D6.1: Consumer Awareness and Behavioural Change Support Framework for Water Consumption and Usage Savings

Greening the economy in line with the sustainable development goals

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A holistic water ecosystem for digitisation of urban water sector

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Digital solutions for water: linking the physical and digital world for water solutions

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Summary

One of the main objectives of the NAIADES project refers to enhancing water end-users as well as related stakeholders, such as managers of water companies and public officials, awareness on water consumption, and promoting user engagement in water conservation activities. This deliverable describes the work performed within T6.1 of the project and provides the basis for the NAIADES awareness and behavioural change support services. The deliverable first focuses on a systematic analysis of existing approaches that implement public awareness through dashboard technologies. Then it provides a thorough analysis and review of behavioural change support systems and approaches for resource management and specifically within the water conservation domain. The analysis has focused on theories of awareness and behavioural change, as well as on the implementation aspects and the effectiveness and acceptance of related approaches and systems. The aim of the analysis and review was to identify the most suitable elements to be further extended, developed and enhanced in NAIADES, in order to address the requirements of the pilot cases. These elements are captured in the definition of the NAIADES framework for water consumption awareness and behavioural change support. The framework synthesizes awareness and behavioural change support services for different types of users, including water consumers, employees of water companies and public administrations, which leverage the data and AI services residing in the NAIADES intelligence framework.

1 Introduction

One of the main objectives of the NAIADES project refers to enhancing water end-users as well as related stakeholders, such as managers of water companies and public officials, awareness on water consumption, and promoting user engagement in water conservation activities. The objective is mainly addressed in WP6 "Water Consumers Awareness and Behavioural Change Support" where related services are being designed and developed. This deliverable, the first of WP6, is the outcome of T6.1 and reports related activities performed in this task.

The main goal of T6.1 was to provide the basis for the NAIADES awareness and behavioural change support services through a systematic analysis of existing approaches that implement public awareness and behavioural strategies for resource management and specifically within water management applications. The analysis has focused on theories of awareness and behavioural changes, as well as on the implementation aspects and the effectiveness and acceptance of related approaches and systems. The target was to identify the most suitable elements to be further extended, developed and enhanced in NAIADES, in order to address the requirements of the pilot cases and has been reached with the definition of the NAIADES framework for water consumption awareness and behavioural change support. This framework synthesizes awareness and behavioural change support services for different types of users, including water consumers and employees of water companies / public administrations) which leverage the data and AI services residing in the NAIADES intelligence framework.

1.1 Background and Motivation

One of the main sustainability challenges faced by human societies nowadays refers to the sustainable use of freshwater resources, which are essential for life, nature and economic activities. Freshwater is increasingly at risk in many areas of the world as a result of unprecedented population growth, ever increasing number of inhabitants in urban environments resulting to land-use changes and pollution, as well as the ongoing climate change induced by over-consumption earth's resources.

In order to deal with the aforementioned consequences of urbanization and climate change and because water is an essential pillar of sustainability, means for efficient water management have been widely considered by countries, water utilities, public administrations and municipalities around the world. These stakeholders are forced to revise water policies and design interventions that promote sustainable water use, i.e. promote patterns of water use that ensure satisfaction of needs for the present and future generations.

Common interventions aiming to reduce water demand, rely on pricing and usage restrictions (Inman & Jeffrey, 2006). It has been shown that higher prices in the consumed water can lead to less water use (Olmstead, 2010). However, such approaches can be slow to implement, and are not well accepted by citizens leading causing unwanted reactions to public officials while their impact can be limited especially to users with higher income (De Oliver, 1999). For example, a recent study provided by the Los Angeles Department of Water and Power showed that a 1% water price increase decreased consumption by 0.1% (Miller et al., 2017). Formal restrictions can also be effective (Haque et al., 2014; Kenney et al., 2004; Renwick and Archibald, 2019) and are common (Palazzo et al., 2017). Such restrictions can be difficult to implement due to limited political will and public acceptance. Furthermore, it has been shown that they do not lead to long term reductions in water use, can be difficult to enforce, and can be less effective than other means (Brennan et al., 2007; Grafton & Ward, 2008).

A different kind of interventions refers to the deployment of awareness and behavioural change support systems (Oinas-Kukkonen and Harjumaa, 2009) for sustainable water use and consumption. Such systems rely on theories of behavioural change and the use of technology for nudging or persuading users to adopt sustainable behaviours. Essentially, the advent of Web 2.0 and widespread use of smartphones and mobile devices provides new ways to create, access and share information has allowed the development of this kind of information systems that have the potential of influencing users' behaviours (Oinas-Kukkonen and

Harjumaa, 2009). In recent years, awareness and behavioural change support systems have raised the interest of the research community that has focused on designing related solutions and studying their potential for inducing sustainable behaviours with respect to water use.

1.2 The NAIADES focus

NAIADES aims to provide a set of innovative services that will enhance public awareness on water consumption and usage savings, promote user engagement and enhance user participation in water conservation activities. These include awareness services that present detailed information about water consumption and behavioural change support services that leverage the power of behavioural change support and persuasive strategies and features such as social proof, tailoring, self-monitoring, goal setting/commitment and rewards. The goal is to change the attitudes and practices towards water conservation by enhancing public awareness on water consumption and usage savings, promoting user engagement and enhancing user participation in water conservation activities. These services will make use of the data middleware and AI services which are part of the NAIADES solution. More specifically the NAIADES awareness services and behavioural change support services focus on the following set of use cases:

1. Water consumption awareness for water management companies and public officials. This use case will show how to make use of the NAIADES data aggregation middleware and optimally water consumption data to interested stakeholders in order to monitor and understand how water is consumed in a specific area or consumption point, while considering contextual parameters such as the time of consumption, weather conditions. Decisions on water consumption mitigation measures can rely on such information and such measures can be monitored after their implementation.
2. Behavioural change support for inducing sustainable water use behaviours among water consumers. This use case will show how ICT solutions can be used in order to change consumers' perceptions and actions towards water conservation. In NAIADES we focus on school students, a group of consumers that can provide a channel for generating great impact as students i) will evolve to the responsible citizens of tomorrow and ii) they can transfer the knowledge, attitudes and behaviours they shape to their families, leading to a cascading effect of the NAIADES impact.
3. Water consumption awareness for public employees. This use case will show how to make use of watering data and AI services for watering predictions in order to inform public employees decisions related to plants watering tasks. Plants watering is performed in nearly every municipality and public building, and commonly leads to unnecessary water consumption and waste of human resources. The NAIADES approach aims to inform watering decisions for timely watering actions and water savings.

1.3 Structure of the deliverable

The remainder of this deliverable proceeds as follows:

- Section 2 focuses on consumption awareness dashboards. A theoretical background on the use of information presentation dashboards is provided together with recent technological developments. The results of a review of related systems that present information related to water use are also provided.
- Section 3 focuses on the analysis of behavioural change support strategies and related systems and approaches in the water management domain. The strategies and features of related systems that are relevant for NAIADES are identified.
- Section 4 presents the NAIADES Consumer Awareness and Behavioural Change Support Framework, while explaining how it addresses the requirements of the relevant use cases and how it covers the specific pilots of the projects.
- The deliverable concludes in Section 5 with final remarks and the next steps for the coming period.

2 Consumption Awareness Dashboards

2.1 Background

Over the last years, the advancement of ICT technologies and the abundance of stored consumption data has generated the requirement by utility companies to identify ways that will allow them to visualize, communicate and understand available consumption data, with the aim to get better evidence for making informed business and operational related decisions, respond to alerts about business exceptions and use them to raise end users awareness on water consumption. This has led to the emergence of data visualization dashboards which provide functionalities that consolidate available sets of data for a certain purpose and generate visualizations which enables users to monitor and understand the available data, while supporting stakeholders' decisions. Nowadays, dashboards are commonly used in every kind of organizations for optimizing decision making, enhancing operational efficiency, increasing data visibility, driving strategy and transparency, reducing costs, and facilitating communication (Morgan et al., 2017; Lea et al., 2013; Lempinen, 2012; Yigitbasioglu and Velcu, 2012; Zeng and Glaister, 2018).

In the related literature, there have been formal definitions of dashboards. For example, a dashboard can be described as[1]: "a predominantly visual information display that people use to rapidly monitor current conditions that require a timely response to fulfil a specific role." Whereas Wexler et al. (2017) provide a broader definition: "a visual display of data used to monitor conditions and/or facilitate understanding,".

Dashboards are delivered as web accessible applications and connect diverse data sources. Due to their versatile uses, they consist a tool for communicating information while they can be the means for cross-stakeholders interactions (including the public), whereas the ability of data visualization dashboards to provide data stories can create transparency and achieve accountability (Roberts, 2002). The applications of dashboards can be extensive. The related literature reports dashboards providing accountability and legitimacy through transparency (Perez and Rushing, 2007), collecting intelligence and providing cues for action, managing emergencies, benchmarking and comparison, surveilling and controlling (Kitchin et al., 2016), offering democratising tools for civic empowerment and social change (Holden and Moreno, 2015), and providing creative opportunities to hackers, artists, app makers and citizens, like creating data-narratives (de Waal and de Lange, 2014).

Dashboards can support decisions at different levels, including strategic, tactical or operational (Lea et al. 2013; Marx et al., 2012) as well as extend beyond decision support and communicate or educate users, who may lack the context surrounding the presented data (Sarikaya et al., 2018). In terms of decision support, a strategic level dashboard can support an organization's long-term strategy through the visualization of critical success factors. Such dashboards can have an enterprise-wide impact and are mainly used by senior-level management. On a tactical level, a dashboard supports the analysis and monitoring of processes conducted by mid-level management. Though such functionalities the organization can effectively track the performance of defined goals and come up with recommendations for future strategies. For example, sales dashboard tracks sales targets and provides functionalities for various filters and segmentations, such as regional, by sales manager and product. An operational dashboard focuses on the monitoring and support of operations in short time horizons. This kind of dashboards is the most widely used and are based on real time data while can provide alerts about business exceptions in cases of deviations.

Dashboards vary in their visual and functional aspects reflecting the target audience, the visualization experience of the users as well as the domain and context. The audience of a dashboards can be generalized in four groups with increasing levels of specificity and detail (Sarikaya et al., 2018). A dashboard for the general public is intended for general consumption, and provides societially-relevant data. Dashboards for organizations are applicable within a organizational context and provide business related information.

[1] https://www.perceptualedge.com/blog/?p=2793

Dashboards for specific groups are deployed in scenarios of sensitive data or analysis and the access to them is controlled. Personal or individual dashboards are used to quantify the individual and are commonly private or shared with trusted individuals. Required Visualization Literacy (Low, Medium, High) provide three categories regarding the level of a dashboard's visualization complexity: low, medium or high. These directly correspond to levels of the visualization literacy of the target audience. Low complexity refers to basic visualization types such as bar and line charts. Medium complexity provides additional features such as combined dual axes, scatterplots, cumulative measures, and heatmaps. High complexity dashboards target more experienced audiences and may consist of radar graphs, treemaps and network visualizations, error bars or intervals, and other custom visualizations. With respect to the domain, there are dashboards which deal with general data that can be understood by a general audience, for example water consumption. However, there are dashboards which require domain expertise to understand the data they contain such as water metering metrics of a water distribution company.

Another feature that distinguishes different dashboards is that of interactivity and customizability. There are dashboards which allow users to modify the provided views or compose new. These are flexible dashboards and offer functionalities for customizing the placement of views, for modifying the visual representations and selecting the data dimensions and measures to visualize. In terms of presentation, most dashboards provide an all-in-one view. However, there are dashboards which support tabbed layouts for different kinds of reports and visualizations. In tabbed layouts, users can switch between pages, which commonly provide grouped information for different decision-making contexts. The caveat in multipage dashboards is that the provided information can be difficult to consume and their design needs careful consideration. An important interactive feature is the faceting of presented data with the use of slicers and filters as well as the cross-highlighting by selecting data items within the views allowing users to drill up and down the levels of data hierarchies. Furthermore, dashboards may provide interactive functionalities that allow users to highlight and annotate particular data and views. Such functionalities allow users to annotate displays for future examination or for collaboration. Last but not least a dashboard view may allow users to write data to the underlying database and/or interact with external components. For example, a monitoring dashboard of a water distribution company may allow to turn on or off valves of water pumps

Dashboards may also include additional functionalities, including alerts and notifications, benchmarks and automated data updates. A standard use of dashboards is to monitor real time data, detect anomalies and generate warnings them when thresholds are exceeded through explicit alerts or notifications to the users, prompting them to take actions for solving underlying problems. Similarly, benchmarks provide indications of when thresholds are exceeded and can take the form of gauges with ideal goals or warnings in the form of visual aids such red or yellow status lights. Moreover, dashboards can be automatically refreshed as new data are being stored in the underlying database offering a real-time view of how the monitored environments changes.

2.2 Related Systems

With the omnipresence of sensors and Internet of Things (IoT) technologies, which measure consumption, a number of implementations for consumption monitoring, sense making and awareness have been developed. Such dashboards are being used by utility companies in domains such as energy and water and allow strategic, tactical and operational decisions through data visualizations and monitoring. Furthermore, related implementation provide simpler, yet appealing, views of data even at an individual consumption level for motivating users to make more sustainable choices regarding their energy/water consumption through consumption awareness raising. Note that readily available dashboards for water consumption analytics are rather limited. On the other hand, there are numerous implementations of dashboards for energy related analytics. In the following we review related dashboards and approaches implemented to present data related to water and energy consumption with an aim to identify key features that can be adopted and extended within the NAIADES project.

The City of Oberlin in Ohio US has created the Environmental Dashboard shown in Figure 1 (also available at https://environmentaldashboard.org/). This is a joint effort with the Oberlin College and private and institutional partners, and is part of a wider project aiming to improve the resilience, prosperity, and sustainability of their community. The dashboard is designed to make the flows of water and electricity visible to the community through a understandable and engaging manner. Among other information and with respect to water related data, the dashboard presents information for the current consumption of the community, the treated waste-water, the level of water reservoir of the city. Moreover, the dashboard presents informational tips of advices that depend on the consumption of the community aiming to raise awareness for sustainable consumption (e.g. in Figure 1 the tip is "Oy! We have been using too much water").

Figure 1: The Environmental Dashboard of the Oberlin project.

The WaterSmart platform (https://www.watersmart.com/) is tailored for utility companies and provides dashboards for employees and customers. The platform is mainly targeted to the US market and it's customer base is located there. Figure 2 provides an example of the dashboard for the city of Tempe in Arizona. The main functionalities of the WaterSmart dashboard for water consumers/utility companies customers include: Hourly water usage reports, Graphs showing comparisons to similar households, Alerts for leaks based on abnormal water use detection, Notifications in cases of high usage or increased bills, Reports that explain the bill, History of consumption and comparisons to previous periods/years, Interactive water-saving tips. For the utility employees, WaterSmart provides analytics, reporting, and customer relationship tools, including functionalities for customer segmentation and geospatial analytics which allow fine-grained water-use analysis.

