ICT4Water cluster

Vision and showcases

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1. INTRODUCTION

Water systems and water infrastructure are critical and essential components of urban and rural life, encompassing clean water (supply and distribution) systems, waste water systems, irrigation systems, the management of surface water (rivers and freshwater bodies), as well as groundwater. Historically, as cities, water demand and population grew, new water infrastructures followed as needed. **However, these developments had less to do with real long-term planning than with reacting to needs and crisis situations**. Additionally **pollution** of water bodies and water quality in general is an increasing concern, due to industrialisation, rapid urban growth and socio-economic conditions, while **extreme weather, climate change and uncertainty about future climatic conditions** (e.g. droughts) pose additional threats to water security in several regions of Europe.

Besides, water is directly or indirectly linked to several Sustainable Development Goals (SDG), most notably to SDG 6, while several EU directives and policies refer to the water sector. For instance the Water Framework directive (2000/60/EC), the Urban Wastewater directive (91/271/EC), the Drinking Water Directive (98/83/EC), the Floods Directive (2007/60/EC) encompass several aspects of the governance of the water sector. Water is also noted by **the Green Deal**, especially as an integral part of **circular economy, zero pollution, farm to fork strategy and energy efficiency**.

Digital innovation has brought a revolution in the management of **all critical infrastructures** (water, energy, transport, health and telecommunications). Strategic and operational management are becoming more efficient, safe, competent and smart. It creates also new challenges, related to **interoperability, data exchange and the need for combined policies for different sectors (e.g. water and energy).**

Other sectors (e.g. energy and telecommunications) have been **faster in adopting digital innovations** as part of their mainstream strategic and operational management. However, the management and operation of water systems (especially urban water systems) is diverse (public and private), fragmented and characterised by conservatism when it comes to changes and adoption of digitalisation for the sector. This indicates the need for a more systematic and organised approach to the promotion and adoption of digital innovation for the water sector.

The **purpose of this document** is to highlight the work of **the ICT4Water cluster, as a main driver for the development, promotion and dissemination of innovation for the digital transformation of the water sector at EU level** towards a new paradigm for water management.

The document is organised as follows: the history of the ICT4Water cluster is presented in Section 2, followed by the operational mode in Section 3, the range of digital innovations (Section 4) and Vision of the cluster in Section 5. In the last Section 6, a list of characteristic showcases is included, demonstrating the range of digital innovations for the water sector from ICT4Water cluster member projects.

2. HISTORY

The ICT4Water[1] cluster was established in 2012 at the initiative of the European Commission Directorate-General for Communications Networks, Content and Technology (DG Connect). It is a community of EU funded projects aiming to boost the digital transformation of the water sector, scoping at a more efficient and sustainable use of water resources. It started with five sister projects, all targeting digital water innovation, boosted in the following years by more EU projects joining the community. The history of the cluster is shown in Fig 1.

The provenance of the EU funded projects is diverse: The first projects were funded under FP7, followed by several projects funded under H2020, but also other types of funding instruments and calls. Currently (beginning of March 2021) 24 active projects (and 39 completed) are affiliated with the cluster with a total budget of 154,446,058.30 euro. 21 projects are funded by H2020, one by LIFE+, one by EMFF, and one by the EIT Climate KIC.

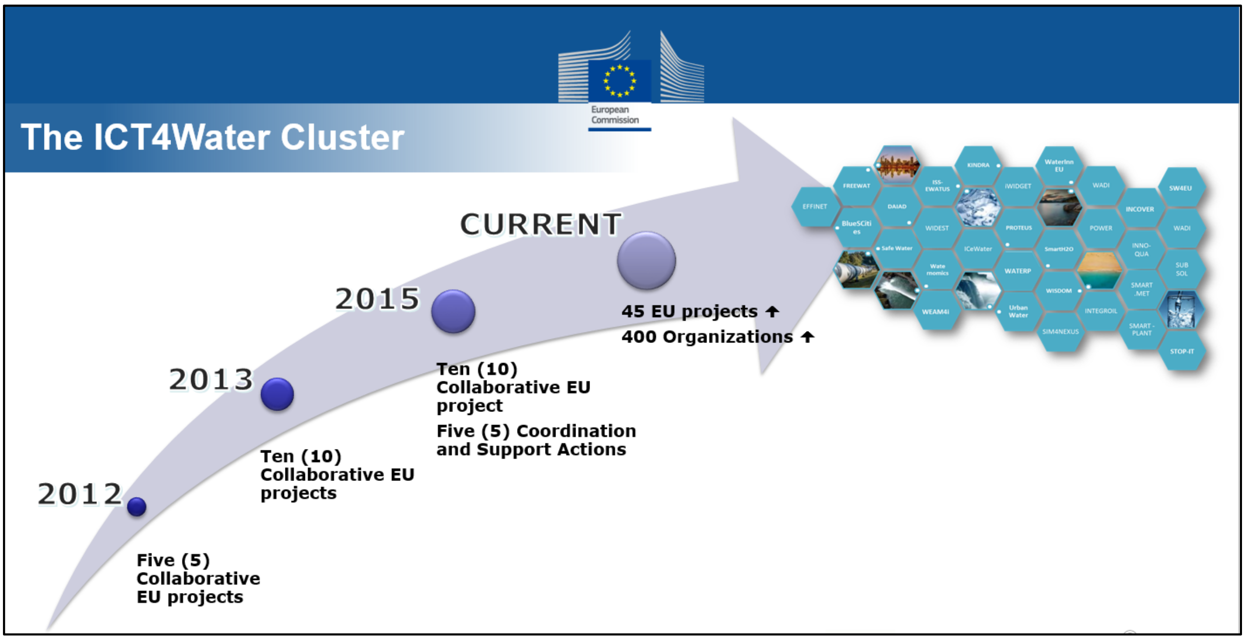

Figure 1: The history of the ICT4Water cluster

The ICT4Water cluster aims to foster collaborations between the member projects, to act as a hub for innovative activities related to digital water, creating synergies, organizing and participating at major exhibitions and scientific events, and disseminating results through major channels, ultimately contributing to EC strategic views and policies.

[1] https://www.ict4water.eu/

3. OPERATIONAL MODE

The ICT4Water mission is detailed in the Action Plan for Digital Market Water Services[2]. The Action Plan proposes actions relating to technology, market, business, awareness and possible regulation in the area of ICT supporting the water domain and its interactions. It will enhance emerging **Digital Water issues (current and future trends) in terms of services, data management, interoperability, intelligence, cybersecurity and standardisation, including synergies between the proposed solutions and with other related sectors (e.g. circular economy, water reuse, transport, energy, agriculture and smart cities)**, also considering social aspects (operators, consumers, legal issues, water value awareness). The Action Plan spans into seven thematic areas, which in turn are further broken down into several activities spanning from 2020 to 2030.

In order to implement the Action Plan, the cluster is being organised in seven Action Groups (AG). The AGs kicked-off in 2019, with two/three co-leaders appointed for each group. The co-leaders are volunteers, who are affiliated with at least one project member. There are four technology-oriented Groups:

A. *Interoperability and Standardization (I&S); Leaders: Aitor Corchero (Eurecat), Xavier Domingo (Eurecat)*
B. *Data Sharing (DS); Leaders: Chrysi Laspidou (University of Thessaly), Pascale Rouault (KWB)*
C. *Smart Water (SW); Leaders: Joep van den Broeke (KWR), Franck Le Gall (e-Global Markets), Evina Katsou (Brunel University)*
D. *Cyber-security (CS); Leaders: Gustavo Gonzalez (ATOS), Theodora Tsikrika (CERTH-iti), Rafael Gimenez (Cetaqua), Anastasios (Tasos) Karakostas (CERTH-iti), Rita Ugarelli (SINTEF), Vasilis Papageorgiou (CERTH-iti)*

Three other groups working on:

E. *Actor Awareness (AW); Leaders: Christos Markopoulos (NTUA), Natacha Amorsi (OIEAU),*
F. *Policy (POL); Leaders: Richard Elelman (Eurecat), Albert Chen (University of Exeter), Kristina Wencki (IWW),*
G. *Business Models (BM)* related to the digital transition of the water sector; *Leaders Eva Martinez Diaz (Aqualia), Francesco Fatone (Università Politecnica delle Marche)*

The Action Groups are coordinated by *Lydia Vamvakeridou-Lyroudia (KWR)* and *Gabriel Anzaldi (Eurecat)*, who are also members of the cluster Management Team.

The cluster seeks continuously to establish new collaborations and partnerships with important stakeholders. The *Interoperability and Standardization* group participates at the Specialist Task Force 566[3] set up by the **European Telecommunications Standards Institute** (ETSI[4])]. This Task Force is working on the **validation of use cases and requirements for the Smart Applications Reference Ontology - SAREF ontology**[5] with application in the water domain. Several Action Groups have made links with the BRIDGE cluster[6], a hub of EU-funded projects

[2] http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=52421
[3] https://portal.etsi.org/STF/STFs/STF-HomePages/STF566
[4] https://www.etsi.org
[5] https://saref.etsi.org
[6] https://www.h2020-bridge.eu, a Cooperation group of Smart Grid, Energy Storage, Islands and Digitalisation H2020 projects.

working in the **domain of Energy**. Similar links have been developed with important European and regional water innovation hubs like, Water Europe[7], the Dream Regional[8] cluster based in Centre-Val and the CWP: Catalan Water Partnership[9].

For the future links and synergies should be sought with other networks, e.g. the Smart Water Networks Forum (SWAN Forum[10]) - the leading global hub for the smart water sector, which is closely linked with water operators and technology providers.

The scope of the ICT4Water cluster is to promote, investigate and disseminate the combined value of water (e.g. water saving) with the value of data and knowledge management, for applications and tools, encompassing the whole range of the water cycle and value chain. Figure 2 shows the range and types of digital innovations related to each part of the water sector and the interrelations among them.

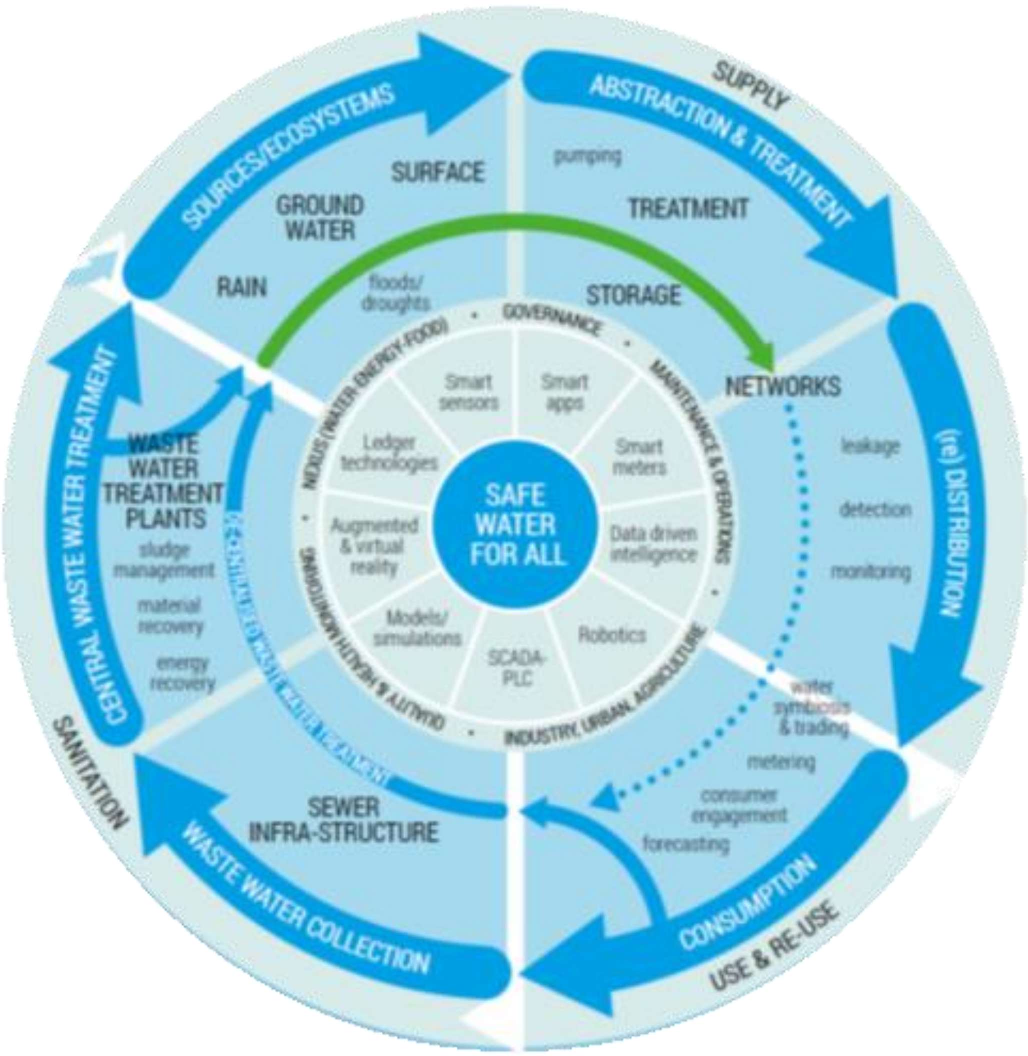

Figure 2: Range and types of digital innovation related to the water sector

[7] https://watereurope.eu
[8] https://www.clustercollaboration.eu/cluster-organisations/dream-cluster
[9] http://www.cwp.cat/en
[10] https://www.swan-forum.com

4. VISION

Europe is embracing the *twin digital* and *green transitions*. Both transitions are at the heart of the **European Green deal**[11], the Commission's roadmap for making the EU economy sustainable by 2050. They are also iterated in the Commission recovery plan from COVID19[12].

