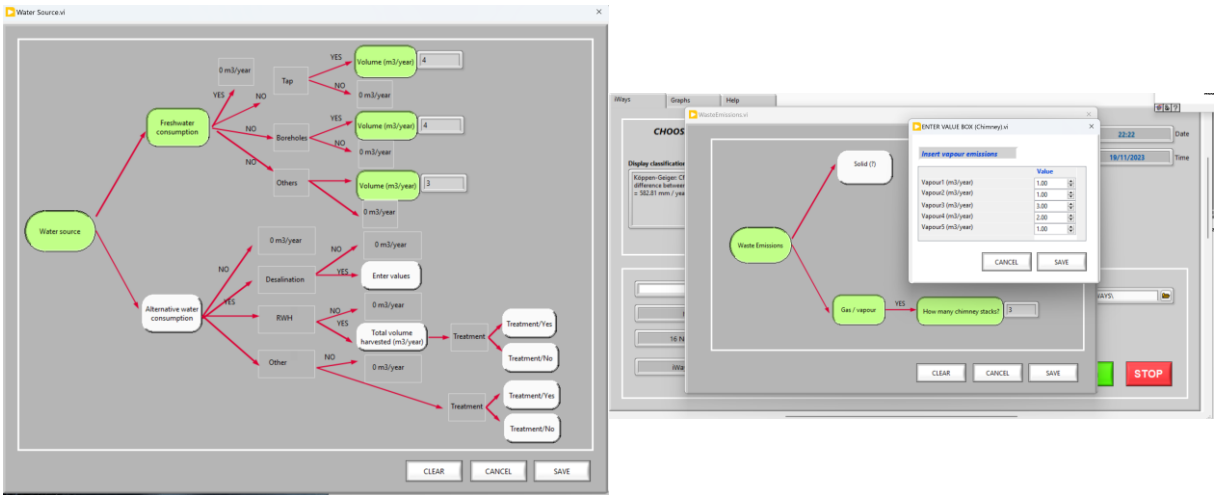


Figure 36 – Popup menu for selecting the constituents of the Water source and Waste emissions.

Each characteristic is selected by the end-user and information entered to the App, therefore to calculate and present the results as graphs (Figure 37). The results are in the same format and information as presented in D3.9, while additional indicators such as the payback period is also considered.

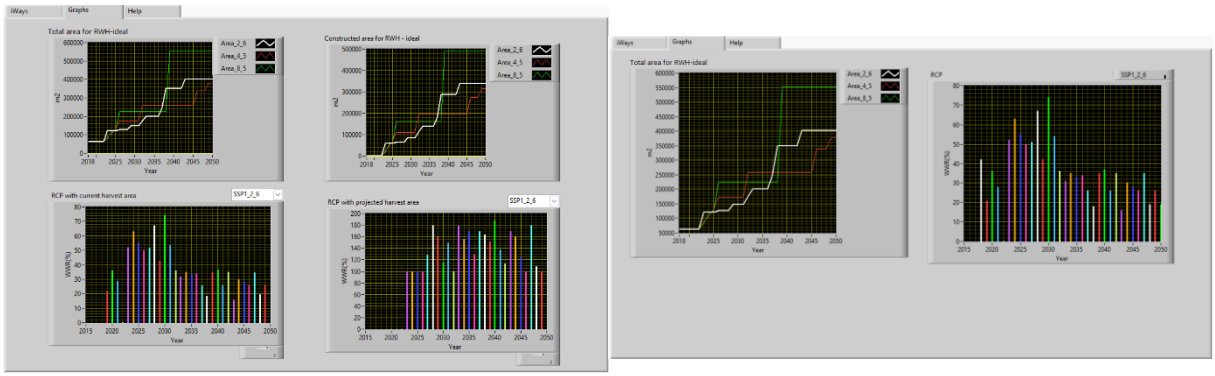


Figure 37 – Results as graphs from outcomes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