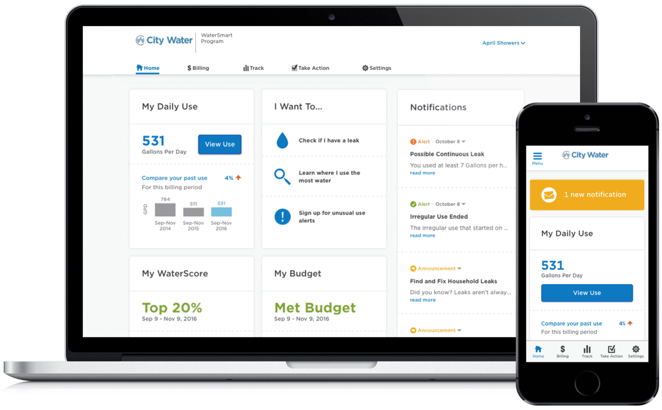

Figure 2: Example of the WaterSmart Portal for the city of Tempe in Arizona US.

Essex (http://www.essexco.com/services/energy-utilities-management/) provides a dashboard that uses a meter-measure-manage approach for energy and water consumption. The Essex dashboards are customized and tailored based on customer needs and requirements. It is mainly focused to facility managers and allows users to understand when they use energy and water, while it transforms input from meters across the facility into an easy-to-read dashboard that pinpoints inefficiencies so that managers can resolve them. The Essex dashboard can also be used by building occupants and present energy usage analytics fostering resource-efficient behaviours. Figure 3 shows an example of the Essex energy dashboard deployed in the Kennesaw University in Georgia US. The dashboard aggregates data from energy meters and provides gauges showing the total consumption and if this is inline with predefined thresholds, CO2 emissions, and graphs with historical energy consumption (monthly, yearly, daily) as well as period to period comparisons (e.g. yesterdays vs todays consumption). Moreover, there are options to view real time data.

Figure 3: The Essex Energy dashboard.

Honeywell provides energy dashboards through its Attune™ Advisory Services solution. These dashboards are created for facility managers and aim at visualizing information collected from building management systems. They serve the purpose of improving energy and operational performance of a facility through energy management metrics trying to increase awareness while providing insights on the operational efficiency and supporting related decisions. Examples of Honeywell's dashboards are shown in Figure 4, and show how they can be set up for an office building and a hotel building. The information provided includes current electricity, natural gas and water consumption, including their costs. Site characteristics are also provided along with graphs of past consumption. The carbon footprint of the building is displayed in the dashboard of the building (left part of Figure 4) as well as external weather information.

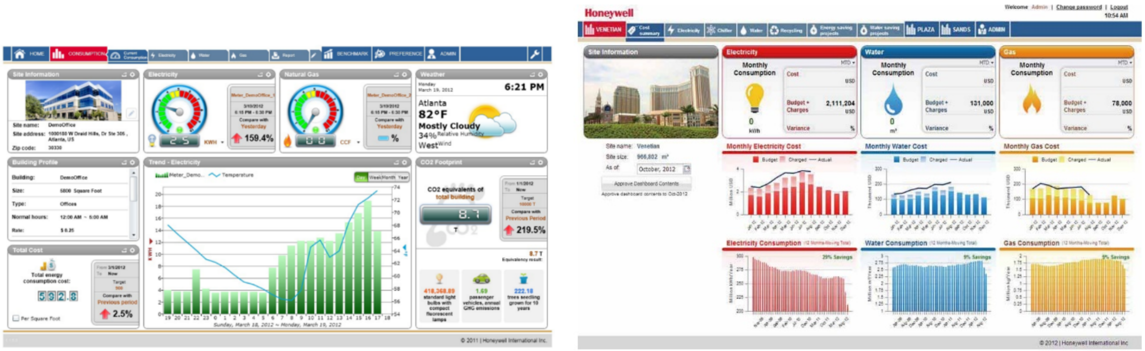

Figure 4: Examples of Honeywell's Attune™ Advisory Services Energy Dashboard.

Datapine (https://www.datapine.com/) provides business intelligence dashboards aiming to empower businesses of all sizes, technical and non-technical users alike, to explore, visualize and communicate information. Datapine also provides dashboard software for energy analytics which gathers electrical and energy consumption data in order to assist energy suppliers to analyse, supervise, and optimize energy related KPIs like production costs, consumption, production and distribution. The Datapine dashboard is tailored for energy distributors and provides access to real-time data. A sample view is shown in Figure 5. This sample provides a strategic view of important metrics of a utility company, including the total consumption of the customers together with the corresponding sales, the consumption and sales by sector, the contribution of renewables in the energy offered, the average energy production costs and aggregate operational metrics regarding power cuts which disrupt the service offered to the customers.

Figure 5: Datapine's Energy analytics dashboard.

3 Behavioural Change Support Systems and Strategies

3.1 Backround

In the recent years, a research field that has been gaining increasing interest is that of persuasive technology. The field was defined in the seminal work of Fogg (2003) who described the potential of pervasive computing technologies to induce and influence people to change their attitudes and behaviours. In this context, a behavioural change support system employs persuasive technology and can be defined as a 'socio-technical information system with psychological and behavioral outcomes designed to form, alter or reinforce attitudes, behaviors or an act of complying without using coercion or deception' (Oinas-Kukkonen, 2013). This kind of technology-mediated persuasion or human-computer persuasion (Harjumaa & Oinas-Kukkonen, 2007), does not require a human persuader and instead relies on some form of computerised intervention (e.g., a software application supporting healthier eating habits) to automate behaviour change (Fogg, 2003; Fogg, 2009). Persuasive technologies have been applied in a variety of domains, such as e-commerce (Kaptein et al., 2011), user training (Forget et al., 2008), health (Chatterjee and Price, 2009), safety education (Chittaro, 2012) and sustainability (Jenkin et al., 2011) with quite promising results.

Persuasive technology integrates concepts from the disciplines of social psychology, communication and persuasion, computer science and information systems (IS) to influence users' behaviours and perceptions. Various strategies can be applied by these technologies to support different outcomes and behaviour change strategies (Berkovsky et al., 2012). In the following sections, we describe the related known persuasive strategies (i.e., proven principles of persuasion) and identify those that are relevant for the Naiades approach.

3.1.1 Six Principles of Persuasion by Cialdini

One of the first descriptions of persuasive strategies was provided by Robert B. Cialdini (e.g., see Cialdini, 1984, 2002) who focused on the strategies of liking, reciprocity, social proof, consistency, authority and scarcity essentially providing the six principles of persuasion. These strategies were proposed by Cialdini (2001) through field work comprising of contextual interviews and observations with persuasion professionals in sales, fundraising and advertising. More details about these principles are provided in the following:

- **Liking**: The strategy of **liking** ("People like those who like them") is based on the phenomenon of the "Tupperware party". In such gatherings, it has been observed that people mainly buy the Tupperware because they like the host and not so much because they like the product. Cialdini (2001) formulated the idea that is true in the Tupperware party, extends to other contexts: "if you want to influence people, win friends.". Past research has identified two core factors that increase and affect liking: similarity and praise. Influences by similar peers are more likely to cause changes in a person's behaviour. This similarity can be achieved by identifying and bringing together people with similar demographics (same age, religion…) or with other commonalities such as habits, hobbies, favourite sports teams, etc. Praise refers to positive remarks on someone's deeds or performance and has been shown to generate persuasive effects.
- **Reciprocity:** Refers to the phenomenon that humans tend to reciprocate on how they are treated themselves, i.e. "People repay in kind" and feel obliged to do something in return because something was done for them. This strategy has been extensively used in in marketing, where companies tend to give small gifts (or incentives) to convince customers to make purchases.
- **Social proof:** concerns the phenomenon that people tend to seek the validation and rely on the behaviour of other people concerning their own cognition and behaviour. Practically this means that people want social evidence and validation on how to think, feel and act. As a consequence, persuasion and behavioural change is extremely effective when relies on examples from social peers as "People follow the lead of similar others".

- **Consistency** is related to the phenomenon that people need to specify and be bound to commitments to actions if they are to follow these action, i.e. "People align with their clear commitments". Cialdini has specified that commitments are particularly effective when they have the following three characteristics: be active, public and voluntary.
- **Authority** refers to the phenomenon that people are greatly affected by the opinion and advice of experts, i.e. "People defer to experts". Past research has shown that the effect of the authority strategy can be significant: a study published in the Public Opinion Quarterly (Groves et al., 1992) showed that the influence of a single expert-opinion featured in the New York Times changed public opinion by a factor of 2%.
- **Scarcity** is based on the fact that people attribute greater value to rare and difficult to obtain items and opportunities, i.e. "People want more of what they can have less of". Known examples of the application of scarcity can be seen in cases when an offer is framed in a manner that shows a sense of urgency ("only two products left, harry up").

3.1.2 Seven Principles of Persuasion by Fogg

Another set of persuasive strategies were defined by Fogg (2003), with a specific focus on strategies that can be coupled with a technology-mediated change in people's attitudes and/or behaviour. Fogg defined seven strategies: reduction, tailoring, tunnelling, suggestion, self-monitoring, surveillance and conditioning, which are described below.

- **Reduction** is concerned with simplifying complex tasks to a series of smaller and simpler actions that are easy to follow and each of them requires short time and effort. Reduction is based on indications from psychology that people seek to minimize costs and maximize gains. Having a set of simple and straightforward actions to follow, the inconvenience (cost) is minimized and the benefit (gain) is maximized for each action so a behavioural change intervention applied to a person is more likely to succeed. Moreover, the reduction strategy can increase a person's self-efficacy and belief in their ability to perform a specific behaviour, increasing even more the chances of a successful behavioural change intervention. A real-world example is the placement of recycling bins next to the trash bin to minimize recycling efforts.
- **Tunnelling** aims to provide guided persuasion through a process or an experience that has a pre-determined sequence of stepwise actions. The concept of this strategies is based on the notion that a "tunnelled" process infuses a certain amount of self-determination and exposes users to information and activities they did not foresee leading them to perform tasks in which they would not have engaged in otherwise. An example refers to a water consumption calculator that guides users to enter related data in order to understand their consumption through a guided process.
- **Tailoring** means to provide targeted information and specific to the individual's needs, aligned with interests, personality, context, or other factors relevant to the individual. Tailored information is effective as people are far more prone to follow a suggestion or react to information this is personalized. An example for the use of this principle can be personalized water consumption presentation and suggestion of related personalized water conservation actions.
- **Suggestion** refers to intervening at the right time and offering behavioural prompts moments which are the most opportune. Key to successful suggestions is to identify a person's decision points and the time that these take place in order to provide related prompts that are appropriate to take action. An example for this principle can be real time displays of water consumption with visual prompts to reduce consumption when this exceeds certain thresholds.
- **Self-monitoring** provides easy ways to track a person's own behaviour which supports behavioural change by offering the means to learn more about themselves and then achieve predetermined objectives or outcomes. Examples using the self-monitoring persuasive strategy are mobile applications providing functionalities for the "Quantified Self" Health Apps monitoring users' health statues or monitoring physical activities and vital signs. In the domain of water this strategy

is used in systems that provide information about consumption and set specific goals to reach a sustainable consumption level.

- **Surveillance** is related to observations from social psychology studies which have concluded that observation has powerful effects on how people behave and when people know they are being
- observed, they behave differently mainly due to the fear of getting into trouble. Commonly this strategy is implemented by have technology to track a person's behaviour and reporting this to a third party. For example, monitoring water waste in public buildings and reporting this information can affect peoples' behaviour and lead to more sustainable consumption.
- **Conditioning** refers to the application of positive reinforcement when reaching certain behavioural objectives or goals. The underlying idea is to associate a reward with a target behaviour. Typical examples for the use of this principle are when positive reinforcements in the form of points, badges and ranks are given to users that achieve sustainable behaviours.

3.1.3 Persuasive design principles by Oinas-Kukkonen & Harjumaa

Oinas-Kukkonen & Harjumaa (2008) suggested 28 design principles which can be applied in behavioural change support systems for ensuring their success, rendering them the most complete available list. Table 1 describes these strategies and provides examples that can be used in ICT applications within the context of water conservation.

Table 1: Design Principles of Behavioural Change Support Systems (adopted by Oinas-Kukkonen & Harjumaa, 2008)

Persuasive strategy	Applied to the context of water conservation
1. Reduction **"A system that reduces complex behaviour into simple tasks** that **help users perform the target behaviour and it may increase the benefit/cost ratio of a behaviour."**	An application that reduces the complexity and cognitive effort: e.g., a mobile application that suggests alternative actions and shows how much water is saved.
2. Tunnelling **"**A **system** that **guide**s **users through a process or experience provides opportunities** for behavioural change**."**	An application offering additional information on how to save water after analysing information users provided in an interactive water habits questionnaire.
3. Tailoring **"Information** provided by a system **is tailored to the potential needs, interests, personality, usage context, or other factors relevant to a user group."**	A system that takes into account the weather and offers tailored information for watering plants.
4. Personalization **"A system that offers** functionalities for **personalised content or services."**	An application that remembers users past behaviour in terms of water use and suggest personalized actions for water conservation.
5. Self-monitoring **"A system that helps track one's own performance or status supports in achieving goals."**	A system that records water consumption and provides graphs showing information regarding past consumption.
6. Simulation **"**A **system that provide**s **simulations** of different scenarios and **enable**s users **to observe**	A graphical representation showing how much water can be saved by changing water habits.

immediately the link between the cause and its effect, leading to behavioural change**.”**	
7. Rehearsal **“A system** that **provide**s **means** that can be used to **rehearse a behaviour.”**	An application allowing the user to understand how to water plants efficiently.
8. Praise “A **system** that offers praises when users reach a specific goal.”	A system providing positive feedback when users' sustainable water consumption goals are met or exceeded.
9. Rewards **“Systems that reward target** behaviours**.”**	Points, badges and other symbolic rewards as reinforcement of sustainable watering choices and behaviours.
10. Reminders “A **system** that **reminds users of their target behaviour.”**	A system that monitors water consumption and displays reminders when the consumption exceeds a certain target.
11. Suggestion **“Systems offering suggestions at opportune moments.”**	A system that reminds users to turn off the faucet while brushing their teeth.
12. Similarity “Systems **that remind** users of **themselves in some meaningful way.** In this way and behavioural change support system infuses trust to the user.”	An application that uses language that mimics the everyday language of the targeted user group (e.g., environmentalists, young families with children, teenagers, etc.)..
13. Liking “Behavioural change support **system**s should be visually attractive for their users.”	Applications that provide and attractive design of the user interfaces.
14. Social role “A behavioural change support **system** that **adopt**s **a social role,** increases the likelihood of being used .”	An application that lets users connect with other users for to exchange best practices for reducing water consumption.
15. Trustworthiness **“A system** should be **viewed as trustworthy (truthful, fair and unbiased).”**	The developers of a behavioural change support system that measures water consumption guarantee that the consumption is properly monitored.
16. Expertise **“A system** should infuse a sense that it **incorporate**s **expertise (knowledge, experience and competence)** for increased behavioural change effects.”	The web site of a city's water provider presents water bills with insightful information showing that the information contained is well designed and the provide analytics are based on robust algorithms.
17. Surface credibility “A behavioural change support system should be clean of distractions and its purpose should be limited to what it is intended to do.”	A watering application that is free from advertisements or unnecessary background illustrations that could get in the way of its main functionalities.
18. Real-world feel **“A system** should be impersonal, rather it should show that there are **people or** an **organization behind its content or services.”**	An application for water conservation should provide information regarding the people or organization that has implemented it and provide contact details to people for questions or feedback.