Both the ***digital and the green transition are at the core of the ICT4Water mission and vision.***

ICT4Water projects are employing **digital solutions as a means to achieve a greener value chain in water management in urban, rural, agricultural and industrial context** and at various hierarchical levels (local, regional, national, EU).

In practice, the ICT4Water cluster is developing solutions along the whole water cycle (as shown in Fig. 2), intending:

- To allow a shift from linear to circular value chain configurations with a maximum water efficiency, saving, recovery and re-use;
- To achieve energy efficiency, energy recovery and CO2 emissions reduction for water utilities;
- To engage water consumers in sustainable behaviours;
- To optimise water resource management overall and to satisfy competing water demands;
- To contribute to the Zero pollution ambition for the toxic free environment[13];
- To influence relevant EU policies linked to water.

These solutions are *ICT-driven* and expand in all directions: from individual solutions applied on niche operational segments to integrated water management solutions, from simple automations to data-driven intelligence. ICT4Water solutions consider a systemic approach, which recognises the interconnectedness of water across sectors, and breaks organisational silos to improve real-time decision-making and benefit sharing. The digital water economy will enable the water sector and its customers to transition towards a new paradigm for water management.

Additionally a number of IT related/driven emerging themes and applications from other sectors are becoming relevant for water systems, such as **digital twins, digital data spaces, artificial intelligence, disruptive technologies and instrumentation and circular economy digital water innovations**. The ICT4Water cluster intends to address them in the near future.

a. Digital Twins:

Digital twin refers to a digital replica of physical assets, processes and systems that can be used for various purposes[14]. There are significant differences between digital twins and classic digital simulation models of systems (e.g. water infrastructure systems). Digital Twin is a disruptive technology that provides a virtual/digital representation of both the elements and the dynamics of a water plant or system. Once implemented properly, a Digital Twin can influence the design, build and operation of the system throughout its life cycle (design-build-operate) and help optimise operation through informed insights. In other words, it is a **dynamic software model**

[11] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, Brussels, 11.12.2019. (COM(2019) 640 final).
[12] https://ec.europa.eu/info/strategy/recovery-plan-europe_en, COM(2020) 456 final.
[13] https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en
[14] https://www.sablono.com/de/blog/bim-and-digital-twin-technology/

(hydraulic model + Artificial Intelligence for Machine/Self Learning) of the physical plant/system based on real-time continuous calibration[15]. Moreover, a Digital Twin is enhanced **with advanced visualisation features**, which allow the user (e.g. water system operator) to visualise, monitor and optimise the system operational assets, processes and resources by harnessing live data (e.g. optimising the combined energy and water use). This provides vital, real-time insights into performance and activity. Moreover, digital twin benefits are easily visible to all – especially when they aim to solve existing day-to-day challenges – thus increases system transparency.

The use of Digital Twins is rapidly increasing for a number of sectors, especially for the operational management of critical infrastructures (e.g. energy and transport systems). It is also **a nascent sector for water infrastructure systems and in the core technologies for smart cities**. Some cities (e.g. Valencia in Spain[16]) have already developed a digital twin for their urban water supply and distribution system. Also digital twins for water systems are growing in the US, and Working Groups on this theme are already operating within the SWAN Forum. This is a theme that encompasses more than one action group of the cluster and it will be developed more with actions across action groups.

But why do we need a digital twin for the water sector?

One response is for all reasons above, plus, because **it can now be done**: many individual parts of the water value chain have a digital equivalent (e.g. the drinking distribution systems is very well modelled, water resources, floods, CSOs, waste water treatment). This is made evident by the operational diversity of the *showcases* presented in the dedicated chapter of this report (see Chapter 6). Thus, the logical next step is: why not put all those modules together, interconnecting them and get a full scale digital equivalent of the water value chain, e.g. in urban or peri-urban areas. But there is more than that. In the future, **water system digital twins will be linked to other digital twins (e.g. energy infrastructure system, transport infrastructure system),** offering the chance of a holistic response to hazards affecting cities (e.g. flooding), by increasing the effectiveness of a holistic response to threats and thus, enhancing the resilience of the city overall.

b. Digital Data Spaces for the Water Sector:

The aim of the European data strategy[17] is to create a genuine single market for data, where private and public entities can fully control the use of the data they generate and where both businesses and the public sector have easy access to a large pool of high quality data. This aimed to capture the benefits of better use of data, including greater productivity and competitive markets, but also improvements in health and well-being, environment, transparent governance and convenient public services. Sectoral common European data spaces[18] (e.g. for manufacturing, energy, mobility, health, agriculture etc.) are planned, as a means to make relevant data available for the implementation and continuous improvement of artificial intelligence systems. A common European Green Deal data space is aiming "*to support the Green Deal priority actions on climate change, circular economy, zero-pollution…*"[19]. In addition, the Digital Europe Programme will support the creation of a local data ecosystem **for**

[15] https://www.swan-forum.com/digital-twin-h2o-work-group/

[16] https://www.researchgate.net/publication/340236600_Development_and_Use_of_a_Digital_Twin_for_the_Water_Supply_and_Distribution_Network_of_Valencia_Spain

[17] A European Strategy for Data, Brussels, 19.2.2020 COM(2020) 66 final, https://ec.europa.eu/digital-single-market/en/european-strategy-data

[18] COM(2020) 767 final, Brussels, 25.11.2020 (Data Governance Act).

[19] p.22, COM(202020) 66 final, https://ec.europa.eu/info/sites/info/files/communication-european-strategy-data-19feb2020_en.pdf

climate-neutral and smart communities as part of the common European Green Deal dataspace. Therefore, ICT4Water cluster has the vision to work and promote **the creation of a dedicated Data Space for Water** and to contribute in creation of smart cities to benefit from cross-sector, cross-city, easily portable data services.

Exchanging and combining data between water and other domains (like energy, climate, agriculture, health, transport), can create significant added value. This has been demonstrated in several cases so far, for instance in showcases #1-SIM4NEXUS[20] project. However, there are additional cases that have not been fully exploited yet, e.g. from ongoing EU funded projects.

For example, in project SCOREwater[21], sewage monitoring combined with census and health data (e.g. e-prescription) can feed models to predict antibiotics consumption over-the-counter (without prescription) and population general health status (including COVID-19 see Sewage4Covid[22] and DEMOS[23]); combined energy and water consumption data[24] can lead to better customer profiling and water tariffs. According to the Financial Times[25] in 2018, *"the disruption to shipping on the Rhine (due to droughts) knocked as much as 0.4 percentage points off German economic output and weighed on fuel prices over two quarters"*. Obviously, seasonal predictions for such droughts events can help companies evaluate hedging strategies.

c. Artificial Intelligence (AI) for Integrated Water Management

Artificial intelligence (AI) is the capability of a machine to perform tasks that would normally require human intelligence. AI is reliant on (big) data and enables their more efficient collection and processing to, for instance, **improve pollution monitoring**, **analyse patterns of pollution to better identify sources and design cleaner and non-toxic products and services.** AI plays an increasing role in the integrated and autonomous management of complex systems, as detailed in the EU White Paper on Artificial Intelligence[26].

Water systems are generating an increasing volume of sensing data due to the rapidly increasing use of heterogeneous sensors, widespread data acquisition, Internet-of-Things (IoT), and the roll-out of 5G networks. The inevitable data explosion requires data analytics and new Machine Learning (ML) methods to harness, explain and exploit structural and dynamic characteristics of the data in networked, interconnected and inherently complex water systems.

AI concepts have started to be implemented for the water sector several years ago. One such case is the Serious Game described in *Showcase #1* (see Chapter 6), where the role of an intelligent Knowledge Elicitation Engine (KEE) is detailed. Other examples are Decision Support Systems (DSS) like in the *Showcase #4* (and in many other projects) or deep neural network (DNN) architectures for micro-sensor fusion like in the in the *Showcase #6*.

However, there is still remaining a strong, yet unexploited, potential for the use of AI methodologies for the water sector. The first example is the implementation of Machine Learning for the continuous calibration of Digital Twins, which lies in the heart of the Digital Twin concept, as described above in section (a).

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[20] https://www.sim4nexus.eu
[21] https://www.scorewater.eu
[22] https://www.exeter.ac.uk/news/university/title_793175_en.html, https://www.exeter.ac.uk/news/university/title_810160_en.html
[23] https://www.kwrwater.nl/en/actueel/demos-digital-epidemic-observatory-and-management-system
[24] https://www.sciencedirect.com/science/article/pii/S095965261732512X
[25] https://www.ft.com/content/6b46014e-cbf6-4152-a8ad-087cddd51706
[26] https://www.europarl.europa.eu/legislative-train/theme-a-europe-fit-for-the-digital-age/file-white-paper-artificial-intelligence-and-follow-up

Another **example** is that **of transferring AI technologies from other fields** (e.g. autonomous self-driving vehicles[27]) **to water management to enhance decisions making for even more complex water and environmental systems**. For instance, long term resilience and protection of cities and settlements from climate hazards (i.e. extreme storms, extreme droughts and sea level rise) involves a complex and dynamic "*landscape*" of interlinked and interacting factors, elements, components and entities. These factors are: *Climate change* (scenarios, impact); *geo-physical elements* (impacts on water, groundwater, water quality, biodiversity, ecosystems, sustainable development, aquaculture); *policies* (land use, incentives for CO_2 targets, sustainability, strategic planning at local, regional, national and EU level); *governance* (organizational structures, administration, legal issues, strategic decision making, participation); *technologies* (sensors, Internet of Things-IoT, big data analytics, hard works and constructions, new materials); *social* (awareness, engagement, social unrest, potential migration/relocation); *economic* (macro-, micro- and financial/business); *management* (surveillance, monitoring, short term/operational decision making). All the above factors are imbued with *uncertainties* at various levels: from the simplest - *numerical* (How much are they? How much will they change in the future?), to *functional/analytical* (How can they be modelled? How are they linked/interacting now and in the future? How to model qualitative entities?), to *deep epistemic*-ones (Is the conceptual model valid? Will it change in the future? Have we included all the important factors? Linked them in the right way? How will changes due to short term measures affect long term planning?), to *risk assessment* (How coastal risk will affect rivers? How extreme climate events will affect coastal management and maintenance of infrastructure?). Within this complex, fluid, dynamically changing "*environment*", stakeholders (citizens, managers, authorities, policy makers, city planners, risk managers, etc.) need to make short-term decisions and implement long-term policies, which affect the city and its people in largely unknown, undefined and even unpredictable ways, especially when the "*environment*" reaches unprecedented, unforeseen "status", due to extreme climate-related events. *Cascading effects,* both between hazards and impacts, result in the "environment" becoming even more complex and unmanageable. In this context, ***Deep Reinforcement Learning*** offers an approach for the autonomous adaptation of water systems and decision-making to altering conditions of the system. It can operate with the same principles as self-driving autonomous vehicles, self-adjusting and learning from its experience and suggesting autonomously the "best" solutions/actions at all circumstances in an ever-changing "environment".