The App can be used as quick scan and planning tool for a step-wise procedure for implementing the iWAYS solutions, reflecting on the investment and operational costs, as well as the gains over the years. It classifies the industry in terms of circularity (D3.9), and will have a component related with sustainability and also build on the economic indicators in D3.9 and report the potential payback period. It will be extended to consider most regions in Europe, where data is available. Currently, it functions with information for the regions and use-cases from this project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

4 Conclusion

The MODSS tool enables optimising the form in which industries can source different grades of water that can be used in their processes. By employing such a tool, benefits can be achieved based on the criteria preferences of the DM in order to optimise their process and consequential product output in a more sustainable and circular manner. The tool has the potential to be applied to any industry, with any onsite WWTP and can be tailored to any preference.

The integration of the tools developed in the D3.9and here into the interactive software enables industries to play around with different configurations and understand what current and potentially future impacts are in terms of energy, water and waste (i.e. emissions to the atmosphere). Additionally, it provides prospective scenarios in regard to potential rainwater harvesting (RWH) solutions depending on different trajectories (it can also be considered a sensitivity analyses), while also recommending alternative ones if the RWH solution is not a viable option. The following conclusions may be inferred:

CON is potentially the most flexible industrial case here, as it can use water with varying quality types, as well as a direct substitute for freshwater needs. This indicates that the baseline scenario already presents an interesting starting point for an RWH solution, as it can potentially cover around 30% of the industries FW needs (following any of the RCP/SSP pathways). Regarding the scenarios, a feasible route for expanding the current RWH potential would be to follow scenario 2 or 3 – 50% of freshwater, especially SSP2's path as it has the smallest harvest area requirement, and in most years is well above the 50% requirements. Capping water consumption also results in benefits in terms of overall harvest area size, allowing for savings of 32% considering SSP2. Therefore, if this is foreseen, it can help propel the adoption of an RWH solution even more.

Out of the three use-cases assessed here, **ALU** is probably the one with the least potential to implement an RWH solution due to the current available harvest area, relatively to the increase in harvest area required to reduce freshwater requirements. The current harvest area will only account for a small fraction (~2%) of the freshwater needs, and this would still need to be treated by the onsite WWTP as ALU requires a high-quality water for its processes. Additionally, the industry's overall freshwater requirements (highest of the three) and lowest precipitation forecast further hinder implementation. Even with the water consumption capped from 2022, the harvest area required would be at least 189 384 m^2 (SSP2 – increase of 3 433% over the original harvest area). Therefore, a joint venture with other industries in the vicinity for implementing an RWH solution, requiring further investigation, or alternative sources of water (e.g. desalination) would be recommended for ALU use-case.

TTI out of the three use-case sites is the best positioned to implement an RWH solution due to its current available harvest area which can cover 41% (until 2050) of its current freshwater needs even with a progressive increase in overall water consumption. This is already a good indicator of the potential at the site for RWH, and that an increase the harvest area, (below a total of 200 000 m^2 for scenario's 2 and 3). The potential of directly employing the harvested rainwater in the processes without specific treatment further contributes to the feasibility of an RWH solution. The best solution for the industry would potentially be scenario 2 or 3 – this implies that until 2050, the harvest area would need to increase at least 66% of its original size (if capped) or double (not capped). Following SSP1 pathway would potentially be the best choice, as for later stages it presents the smallest increment in overall harvest area, and guarantees at least 50% of the freshwater requirements are covered by harvested rainwater. Alternatively, the current available area for RWH would also be an interesting option, and if water consumption were capped the baseline scenario would be more attractive.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

5 References

Alabi, M., Arnesh, T., Van Rensburg, N.J. (2019). Industry 4.0: innovative solutions for the water industry. *Proceedings of the American Society for Engineering Management 2019 International Annual Conference E. Schott, H. Keathley, and C. Krejci eds*.