19. Authority **"A** behavioural change support **system** should **leverage roles of authority** to **enhanced** its persuasive ability**."**	An application for water conservation can benefit from a statement from the officials of the water company who state the sustainable water use vision and how users of the application could be part of that vision.
20. Third-party endorsements **"Third-party endorsements, especially from well-known and respected sources, boost perceptions on system credibility."**	A behavioural change support system for sustainable water use that has received a certification from an independent organization that it fulfils its purpose.
21. Verifiability "A **system** that **makes it easy to verify the accuracy of** its content increases the perceptions of its credibility and users are more likely to follow its suggestions**."**	An application for water conservation providing links to other sources that allow users to verify claims regarding sustainable watering behaviour.
22. Social learning "A system that allows users to observe others performing a target behaviour can provide motivation to its users to **perform** that **behaviour."**	An application that presents best practices from other users regarding water conservation.
23. Social comparison "A **system** that provides functionalities so that its users can compare their performance with the performance of others **users** can infuse **greater motivation to perform the target behaviour."**	A water consumption application that compares the users own consumption to that of similar peers.
24. Normative influence **"A system** that **leverage**s **peer pressure to increase the likelihood that a person will adopt a target behaviour."**	Challenges such as a watering challenge where different teams within and across areas compete for the least water consumption.
25. Social facilitation "A **system** which shows to **users** that others **are performing** a targeted **behaviour along with them."**	An application that provides functionalities to blog about one's own sustainable watering behaviours and achievements, while presenting this information to other users.
26. Cooperation **"A system** that **leverag**es **human beings' natural drive to co-operate.**"	An application that provides group challenges where users co-operate to meet certain targets (e.g., reducing water consumption by 1% target per registered group).
27. Competition **"A system** should **leverag**e **human beings' natural drive to compete."**	Online competitions to motivate water conservation.
28. Recognition "A **system** that offers public recognition (for an individual or a group)**."**	Featuring the top scoring teams of a water conservation challenge on a web site, handing out medals/trophies to the top scoring team members.

3.1.4 Designing Behavioural Change Support Systems

The design of a successful behavioural change support system can be a cumbersome process. A structured process for the design of such systems can be found in Fogg (2009). This process comprises of eight steps which are shown in Figure 6. The first four steps focus on understanding the requirements, context and the end users to whom the intervention is to be applied. The requirements determine the appropriate technology channel to be used. Steps five to seven refer to the actual implementation of the behavioural change support system. The implementation should rely on the identified requirements and also combine other successful implementations. Testing and frequent iteration in close collaboration with a set of test users is needed to achieve the desired results. The final step concerns the deployment of the system.

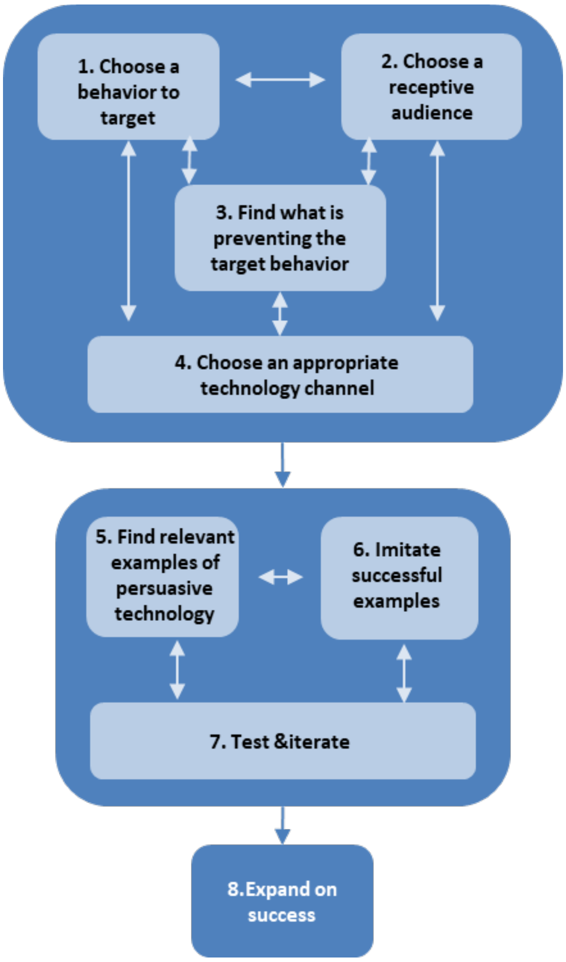

Figure 6: Design process for the creation of persuasive technology (adopted by Fogg (2009))

Another approach to architecting behavioural change support systems has been described by Loke et al., (2008) who propose a set of building blocks for systems that empower users to take action related to environmental sustainability, including the management of water usage. They break down the design of such a system into four main building blocks as follows.

The first aspect refers to applying methods for fine-grained metering and monitoring which should be performed by devices able to monitor consumption (of energy, water, etc.) on different levels. For example, depending on the requirements, it should be possible to monitor the water consumption of one single outlet as well as the water consumption on a whole floor or even on the overall household-level.

The second aspect refers to data processing and situation understanding. Data coming from the metering and monitoring devices should be processed and shown to users in forms that are appropriated and comprehensible, such as visualizations of status displays. The display of data should be designed such that it triggers particular persuasive strategies and influences users' behaviours and attitudes towards goals for sustainable use of resources. The system should also be designed such that it also performs longer term analysis of available data to determine usage trends and allow the understanding of situations of use in order to help inform further designs or allow the adaptation of persuasive strategies to specific contexts.

The third aspect refers to action strategizing. This means to incorporate a set of rules to the systems that map (i) metered data, (ii) usage trend knowledge, (iii) effects of the resource consumed, (iv) policies and associated goals, and (v) the inferred situations of use, to actions that have the potential to influence users and regulate usage. Examples of actions can be notifications, i.e. displaying to users cost or water levels in a visual form, advice on water-saving for specific tasks, various forms of reinforcement messages, just-in-time prompts, social validation (e.g., where possible show the best water users in the home), adaptations (according to usage history or current needs), negotiation (e.g., to keep to a previously specified budget, the user can use more water this time but have less to use next time), recommendations of water saving devices, to taking action on behalf of the user (e.g., stopping water flow at certain times – if the user so authorises such pre-settings) (Loke et al., 2008).

The fourth aspect refers to feedback and strategy revision. The design process should have a monitoring cycle, that allows to revise feedback and strategy, and apply changes to the employed persuasive strategies depending on the behaviour of the user and related effects.

Figure 7 gives an overview of the aforementioned design aspects. A behavioural change support system senses/monitors the behaviour of the user, for example the consumption of resources (e.g., water), it records and analyses this data and then it uses persuasive strategies and principles to inform the user about his consumption patterns and resource usage behaviour, and persuade the user to act in a more sustainable way through a set of actions. A feedback loop ensures that the design of the persuasive strategies is frequently revisited and adapted if needed, in order to maximize the desired behavioural change outcome of the system and related interventions.

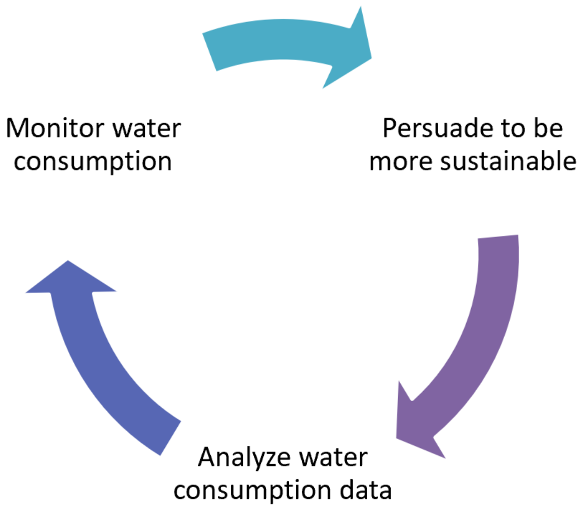

Figure 7: Design aspects for architecting behavioural change support systems proposed by Loke et al. (2008).

3.2 Behavioural Change Support Systems and Strategies for Sustainable Water Consumption

Over the last years, a number of systems and applications that leverage the power of behavioural change support theories and persuasive technology have been implemented, aiming to support users in sustainable water consumption. In order to understand the current state of the art and identify approaches that could be relevant and extended in the context of NAIDES, we performed an extensive review. For our search we chose scientific bibliographic databases that cover the majority of journals and conference papers published in the field of persuasive technologies and computer science in general, as well as general purpose search engines, including google search and bing search. In more details, we selected the following scientific bibliographic databases as relevant: ACM, Web of Science, IEEE, ScienceDirect, Springer, Emerald, Google Scholar and Ingenta Connect. To retrieve the relevant prior work (including scientific papers and commercial/marketing reports), we carried out searches with combinations of the following keywords:

"behavioural change", "persuasion", "persuasive technologies", "water conservation", "water savings", "sustainable water consumption". The selection of these databases ensured a good coverage of related work across various fields including Human-Computer Interaction (HCI), water conservation information systems, and other related research fields. Finally, we examined the reference lists of the included papers in order to identify additional relevant work. The total number of papers retrieved through the above method was 152. We first examined the title of retrieved papers and filtered them based on their relevancy. We excluded 100 papers and for the remaining we went through their abstract, introduction and conclusions. Our aim was to select the papers that employ behavioural change support strategies and/or implement a behavioural change support system for water conservation and/or present results from pilot cases. Considering the above restrictions, we selected 24 papers for final review. This process we followed is depicted in Figure 8.

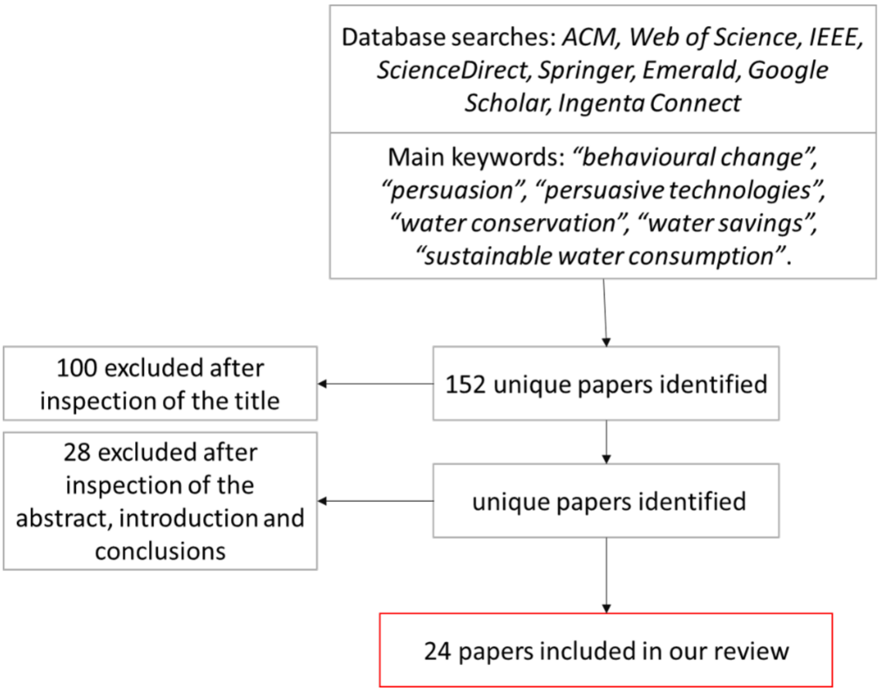

Figure 8: Overview of the related work identification process. We include 24 papers with related work in our review out of 152 initially identified.

The process of engaging in the detailed review of the identified 25 papers involved the development of a coding scheme where we documented the characteristics of each paper using a set of 11 analysis dimensions, which are described in Table 2.

Table 2. Persuasive Technology for Sustainable Water Consumption analysis coding scheme and dimensions.

#	Dimension Type	Dimension	Identified classifications
1	General	Descriptive Information	Year and country
2	System	Type of Application	Web app, mobile app, both, display, shower monitor.
4	Evaluation	Country of Evaluation	Country where the study/pilot was conducted.
5		Duration of Evaluation	Hours, Days, Weeks, Months, Years.
6		Number of Participants	Number of participants involved in the evaluation.
7			

8		Evaluation Method	Quantitative, Qualitative, Mixed.
10		Evaluation Results	Successful, partially successful.
11	Design, System, Evaluation	Persuasive Strategies Integrated	Persuasive strategies used in the design of the system (see Table 3 for an overview of the persuasive strategies which are used in the reviewed papers).

The process for defining these dimensions was iterative and new dimensions were added as the analysis progressed. The first dimension is general and is applicable to all papers. Dimensions, such as the one of type "evaluation" are applicable to papers dealing with the evaluation of a behavioural change support approach, while those of type "system" are applicable only to papers that focus on the description of a behavioural change support system. It should be noted that the dimensions are not mutually exclusive, meaning that a paper may be relevant to more than one dimensions; e.g. a paper describing both a behavioural change support system and its evaluation.

Table 3 provides an overview of the behavioural change support systems and approaches we identified in the domain of water conservation and in the remainder of this section we provide a summary of each paper.

Table 3: The behavioural change support systems and approaches for water sustainability we identified in the literature.