d. Disruptive technologies and instrumentation for the Water Sector:

Online monitoring of water and wastewater quality is a powerful enabler in the water industry. It is a crucial component in the pro-active management of processes, assets, and services, and helps improve performance and cost efficiency. A number of emerging sectors in IT-related technologies are finding increasing applications for the water sector and are proving useful for alerts and monitoring. For instance ***wearable sensors*** for water quality are being developed for detecting pathogens in drinking water for first responders[28]. ***Nano-sensors***, even portable and cheap ones, with the capacity to monitor multiple substances have also started to be applied for water quality[29][30][31], while ***quantum technologies*** are being used for increased computational capacity and speed for computer systems and AI applications. Innovations related to these technologies need to be increasingly developed for the water sector and their potential exploited. Furthermore, not only instrumentation/smart water devices as such should be further

[27] https://arxiv.org/abs/2002.00444
[28] https://pathocert.eu
[29] http://www.proteus-sensor.eu
[30] https://www.lotus-india.eu
[31] https://www.fiware4water.eu/demo-cases/france-water-supply-system-management-case

developed together with a collection of long-term credible data. It is equally important in putting together all smart instrumentation into one holistic system and testing it. ICT4Water community is further foreseeing actions in developing sensors but also in assessing developed applications (models, analytics), smart online control systems with transition to the Internet of Things (IoT) platforms, and monitoring performance of these systems. The DW2020 synergy group[32], formed in 2020 with the participation of five ICT4Water cluster projects[33] are focusing on this. In this way the cluster foresees smartening integrated water management.

e. Circular Economy digital water innovations

Circular economy (CE) is closely linked to water use, and re-use, to waste water treatment, to energy and material recovery. It is a domain that has an increasing importance for the Green Deal at the European and global level. Several innovations related to CE are linked to technological advances and methodologies (e.g. membranes, filters, sludge treatment, etc.) However, there is also potential for **digital innovations**. The most obvious and prominent digital innovations are linked to business models and contribute to the creation of **cloud marketplaces** for specific CE technologies and products for the water sector. These specialised digital innovations for CE need to be further promoted, supported and enhanced and several recently funded CE projects for the water sector are started to test and implement these digital solutions. Furthermore, synergies and combined actions are required for developing, populating and maintaining digital marketplaces for water in the CE. Another digital innovation potential is the development of digital **Serious Gaming, Augmented Reality and Virtual Reality** tools for circular solutions, to enable decision makers, students and citizens to understand better the CE impacts. Digital market places, Serious Gaming and Augmented Reality and Virtual Reality CE tools have already started being developed through ongoing ICT4Water member projects[34].

[32] https://ec.europa.eu/easme/en/section/horizon-2020-environment-and-resources/synergy-group-digitalwater2020

[33] https://aqua3s.eu, https://www.digital-water.city, https://www.fiware4water.eu, https://naiades-project.eu, https://www.scorewater.eu

[34] E.g. https://nextgenwater.eu, https://ultimatewater.eu, etc.

5. CONCLUSIONS: OPPORTUNITIES, CHALLENGES AND DRIVERS

a. Drivers

The cluster member projects are funded by diverse calls for proposals and instruments and thus are dealing with diverse technologies to achieve different purposes. This diversity in funding calls and instruments is an **opportunit**y that has benefitted the cluster significantly and will continue to be a driver of added value in the future. In the coming years the cluster will continue to expand by engaging new member projects, working on the digitalisation of the water sector. Additionally, the cluster looks to attract projects that come from different funding instruments (e.g. LIFE+, KIC, EMFF), but also, recently from the more scientific/basic research ERC grants[35]. This diversity ensures that a variety of approaches, innovations and knowledge is included in the activities of the action groups of the cluster AG, as an added value to the outcomes.

When looking at the cluster showcases, diversity is also observed in the **drivers that boost the digitalisation of the water sector.** Some of those drivers are: optimisation of OPEX/CAPEX costs in monitoring water quality, risks or contingency management; cybersecurity and safety of infrastructure; policy-making and compliance with regulations and policy enforcement; customer management (understanding demand and improve customer behaviour in saving water); support to circular economy models, environmental hazards forecasting and impacts mitigation; competitive advantage for water intense industries [36].

b. Opportunities

The cluster will also seek opportunities to liaise with **external stakeholders** such as water regulators, water industry associations, investors in the water sector, international organizations focusing on water, and other stakeholders. External stakeholders could advice the cluster and provide insights on their own research/ innovation and/ or strategic agendas. This could benefit both sides turning the cluster into a **boundary organization** where several parties, even with conflicting interests, exchange views and agendas to reap mutual benefits.

c. Challenges

The main **challenges** the cluster projects are facing in pushing digitalisation of the European water sector is that water utilities and water operators (that could be defined as the end-users) are generally *conservative* and *fragmented*. On the contrary, information science (ICT), data science and digital technology are relatively recent additions in the water sector (compared, for instance to other infrastructure sectors like energy or telecommunication). However, more digital water solutions are rapidly becoming available on the market forming a new digital reality for the sector. The IoT (Internet of Things), technologies centred around digital twins and affordable sensors are putting pressure, transforming the water sector. On the other hand, water utilities are feeling the need for integrating new smart technologies that can put the sector in a greener path. Therefore, currently the water sector in Europe is in transition and the ICT4Water cluster is following closely this trend, working on dissemination, knowledge transfer and acceptability of digital innovation for the water sector.

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[35] https://erc.europa.eu/news-events/magazine/erc-2020-synergy-grants-examples

[36] "Business Models for digital water solutions" study authored by Eva Martinez Diaz (AQUALIA) on behalf of EASME and the Action Group on Business Models (https://op.europa.eu/en/publication-detail/-/publication/17602700-821a-11eb-9ac9-01aa75ed71a1/language-en/format-PDF/source-194512849)

6. SHOWCASES

Before it embarks with Horizon Europe activities in 2021, the ICT4Water member projects have compiled a selected list of characteristic ***showcases***, demonstrating the innovation potential of the cluster and the breadth and depth of the solutions that have already been achieved in the domain of ***digital solutions for water management***.

The showcases encompass a wide range of water-related domains and users: Serious Gaming for the Water-Energy-Food-Land-Climate nexus (#1), flood modelling with the use of Artificial Intelligence techniques for combined urban and rural areas (#2), resilience of critical infrastructures to climate-related hazards (#3), waste water treatment plant optimal management (#4), assessment of cyber-physical threats for water utilities (#5), innovative sensors for water quality (#6, #7) and sensor monitoring for water quality in IoT context (#8 and #9), integrated water resources management tools (#10), and sustainable water management at watershed level (#11). The last showcase (#12) refers to a whole project, demonstrating an innovative IoT system for agricultural use (agro-technological solutions).

Show Case 1 Serious Gaming for the nexus: A digital tool for the interactions between the Water and other Sectors

Background and general description

The **Serious Game (SG)** developed by SIM4NEXUS (www.sim4nexus.eu) (GA 689150) (2016-2020) investigates bio-physical and policy interlinkages across five nexus domains: **water, land, food, energy, and climate** and facilitates learning and design of policies within the nexus [1], [2]. The serious game is delivered as a cloud-based integrated tool to test and evaluate 30+ year policy decisions [37]. The game shows the impacts of resource use in relevant policies, such as agriculture, water, energy, land use and climate, through a model-based analysis using real data from selected case studies at regional, national and transboundary scale [3].

Figure 1: Screenshot from the SIM4NEXUS Serious Game demonstration

The Serious Games are now being demonstrated and "played" in various fora (e.g. the business sector, water utilities, etc.), raising awareness on the nexus and related policies. The best results have been achieved through facilitation of trainings (for local authorities, NGOs, water and energy utilities, agriculture cooperatives, environmental groups) on case studies. This enables the researchers to obtain feedback on the scenarios and to define facilitation methods for different audiences and cases. After each session the participants provided feedback. The feedback has been overall positive and the participants have described how their learning experiences on the nexus interlinkages have been enriched through the game. Demonstrations, facilitating and training can also be provided on request[38].

Artificial Intelligence (AI) lies in the background of this Serious Game in the form of a Knowledge Elicitation Engine (KEE). The KEE is the digital smart core of this Serious Game. It acts as a central connector between other components, such as the SG User Interface (UI), the Semantic Repository (SR) or the System Dynamic Models (SDM) analytical simulation engine, and implements all the Serious Game logic.

The Serious Game platform relies on the KEE to i) integrate knowledge and strategies at different spatial and temporal scales and ii) to provide the Serious Game with the system-

[37] https://www.youtube.com/watch?time_continue=50&v=mFnOaSW82Bw&feature=emb_logo
[38] https://www.kwrwater.nl/actueel/what-is-sim4nexus

wide impact of each action (nexus policy) implemented under a case study or specific scenario, considering the interactions modelled in the SDM. Moreover, the KEE permits a top-down learning approach based on Serious Game front-end user decisions and a bottom-up approach based on classical machine learning methodologies applied to data. Figure 2 shows schematically how it works.

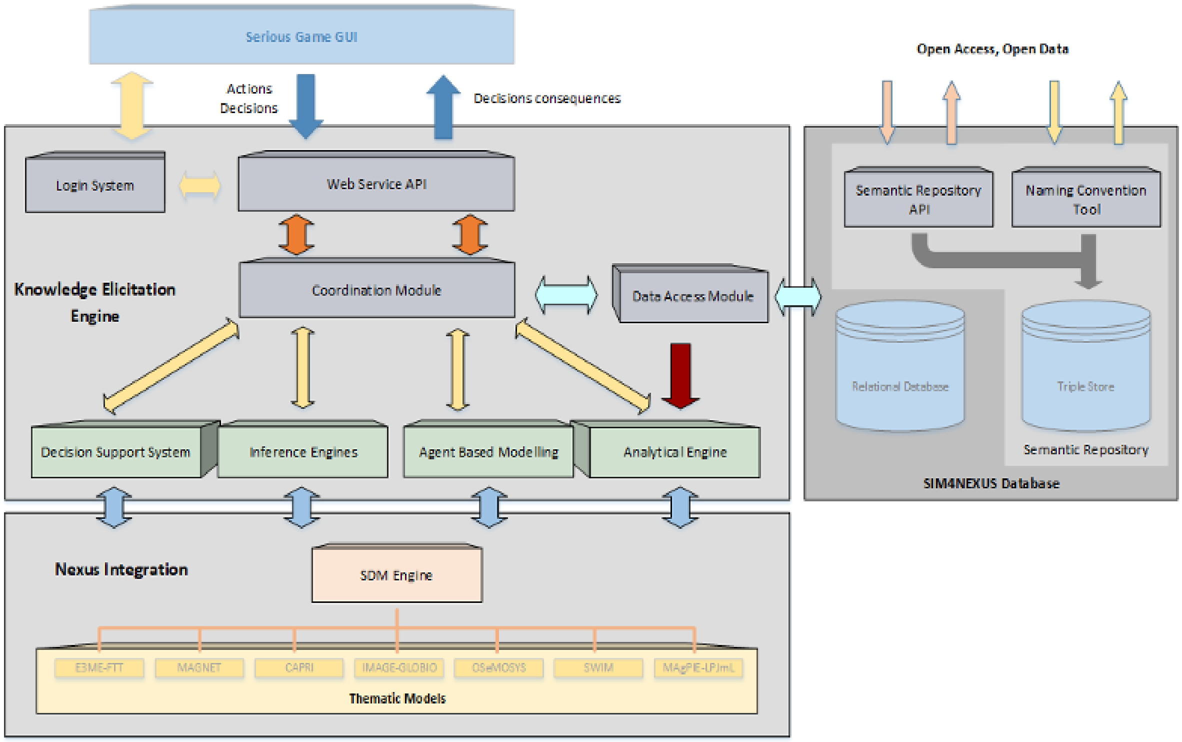

Figure 2 : The Knowledge Elicitation Engine (KEE) for the Serious Game

The main responsibilities for the KEE are to:

- Integrate the login system,
- Provide the knowledge stored in the Semantic Repository to the Serious Game user interface (learning goals, scenario setups, available policies, restrictions, etc.),
- Embed, deploy and run the SDM models considering the current game status and adapting the different parameters accordingly,
- Compute Game performance indicators at each turn,
- Provide the contents to be displayed to the user in the Serious Game User Interface,
- Collect user actions and reactions while facing different scenarios and situations in the game,
- Learn from these actions to provide advice (DSS) also considering knowledge in the Semantic Repository and Sim4nexus databases,
- Provide virtual players based in agents (Agent Based Modelling - ABM).

