

Smart Meters and In-Home Displays to Encourage Water Conservation through Behavioural Change

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Abstract—Urbanization, population growth, climate change and the current increase in water demand have made the adoption of innovative demand management strategies crucial to the water industry. Water conservation in urban areas has to be improved by encouraging consumers to adopt more sustainable habits and behaviours. This includes informing and educating them about their households' water consumption and advising them about ways to achieve significant savings on a daily basis. This paper presents a study conducted in the context of the European FP7 WISDOM Project. By integrating innovative Information and Communication Technologies (ICT) frameworks, this project aims at achieving a change in water savings. More specifically, behavioural change will be attempted by implementing smart meters and in-home displays in a trial group of selected households within Cardiff (UK). Using this device, consumers will be able to receive feedback and information about their consumption but will also have the opportunity to compare their consumption to the consumption of other consumers and similar households. Following an initial survey, it appeared necessary to implement these in-home displays in a way that matches consumer's motivations to save water. The results demonstrated the importance of various factors influencing people's daily water consumption. Both the relevant literature on the subject and the results of our survey therefore led us to include within the in-home device a variety of elements. It first appeared crucial to make consumers aware of the economic aspect of water conservation and especially of the significant financial savings that can be achieved by reducing their household's water consumption on the long term. Likewise, reminding participants of the impact of their consumption on the environment by making them more aware of water scarcity issues around the world will help increasing their motivation to save water. Additionally, peer pressure and social comparisons with neighbours and other consumers, accentuated by the use of online social networks such as Facebook or Twitter, 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. Finally, including a virtual water game within the display will help the whole household, children and adults, to achieve significant reductions by providing them with simple tips and advice to save water on a daily basis. Moreover, by setting daily and weekly goals for them to reach, the game will expectantly generate cooperation between family members. Members of each household will indeed be encouraged to work together to reduce their water consumption within different rooms of the house, such as the bathroom, the kitchen, or the toilets. Overall, this study will allow us to understand the elements that attract consumers the most and the features that are most commonly used by the participants. In this

way, we intend to determine the main factors influencing water consumption in order to identify the measures that will most encourage water conservation in both the long and short term.

Keywords—Behavioural change, ICT technologies, water consumption, water conservation.

I. INTRODUCTION

CURRENT global issues such as population growth, urbanization and climate change have made it critical to encourage the development of more sustainable ways of life worldwide [1]–[3]. Engaging people in new habits and environmentally responsible behaviours has now become crucial to tackle increasing water scarcity [4]–[6]. In particular, there is the necessity to encourage a change in the way consumers use water resources in urban areas [3], [7]. This can be achieved by using new technologies to boost the adoption by water companies of adequate water demand management strategies. Communication with their consumers should be improved in order to inform, guide and educate them about water conservation. Studies conducted in Australia have demonstrated that sending frequent feedback and encouragement to consumers can lead to a reduction in their water use [8], [9]. Concerning the way this feedback is presented to the household, in-home displays appeared to be the most appropriate choice and were likely to be preferred by consumers [8], [9].

This paper presents the Demand Management Aspects of the European FP7 WISDOM Project which aims at achieving a change in water and energy savings by developing and integrating innovative Information and Communication Technologies [10]. As part of the ICT4Water cluster, this research project co-operates with other studies conducted in the context of the SmartH20 project, the WatERP project, the WATERNOMICS project and the ISS-EWATUS project [11]–[18]. Achieving behavioural changes in consumers' water use are two key aspects of the WISDOM project. Two key goals of achieving a reduction in peak demand and in consumers' total water use will be achieved by educating and informing consumers. The WISDOM project will test whether targeted behavioural changes, adapted to the consumers' social and cultural characteristics, have a greater impact on their water consumption habits. To achieve positive results, near real-time data will be used to send feedback to consumers on an in-home display. This will be implemented in a trial group of households. The WISDOM Project will help in understanding the impact of water-saving technologies and of economic, financial, environmental and social features, including water gaming, on consumers' habits and behaviours.

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More generally, it will determine if increasing consumers' awareness of their own consumption can motivate them to reduce their water usage.

The remainder of this paper is structured as follows: Section II outlines the background of our research by referring to the relevant literature on the subject. More specifically, it mentions the factors found to influence water consumption on a daily basis; Section III describes the overall methodology of our study and the key goals we aim to reach; Section IV presents the early results for our existing consumer engagement which improve our understanding of consumer's beliefs and perceptions of their water usage, while Section V outlines the future work to be undertaken in accordance to the results of this initial survey. Finally, Section VI concludes the paper.