ID	Ref.	System	Communication Form	Implemented Behavioural Change Support Strategies
1	Visser et al., 2019	N/A	Weekly usage reports via email	Self-monitoring, competition
2	Sun et al., 2019	N/A	Water conservation tips	Suggestion
3	Goette et al., (2019)	N/A	Feedback and monetary rewards	Feedback, Rewards
4	Otaki et al.,(2019)	N/A	Mockup views	Feedback
5	Novak et al., 2016	SmartH2O	Mobile/web	Self- monitoring, Challenges & Goal Setting, Social comparison, Gamification, Personalized messages
6	Terlet et al., 2016	WISDOM	Displays	Self-monitoring, feedback
7	Tiefenbeck et al., 2016	Amphiro on-shower	Mobile/web	Feedback
8	Magoutas et al., 2015	WaterCity	Web	Self-monitoring, goal setting/commitment, social comparison, tailoring, reward
9	Kossieris et al., 2014	IWIDGET	Web	Self-monitoring, social comparison

10	Marinho et al., 2014	TECLIM	Web	Self-monitoring
11	Fielding et al., 2013	N/A	Information provided through utility bills	Suggestion, advice, self-monitoring
12	Stewart et al., 2013; Willis et al., 2010	WaiTEK Shower Monitor	LCD display at the point of consumption	Feedback, Self- monitoring
13	Ferraro and Price (2013)	N/A	Messages delivered through mail	Authority, Social Comparison, Suggestion
14	Paay et al., 2013	WaterAdvisor	Mobile application	Self-comparison, trigger messages, use of mobile devices, understandable messages, personalized information, expert advice
15	Erickson et al., 2012	Dubuque Water Portal	Web portal	Self- monitoring, Social comparison, Reward, Gamification
16	Froehlich et al., 2012	N/A	Mockup Views	Self-monitoring, comparison, simulation
17	Laschke et al., 2011	Shower Calendar	Ambient LED lights showing consumption	Goal setting, comparison, competition, and communication
18	Kilgren et al., 2010	N/A	Water schedules, educational material	Authority, Suggestion
19	Kappel et al., 2009	Show-me	Displays attached to water appliance	Feedback
20	Petersen et al. 2007	Dormitory Energy	Web	Self- monitoring, Social comparison, Reward
21	Pearce et al., 2010	SmartGarden Watering	Web	Self-monitoring, comparison, simulation
22	Arroyo et al., 2005	Waterbot	Displays attached to water appliance	Positive and negative reinforcements, 'just-in-time prompts' through audio feedback, social/historical comparison
23	Kurz et al., 2005	N/A	Information leaflets	Suggestion, Social Comparison

Visser et al. (2019) investigate the effect of interventions to encourage responsible water usage in schools across the Western Cape, South Africa. They conducted a randomised control trial with behavioural change support interventions in 105 schools. The interventions had the form of water consumption information feedback and interschool competitions. In more details, the schools were divided into three groups: the control group consisting of 30 schools that didn't receive feedback on water usage; the treatment group 1 consisting of 33 schools that received feedback on daily and weekly water consumption; and the treatment group 2 consisting of 42 schools that received feedback about daily and weekly water consumption along with comparative feedback on the relative consumption to other schools. All water consumption reports were sent via email and text messages to school staff members, whereas a poster displaying consumption information was placed in notice boards and was visible by the schools' students. In the paper, it is reported that the behavioural change interventions led to reduced water usage by 15 to 26% and significant water savings of 380 kilolitres per school per year on average. It is interesting that the authors observed significant water consumption reduction in night time water use, indicating better water usage by the staff. Moreover, schools that participated in interschool competitions were found to reduce water consumption during day time, indicating better water usage by the pupils.

Sun et al., (2019) investigated if campaigns with quantitative information or social norm information could boost water-conserving behaviors in China households. To examine the impact of the campaign description on water usage change, they designed three versions of the water conservation tips that were incorporated in the former: i) the basic information version, in which they presented four simple tips to effectively save water in a household context; ii) the norm information version, in which they added the corresponding norm information on each tip about how other people behave and iii) the quantitative information version, in which they added the corresponding quantitative information on each tip. They found that 1) residents who received water conserving tips significantly reduced the subsequent water consumption relative to the residents who did not receive; 2) adding (vs. not adding) quantitative information into tips made the residents reduce water consumption; 3) adding (vs. not adding) norm information into tips failed to make the residents reduce water consumption.

Goette et al., (2019) compare different incentives in motivating water conservation in Singaporean households. They provided regular feedback with informative, normative and monetary incentives to different groups. Results show that all households saved an average of 4 litres of water per person per day, with no difference in treatment effect found across various groups. Perhaps unsurprisingly, the water saving effect is also found to be more significant with high baseline users, who saved up to 5.9 Litres per person per day. High baseline households also respond more positively to the non-monetary incentives.

The study of Otaki et al. (2019) investigates the efficacy of historical self-comparison as a water demand management tool, and more specifically aims to identify effective presentation methods used for historical self-comparison of residential water consumption that will lead to the continuous efficient use of water. 633 households in Tokyo were monitored by water meter readings once every two weeks over 24 weeks. Participants received e-mails informing them of the historical self-comparison within four to five days of each observation. To compare each household's current and previous water consumption, illustrations of water droplets were used as feedback, with the number of water droplets indicating the change rate from the previous two weeks to the most-recent two weeks. The more water consumption decreased (or increased), the fewer (or more) water droplets they received. Two different means of communicating the feedback were used, in terms of the droplet colour, as shown in Figure 9. One user group received blue water droplets only. The other group received either blue or yellow and red water droplets in case the consumption decreased or increased compared to the previous period, respectively. The shade of blue darkens as the amount of water used increased, and it then changes to yellow and finally to red to represent even greater increases in consumption. The authors reported that when using yellow and red droplets in cases of increased water use, the water consumption declined, while no change was found when using the same blue droplets.

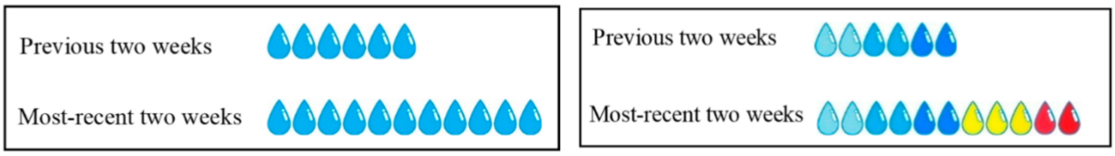

Figure 9: Example of pictures shown to the intervention groups

The SmartH2O system by Novak et al. (2016) aims to motivate users to reduce their water consumption by combining smart meter data with motivational mechanisms that stimulate sustainable water use. These mechanisms include self-monitoring water consumption visualisations, water saving tips, goal setting, different types of gamified incentives and a hybrid physical-digital card game. The water consumption visualisation has two elements as shown in Figure 10. The first is a visual display of the user's water consumption as bar charts over different time spans, while the second is a display of the user's water consumption level as a pipe filled with water. Dashed lines in the pipe depict the historical baseline value as well as water saving levels at 5%, 10% and 15% which aim to encourage users to save water. Above the pipe, a light is displayed that can be either green (as shown in Figure 10) or red highlighting if the user's consumption is lower or higher that the historical base value respectively. Moreover, this screen provides a positive reinforcement message if the consumption is lower that the historical base value or a warning message if the consumption is higher. Water saving tips show users how to save water and are presented in the form of textual messages or engaging videos that demonstrate how water can be saved. Moreover, users can set water saving goals (goal setting) by selecting one of three levels for water usage reduction (5%. 10% and 15% reduction). This mechanism is coupled with gamification elements and users earn points when they reach their set goal. It is interesting that users receive more points when they set more ambitious goals. A visual aid is implemented to make the user understand the impact of her/his goal in the form of bathtubs that can be filled if the goal is reached (see Figure 10), while a leader board of users, ranked by the points they have collected, aims to stimulate competition and comparison between them. Novak et al. (2016) report the results of a small-scale evaluation with 40 households in Switzerland. They found that users agreed that the visualizations were useful and supported them to understand how much water is consumed in their households. However, users had a neutral opinion when asked if they would follow water saving tips. In terms of the system's effect in actual water reduction. Moreover, they also report that an average reduction of 34% was achieved with the use if the SmartH2O system. Nonetheless, they recognise that some of the reductions were due to seasonal effects and the fact the pilot took place in the winter season which commonly is low in water consumption. The authors state that the water consumption reduction induced by of the use of the SmartH2O was in the range of ~3.4% to ~8.4%.

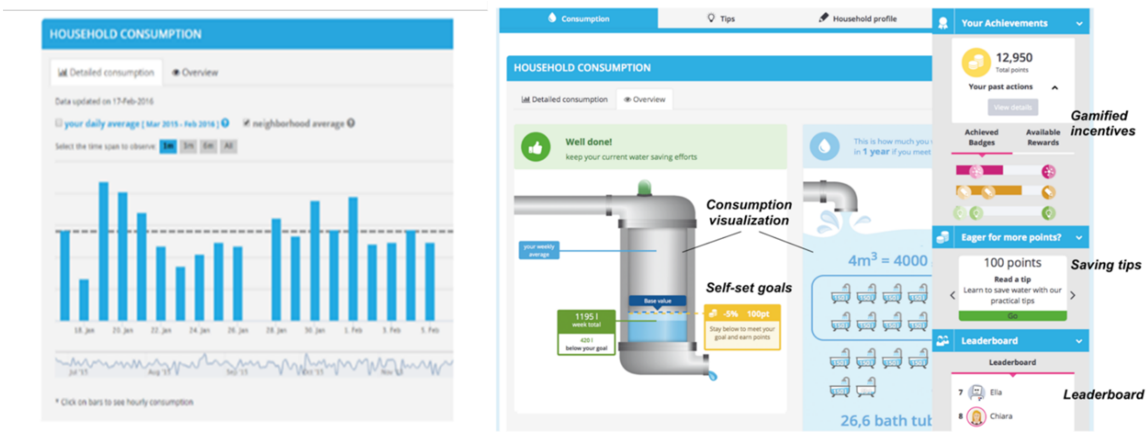

Figure 10: Water consumption visualizations of the SmartH20 system.

Terlet et al. (2016) suggest the use of smart meters for water consumption monitoring and in-home displays that provide feedback and information in order to encourage water conservation. The work was performed in the context of the FP7 WISDOM[2] project and the design of the display includes four different aspects that influence water consumption. The first aspect refers to a representation of the evolution of consumption depicting also the costs savings according to the amount of water conserved. A set of notifications for important feedback (e.g. in cases of excessive water consumption) are also proposed. The second aspect includes a visual of the environmental impact of excessive water consumption, with pictures of drought or signs of environmental distress. The third aspect concerns comparisons over periods of time, e.g. consumption in the current month vs the same month one year ago. Social comparisons that could foster competition are also included (e.g. the consumption of a household vs other similar households). Last the authors mention that the proposed display will include a virtual game in the form of an aquarium where participants gain points by accomplishing water conservation tasks. A mock-up display of the proposed system is shown in Figure 11. The authors also report the results of a survey which allowed them to obtain information consumers views related to water consumption. The survey was conducted with 3000 households in Cardiff. The authors report two main observations. First, although participants were inclined towards water conservation and would like to install devices or displays such as the one proposed by the authors, they wouldn't be willing to pay for or invest in such devices. Moreover, they find that most respondents checked their water consumption quarterly or yearly, whereas in terms of the costs these should be displayed on a yearly basis as in short periods they may seem negligible.

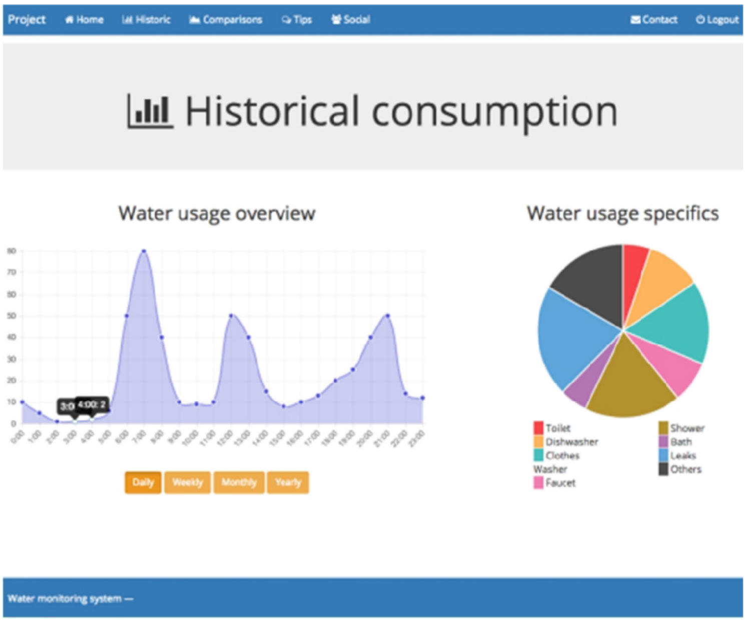

Figure 11: A mockup of the display for encouraging water conservation proposed by Terlet et al. (2016) with a view of the historical consumption.

Tiefenbeck et al., 2016 measured and recorded data on individual showers with the amphiro a1 smart shower meter. The shower meters were deployed for two months and recorded energy and water consumption, average water temperature, interruptions, and duration of each shower. They implemented three experimental conditions. In the real-time condition, the device displayed water use in tenths of liters. Thus, it provided individuals with objective and easily understood feedback on their resource consumption during a shower. The device also displayed water temperature in degrees Celsius, energy consumption in kilowatt-hours, an energy efficiency rating (ranging from A to G), and a polar bear animation. In a second condition, the real-time plus past feedback group, the display showed all these elements and, in addition to that, the total amount of water used in the previous shower. In the control condition, they supplied no feedback on

[2] https://cordis.europa.eu/project/id/619795

energy and water consumption: the device displayed only water temperature. They find that real-time feedback reduced resource consumption for the target behavior by 22%.

Magoutas et al. (2015) propose WaterCity, a web-based persuasive application, which aims at promoting engagement and enhancing residential consumer participation in water conservation activities. The application makes use of persuasive strategies, gamification and social networking features and integrates the behavioural change support strategies of self-monitoring, goal setting/commitment, social comparisons, tailoring, and rewards. It is targeted to households and provides information and feedback about their water consumption, functionalities to compare their consumption to that of similar others and the setting and monitoring of water reduction goals (see Figure 12). More specifically, the WaterCity user can see the current consumption statistics in a histogram depicting the monthly average together with a comparison of the current year, the average of the city and the average of the same user during the past years. In terms of goal settings, the application provides the three most recent goals and achievements regarding the reduction of water consumption. Social features are implemented using the Facebook social network where users can share their personal water conservation achievements. Social comparisons are also shown as users can see their consumption to that of the three most similar efficient Facebook friends and the three most similar efficient non-friends. In order to avoid potential doubts about the credibility of the similarity calculation, the detailed profile of similar friends is presented to the user. Financial savings from consumption reduction are also provided in the platform, allowing users to understand how their water conservation efforts are translated to financial benefits. Gamification is implemented as a Hall of Fame that lists the top three users, who have achieved the highest reduction on their average daily consumption.

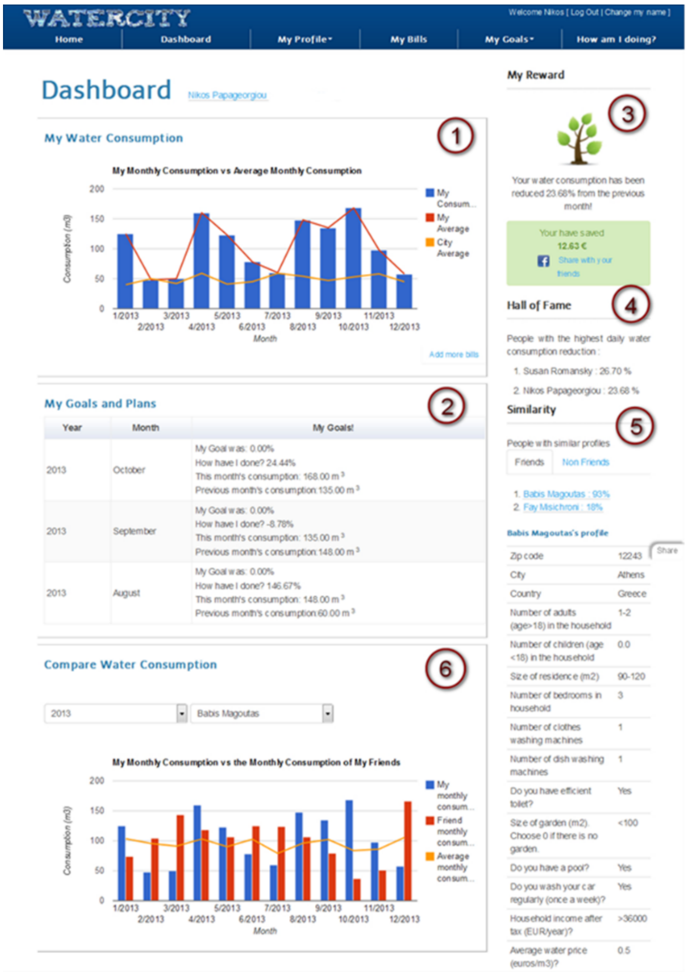

Figure 12: WaterCity Dashboard integrating the behavioural change support strategies of self-monitoring, goal setting/commitment, social comparisons, tailoring, and rewards. Users receive

personalized information regarding their consumption, while they can compare current consumption with that of previous time periods, and the average of the area (1). Moreover, they can compare it to that of similar peers (6) and see their profile to check how much similar it is to their own (5). The application allows users to set and monitor goals for reducing water use (2). When they reach their goals, users can receive non-monetary rewards (3) and improve their ranking in a hall of fame (4).