The S4N Decision Support System (DSS) is based on the Inference Engine (IE) and the Agent Based Modelling (ABM) modules, both supported by the Analytical Engine (AE), which provides them with Artificial Intelligence (AI) and Machine Learning (ML) capabilities. First, the IE uses different Statistic and ML data-driven algorithms to analyse user decisions to obtain derived potential knowledge, which can be used to study and understand users' behaviours. Second, the ABM implements AI agents able to optimally and autonomously operate different Case Studies through Deep Reinforcement Learning methodologies. And, finally, the combination of the IE and the ABM enables the DSS to provide advanced advice to the S4N real players guiding them, and their decisions, in order to maximize its results.

Impacts (financial, environmental, operational, other)
Virtual digital tools (as this Serious Game) enable players to implement different policies and "see" their long-term impact on the nexus. For instance, they can investigate whether the setting of a target to reduce by 30% CO2 emissions may be implemented at all, and what will be the impact on the five nexus components (water-energy-food-land-climate), the trade-offs and the impact of a sectoral decision (e.g. a water policy) to the other sectors. The latter is shown to the player through specific indicators, representing the "health" of the nexus. The video[39] provides more details. As tools, Serious Games have a significant impact in actor awareness and capacity building in the domain of the nexus, and in other water-related challenges [3]. Thus, stakeholders (decision and policy makers, citizen groups, NGOs, students) can learn about the interactions between the water sector and the other nexus sectors. Serious Games development involves Complexity Science Modelling, where ontologies (activity linked to Action Group 1 of the ICT4Water cluster) and data from different sectors are shared (activity linked to Action Group 2) and combined (the SIM4NEXUS approach) [3]. Synergies among the different nexus sectors are key for the Green Deal and the related EU policies. Consequently Serious Games, as the SIM4NEXUS one, have the potential to contribute to social awareness, but also to help decision makers to investigate alternatives for potential policies at regional or national level.
For whom? Who can benefit?
It can benefit stakeholders (water managers, citizen groups, policy makers, NGOs), students and the general public. With the serious game trainings, diverse groups of stakeholders or students can improve their understanding of the interlinkages between sectors and the decision making, while expert audiences can engage in more technical and complex conversations in finding the most effective policies to address synergies and trade-offs. A full report on outcomes of serious gaming for the water sector, for different audiences is given in [4].
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[39] https://www.youtube.com/watch?app=desktop&time_continue=50&v=mFnOaSW82Bw&feature=emb_logo

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Show Case 2: High performance flood modelling tool for flood protection planning

Background and general description

The rapid computer model CAFlood and analysing algorithms have been created in EU-CIRCLE project to simulate a wide range of flood scenarios in high resolution (order of cm). The application assesses of the impact of flood to critical infrastructure and private properties for different future climatic scenarios and conditions. The model enables strategic planning, development of prevention and mitigation measures to strengthen community resilience to flood hazards [1, 2]. A specific example of measures is given in the next section.

CAFlood was also adapted to create the critical database behind a Serious Game (see also Showcase #1), allowing stakeholders (farmers, citizens, water authorities) to explore various strategies for farming practices (e.g. crop selection) and drainage management [3].

Impacts (financial, environmental, operational, other)

The CAFlood value is due to its capability to undertake a full range of flood simulations within the required timescales, from minutes to several days (the latter offline). The analyses include evaluation of the effectiveness of various adaptation/ prevention measures, such as raising the existing wall or adding a secondary flood wall with different height options. Figure 1 demonstrates one of the analysis outcomes using CAFlood in Paignton (UK). This result is also presented in an online video [4].

Figure 1 CAFlood analysis in Paignton (UK)

High efficiency and accuracy of CAFlood model can offer near real-time flood forecasting and early warning to improve emergency response in order to protect the general public. It can also provide reliable assessments of possible flooding under future climate scenarios, by quantifying the probability and uncertainty associated with flood risk, which enables well-informed development of adaptation measures and investment plans.

For whom? Who can benefit?

CAFlood has been recognised by global businesses[40] for commercial applications in multiple sectors, such as insurance, water, risk analysis services, and engineering consulting.

For Torbay Council (UK), CAFlood provided the Return over Investment evidence that flood damage could be reduced from £78m to £0.2m by installing the secondary flood wall, safeguarding more than 3,000 people in 700 residential households, 330 commercial properties and 165 hotels. This Return over Investment evidence helped Torbay Council to secure £3.4m UK government investment in the critical infrastructure to improve the community resilience against flooding.

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[40] http://munichre.com, https://www.icsconsulting.co.uk/services, https://www.icsconsulting.co.uk/services, http://risq.io

Show Case 3: Hazard impact assessment toolbox for disaster risk management and resilience building

Background and general description

This hazard impact assessment toolbox has been continuously developed and enhanced in EU projects CORFU, PEARL, EU-CIRCLE and RESCCUE to evaluate flood disaster impact to properties and the cascading effects of critical infrastructure failures [1, 2].

The toolbox integrates hazard information, land or building uses, facilities, interconnectivity between critical services, and socio-economic data to quantify the direct damage - hazard-vulnerability relationships for various assets or populations, as well as the cascading effects and associated impacts to the society.

Impacts (financial, environmental, operational, other)

The toolbox has been widely adopted in several cases around the world to analyse the consequences of flooding for current and future climate and urban development scenarios. The applications include Bangladesh, China, Cyprus, Germany, France, India, Spain, Taiwan, USA, UK, ranging from local communities to mega cities. Figure 1 shows the results in five selected cities.

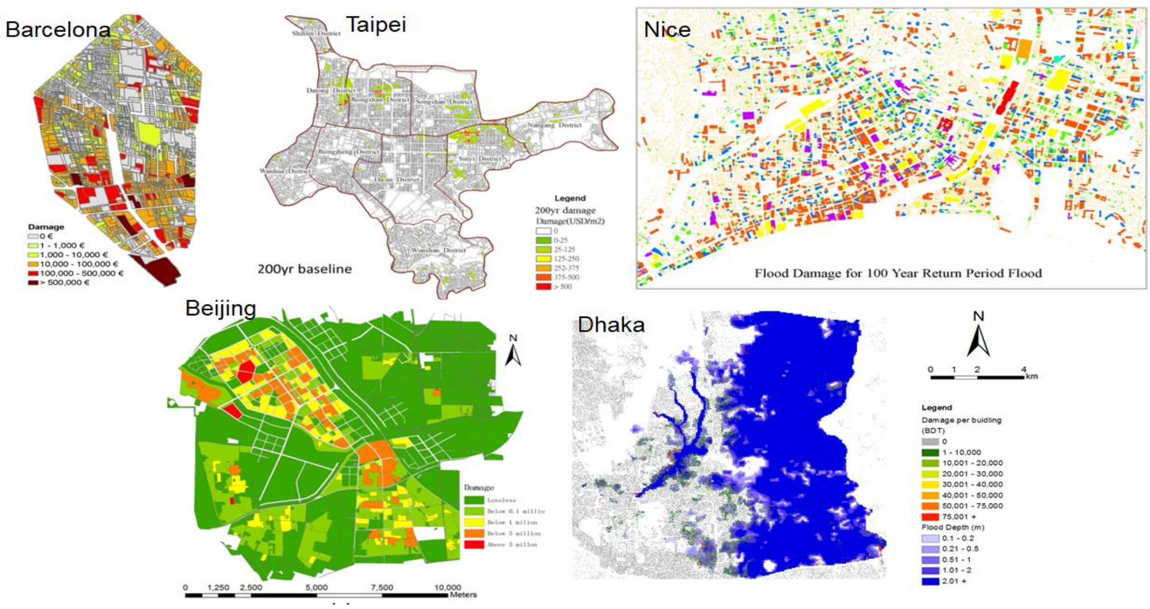

Figure 1 The hazard impact assessment toolbox applications in multiple cities

For whom? Who can benefit?

The toolbox helped urban planners and policy makers to understand the potential risk of flooding in different cities and to shape the strategies in hazard mitigation. The combination with a high performance flood model, such as CAFlood, can provide impact-based forecasting in a way that the authorities and communities can prioritise resources and actions to promptly assist vulnerable stakeholders and minimize the impact.

The toolbox is capable of analysing multiple types of hazards and impact such as property damage from storms, pedestrian safety in floodwater, likelihood of getting illness due to contact with polluted flood water.

The outcome also contributes to risk communication with stakeholders and the general public that has strengthened the decision making and consensus building for future resilient cities.

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Show Case 4: SMART-Plant: Material Recovery Techniques for upgrading existing wastewater treatment Plants

Background and general description

SMART-Plant developed a portfolio of digital solutions for supporting decision making and facilitating the implementation of the circular economy (CE) concept in the water utilities. Those solutions are:

WeSave Platform: It provides a validated framework for monitoring the real-time energy consumption and carbon footprint of the processes that consider the water-energy nexus in water utilities (e.g. in waste water treatment processes). To this end, energy meters and greenhouse gas (GHG) sensors have been integrated as **SMARTechs**; all measured variables are translated into CO_{2eq} emissions and are directly shown in an online tool. An operation manual of the on-line carbon footprint monitoring tool has been developed to guide operators on the use of the platform. The Application Programming Interface (API) of the WeSave platform is harmonized with the INSPIRE directive. The process of digitalisation of treatment plants and the integration of operations has been demonstrated within SMART-Plant through the web application that is transferable to any new/existing plant.

Data mining & Knowledge Discovery Framework: A novel data-mining and knowledge discovery framework for GHGs emissions prediction in water operations was developed and applied within SMART-Plant. The framework extracts useful information from sensor data and laboratory analyses, combines it with wastewater treatment domain knowledge in order to maximize insights on the long-term carbon footprint dynamics and support carbon footprint minimization of the SMART-Plant solutions. Project demonstrated that data-driven models can reliably estimate emissions behaviour in wastewater processes under given operational conditions.

Decision Support System (DSS): The effort to upgrade urban WWTPs into bio-refineries capable to recover and to produce valuable resources (e.g. nutrients) is hindered by the fact that technical, economic and environmental impact analyses are complex and time expensive. Technologies were tested and optimized under real operational conditions and considered in the DSS. These technologies are modelled and integrated into a plant-wide model superstructure with the aid of the Modelica and Python programming languages. The DSS implements a framework that allows for a multi-criteria based design, where all the possible WWTP-configurations given by the superstructure are sorted out in relation to their economic, effluent quality and environmental impact objective value. The framework consists of five steps: (i) design problem set-up, (ii) wastewater inflow generation, (iii) superstructure generation and plant-wide model simulation, (iv) estimation of the values of the different criteria, and (v) design configuration sorting.