II. BACKGROUND

There are a variety of factors that have an important influence on water consumption. Our research has identified four different types of influences that have an impact on the way people consume water: (a) financial savings, (b) environmental impact, (c) social competition and (d) gaming [19]–[23].

It has been demonstrated that consumers have an interest in observing their water consumption in monetary units [24]. People tend to look more at the price they have to pay rather than at the amount of water consumed [25]. Thus, showing costs related to water consumption can lead consumers interested in saving money to reduce their consumption [19]. However, a major drawback of displaying water costs could be the switch from an environmental focal point to a financial one for consumers [19]. To prevent this, it is important to emphasize on the fact that an in-home display can help achieving significant water savings and improve the state of the environment [9]. The impact of economic and financial measures on water consumption is diverse. On the one hand, according to some authors, the low cost of water makes financial incentives ineffective [24], [26]. Moreover, even in the energy domain, in which prices are usually higher, changes driven by financial concerns tend to only be short term [27]. Financial incentives especially appear to make little lasting impact [28]. On the other hand, pricing is sometimes considered as one of the most effective methods when dealing with water conservation [11]. For Harou et al., in order to increase its efficiency, the implementation of smart meters should be coupled with water pricing policies [11]. Harou et al. propose to reassess the price of water depending on indoor activities that are "essential" and outdoor activities that are "non-essential" [11]. Increasing block tariff or adaptive pricing depending on the time of day or on the seasons are also suggested. Moreover, according to the "Prospect Theory", people are more willing to act to prevent losses than to obtain gains [29], [30]. This is in line with the idea that pricing policies that take the form of financial sanctions usually have more impact on consumption than financial incentives. Overall, individuals that are reluctant to act in a more

sustainable way if the changes targeted require them to spend money [27].

A consumer's beliefs, opinions or convictions are another factor affecting their water consumption. People will engage in water saving measures depending on the viewpoints they have and whether or not they can perceive that their actions will efficiently help solve environmental problems [1]. More water savings are achieved when a person's motivation to save water increases. This is why, in time of scarcity and drought, people generally put more effort into saving water [31]. Additionally, people living in water-scarce areas tend to be more involved in water saving actions [32]. More generally, Wolters argues that people committed to help finding environmental solutions are more involved in water conservation [1].

When it comes to changing a consumer's behaviours, previous studies have shown that methods focused on economic and financial measures were not as effective as those based on social interaction [8], [9]. Likewise, social normative messages seem to have a larger impact than messages concerning environmental or financial benefits [8], [9]. Although people generally consider economic and environmental messages as effective ways to increase their environmental interest, social reputational aspects of conservation tend to influence more largely the adoption of sustainable behaviours [21], [29]. Altruism and "prosocial" actions that can be demonstrated through conservation behaviours that positively influence social reputation [21]. Individuals performing "prosocial" actions tend to be perceived as friendlier and trustworthy [21]. This highlights the importance of social networks such as Facebook or Twitter in shaping behaviours. Being confronted by the positive attitudes of their peers can increase individuals' involvement in water conservation [20], [33]. They are indeed more likely to engage in a behaviour if they know that their peers expect them to act in a certain way [34], [35]. For these reasons, social comparisons can be used to increase consumers' motivation to save water [9]. The increasing social presence of individuals on social media and online communities therefore tends to develop a sense of competition but can also encourage collaboration and cooperation between consumers [36]. Additionally, cooperation promotes social consensus and this improves consumers' social involvement in resource conservation issues [36]. Likewise, social norms seem to influence consumers' water use on both long term and short term as they encourage individuals to think that changes in water consumption are "the right thing to do" [35]. Social strategies can also involve setting goals and developing a sense of community, which usually induce a real change in consumers' behaviour [8].