Kossieris et al. (2014) present a web-based platform called IWIDGET that target householders and supports them to reduce water consumption. The functionalities of the platform follow six use cases as follows (see Figure 13).

1. Users obtain feedback on water demand through real-time monitoring of consumption using data from smart water meters. The platform displays information on the progress of water demand and how this is allocated to different uses and appliances.
2. Users obtain feedback on energy consumption related to water demand. The feedback is provided for the total energy consumption and the corresponding cost, also disaggregated into appliances that consume water and energy.
3. The platform supports users to understand water consumption. This is accomplished by presenting consumption related information compared to other neighboring consumers, consumers of similar characteristics and other efficient households as well as past consumptions of the same household. These comparisons provide the means to identify inefficient water use and potentially detect faults and leakages.
4. The platform supports users to understand energy associated with water consumption. The system provides comparative information on past energy consumption and views of energy consumption for various uses.
5. Users are provided with assistance to increase water use efficiency as the system displays practices, tips and interventions guiding them to follow actions for sustainable water use.
6. The platform supports users to control water use with functions that support users to optimize their water use through e.g. proper scheduling of watering related activities.

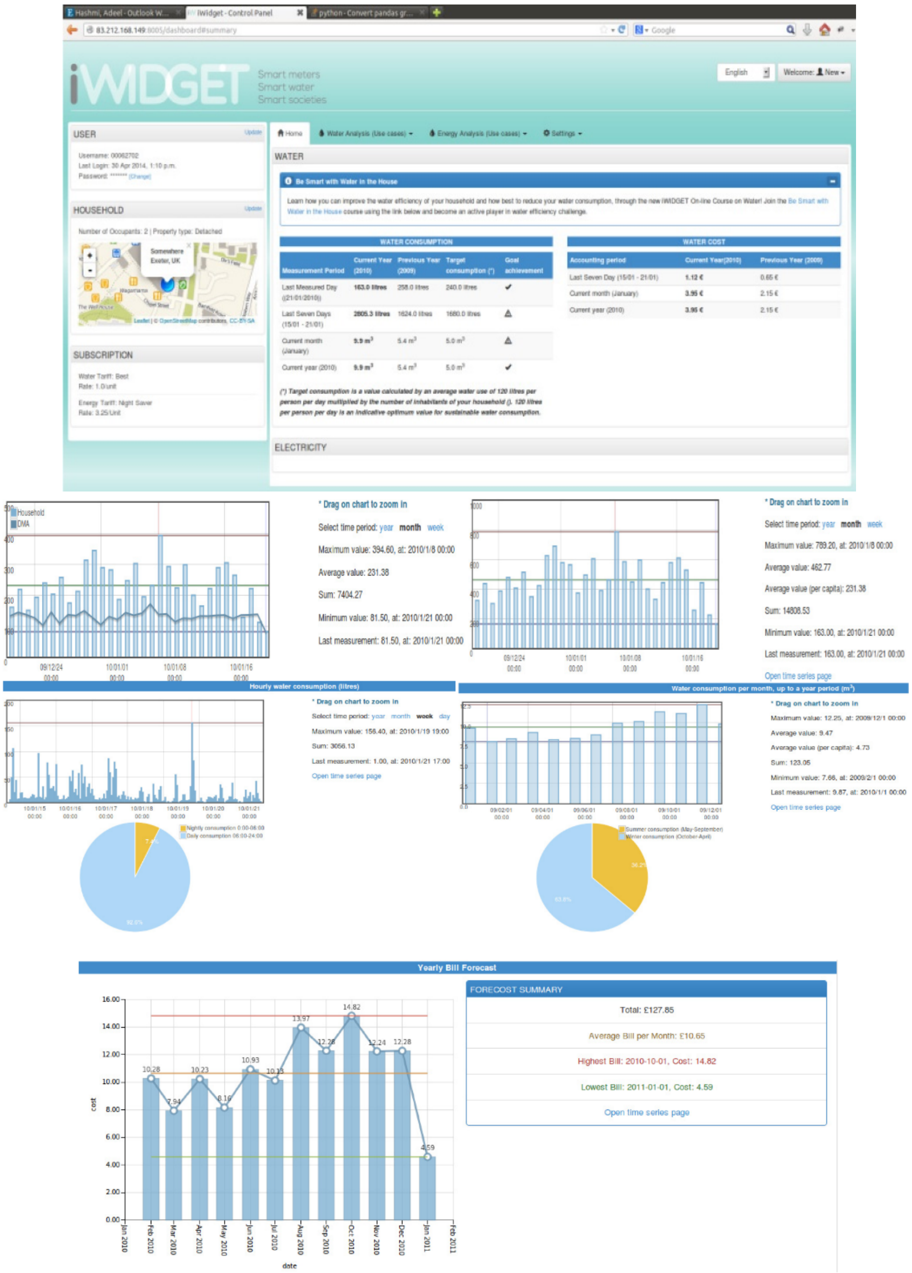

Figure 13: Indicative views of the IWIDGET system. Users receive feedback through real time monitoring of consumption in different graphs.

Marinho et al. (2014) report the results of a water saving program case study at the university of Bahia e Aguarupe in the northeast of Brazil. They developed a system (Figure 14) that provides easy access to several functions, such as data insertion, on line daily and monthly water consumption, widespread disclosure of information, communication between unit teams, supervisors and program coordination, installation and maintenance operations recordings, historic consumption, on-line training for users of the system. From 1999 to 2008 the program reduced per capita water use by half at the university.

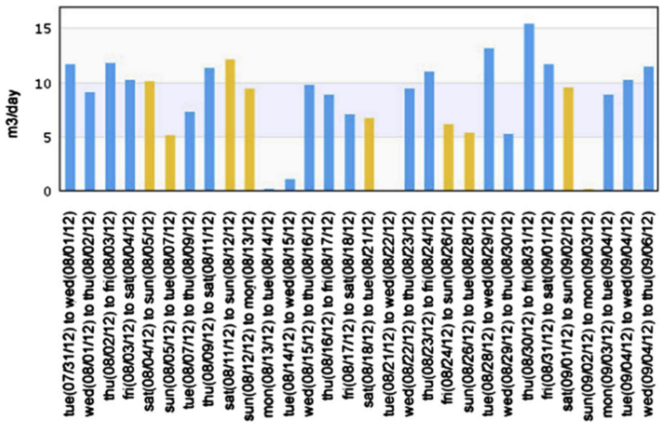

Figure 14: A view of graphs shown at the system described by Marinho et al. (2014).

Fielding et al., 2013 conducted a longitudinal study in which the applied behavioural change interventions in 221 households in South-East Queensland, Australia. The interventions had three levels. Participants allocated to the first level received basic information and advices regarding actions to reduce water consumption. Such information included tips on how to save water in the bathroom (e.g., taking shorter showers), laundry (e.g., washing full loads), kitchen (e.g., running dishwashers with full loads), and fixing leaks. Participants in the second level received recommendations of actions that similar households with lower water consumption did. Such recommendations are "descriptive norm conditions" and according to behavioural change theories can affect behaviours as when people know what action peers take, they are motivated to follow these actions. This was additional to the information of the first level. Participants in the third level received actual consumption information coming from installed smart meters. The information was presented in the form of a pie chart water consumption in the different fixtures of the household together with the average daily usage per person. The authors report that all three intervention groups reduced water consumption compared to the control group. However, the authors did not measure significant differences between the intervention groups. Moreover, the treatment effects disappeared after 12 months. The authors conclude low cost behavior change strategies (e.g. providing water saving information) could be as effective as feedback from smart meters. Nonetheless, the study results could be affected by the fact that in the area and period of the study there were no water supply problems. The authors report that the in the study area a dam used for water supply was full to overflowing, a situation which may led participants to increase water consumption after the first months of the intervention.

Stewart et al., 2013 and Willis et al., 2010 study the effects of visual display of water consumption. For their purposes they installed the WaiTEK® Shower Monitor© in bathroom showers of 44 households located in the Gold Coast City in Australia. These displays are shown in Figure 15 and provide real-time information about water flow-rate, duration and temperature on an LCD screen. Furthermore, they offer a setting to generate an alert sound once the water consumption exceeds a predefined limit. In the referenced study this limit was set to 40 litters. The water consumption monitors were also set for a delay time of 1min between showers. This means that if a person started another shower before the 1min is over, the monitor generated an alert sound. The study included a baseline water consumption monitoring period and a two-weeks usage of the visual display. Based on the reported results, the authors observed an average reduction of the mean shower duration from 7.19 to 5.86 min, which equates to a saving of 1min and 20 s (i.e. 1.34 min) or 18.6% water consumption time. In terms of water volume, the mean shower event volume decreased from 57.37 L to 41.97 L which resulted to a saving of 15.40 L per shower event or 27%. It is interesting that the authors estimated the payback period for the device from water bills savings and this was determined to be 1.65 years. Furthermore, they show that if the devices were installed in all homes in the region the savings would amount to 3% of total city consumption.

Figure 15: The WaiTEK® Shower Monitor© employed in the study of Willis et al. (2010). The device provides the alarming visual feedback intervention in the form of a digital read-out of shower parameters such as flow rate, duration and temperature. Moreover, the device allows to set a shower duration, after which, it beeps for 1min indicating that it is time to stop the shower.

Ferraro and Price (2013) examine the use of normative messages to promote changes for sustainable water use in households. They run a large-scale study in the Cobb County of Atlanta Georgia US where they involved 100,000 households in cooperation with the local water utility company. The study involved three intervention and one control group. The intervention groups received mail letters which had different types of normative messages aiming to affect users' water consumption. More specifically, the first intervention group received messages with technical advices for reducing consumption, as a list of listing ways to most effectively reduce water use and who to contact for more information. The second intervention group was treated with a weak social norm approach and received messages signed by the local water conservation authority, explaining in a formal language the need for reducing water consumption for the common good. These messages aimed to trigger prosocial behaviour. The third group was treated with a strong social norm approach and received social comparison messages, informing water consumers how much water they use compared to their neighbours. The authors report that social comparison messages had a greater influence on behavior than simple prosocial messages or technical information. Moreover, they found that the greatest effects were observed in high consuming households. This is attributed to the fact that such households can take more actions to reduce their consumption. Another interesting observation was related to the impermanence of the effects. In all treatment groups an initial reduction of water use was identified when the mails were received by the households, but then faded over time. Due to this fading effect, the authors conclude that such norm-based water consumption reduction strategies should be reserved for situations where "immediate but short-lived conservation efforts are desired" and can be complementary to pecuniar-based strategies which can be slow to implement.

Paay et al. (2013) explored the use of mobile persuasive technology to promote pro-environmental behaviour towards sustainable domestic resource consumption. Two research studies were conducted: a water conservation study in Melbourne, Australia in November 2010, and an electricity consumption study in Aalborg, Denmark in April 2011. The primary goal of the water conservation study was to explore the role of mobile devices as a tool to support people in their watering practices in their home gardens. The primary goal of the electricity consumption study was to explore whether a tailored mobile application could raise people's awareness of power consumption in their households. Based on the analysis of the results, the authors suggest a set of eight key concepts, empirically proven to persuade behaviour change, to consider when designing mobile technology to promote pro-environmental behaviour: (i) Self-Comparison - give access to the user's own situation; (ii) Triggering Messages - push messages that push the user in a proposed direction; (iii) Mobile Platform - smartphones are the most desired platform; (iv) Understandable Messages - Use smileys and a combination of positive and negative reinforcement in messages; (v) Tailored Information - Tailored information is more persuasive; (vi) Community Information - Use community information for comparison; (vii) Expert's Advice - Use expert's advice for comparison; and (viii) Behaviour Change Over Time - Mobile persuasive technology needs to be used over time to change peoples' behaviour.

Erickson et al., 2012 developed the Dubuque Water Portal (in Iowa, US), which involved a near-real time water consumption feedback system for households and evaluated its effectiveness. The system included smart-meters which recorded consumption data in 15-minute intervals. The data were then analyzed and presented to water consumers showing water consumption in gallons, dollars and pounds of CO2 while maintaining a strong focus on privacy. The presentations included hourly usage graphs representing overall household usage, and information regarding how the given household consumption compared to similar neighbours (see Figure 16). Moreover, the system involved a team-based weekly game focused on water conservation, and a chat room in which participants could communicate anonymously. The evaluation span over a 15-week period, and involved 303 households as well as the water company via an online portal. A two-phased deployment was followed. During the first phase, which lasted 9 weeks only half of the participants had access to the system. This allowed a controlled comparison of its impact on water consumption. In the second phase 2 which lasted 6 weeks everyone used the system. The results showed a 6.6% reduction in normalized water consumption of the intervention group (phase 1).

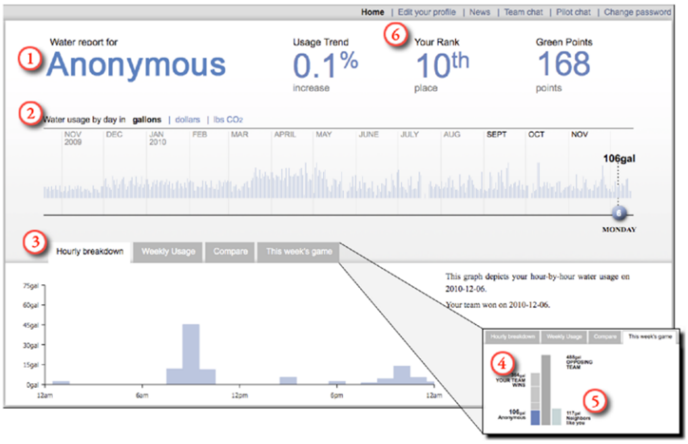

Figure 16: The Dubuque Water Portal. A time series graph (2) shows the daily water usage for the last year. Graphs for hourly/weekly consumption are also shown (3). The Compare option (3) provides daily consumption differences in the last three weeks. The game option (4, 5) shows the results of an ongoing game where households are automatically matched to peers with similar consumption and are asked to compete in reducing water consumption. Households are ranked based on their consumption (6). The chat functionalities are provided in the top of menu of the system.