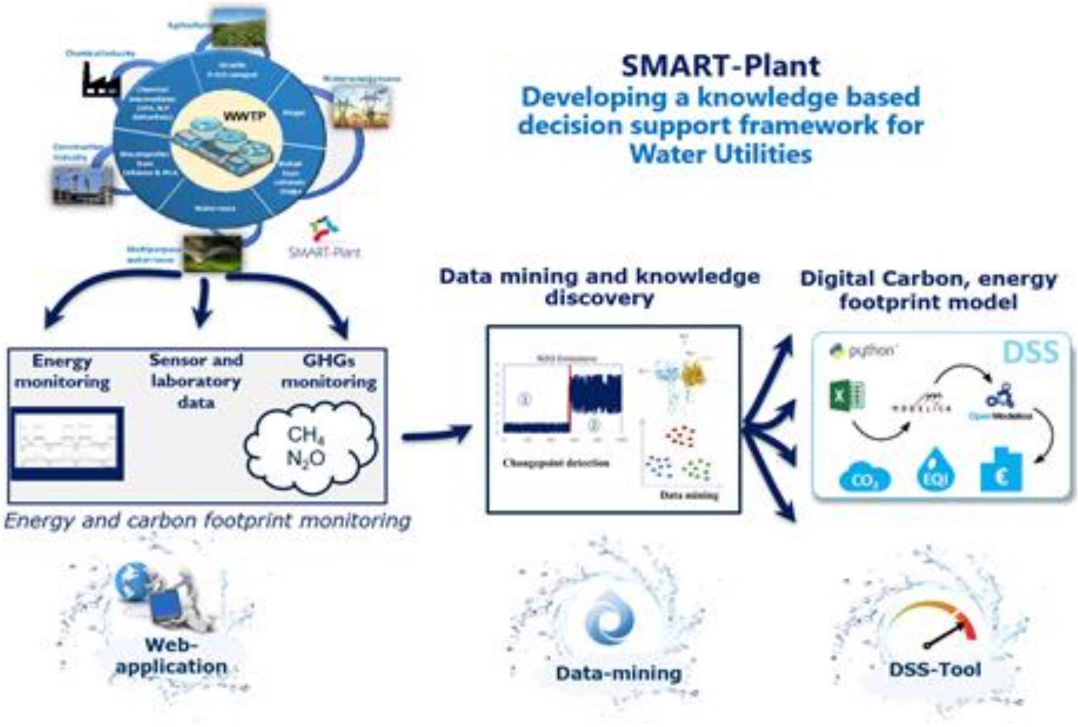

Figure 1: The three components (portfolio) developed in SMARTPLANT

Impacts (financial, environmental, operational, other)

The DSS facilitates the implementation of the best SMARTEchs configurations at the optimum ratio between environmental and economic impact (e.g. energy recovery versus cost). SMART-Plant processes have been applied and introduced into a cost-effective, dynamic and robust carbon-footprint assessment platform. The operational carbon footprint monitoring confirms that the SMARTechs result in low direct and indirect GHG emissions. Our SMART-Plant platform dynamically integrates crucial environmental performance variables into the monitoring and control system of the SMARTechs. Knowledge discovery and data-mining techniques were employed to extract useful information about the dynamic behaviour of GHGs emissions and predict their behaviour. Additionally, the web application offers the on-line monitoring of energy consumptions and carbon footprint calculation.

For whom? Who can benefit?

SMART-Plants solutions are mainly directed to water utilities and industries interested to find the optimal configuration of a WWTP considering SMART-Plant energy-efficiency and resource recovery processes. SMARTechs can even have important market outreach in the food waste management and valorisation. Application and replicability is highly facilitated by the specific SMART-Plant DSS. The SMART-PLANT suite of technological innovative solutions integrated by advanced digitalisation is showing signs of early interest and potential uptake by the WWTPs, as a promising route to exploitation. Thus, this activity, through the utilization of the available monitoring data supports plants operation and facilitates the integration of sustainability metrics in the decision making.

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Show Case 5: Risk Analysis and Evaluation Toolkit (RAET) – An integrative risk assessment platform for cyber-physical water systems security

Background and general description

Due to an increasing trend of cyber-attacks worldwide [1], the water sector needs to strike a balance between the (many) merits of its ongoing digital transformation and the inherent risks of this transformation, by reinforcing its strategic and tactical planning procedures with novel, cyber-physical concepts and tools [2]. The **Risk Analysis and Evaluation Toolkit** (**RAET**) was developed as part of the STOP-IT project [3] (G.A. 740610, www.stop-it-project.eu) to allow utilities to assess their preparedness and awareness against a complex cyber-physical threat landscape, as well as to assess their system resilience [4] under a wide range of cyber and physical attacks and their combinations. RAET is a platform that facilitates a complete workflow for cyber-physical risk assessment, based on the logic of ISO 31000 [5]. It helps water companies to a) identify, b) analyse, c) evaluate threat scenarios and d) to explore appropriate mitigation options that can manage these threats effectively.

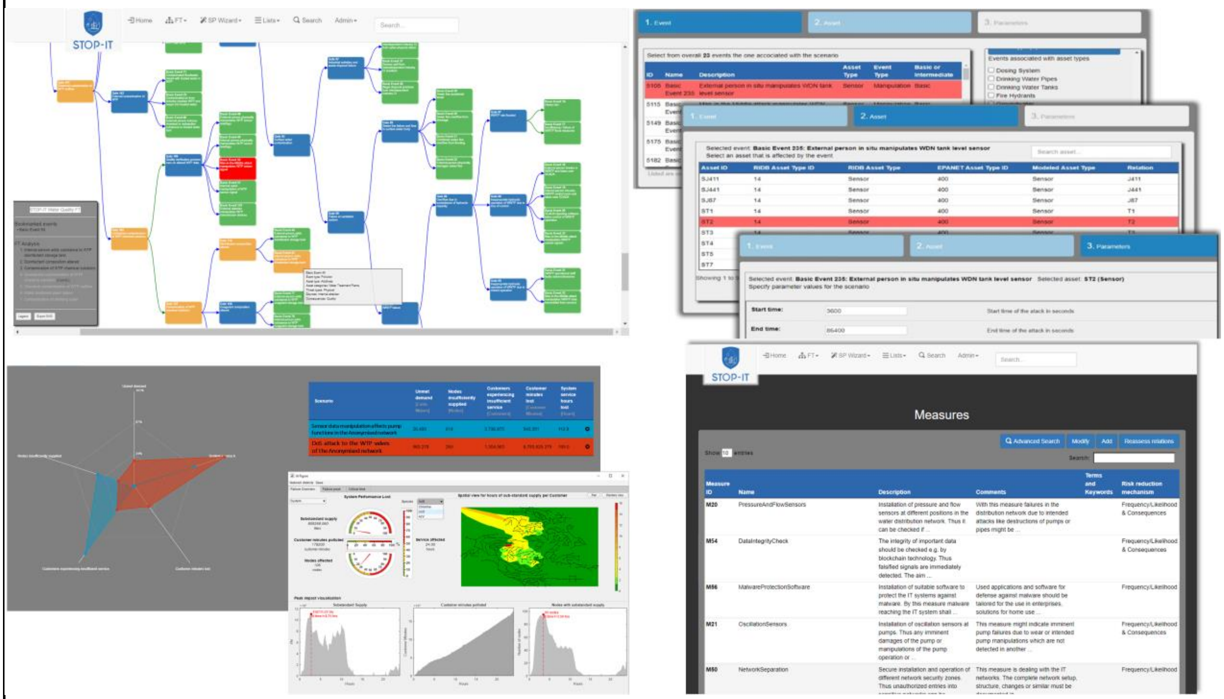

Figure 1: Screenshots from the RAET platform

RAET is designed as an expandable, modular platform that contains state-of-the-art tools that can be customised to the data, risks, and mitigation measures relevant to each water utility. Users can employ a Fault Tree analysis, which helps them visualise the interplays, failure paths and cascading effects between the cyber and physical domains of the entire urban water cycle. They can then use this understanding of the cascades between different events to assess the resulting risk for their particular system by utilizing an intuitive scenario planning environment, capable of preparing and simulating scenarios of complex cyber-physical attacks. Within this environment, a user can, for example, explore the effects of biochemical contaminant injections in several nodes of a water distribution system, combined with a cyber-attack on the water quality sensors that are monitoring the system and take decisions regarding sensor placement (from a cyber-physical perspective) as well as decisions on control logic and mitigation measures to minimise the effects of such a cyber-physical attack scenario.

To do that, RAET employs novel tools for the simulation of complex cyber-physical scenarios, including the RISKNOUGHT cyber-physical water distribution system model [6], which can realistically simulate the interaction between control logic / SCADA of any water distribution network and the network's hydraulic and water quality processes. RISKNOUGHT can evaluate a wide range of cyber-physical attacks, including denial of service (DoS) attacks, sensor data manipulation, biochemical contaminant injections, sabotage, and their combinations.

Scenario results are presented to users via key performance metrics (e.g., unmet water demand, spatial extent of contamination, time of system downtime etc.) visualized though interactive graphs, to help users acquire situational awareness about the cascading effects to their system in both space and time [7]. Finally, a smart matching algorithm in RAET helps users identify potential mitigation measures that are more suitable for a given risk. The platform has been recently introduced to the water sector through demonstration and hands-on training events in collaboration with major European water utilities.

Impacts (financial, environmental, operational, other)

RAET helps water companies to understand and be prepared for potential cyber-physical attacks against their systems thus minimizing their risk exposure and ensuring significant financial, operational and reputational benefits for water utilities.

It is understood that cyber-physical attacks on key water systems can have detrimental effects on both citizens and the environment e.g., a contamination attack on a water distribution network can render large quantities of water unsafe for consumption and if undetected, may lead to significant public health impacts. Even if such an attack is detected, the disposal of contaminated water may potentially cause significant environmental damage. Cyber-attacks can alter control schemes of critical water system components leading to reservoirs emptying or overflowing. Such manipulation would result in loss of service or loss of resource respectively, both directly translatable to potentially significant economic losses for the water company and its customers.

Furthermore, RAET specifically helps water companies to better protect the most critical parts of their system and their community (e.g., hospitals, government buildings etc.) and as such provide significant co-benefits in terms of security and resilience of societies against emerging concerns of cyber-criminality and hybrid warfare.

RAET also has significant internal operational benefits for water companies as it manages and communicates actionable risk information between key company personnel allowing safe intra-organisational communication and collaboration between departments (notably between cyber and physical operation experts), first responders and decision makers. Its workflow and data sharing architecture allow cyber-physical risk assessment to be supported in a standardized and efficient manner, leading to more robust evaluation results, case-driven crisis management training and data-driven decision making, with significant gains in organisational efficiency.

For whom? Who can benefit?

The main end-users of RAET are professionals responsible for the assessment and management of cyber-physical risks against Water Critical Infrastructure at the strategic and tactical levels. Such professionals are usually employees or consultants of the strategic planning and risk management department of water utilities and report to the company's chief risk officer or equivalent.

Another group of end-users are experts and researchers working in the field of Critical Infrastructure Protection, Cyber-Physical and Hybrid Threats analysis and assessment and Critical Societal Systems Security. They could use RAET as a platform for an integrative approach to risk assessment, testing state of the art simulation tools and incorporating results from RAET in their own tools and methods (e.g., to make table top exercises for critical infrastructure crisis management more realistic).

The main beneficiaries of RAET are, of course, water companies, which will be better prepared to manage cyber and physical attacks and their combinations and water users, which will be better protected against interruptions of supply of high-quality water at their taps.

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Show Case 6: Edge-neurocomputing multisensor architecture for the physico-chemical analysis of fluids

Background and general description

The EU H2020 MSCA-IF project ProbSenS developed a novel neuro-computational miniaturized multi-sensor architecture for the physico-chemical analysis of fluids in situ and in real time. The technology was applied to monitor multiple configurable conductivity, ORP, temperature, ionic concentration, and organoleptic properties in a drinking water treatment plant (DWTP), so as to beat current sector benchmarks on power consumption, miniaturisation, and on operational costs and latencies.

Current online water monitoring instrumentation is generally expensive, bulky, mono-parametric, non-predictive, and requires periodical calibration in front of environmental changes. Measurements not feasible with such specific equipment are conducted in laboratories with higher associated costs and delays and, when used, predictive models are deployed in the cloud. This translates into latencies due to data transmission, storage, and processing bottlenecks that accentuate as the volume of information accumulates over time. The technology developed in the project can be trained to predict new measurements of interest resiliently to sensor non-idealities, and can be deployed to efficiently fuse multimodal micro-sensor data for preventing quality events at the edge.