Asghari M, Fathollahi-Fard AM, Mirzapour Al-e-hashem SMJ, Dulebenets MA (2022). Transformation and Linearization Techniques in Optimization: A State-of-the-Art Survey. *Mathematics*, 10(2):283.

Blythe, J., Nash, K., Yates, J., Cumming, G., 2017. Feedbacks as a bridging concept for advancing transdisciplinary sustainability research. *Curr. Opin. Environ. Sustain.*, Open issue, part II 26–27, pp. 114–119.

Danishvar, M., Danishvar, S., Katsou, E., Mansouri, S.A. & Mousavi, A. (2021). Energy-aware flowshop scheduling: A case for AI-driven sustainable manufacturing. *IEEE*, 9, 141678 – 141692.

European Commission, ICT4Water, (2018). *Digital single market for water services action plan: final report*. Publications Office, LU.

Gittins, J.R., Hemingway, J.R., Dajka, J.-C., 2021. How a water-resources crisis highlights social-ecological disconnects. *Water Res*. 194, 116937.

Henggeler Antunes, C., Alves, M. J. and Clímaco, J. (2016). *Multiobjective linear and integer programming*. New York, NY: Springer, pp. 1 – 216.

Klein Tank, A.M.G. (2002). Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *International Journal of Climatology*, 22, pp. 1441 – 1453.

Kriegler, E., Edmonds, J., Hallegatte, S., et al., (2014). A new scenario framework for climate change research: the concept of shared climate policy assumptions. *Climatic Change*, 122, 401–414.

Lu, H.-P., Yu, H.-J., Lu, S.S.K., (2001). The effects of cognitive style and model type on DSS acceptance: An empirical study. *Eur. J. Oper. Res*. 131, 649–663.

McIntosh, B.S., Ascough, J.C., Twery, M., Chew, J., Elmahdi, A., Haase, D., Harou, J.J., Hepting, D., Cuddy, S., Jakeman, A.J., Chen, S., Kassahun, A., Lautenbach, S., Matthews, K., Merritt, W., Quinn, N.W.T., Rodriguez-Roda, I., Sieber, S., Stavenga, M., Sulis, A., Ticehurst, J., Volk, M., Wrobel, M., van Delden, H., El-Sawah, S., Rizzoli, A., Voinov, A., (2011). Environmental decision support systems (EDSS) development – *Challenges and best practices. Environ. Model. Softw*. 26, 1389–1402.

Miettinen, K. (1998). *Nonlinear multiobjective optimization. International Series in Operations Research & Management Science*. Springer; M. Ehrgott, 2000, Multicriteria optimization, 1st, Springer

Mysiak, J., Giupponi, C., Rosato, P., 2005. Towards the development of a decision support system for water resource management. *Environ. Model. Softw., Policies and Tools for Sustainable Water Management in the European Union* 20, 203–214.

Newman, S., Lynch, T., Plummer, A., 2000. Success and Failure of Decision Support Systems: *Learning as We Go. J. Anim. Sci*. 77.

O'Neill, B. C., Tebaldi, C., Van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., ... & Sanderson, B. M. (2016). The scenario model intercomparison project (ScenarioMIP) for CMIP6. *Geoscientific Model Development*, 9(9), 3461-3482.

Poch, M., Comas, J., Cortés, U., Sànchez-Marrè, M., Rodríguez-Roda, I., (2017). Crossing the Death Valley to Transfer Environmental Decision Support Systems to the Water Market. *Glob. Chall.* 1, 1700009.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Texas Water Development Board (2005). *The Texas Manual on Rainwater Harvesting. Third Edition*. Published by: Texas Water Development Board.

Walling, E., Vaneeckhaute, C., (2020). Developing successful environmental decision support systems: Challenges and best practices. *J. Environ. Manage*. 264, 110513.

Zasada, I., Piorr, A., Novo, P., Villanueva, A.J., Valánszki, I., (2017). What do we know about decision support systems for landscape and environmental management? A review and expert survey within EU research projects. *Environ. Model. Softw*. 98, 63–74.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N°958274