Froehlich et al., (2012) designed and evaluated a series of water consumption displays aiming to understand which visual elements of eco-feedback are more interesting to users. The authors created mockup displays (see Figure 17) and performed an online survey involving 651 North American respondents and interviews with 10 families (20 adults) evaluating the displays. Their designs firstly focused understanding isolated design dimensions, including data granularity (i.e. "the degree with which data is sub-divided or grouped"), time granularity (i.e. "the time window with which data is calculated and presented.") and comparisons (including self-monitoring, goal-comparison and social comparison). The displays of isolated design dimensions provided bar-chart visualizations of data. Figure 17 shows the indicative example reported by the authors where consumptions are displayed by individual fixture; by fixture type; and by hot/cold water consumption breakdown. Secondly, they provided a number of "design probes", i.e. visually attractive presentation of water consumption. Specifically they focused on presentations of consumption time series data, spatial presentation of water consumption (per room), consumption per household occupant, an abstract display that showed an aquarium that evolves in a positive manner when users water consume less water, a rainflow presentation of consumption, geographic comparisons that use maps to compare usage across an area and displays of metaphorical units based on the use of common, everyday objects such as a gallon jugs or oil trucks to depict usage. Indicative displays reported by the authors are shown in Figure 17.

Regarding the findings, of the study, there several interesting points which can be summarized in the following:

- Participants expressed preference for more granular information, i.e. at consumption reporting at fixture level. Moreover, they would prefer that consumption information is coupled with suggestions of actions to reduce usage.
- In terms of time granularity when displaying past consumption, participants stated that they would like to be able to switch between different views (e.g. view weekly, monthly, hourly consumption). Moreover, concerning the measurement units of consumption the survey respondents liked to see both volume and cost-based consumption.
- Participants liked the self-monitoring displays, however they expressed concerns regarding the social comparison and they would be more willing to share anonymous data only.
- The playful designs were well received but there were certain concerns related to the actionability of such designs. For example, in the aquarium display, if a fish dies, it may worry the children in a household, or in the "rainbow" display, children may consume more water just to see a more colourful display.

Figure 17: The water consumption displays designed by Froehlich et al., (2012). The designs provide views of consumption time granularity and comparisons, including self-monitoring, goal-comparison and social comparison. Moreover, consumptions are displayed by individual fixture; by fixture type; and by hot/cold water consumption breakdown. Additionally, they designed visually attractive presentations of water consumption including spatial presentation of water consumption (per room), consumption per household occupant, an abstract display that showed an aquarium that evolves in a positive manner when users water consume less water, a rainflow presentation of consumption, geographic comparisons that use maps to compare usage across an area and displays of metaphorical units based on the use of common, everyday objects such as a gallon jugs or oil trucks to depict usage.

Laschke et al. (2011) describe the "Shower Calendar" aiming to support users to reduce water consumption when bathing and showering. The proposed system consists of screen placed in the bathroom stall that displays a calendar where the consumption of different users is visualized with dots of different colors (each color corresponding to a different user) and size, depending on the consumption. An indicative view of Shower Calendar is provided in Figure 18. When the user begins taking a bath, s/he identifies herself in the system and a dot with the color selected by the specific user appears at the current date. The initial size of the dot is set to represent a consumption of 60 litres. The dot begins to decrease when the user takes a shower following the water consumed. At the end, the remaining size of the circle is saved on the screen. The goal is that users try to decrease their water consumption during showering by the consumption feedback they receive. The authors carried out an evaluation with 2 families each consisting of 6 users for one month. The results show that parents showed decrease their water consumption, while the child of one family either conformed and the other not.

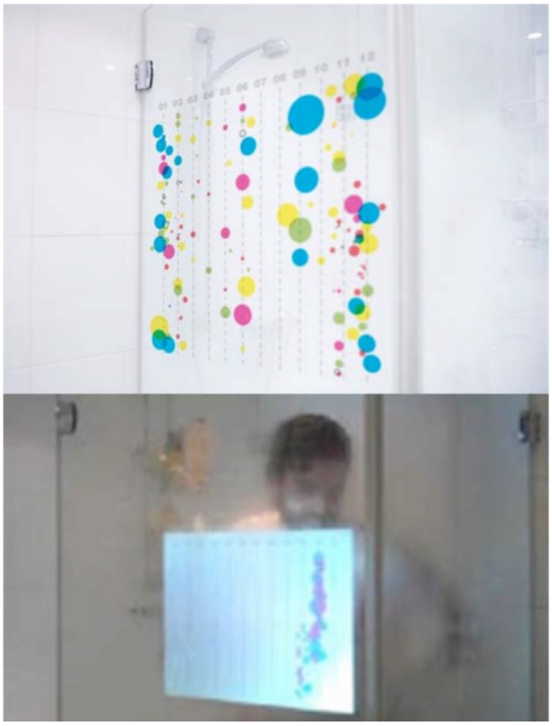

Figure 18: The Shower Calendar proposed by Laschke et al. (2011). A is screen placed in the bathroom stall that displays a calendar where the consumption of different users is visualized with dots of different colors (each color corresponding to a different user) and size, depending on the consumption.

Kilgren et al., 2010 focus on strategies for water conservation in the irrigation of landscapes in public schools. Their study involved thirty five elementary schools in the Salt Lake Valley located in Utah US where they compared manual vs automated irrigation control and three different water conservation interventions, namely directive, prescriptive and educational The directive intervention involved a formal letter to the managers of landscape irrigation which informed them to save water in any way possible. In the prescriptive intervention, managers received a predefined irrigation schedule based on plant water use information, which they had to follow. With respect to the educational information, managers had to attend a one day water conservation workshop. A pre-study period allowed authors to gather data regarding the consumption levels before applying the interventions. The results showed that the schools with automated systems applied 40-85% more water to their landscapes than the schools with manual systems. Moreover, the prescriptive intervention was the least effective while the directive intervention was the most successful, while the educational and directive interventions were more successful than the prescriptive intervention, resulting in significant reductions in yearly school water use compared to the pre-study period. Note that in this study there was no behavioural change support system employed.

Kappel et al. (2009) designed an ambient display system to inform water consumption in real time used in the shower. Instead of providing exact numbers of water consumption they developed a water metering device that had a set of LEDs assembled on a stick that lit depending on the consumption – the higher the consumption the more LEDs lit, as shown in Figure 19. The authors' argument is that this method of feedback allows users to better understand their consumption and set goals such as reducing a shower by 2 LEDs. The device was named "show-me", after "shower water meter". A pilot study was conducted with 4 households, where the it was installed for 3 weeks. In the first day of the device usage a significant reduction was observed, however during the next days water consumption increased and fell again after day 5. The authors attribute these changes to the fact that users were exploring how much water they normally use and how much water they can save without losing comfort. In any case, throughout the pilot study, the average shower was reduced about 20% or 10 L.

Figure 19: A model of the ambient device "show-me" developed by Kappel et al. (2009).

Petersen et al. (2007) focus on feedback technologies for reducing energy and water consumption. They installed an automated data monitoring system which collected electricity and water data in two college dormitory buildings. The meter readings were fed to an online portal (web application) which was accessible by the residents of the buildings. In the portal, users could see the consumption in terms of KW (electricity) and gallons (water) consumed. Moreover, the portal provided the consumption impact in terms of environmental and financial costs. The effects of the consumption feedback portal were evaluated in a study with two groups. One group was provided with low-resolution, aggregate data readings once a week and a second group had access to fine grained consumption measurements through the online portal. After a baseline period where participants received the consumption feedback, an energy and water saving competition between the two groups was initiated and a prize was given to the winner of each group that achieved the lowest consumption. The authors report that reductions in water use were considerably less than reductions in electricity throughout the study. Further, there was a greater reduction of electricity and water use during the competition period, whereas the group that had access to detailed meter ratings achieved higher reductions. The authors note that the consumption reductions were greater in dormitory buildings that already had high consumption compared to other buildings before the study.

Pearce et al. (2010) describe the SmartGardenWatering web application that supports gardeners (including people maintaining their own domestic garden) to make sustainable use of water when maintaining their plants. The application provides a set of functionalities around the concepts of modelling, exploring and sharing and is mainly targeted for the Melbourne area in Australia. Gardeners can model a garden (define plants, soils, micro-conditions, climate information) and the system provides a schedule for watering throughout the year. Moreover, they can simulate a water tank used to supply the garden and identify the best combination of size and catchment roof. With respect to exploring, the application allows gardeners to find garden models that might be of interest and created by others. This can be performed through a map view where the distribution of gardens registered in the system are shown. In terms of sharing, the software supports user interactions through Facebook. When a new garden model is created, a post can be automatically sent to the user's Facebook wall as an announcement. Other users are notified, can see the new model and initiate new discussions. In order to maintain engagement, the authors provide educational material through the application which allows users to learn about the watering needs of their plants and potential benefits from sustainable water use. Figure 20 provides indicative views of the proposed system.

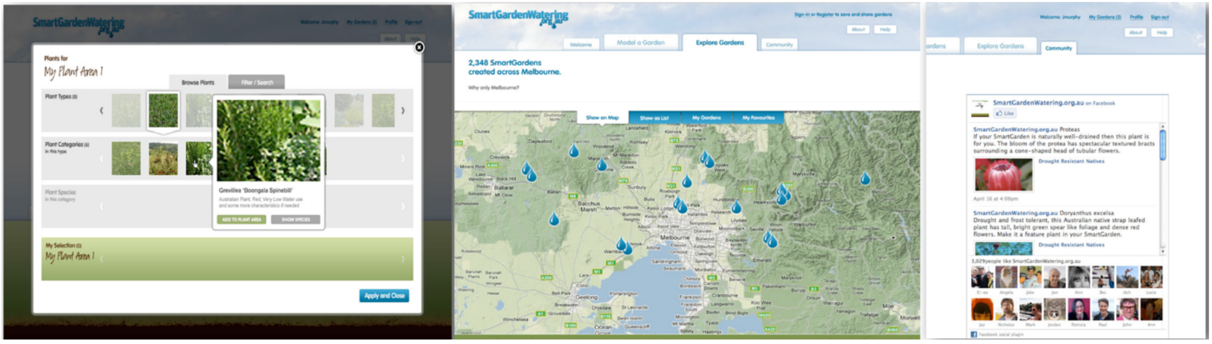

Figure 20: Indicative views of the SmartGardenWatering proposed by Pearce et al. (2010). The application supports gardeners build garden models by defining plants, soils, micro-conditions, climate information and generated watering schedules. Furthermore, it allows gardeners to explore other models and initiate discussions through the facebook social network.

Arroyo et al. (2005) designed Waterbot, a device that informs water consumption and motivates water conservation at the sink. Waterbot is attached to the spigot of a faucet, and implements a range of behavioural change support strategies (see Figure 21). Through a visual display in the form of an illuminated bar graph, the device indicates current water usage implementing the feedback strategy. A second bar graph provides a view of the average consumption of all the members of the household that use the faucet. Essentially this is an instance of social validation to motive water conservation. Furthermore, the device provides audio cues and 'just-in-time prompts' reinforcing positive (low water consumption) actions. Such cues include appealing sounds when the user closes the tap. Another interesting feature is that the device presents novel patterns of lighting at random time intervals when water savings exceed certain thresholds. This is an instantiation of the scarcity strategy since the patterns appear randomly when something positive has happened. In order to evaluate the effects of Waterbot, the authors conducted a pilot study in a laboratory environment with 10 users and a test installation at a community sink with another 15 users. The main aim of the study and test installation was to observe users' reactions, understand how the device is perceived by the users and evaluate its robustness and functionalities. Overall, users reported not being annoyed with Waterbot although there was a learning curve to understand how it works. Also, most participants in test environment (12 out of 15 users) stated that they were engaged after two months of use. Note that the authors did not evaluate aspects relate to water conservation and behavioural change.

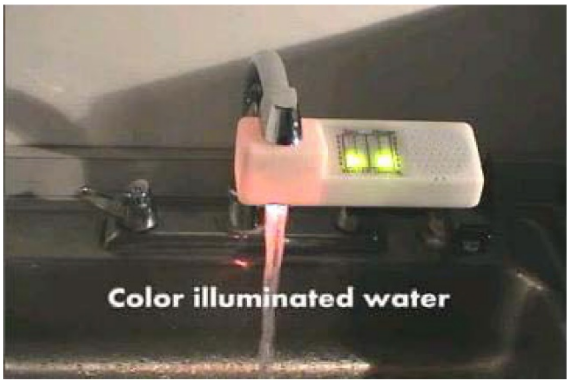

Figure 21: Indicative view of the Waterbot device developed by Arroyo et al. (2005). The device integrates behavioural change support strategies such as feedback, social validation, rewards and positive reinforcements.

Kurz et al., (2005) present a study aiming to compare different interventions for reducing residential water and energy use in a local community. The interventions employed included information leaflets, attunement labels, and socially comparative feedback on the actual levels of energy and water consumption. The study was performed in 166 households over a period of six months. They find a significant effect if information labels as households that received labels using less water than those that did not receive labels leading to a 23% reduction.

3.3 Analysis of Existing Systems and Approaches

The process of engaging in the detailed analysis of the identified 24 papers involved the development of a coding scheme where we documented the characteristics of each work analyzed using a set of 8 analysis dimensions, which are described in Table 4.

Table 4. Analysis coding scheme and dimensions of Behavioural Change Support Systems and Approaches for water conservation.

#	Dimension Type	Dimension	Identified classifications
1	General	Descriptive Information	Year and country
2	Communication Means	Application or approach for delivering interventions	Web / mobile app / both / display or monitor device installed in water fixture / mail, letter, water bill
3	Evaluation	Country of Evaluation	Country where the study/pilot was conducted.
4		Duration of Evaluation	Hours, Days, Weeks, Months, Years.
5		Number of Participants	Number of participants involved in the evaluation.
6		Evaluation Method	Quantitative, Qualitative, Mixed.
7		Evaluation Results	Successful, partially successful.
8	Behavioural Change Support approach	Strategies employed	Behavioural Change Support Strategies used in the design of the system or approach (see Table 8 for an overview of the strategies which are used in the reviewed papers).

These dimensions were defined through an iterative process and new dimensions were added as the analysis progressed.

3.3.1 Behavioural Change Support Systems and Approaches in water conservation by year

With respect to the number of papers per year (see Figure 22), we see that the first related work appeared in 2005 while since 2009 at least one related paper per year is being published. In the figure we observe that 2013 has been the year with the most published papers. Note that our latest search for related papers has been conducted in early 2020, which means that many of the publications for this year are still pending at the time we write this report and thus there are no papers reported for 2020. Note that the nature of studying behavioural change support systems and approaches is such that it requires user engagement, often through long periods of time, in most cases coordination with water utilities, and analysis of significant amounts of results. The related research process can be cumbersome and time consuming which means that the time from the inception of the study idea to being reported and published can be quite long (e.g. the study reported in Kurz et al. (2005) was conducted during 2001 and 2002). These inherent characteristics of behavioural change support systems and studies for water conservation justify the relatively low number of related papers as well as observed bursts in published work, e.g. in 2013.