Towards this goal, ProbSenS achieved the following results:

- Design and installation of new multi-parametric micro-sensor probes in the field.
- Development of deep neural network (DNN) architectures for micro-sensor fusion.
- Algorithmic definition to map the DNNs into low-power neuromorphic VLSI hardware.
- Validation of DNN architectures to predict measurements of interest for the final user.

ProbSenS provides the opportunity to demonstrate the new technology working hand in hand with a leading water management company, encouraging technology transfer to a core EU sector.

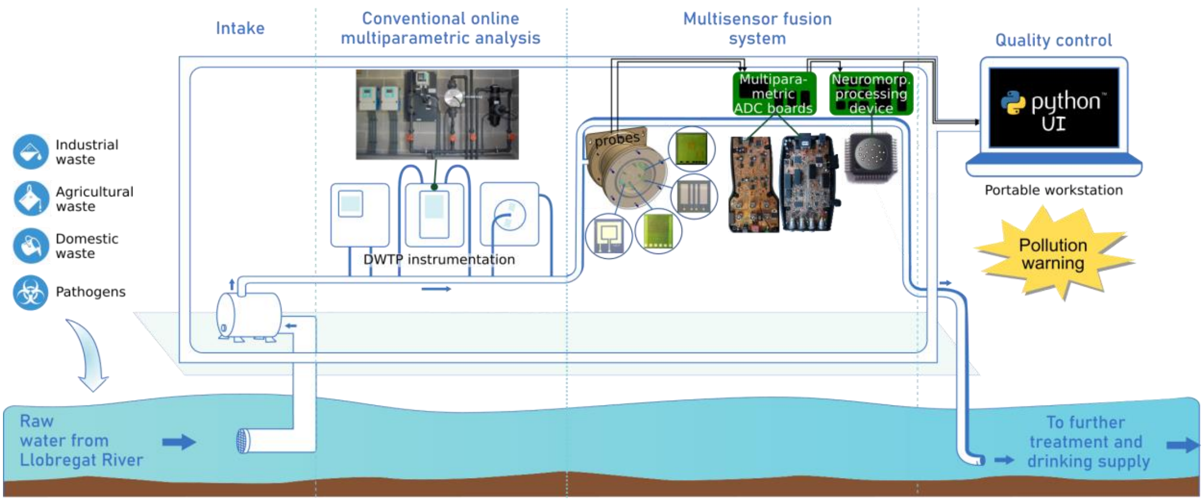

Figure 1: Schematic diagram of ProbSens

Impacts (financial, environmental, operational, other)

The ProbSenS system is conceived:

- to be low cost (using mature sensors and computational substrates mass-manufacturable in standard VLSI circuit integration processes (CMOS)),
- to be energy efficient (~mW),
- to immediately (~ms) and simultaneously predict multiple taste, hardness, and quality anomalies at the edge,
- to be resilient in front of fouling, leaching, matrix, and temperature effects (≤1 cleaning session/week, micro-sensor lifetime ≥2 months), and
- to be easily reconfigurable in terms of sensor array and DNN synaptic weights to incorporate new emerging contaminants (e.g. dioxane) whenever correlated with the measurements read out from the microsensor probes.

As such, in the water sector it has the potential to save CAPEX/OPEX costs by curtailing the equipment needed to perform online water monitoring, electric power consumption, sensor maintenance, laboratory analytical load, and unforeseen plant emergency stops.

For whom? Who can benefit?

By integrating such capabilities in a single measuring instrument, ProbSenS could benefit water utilities/operators (public or private), water user associations, and regulatory actors, optimizing costs, while simplifying water quality data collection and enhancing its sustainability to promote regulation compliance. Ultimately, the high cost-effectiveness, efficiency and adaptivity potential of the ProbSenS technology is intended to help ubiquitizing and economizing water monitoring, with a focus on facilitating access to safe drinking water for all.

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Show Case 7: Sensor systems for predictive maintenance of wastewater systems

Background and general description

The cities have a large infrastructure of wastewater systems (sewage, storm-water and combined sewage and stormwater) to regulate and oversee. One of the main challenges for the cities is the maintenance of these systems. It is hard to know when maintenance is necessary since there is no data available that can indicate clogging or sedimentation in the system. There is therefore a need of monitoring systems based on sensors for predictive maintenance of wastewater systems. The monitoring system needs to be low cost, low maintenance and easy to expand. The sensor elements need to be robust and have a multiple year maintenance free lifetime, to ensure that the operational costs do not get too high. This means that the sensor elements need to be resilient to the wastewater environment and have a long operational life length. Also, they need to be put into a system where a network of many sensors can produce data that could be analysed by AI to find relevant patterns that assist predictive maintenance in the whole system.

Figure 1: New patented turbidity and water level sensor based on image processing and AI.

IVL Swedish Environmental Institute is developing a patented turbidity and water level sensor, called "The Turbinator", which is based on image processing and AI. By combining monitoring of sediment content in the water (turbidity) with monitoring of water levels and processing the information on both sensor and system level with AI it is believed that the need for maintenance could be better predicted. Tests are now made in the stormwater systems in Gothenburg. The sensor is designed for monitoring wastewater in a dark environment, and therefore is well fitted for applications like manholes. It differs from other turbidity sensors currently on the market as the sensor is not in contact with water, it uses a battery, thus, does not need additional power supply. It is also easy to install and uninstall the sensor when the battery needs to be changed or the sensor needs to be moved to a new location, since it is mounted in the pipe close to the ground. No drilling is needed and it can be done without entering the manhole, which comes with hard regulation of safety. Therefore, "Turbinator" has these three major advantages and it reduces the workload related to maintenance. While to the commonly used sensors needs cleaning, as they are in contact with water, needs additional power supply preparation and specific placement/montage.

Figure 2: The sensor needs to be robust to withstand the wastewater environment, easy to install and de-install as well as requiring little maintenance.

Impacts (financial, environmental, operational, other)

Today, the need for maintenance in wastewater systems is usually identified by manual inspection. This is very costly. Also, failure to in time identify clogging and sedimentation can lead to odour, overflow and make the impact of flooding events more severe, leading to damage to property and business. Early estimates in the SCORE-water project on the case of Gothenburg city suggests that the investment costs of a monitoring system based on sensors for predictive maintenance of wastewater systems in the city could be in the magnitude of one tenth of the annual maintenance costs. If the sensors could have a multiple year maintenance free lifetime, to ensure that the operational costs don't get too high, the relatively low CAPEX of the system compared to the relatively high OPEX of maintenance suggests that just a few percent lower OPEX by more efficient maintenance can make the system profitable. However, the system is still in an early development phase and the low operational costs are not yet proven, even though results so far are promising.

For whom? Who can benefit?

Cities often have several departments that are involved in the maintenance of the wastewater grid depending on its location. The main owner that maintains the wastewater system is usually the city water utility. Some parts of the stormwater system, which are located below roads and parking areas can be owned by different responsible entities, such as traffic/transport department or parking department. Furthermore, there could be also pipes owned by private actors when storm sewers are located in private areas. All these actors might benefit. In addition, real estate owners, business and insurance companies might benefit from less damage if the overflows and flooding events can be less severe due to less clogging and sedimentation when the control of the wastewater system is increased.

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Show Case 8: Semantic Sensor Hub applied to explore water sewage information and bathing areas information.

Background and general description

The Semantic Sensor Hub is a context-broker tool devoted to integrating information from heterogeneous data sources deployed inside the sewage infrastructure (sensors, pumps levels, external quality monitoring tools, etc.). The main intention of this context-broker is to harmonise information coming from digital devices that make it available using heterogeneous data sources (e.g. Custom REST-APIs, COAP, Modbus, etc.). This harmonization comprises of the elaboration and promotion of a common vocabulary for data exchange based on open standards and internet adoptions (combination between NGSI-LD standards for API and SAREF4WATR as a common vocabulary).

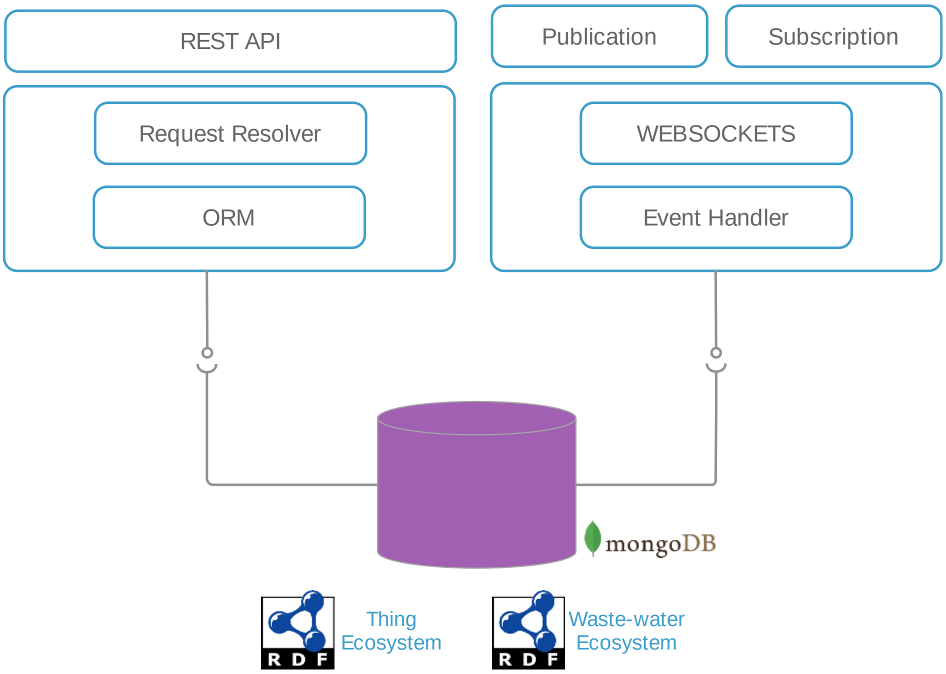
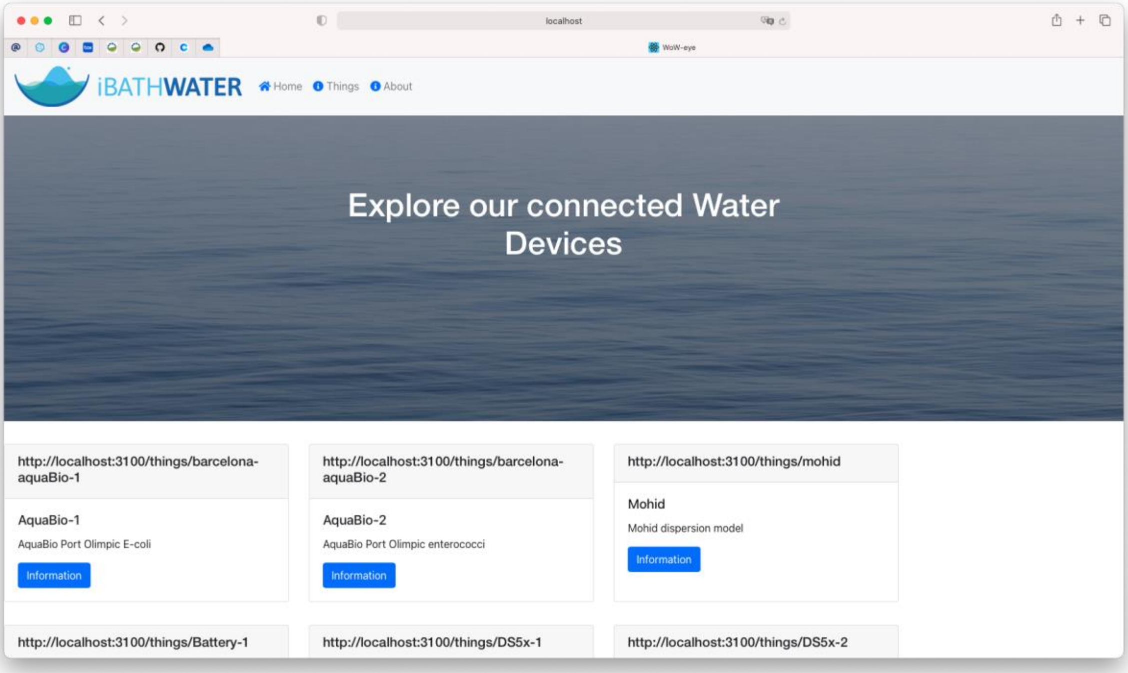