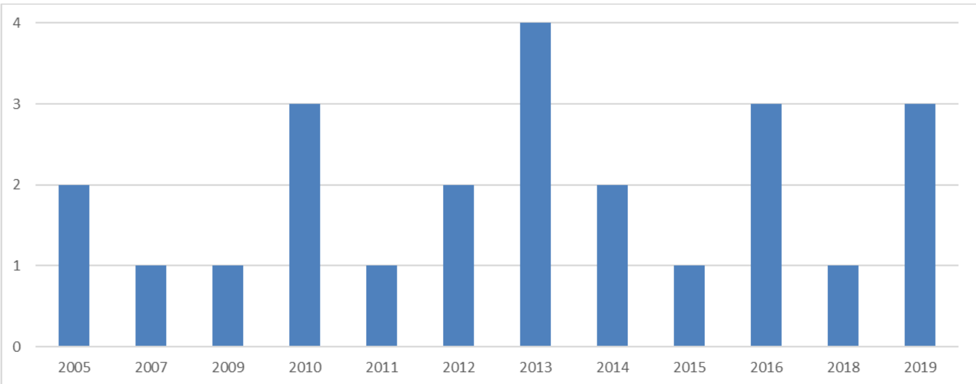

Figure 22: Published papers related to behavioural change support systems for sustainable water consumption by year.

3.3.2 Employed Behavioural Change Support Strategies

In summary, we observe that self-monitoring is the most frequently used behavioural change support strategy and takes the form of visual feedback. The information being displayed is commonly the daily, weekly and monthly water consumption (Novak et al., 2016, Erickson et al., 2012, Froehlich et al., 2012, Magoutas et al., 2015, Marinho et al., 2014, Kossieris et al., 2014). Certain approaches provide visualizations of the cost per day, week or month (Novak et al., 2016, Erickson et al., 2012, Froehlich et al., 2012, Magoutas et al., 2015). Other approaches provide spatial-based presentation of information, particularly for appliance- or device-level usage. In the home water use the following rooms are used: bathrooms, kitchens, laundry rooms, and outdoor spaces.

Two forms of feedback are commonly used. Visual designs aim to communicate in a simple and user friendly manner aggregate statistics and take the form of cognitive representations of concepts that transform based on users' water consumption. These concepts commonly rely on trees that grow as users adopt more sustainable habits (Magoutas et al., 2015), while in Froehlich et al., (2012) an additional concept of a growing iceberg was used, which provides conceptual correlations to climate change. The second form of feedback refers to charts (including bar and pie charts) presenting detailed statistics of the users' behaviour (Novak et al., 2016, Erickson et al., 2012, Froehlich et al., 2012, Magoutas et al., 2015, Marinho et al., 2014, Kossieris et al., 2014). Visual feedback is typically combined with and supports other behavioural change support strategies e.g. support for goal-setting and challenges, social comparison, inclusion of gamification and rewards (playful aspects), or personalized suggestions/messages.

Social aspects take the form of comparing the individual user performance to that of her/his peers (commonly other users who participate in the studies). The comparison can be provided by the system through visual feedback that provides analytics and information of user's performance compared to others, or through social recognition with leaderboards that rank users according to their performance (Erickson et al., 2012, Magoutas et al., 2015). Additionally, it can be supported with functionalities that allow users to post their performance in social networks (Novak et al., 2016). Rewards are commonly given to users in the form of points when they opt for water conservation (Novak et al., 2016, Magoutas et al., 2015). Persuasive messages are commonly text based, whereas in Paay et al., (2013) an approach that combines text with images is proposed.

3.3.3 Evaluation of Behavioural Change Support Systems and Approaches for Water Conservation

Table 5 presents the main details of the pilot studies examined, including the goal, the number of users involved, the place where the study took place, and the way that the goal achievement was evaluated. Note that all studies had the ultimate goal of promoting water conservation and changing water behaviour using different behavioural change support strategies and means of communicating the corresponding strategies.

With respect to the number of users, we observe that in studies where behavioural change support systems are deployed, it is fairly small. In these cases, the number of participants is under 300. On the other hand the evaluation of other approaches (including informational messages and evaluation of behavioural change support systems designs), commonly involves higher number of participants. The geographical spread of the analysed studies diverse. Five studies took place in USA, four in Australia, two in Switzerland and another two in UK, while one study was conducted in each of Germany, Brazil and South Africa. As far as the evaluation type is concerned, most studies were evaluated both quantitatively through surveys and gathering of water consumption data as well as qualitatively through interviews.

Table 5. Main implementation details of the studies we examined including their focus, number of users, country and type of evaluation.

Ref.	Focus of the proposed approach	Users	Place	Duration	Evaluation Type
Visser et al., 2019	To investigate the impact of feedback from smart meters, and an interschool competition to encourage responsible water usage.	105 schools	Western Cape, South Africa	8 months	Mixed
Novak et al., 2016	To stimulate water saving combining smart meter data with consumption visualisation and gamified incentive mechanisms.	40 households	Switzerland	4 months	Mixed
Fielding et al., 2013	To explore voluntary strategies for urban water demand management.	221 households	Four regions of South East Queensland, Australia	12 months	Quantitative
Erickson et al., 2012	To evaluate the uptake, use and impact of residential water consumption feedback.	303 households	Dubuque, Iowa US	15 weeks	Mixed
Petersen et al., 2007	To examine the impact of real-time visual feedback and incentives on reducing electricity and water consumption.	18 college Dormitories	Oberlin, USA	2 weeks	Mixed

Stewart et al., 2013; Willis et al., 2010	To test alarming visual display devices in the shower for water consumption reduction.	44 households	Gold Coast City, Australia	3 months	Mixed
Kurz et al., 2005	to study the influence of information leaflets, attunement labels, and socially comparative feedback on the actual levels of energy and water consumption.	166 households	Melville, Australia	14 weeks	Quantitative
Kilgren et al., 2010	To evaluate water conservation programs for irrigation at schools.	15 schools	Salt Lake Valley, Utah US	3 years	Mixed
Froehlich et al., 2012	To evaluate novel eco-feedback displays that motivate users reduce their water consumption	651 participants	US	N/A	Mixed
Terlet et al., 2016	To understand the elements that attract consumers the most and the features that are most commonly used by the participants	198 participants	Kardif, UK	N/A	Qualitative
Arroyo et al., 2005	To test the impact of a visual feedback devices attached to water taps.	15 users	Oregon, US	2 months	Qualitative
Kappel et al., 2009	To study the impact of a feedback LED based lighting display attached to the shower on water conservation.	4 households	Vienna, Austria	3 weeks	Mixed
Tiefenbeck et al., 2016	To motivate users, reduce their water consumption in the shower through real-time consumption feedback.	620 participants	Switzerland	2 months	Mixed
Ferraro and Price, 2013	To understand the impact of nonpecuniary behavioural change strategies in the form of informational messages.	100.000 households	Atlanta, Georgia US	8 months	Mixed
Paay et al., 2013	To evaluate a watering advise system for gardeners.	10 participants	Aalborg, Denmark	3 weeks	Qualitative
Laschke et al., 2011	To test a display of a water consumption calendar at the shower as a tool for reducing related water consumption.	2 families (6 participants)	Germany	1 month	Mixed
Marinho et al., 2014	To evaluate a web based feedback system that provides water consumption related information.	90 university buildings	Bahia, Brazil	2 years	Quantitative
Goette et al., 2019	To understand the impact of information and feedback through printed leaflets in the form of door hangers.	1000 participants	Singapore	4 months	Mixed

Otaki et al., 2019	To identify effective presentation methods used for historical self-comparison that will lead to the efficient use of water.	633 participants	Tokyo	24 weeks	Mixed
Sun et al., 2019	To investigate if tips with the quantitative information or the social norm information could boost household water saving behaviors in China.	892 participants	China	2 months	Mixed

3.3.4 Results of Evaluations

This section summarizes the evaluation results of the reviewed studies. We focus only on the studies which measured or report results related to behavioural changes. We identified studies which report successful results, i.e. they conclude that one of the evaluation targets was achieved and studies which are partially successful, i.e. they conclude that some effects were observed but further work is needed to verify the results. Overall, 89% of the studies report successful results and 11% partially successful, as summarized in Table 6.

Table 6: Successful and partially successful results

Outcome	Study
Successful	Visser et al., 2019; Novak et al., 2016; Fielding et al., 2013; Erickson et al., 2012; Petersen et al., 2007; Stewart et al., 2013; Willis et al., 2010; Froehlich et al., 2012; Tiefenbeck et al., 2016; Ferraro and Price, 2013; Paay et al., 2013; Marinho et al., 2014; Goette et al., 2019;
Partially successful	Kurz et al., 2005; Laschke et al., 2011; Otaki et al., 2019

Table 7 provides a summary (snippets) of the results reported in the studies examined relevant to the outcomes of the evaluations. Note that it has not been possible to perform a quantitative comparison of effect sizes of the different systems and approaches due to large differences in the methodological approaches, sample sizes, geographic locations and contexts. It is interesting that most of the studies provide evidence of actual behavioural changes although there is no evidence for long lasting effects. Furthermore, several studies identify positive changes in users' perception of water conservation and their increased concern regarding the impact of their choices on the environment.

Table 7: Overview of the results reported in the evaluation studies.

Ref.	Summary of Results (snippets from the papers)
Visser et al., 2019	Interventions reduced water usage in these schools by 15 to 26%, translating to significant water savings of 380 kilolitres per school per year on average.
Novak et al., 2016	The average water consumption reduction is 33.4%.
Fielding et al., 2013	All interventions showed reduced levels of household consumption (an average reduction of 11.3 L per person per day, approximately 7.9% reduction).
Erickson et al., 2012	The system resulted in a 6.6% decrease in water consumption.

Petersen et al., 2007	They observed a 32 percent reduction in electricity use (amounting to savings of 68,300kWh, $5,107 and 148,000lbs of CO2) and a 3 percent reduction in water use. Dormitories that received high resolution feedback were more effective at conservation, reducing their electricity consumption by 55 percent compared to 31 percent for low resolution dormitories.
Stewart et al., 2013; Willis et al., 2010	The study resulted in a saving of 15.40L per shower event or 27% average consumption reduction
Kurz et al., 2005	The results suggest that the labels led to a 23% reduction in water consumption. However, they found that feedback had no effect on water consumption.
Kilgren et al., 2010	The educational and directive interventions were more successful than the prescriptive intervention, resulting in significant reductions in yearly school water use compared to the prestudy period.
Froehlich et al., 2012	Participants preferred specific, detailed information about water usage at the individual fixture level in both volume and cost metrics. They also strongly preferred the ability to see their usage broken down by hot/cold, and their usage contextualized by some sort of comparison data (self-comparison was most preferred).
Terlet et al., 2016	The most important feature is to make consumers aware of the financial savings that can be achieved by reducing their household's water consumption. Likewise, reminding participants of the impact of their consumption on the environment help increasing their motivation to save water. Additionally, peer pressure and social comparisons with neighbours and other consumers, using online social networks, will likely encourage consumers to reduce their consumption. Participants will also be able to compare their current consumption to their past consumption and to observe the consequences of their efforts to save water through diverse graphs and charts.
Arroyo et al., 2005	The users reported not becoming annoyed with Waterbot, most participants stated that they were engaged after two months
Kappel et al., 2009	The average shower was reduced about 20 % (10 L).
Tiefenbeck et al., 2016	They find that real-time feedback reduced resource consumption for the target behavior by 22%.
Ferraro and Price, 2013	Social comparison messages had a greater influence on behavior than simple prosocial messages or technical information alone.
Paay et al., 2013	The results indicated that the messages received during the use of water and energy were very well received in the sense of awakening the awareness of their energy consumption.
Laschke et al., 2011	All parents showed decrease their water consumption, while the children either conformed or not.
Marinho et al., 2014	A 38% reduction in water consumption. Per capita consumption fell by 49,5%.
Goette et al., 2019	Results show that there is an average treatment effect of water saving around 4 Litre for all households, and 5.9 Litres for high baseline households

Otaki et al., 2019	When only using the same blue water droplets, there was no change in water consumption. However, when using yellow and red droplets in cases of increased water use, they observed that water consumption declined
Sun et al., 2019	They found that residents who received water-conserving tips significantly reduced the subsequent water consumption compared to the residents who did not receive any tips. The tips with the quantitative information made the residents reduce water consumption the most, whereas the tips with the norm information appeared to have no effect on water-saving behaviors compared to the counterpart.

Table 8 provides an overview of the evaluation results for individual behavioural change support strategies in the studies that employ them. We notice that a higher number of studies has focused on the strategies of Self-monitoring & Feedback, Social Comparison, and Gamification & Rewards.

Table 8: Evaluated behavioural change support strategies and the reported results per type of outcome.

Behavioural Change Strategy	Studies with successful outcome	Studies with partially successful outcome
Challenges & Goal Setting	Novak et al., 2016; Magoutas et al., 2015	N/A
Self-monitoring and Feedback	Visser et al., 2019; Novak et al., 2016; Fielding et al., 2013; Erickson et al., 2012; Petersen et al., 2007; Stewart et al., 2013; Willis et al., 2010; Kilgren et al., 2010; Froehlich et al., 2012; Terlet et al., 2016; Arroyo et al., 2005; Kappel et al., 2009; Tiefenbeck et al., 2016; Ferraro and Price, 2013; Paay et al., 2013; Marinho et al., 2014; Goette et al., 2019; Sun et al., 2019	Kurz et al., 2005; Laschke et al., 2011; Otaki et al., 2019; Sun et al., 2019
Social comparison	Visser et al., 2019; Novak et al., 2016; Fielding et al., 2013; Erickson et al., 2012; Petersen et al., 2007; Arroyo et al., 2005; Ferraro and Price, 2013; Paay et al., 2013	Laschke et al., 2011; Otaki et al., 2019
Gamification & Rewards	Novak et al., 2016; Erickson et al., 2012; Petersen et al., 2007; Goette et al., 2019	-
Suggestion	Kilgren et al., 2010	Kurz et al., 2005; Sun et al., 2019

3.3.5 Discussion

The first papers applying behavioural change support approaches in water applications emerge in 2005, while in the recent years we observe a tendency of increased number of papers and corresponding researchers who apply such technologies in this domain. This is in line with the increased interest of researchers in the field of behavioural change support systems, driven by the widespread adoption of ubiquitous technologies, including smartphones which provide the means to apply such technologies, as well the pressing need for moving towards sustainable behaviours.

As presented above we identified 24 studies of behavioural change support systems and approaches for water conservation. It is difficult to provide a clear conclusion on whether the effect of such technologies leads to long term behavioural change and change of habits towards water consumption. In the majority of the studies the interventions have been applied for a period of one to four months (12 out of 24 studies). In 3 studies the interventions were applied for a period of eight to twelve months while two studies spanned in a timeframe of two to three years. The fairly short timeframes in the majority of studies fail to capture important aspects such as seasonality and the effectiveness on a longer term basis. Seasonality is an important factor for habits related to water consumption as there are several important contextual parameters which vary throughout the year and affect user decisions, with the most important being the weather and the everyday schedule of users.

In our review we identified five main behavioural change support strategies which have been implemented in the form of features in mobile or web applications that nudge users to reduce their water consumption. Most approaches focus on providing challenges and goals, self-monitoring and feedback information, social comparison, gamification and rewards and suggestions. These approaches rely on capturing data from users' water habits and using these data for implementing the relevant strategies, and will be considered in NAIADES along with the pilot requirements, as described in the next section.

4 NAIADES Awareness and Behavioural Change Support Framework

The NAIADES Awareness and Behavioural Change Support Framework aims to address the requirements of two main cases of the project namely those of the water utility in Alicante, Spain and the municipality of Carouge, Switzerland. The water utility in Alicante is transforming its water supply network with smart sensors that measure consumption at different levels. There is an abundance of data that remain unexploited and which can be used to raise water consumption awareness in different stakeholder levels as well as target consumer groups and support sustainable water use and reduced consumption. The provision of solutions for awareness and behavioural change support is a common need among many water utilities across Europe and NAIADES aims to provide an innovative approach showcasing the benefits of such solutions. The Carouge case focuses on the problem of efficient watering of plants in municipalities. The aim is to leverage AI supported solutions for plants' watering predictions and couple them with awareness technologies targeted to personnel responsible for watering. This is also a common need among municipalities across Europe and the Carouge case provides the opportunity to deploy and demonstrate a solution which can be adopted by other stakeholders. In the following we provide further details and relevant requirements for the aforementioned use cases.

4.1 Use Cases and Requirements

4.1.1 Alicante (Spain)

The water supply in the Alicante area of Spain is managed by Aguas de Alicante. The utility company serves a significant population pf 500,000 inhabitants, which rises to 700,000 during the summer period. The water distribution network in the area extends to 2,043 Km and a significant amount of over 150,000 smart meters have been installed.

After discussions with the stakeholders of Aguas de Alicante, two main problems have been identified. The first refers to the analysis of water consumption data coming from smart meters in order to be able to generate awareness over municipal water consumption. Much of the data remain unexploited and cannot be viewed by interested stakeholders in a manner that can improve efficiency and consumption awareness. The main stakeholders who should have access to the data include the Communication/Marketing department., R&D department and local authorities such as municipal services.

The available metering data are provided hourly whereas there is availability of manual meter readings registered in the Customer Management System on a monthly and quarterly basis. Particularly, 100% of the municipal (public) consumption points are equipped with metering devices, including schools, sport facilities, local administration offices, cultural premises, etc.

In terms of water consumption data awareness Aguas de Alicante needs the following initial set of functionalities to be developed in the water consumption awareness system:

- A holistic water consumption awareness dashboard should be accessible by different stakeholders and provide data views for strategic, tactical and operational decisions, leveraging the available consumption metering information either coming from smart meters or manual readings. The dashboard should be mainly addressed to city stakeholders and officials.
- Analytic record of public buildings and gardens water consumption. The available sensor data, need to be categorized per consumption point and related information per point should be accessible by interested stakeholders.
- Segmentation per use. The consumption should be categorized taking into account different uses, including water consumed in schools, sport facilities, gardens, other buildings.
- Comparison of standardized consumption. Consumption comparisons should be provided across various dimensions, including per groups of consumers, areas types of consumption points and time periods. Stakeholders should be able to create comparison using filtering functionalities and become aware of the consumption across the different dimensions.

- Impact of consumption awareness interventions. Stakeholders should be able to understand the impact of any consumption intervention campaigns. Mainly they should be able to compare consumption pre- and post- interventions.
- A required feature is the presentation of consumption points and related information in a map view. This should support stakeholders in better understand the different consumption points.

Besides data awareness Aguas de Alicante needs to be able to deploy behavioural change support programmes and be able to engage more consumers with less investment in water savings. Within the context of NAIADES, the special attention is paid to behavioural changes on younger users at public schools, due to its educational potential, expected higher responsiveness, longer term effect of the intervention, and the multiplier effect at social level. The related requirement is to provide the municipality with a comprehensive tool to run behavioural change support campaigns at schools, monitor them and assess their impact.

Consumption points will be assigned to either an experimental or control group (50 % in each group) in the NAIADES project. Consumers in the experimental group will receive information through their personalized water behavioural change app and have their water consumption monitored at facility level. The others in the control group will have only their water consumption monitored. Consumers in both groups will complete a series of additional surveys, at the end of the mid-term evaluation and final evaluation periods, regarding their self-reported water consumption behaviours and awareness. Those in the experimental group will also complete a survey about the usability and attractiveness of the NAIADES app.

The NAIADES project will use two main experimental designs and several impact indicators (such as water consumption, awareness, and social media activity) to assess the impact of the intervention. The initial approach involves two main designs which will be able to showcase the impact of technology support behavioural change campaigns. Pre-post-comparisons are required which will enable monitoring the same group of water consumers, before and after the implementation of the campaign. In order to calculate the effect of the intervention a comparison of the impact indicators before (baseline evaluation), after the intervention starts (mid-term evaluation) and at the end of the intervention (final evaluation) will be undertaken. Both the baseline and intervention period will cover, at least, a full operating cycle each (one year). Comparisons with control group will enable to understand the behaviours of two different groups (experimental and control group) of consumers, one with the NAIADES system and the other without, observed during the same period. This will allow examining the effect of the intervention by comparing the change in impact indicators between groups. The control group will comprise similar building types and occupant characteristics to the experimental group (e.g. building type, location, occupants). The main advantage of the control group design is that it provides the opportunity to control for both intervention impact and for other influencing effects (e.g. water price increases, new living situation, man-made/natural disasters, etc.). Ideally, the only difference between the experimental and control group will be the provision or absence of the NAIADES app.

The NAIADES bahavioural change support system should support different strategies that have been effective in past experimental studies, including self-monitoring and feedback, social comparisons and rewards, suggestions and social norm based messages while enabling social interactions and fostering discussions among water consumers.

4.1.2 City of Carouge (Switzerland)

The case in the city of Carouge targets efficient watering of flower boxes through an awareness application that aims to enable IoT-based precision irrigation. The aim of the application is to nudge city workers to follow the suggested watering schedule, making them aware of the water consumption and the plants watering needs. The application accommodates the city staff needs and should provide functionalities for capturing information related to the flower boxes to be irrigated as well as present watering schedules related information and consumption per watering point. With respect to the flower box information, this should include the type of soil and the type of flowers, the location of the box, the exposure to sun, the date of the box installation and its size. Furthermore, users of the application should be able to report problems related to watering, including broken sensors, wrong data, problems with the box, flowers destroyed etc.

4.2 The Naiades Conceptual Framework

Following the description and requirements of the cases provided in the previous section we set to describe the Naiades conceptual framework for water consumption awareness and positive behavioral changes in citizens to opt for more sustainable water consumption choices. The framework is shown in Figure 23 and consists of three main layers offering different functionalities. The layers align with the work which is being performed in corresponding tasks of the Naiades WP6 and will drive the development of the related applications in these tasks. Moreover, Figure 23 shows the interactions of the framework with the Naiades services developed in WP5 and WP3.

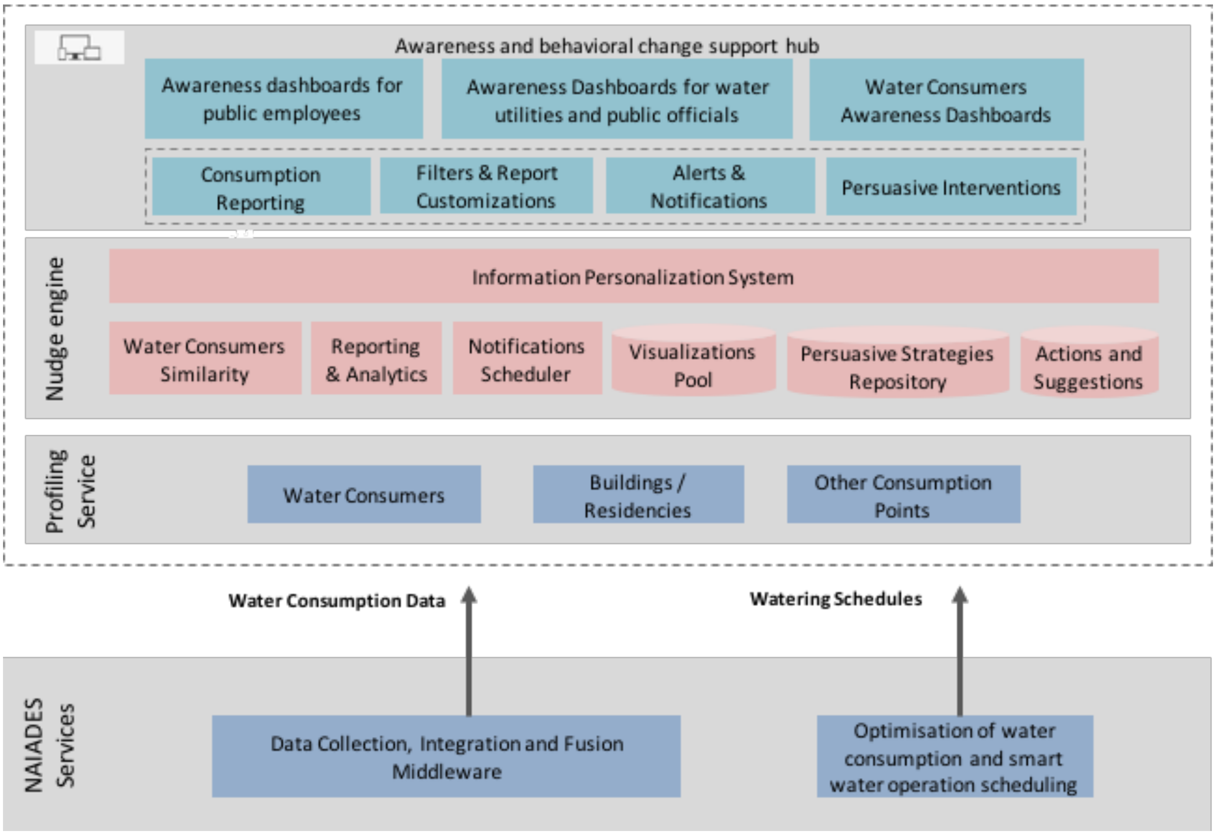

Figure 23: The Naiades Conceptual Framework for Water Consumption Awareness and Behavioural Change Support.

In the bottom layer shown in Figure 23, the Profiling Service describes water consumers, such as buildings and watering points (e.g. fountains) in the Naiades platform. Related information is captured for public buildings and consumption points such as schools, sport facilities, gardens, with characteristics such as location, type, size, consumption type, number of students, etc. and water end users in public buildings. The characteristics of the consumption points include:

- Type of consumption point such as public buildings, schools, sport facilities, gardens
- Location
- Size
- Historical water consumption
- Frequency and type of measurements (automated or manual)

Specific information is captured for the case of school's interventions, including: school class size, school hours and socioeconomic information of the area, the existence of garden, pool and other water consuming facilities.

The nudge engine layer provides functionalities that enable filtering and selecting appropriate information to be displayed to end-users aiming to raise water consumption awareness and nudge them towards efficient water usage.

- The Reporting and Analytics module handles water consumption data stored in related repositories and serves these data for the generation of reports in different time scales. Moreover, it performs data normalizations where needed, for better data understanding.
- The Water Consumers Similarity module generates a similarity score between the different consumption points stored in the database. The similarity score should be based on the characteristics of the consumption point and historical consumption measurements.
- The Notifications Scheduler is responsible for delivering notifications (such as watering actions) at proper times while considering contextual parameters such as the time of day and past consumption trends. The goal is to carefully select the timing of the notifications in order to be noticed and considered by the end-users.
- The Visualizations Pool is a repository of smart visualizations that can be used to visualize water consumption. Such visualizations may include different kinds of graphs (e.g. time-series, bar charts, pie charts etc.) as well as playful designs that communicate water consumption in different ways, such as a tree that grows more when the user conserved water.
- The behavioural change support strategies repository provides the details for implementing different strategies. In Naiades we consider the most relevant to be self-monitoring and feedback, social comparison, rewards and suggestion for implementing public awareness and behavioural strategies within water management.
- The repository of Actions and Suggestions contains informative messages and tips which can be displayed to end-users and nudge them towards actions for sustainable water use.
- The information personalization system consists of tailoring the behavioural change interventions, suggestions, alerts and reports, to accommodate specific groups or segments of individuals (employees, consumers, schools, etc.).

Note that the nudge engine is being developed in T6.3.

The awareness and behavioural change support hub includes the user facing presentation layer and functionalities that enable water consumption awareness and assist water consumers in their daily routines towards behavioural changes for efficient water usage.

More specifically, the awareness and behavioural change support hub consists of three dashboards: the awareness dashboard for water companies and city officials, the water consumers' awareness dashboard and the awareness dashboards for public employees. The awareness dashboard for water companies and city officials is addressed to stakeholders who want to make sense of water consumption data, such as Alicante. The water consumers' awareness dashboard is addressed to water consumers. In the Naides project these are students and school teachers in Alicante. The awareness dashboard for public employees is addressed to city workers responsible for irrigation of public spaces, such as the Carouge employees. The awareness and behavioural change support hub facilitates water end-users to know how much water is consumed, to get recommendations of action plans for water conservation along with an estimation of their impact and to be nudged towards water conservation-related behavioural change interventions provided by the nudge engine.

The dashboards integrate the following functionalities:

- Consumption reporting. Different types of reports should be provided, including reporting of consumption by time, reporting of consumption by point type and comparisons of different periods and consumption points.
- Filtering and report customizations refer to functionalities that allow users to select subsets of data to be reported and generate customized reports based on the selected data.
- The Alerts and Notifications functionality is used to display in the user interface alerts, tips and other notifications generated by the notifications' scheduler. Placeholders or notification pop-ups should be created in the dashboards to present the relevant data.
- The behavioural change interventions refer to specific views in the dashboards that instantiate behavioural change strategies. These include consumption feedback and self-monitoring views, consumption rankings that allow social comparisons and related discussion forums that enable communication among consumers.

5 Conclusions and Next Steps

This deliverable described the work performed within T6.1 of the project and provides the basis for the NAIADES awareness and behavioural change support services. The deliverable focused on a systematic analysis of existing approaches that implement public awareness through dashboard technologies. Then it provided a thorough analysis and review of behavioural change support systems and approaches for resource management and specifically within the water conservation domain. The analysis has focused on theories of awareness and behavioural change, as well as on the implementation aspects, the effectiveness and acceptance of related approaches and systems. The aim of the analysis and review was to identify the most suitable elements to be further extended, developed and enhanced in NAIADES, in order to address the requirements of the pilot cases. These elements are captured in the definition of the NAIADES framework for water consumption awareness and behavioural change support. The framework synthesizes awareness and behavioural change support services for different types of users, including water consumers and employees of water companies / public administrations) which leverage the data and AI services residing in the NAIADES intelligence framework.

In terms of next steps, the Naiades services for awareness and behavioural change support are being developed within Tasks 6.2, T6.3 and T6.4. The first prototypes of the services are already available and are being refined in an agile and iterative manner in close collaboration with the project pilots. The results of this development work will be reported in deliverables D6.2 (due in M18) and D6.3 (due in M30).

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