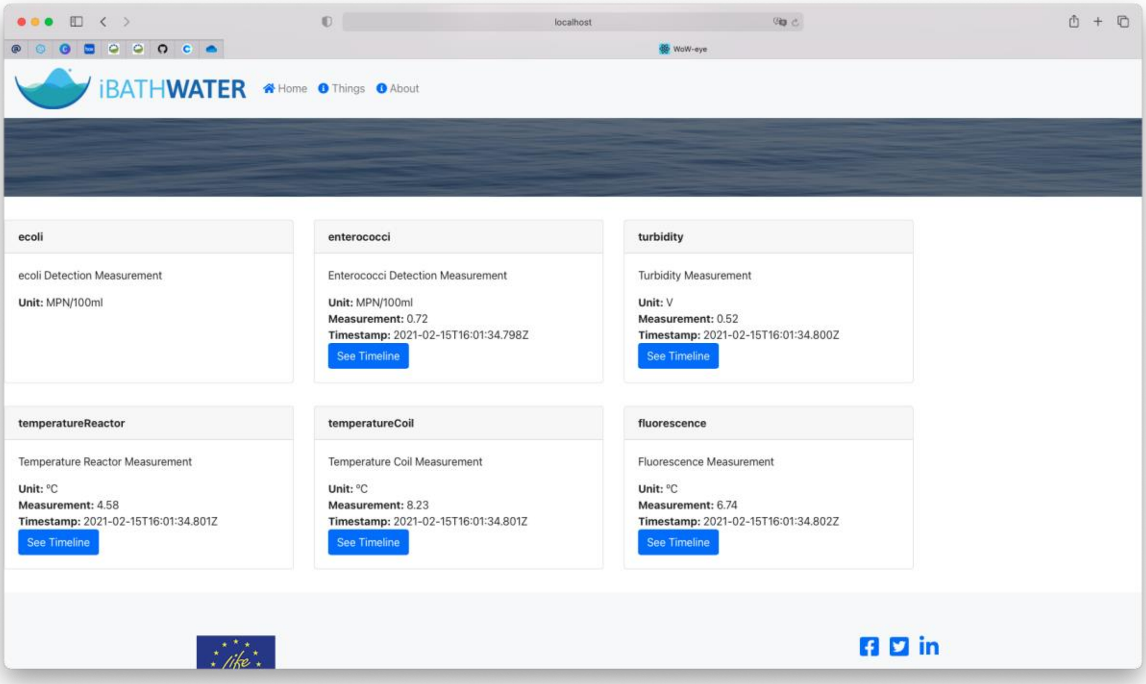
Figure 1: Schematic diagram of the Semantic Sensor Hub

Based on this common definition, the Semantic Sensor Hub integrates the information using specific “plugins”. These plugins are aimed at transforming specific protocols (including connections to external systems) into a common vocabulary (SAREF4WATR). Inside IBathwater project created specific plugins to connect COAP tools (specific sensors), SOAP XML APIs (Connection to water utilities information), and REST-API connections (to connect AquaBio information and some risk models results).

The information is exposed using Pub/Sub and Open REST API. On the one hand, the Pub/Sub paradigm permits to publish and subscribe information using web-sockets considering the different measurements defined. The Open REST API follows the NGSI-LD specification[41] to expose the information of the integrated and registered systems.

[41] https://www.youtube.com/watch?app=desktop&time_continue=50&v=mFnOaSW82Bw&feature=emb_logo





The main benefits provided by the application can be summarized on:

- Semantic interoperability between the digital systems of the water infrastructure.
- Common visualization and data exploration of the digital systems.
- Interlink between the different variables of the water and interrelated domains.

Impacts (financial, environmental, operational, other)

Water management is a fragmented sector in which the data exchange between the different parts of the water value chain is limited. In order to enable data and information exchange between different systems, tools like the semantic sensor hub provide **interoperability** between the operational tools. Exchange of data and making information more accessible for the sewage operators, supports in turn enhanced decision-making. Moreover, the semantic sensor hub also impacts on the CAPEX/OPEX of the water infrastructure in terms of high-scalable digital architecture for collecting and analysing information.

For whom? Who can benefit?

The main beneficiaries of the platform are:

- **Sewage Operators**. Through making operational information accessible and linked under a common dashboarding tool.
- **Authorities**. To offer them near-real time information about the situation of the bathing areas and the infrastructure.
- **Citizens**. Offering them updated information about the quality of the bathing areas.

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Main contact for more details and clarifications: Aitor Corchero (aitor.corchero@eurecat.org)

Show Case 9: Open, Low-Cost and Enhanced Standards-Based IoT Architecture for Holistic Smart Water Quality Monitoring

Background and general description

Currently, **water quality monitoring** is a very important research area that would ensure safe water to be delivered to the users and reusable water run off to the environment. Nevertheless, despite this need, the existing Wireless Sensor Networks (WSN) are applied to large areas and are based on expensive hardware and proprietary software thus hindering the deployment for wide water quality monitoring. INNOQUA project proposes a novel, smart, and low-cost, ICT architecture to monitor and control an unattended an innovative ecological on-site sanitation system by using open hardware and software solutions.

The **monitoring and control unit** developed by INNOQUA project (https://innoqua-project.eu/) (GA 689817) (2016-2020) consists of an Internet of Things (IoT) full stack solution, enhanced with local intelligence, to perform humanlike actions and enhance the measurements accuracy by using cross-correlations. It provide a major contribution to: (i) reduce water monitoring deployment costs by using virtual sensors (e.g. predict removal rate for different water quality parameters such as ammonium, TSS, BOD, COD , among others); (ii) minimize the human intervention thanks to edged-analytics; (iii) integrate heterogeneous sensors and actuators by using IoT standards; (iv) real-time transformation and correction of RAW data by using embedded-knowledge; (v) improve the quality metering by using machine learning models; and (vi) encourage the water quality monitoring fostering behavioural change.

Figure 1: Screenshot and Monitoring and Control Unit

The monitoring and control unit are now being demonstrated at 13 demonstration sites across 11 countries – in both urban and rural environments.

Impacts (financial, environmental, operational, other)

- Boosting digitalization of the rural and remote water sector;
- Low-cost, affordable or cost-benefit water monitoring solution.
- Decentralised smart water services at the equipment/sensor level;
- Standardized data-driven models integration to design virtual sensors based on complex correlations.
- Encourage the water quality monitoring and control of isolated water infrastructures by using low-cost, open source, smart and based-standards solution allowing an unattended remote control and monitoring.

For whom? Who can benefit?

Monitoring and control unit is mainly directed to smart and large water utilities, cities and industries interested to find a low-cost water monitoring and control solution with edge capabilities. It can be deployed to autonomously monitor water environments or monitor and control remote water infrastructures. The Monitoring and control unit monitors the pH, temperature, conductivity and dissolved oxygen water quality parameters. Nevertheless it allows connect any water quality sensors through 0-5V and 4-20mA hardware interfaces.

References

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Show Case 10: Enhanced knowledge-based Decision Support System for integrated water resources management in the water distribution system

Background and general description

Currently, management tools are designed to solve specific water issues. They cannot interoperate and are losing decisional dependencies along the water **supply distribution chain**. WatERP project (GA 318603) developed a web-based Open Management Platform (OMP) [1,2,3], supported by real-time knowledge on water supply and demand, enabling the **entire water distribution system** to be viewed in an integrated and customized way.

The OMP uses the decisional knowledge to improve daily operations. A specially designed Water Management Ontology (WMO) is used to encompass the water cycle from water management perspective. WMO is combined with two inference engines, which provide recommendations to the water manager. This knowledge characterization permits to semantically represent human and natural paths interactions in order to discover hidden knowledge, hence founding new Integrated Water Resources Management strategies to improve resource management and energy efficiency.

The general architecture is based on OGC stack (SOS, WPS and WaterML2) to ensure interoperability and it includes two engines: (i) rule engine for improving water allocation in order to satisfy different water usages demand, and (ii) case-based inference engine aimed at generating pumping scheduling recommendations for water distribution [4].

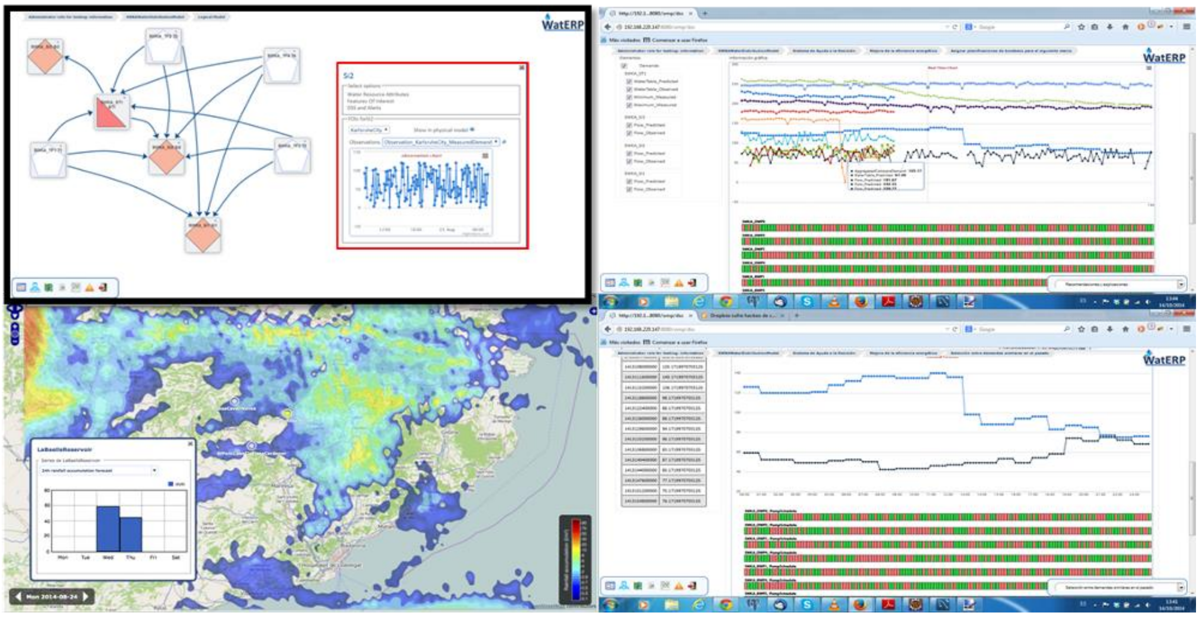

Figure 1: Screenshot of OMP

Impacts (financial, environmental, operational, other)

- Enhancing the coordination between the different stakeholders on water supply and distribution management, making them participants in the global situation, and recommending correct actions to be taken.
- Water resources optimization and reducing water and energy consumption.
- Improving allocations of water supply to users and needs, by making information regarding available water and demands more accessible.
- Real-time tracking of water supplies, flows and distribution efficiency across the entire distribution network.

For whom? Who can benefit?

OMP is mainly addressed to smart and large water utilities, cities and water decision makers interested to coordinate and manage the water supply and distribution.

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Main contact for more details and clarifications: Edgar Rubión (*edgar.rubion@eurecat.org*)

Show Case 11: Detection and Integrated Assessment of Non-authorised water Abstractions using EO (DIANA)

Background and general description

Water scarcity and droughts increases the need for a sustainable and integrated management of water resources in Europe. Agriculture is a significant user of freshwater for irrigation, aiming to enhance the yield and quality of crops, to reduce risks of crop failures due to dry periods, and to stabilise yields. More specifically, agriculture accounts for approximately a quarter of the 182 billion m³ of water extracted every year in Europe. At the same time, irrigation is also a major cause **of non-authorised water abstraction or over-abstraction**. Therefore, irrigation is responsible for the abstraction of larger volumes of water than officially permitted and/or sustainably available. A sequence of record-breaking temperatures in the last few years led to a severe drought that decreased harvests and increased water shortages, therefore it urgently raised the need for integrated water management solutions.

In this context, DIANA project (GA 130907) developed a commercial service platform that was co-created and co-designed together with water management authorities. The core services provided by DIANA platform are:

- a non-authorised water abstraction detection and monitoring service for control optimisation
- a seasonal drought forecast service
- a support service to the implementation and monitoring of the Water Framework Directive (WFD).

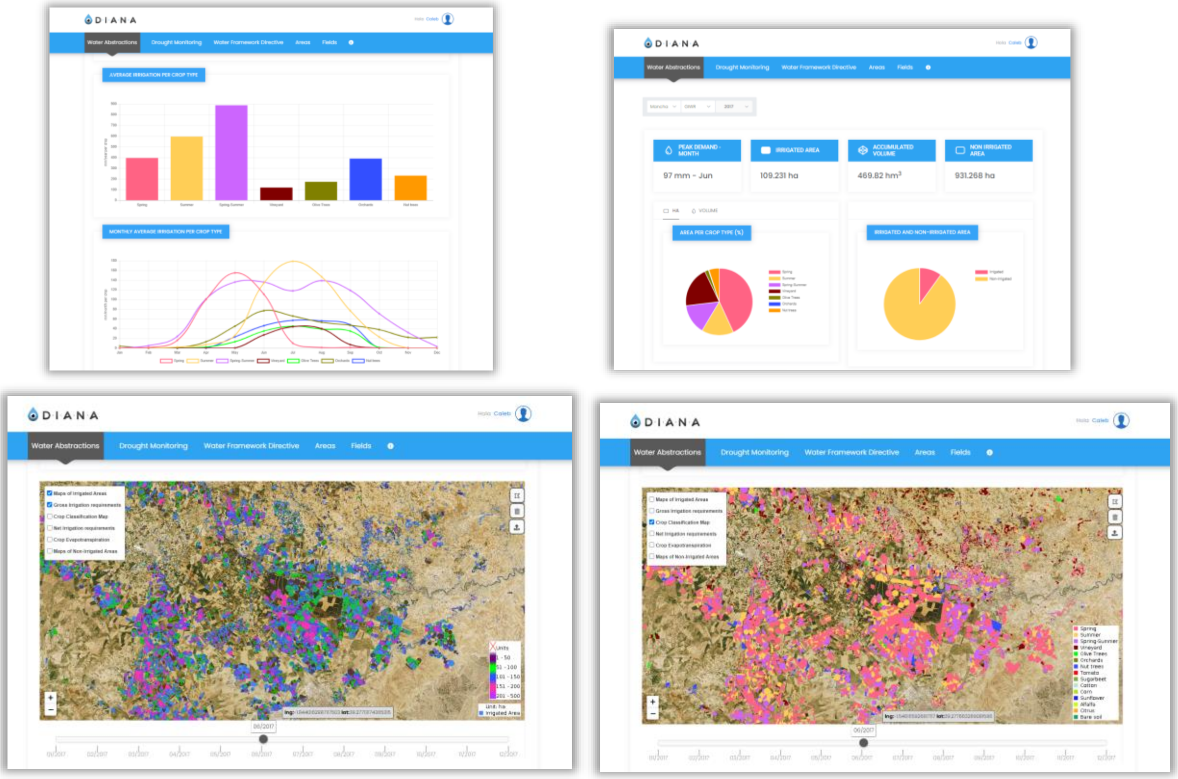

Figure 1: Screenshot from DIANA Platform

Users engagement in the project, ensured that they have at their disposal a “customized”, powerful tool, to support them in their efforts to optimise the identification and inspection of non-authorised water abstractions for irrigation. Along with the use of drought service that can be used to forecast extreme conditions, DIANA significantly improves the monitoring and assessment of water management policies and practices.

Impacts (financial, environmental, operational, other)

DIANA services are intended to address complex water management challenges across Europe.

The non-authorised water abstraction detection and monitoring service is the core service of DIANA. The service is able to detect areas where non-authorised water abstraction has occurred and provide timely alerts to the users. In addition, time sequences of irrigated areas provide users with maps of irrigation water consumption and abstracted volumes, along with estimates of water consumption. The alerts provided by DIANA can be used to guide and optimise field inspection procedures, while the service also empowers users to:

- monitor **irrigated areas and the abstracted volumes** on a systematic basis,
- better **target field inspections** aimed at assessing compliance with legal water allocation,
- ensure the **legitimacy of self-declared irrigation** water abstractions and
- **safeguard compliance with water restrictions** set in special occasions such as drought.

By using seasonal climate forecast in combination with hydrological and crop growth models, the **drought forecast service** is the **second service** provided to users for their region of interest by DIANA. The service enables users to apply more pro-active planning to improve water resources management. By providing required decision support tools, users can develop **evidence-based water/drought management plans or review existing** ones, and to adjust the water rights in cases of drought.

Furthermore, DIANA produces a huge amount of high spatial and temporal resolution, meteorological and hydrological data at river basin scale. The data is the **third service of DIANA** project, proposed to the authorities, responsible for the implementation of the WFD, to fill the spatial and temporal data gaps. The service provides users with a better understanding of how the water resources of the area under their authority are used (including irrigation requirements and abstractions), as well as with valuable evidence for evaluating the efficiency of their water saving actions, aiming to drive better informed decisions and actions in the process of WFD implementation.

For whom? Who can benefit?

DIANA services can be beneficial to:

- <u>**National Authorities (NAs)**</u>
  - To enable near real time full geographical coverage to detect potential areas with non-authorised abstractions;
  - To contribute the implementation of the EU and national legislation to reduce wasting of water and to preserve water resources;
  - To enable a long term collection of valuable statistics regarding management of irrigation and water abstraction;

  - To evaluate the efficiency of water saving actions;
  - To improve water management policies and practices.
- **Regional and local authorities (RLAs)**
  - To enable near real time full geographical coverage to detect potential areas with non-authorised abstractions;
  - To provide accurate estimates of abstracted water volumes;
  - To enable a long term collection of valuable statistics regarding management of irrigation and water abstraction;
  - To improve water management policies and practices;
  - To evaluate the efficiency of water saving actions;
  - To support the improvement of Drought Management Plans.
- **Water Users Associations (WUAs)**
  - To enable near real time full geographical coverage to detect potential areas with non-authorised abstractions;
  - To improve water management policies and practices;
  - To evaluate the efficiency of water saving actions;
  - To provide accurate estimates of abstracted water volumes;
  - To provide adequate spatial resolution and accuracy to identify potential non-authorised irrigated areas;
  - To manage field inspections in a more efficient manner;
  - To reduce overall costs for monitoring and detecting non-authorised water abstractions;
  - To support the introduction of fairer and more refined water tariffs that take into account abstracted water volumes and not just irrigable surfaces;
  - To reduce non-revenue irrigation water;
  - To contain costs for energy consumption related to water abstraction and irrigation;
  - To support the improvement of Drought Management Plans;
- **Other Stakeholders interested in hydro-meteorological data**
  - To obtain information on the canopy and the usage of the agriculture land;
  - To enable a long term collection of valuable statistics regarding management of irrigation and water abstraction;
  - To support the improvement of Drought Management Plans;
  - To enable the optimal crop selection and crop production planning;
  - To increase the productivity and quality of crops.

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Show Case 12: SAPIENCE – Sustainable Agricultural Practices and Incentives for ENvironmental Care Ecosystems (EIT Climate KIC Pathfinder Project)

Background and general description

SAPIENCE is a 'pathfinder' project funded in 2020 by EIT Climate KIC. The aim of the project is to assess and validate the use of IoT and blockchains integration in agriculture as enablers to reduce natural resource use and incentivize virtuous behaviours and sustainable practices (i.e. saving irrigation water).

The project has several objectives in showing the advantages of agritech solutions with the purpose to reduce water use and to produce better yields with more knowledge, data and information collected from the fields. To validate proposed solutions project has few pilots between the Italian regions of Trentino (vineyards), Emilia Romagna and Sicily (horticulture) with the involvement of Cantina Sociale Roveré della Luna, related growers and irrigation company as well as cooperative Agribologna with a selection of its registered growers.

Selected farmers installed IoT monitoring devices in their fields to be able to better assess crops current water needs and avoid wasting such a precious natural resource. The experimentation used IoT monitoring data and wireless electro-valves to enable growers to better control irrigation based on real crop needs and to produce evidence of achieved water savings. Smart contracts between farmers and stakeholders regulate the distribution of incentives from who values preserving the resources (i.e. water companies, hydro-power utility companies) from who needs to use them (growers mainly) companies, hydro-power utility companies) from who needs to use them (growers mainly).

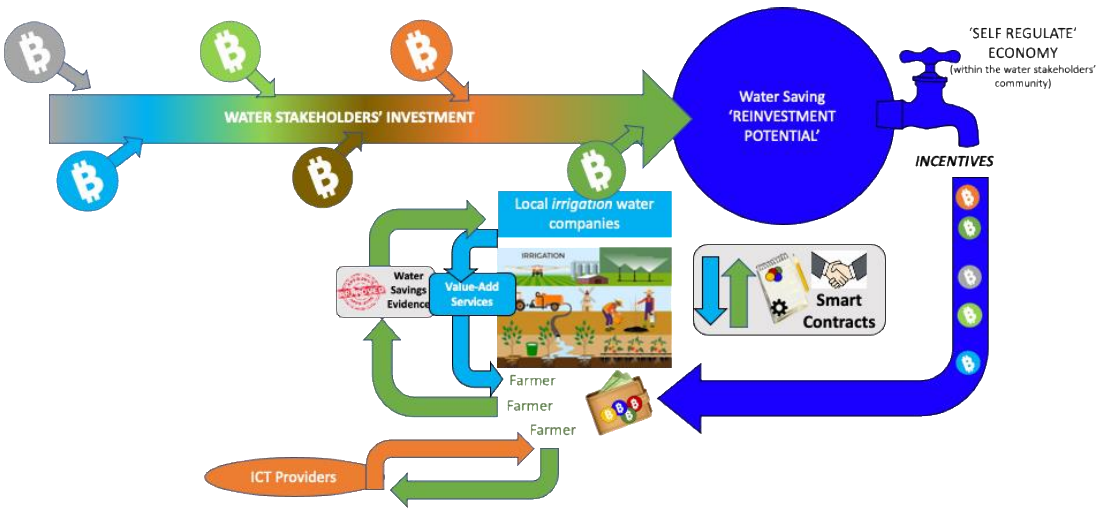

Fig. 1: the SAPIENCE Model

Impacts (financial, environmental, operational, other)

Climate change is forcing an attitude shift in many Mediterranean regions. SAPIENCE is providing tools for mitigating the effects of more and more extreme weather occurrences such as droughts, helping the European agricultural sector protect its business and maintain its competitiveness.

The SAPIENCE model provides a framework to incentivise sustainable behaviours, ensuring "tragedy of commons" deadlocks (typical on shared resources) that can be resolved, having the interests of the community reconciled with the interests of the individuals in the primary food production (and consumption) sectors.

The environmental impact relates to the novel mechanisms designed to reward and monetise sustainability of agricultural practices as well as providing means to better control crop quality and yield. This is achieved with the help of IoT sensing in the fields, making agronomists and growers more aware of crop needs. The incentives are expected to offset costs and ease the overcoming of current resistance to adoption of digital agriculture solutions.

For whom? Who can benefit?

The primary beneficiaries of project results are expected to be the growers operating in the primary food production sector as well as the agronomists advising them. The citizen's benefit is reaped as a consequence with better quality products available and produced with attention to the optimal use of natural resources.

The whole agricultural primary production sector is expected to have the benefits of this innovation as SAPIENCE project should enable new funding from additional stakeholders that would have interests through project results, directly investing in water savings or more sustainable production.

Less water used in agriculture leaves more water in the reservoirs for hydropower generation or more water for other civilian use, especially in times of water scarcity. SAPIENCE enables a fairer allocation of such a precious resource, based on virtuousness in its use.

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3. **Twitter**: @sapience_eit

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