Another popular strategy for resource saving that has been examined in literature is gamification. Gamification can be described as "an informal umbrella term for the use of video games elements to improve user experience and user engagement in non-gaming systems and applications." [37]. Persuasive technologies, including games, can help shape and influence consumers' behaviours [37], [38]. Some authors

have pointed out the natural persuasive power of computer games [38], [39]. However, the use of attractive user interfaces is an essential aspect of the persuasive impact of these games [39]. This is a crucial fact to take into account when designing these games. Simulation games recreating real life can lead people to adopt targeted behaviours and carry out specific tasks [39]. Pervasive games on the contrary require the player to perform activities in their real life [40]. They can increase the motivation and knowledge of participants especially regarding conservation habits. Commonly, within these games, players have to accomplish, within their households, tasks that stimulate the development of new behavioural changes [40]. Furthermore, the desire to win a game or to perform well is influenced by peer pressure and social demand [40]. Thus, water games including a competitive and a social aspect will tend to increase players' motivation to conserve water. Games based on a nurturing interaction with virtual pets often contribute to the player developing an emotional attachment to the pet. When using virtual animals that are directly affected by climate change, such as polar bears, this attachment was proved to encourage players to commit to environmentally responsible actions and to fulfil this commitment. It also increases their environmental concern and stimulates them to pay particular attention to the environment [41].

III. METHODOLOGY

The study described in this paper aims at (a) improving households' awareness regarding their water consumption and at (b) inducing a change in consumers' behaviour by encouraging the adoption of sustainable habits through the use of Information and Communication Technologies.

The first step in our study is to perform an initial engagement with consumers in our target area. The aim of this is to gather information about consumer's perceptions of their water usage, their level of preparedness for change, their motivation to reduce their consumption and their general level of awareness of water related issues. Following this initial engagement, interested parties and households (gathered from the responses to the previous engagement) will be identified and group of households will be selected to have smart meters installed within their home. Further consultations will be carried out with these households in order to obtain more detailed information about (a) the households' perceived importance of social interaction and social networks, (b) the households' current use of new technologies, (c) detailed home characteristics and (d) the extent of the households' interest in water conservation. Smart meters will then be installed in the selected households. The water consumption of each household will begin to be measured to obtain information about their average level of water consumption.

A subset of the first group of households will then form a second trial group and will have access to an in-home display to help them save water. The remainder of the households will form the control sample. Following this selection, a workshop will be held for those households selected for an in-home display in order to (a) provide an opportunity to consult

directly with participants, (b) allow training on the in-home device and (c) function as a UI workshop to improve the existing in-home device.

The in-home display will then be implemented in the participants' houses. This display allows consumers to access information about their household's consumption. It includes a breakdown of the consumers' water usage per device and per room. The use of this device will allow participants to receive frequent normative feedback about their water use, to take part in different online activities and to compete with other households in order to reduce their consumption. In order to target the most appropriate behavioural change approaches to water consumers, the device will display information in relation to the four major factors found to influence water consumption: (a) the environmental impact, (b) financial savings, (c) social competition and (d) water-gaming. The user interface of the device will be instrumented to record the ways in which consumers interact with the device.

Through the use of smart meters, the consumption of each household will be metered continuously during and after the implementation of the display. The in-home device will then be removed from the house but the household's water consumption will continue to be metered. This will help determining whether or not the behavioural changes achieved can last over a longer term. The consumer's perceptions of their water usage and of water related issues and their motivation to reduce their consumption will be evaluated in follow-up surveys to determine if the implementation of the device has achieved any changes in consumer attitudes. The results of this live trial will help determining if increasing consumers' awareness regarding water use can lead to a reduction in their consumption and in peak demand. Finally, by analysing the data gathered, the potential benefits for consumers and water suppliers resulting from the implementation of such system will be assessed.

IV. INITIAL USER ENGAGEMENT

As was mentioned above, the objective of this initial survey was to obtain information about consumers' general views on water consumption. To achieve this, a survey, suitable for larger samples of population, was carried out in Cardiff in 2014 to obtain information about consumers' general views on water consumption [26], [42]. A first questionnaire was sent to 3000 households within Cardiff as part of the "Ask Cardiff" survey. Respondents answering to this short questionnaire were asked if they wanted to take part in another questionnaire in the context of the WISDOM Project. Those who agreed to be consulted again received an email containing a web link to a more detailed online questionnaire. The results presented in this paper are considered as the first part of a longitudinal study that will last three years.

One hundred and ninety-eight Cardiff inhabitants responded to the more detailed questionnaire. This larger questionnaire contained a set of 40 questions divided into five main sections: Personal information, home characteristics, water usage, water supply and interaction with water companies and daily/weekly consumption. The first section was focused on the

participants' personal information with questions related to their age, gender, the area they live in, their level of education or their employment status. The second section aimed at gathering information about the type of house and property as well as the number of adults and children living within the household. It also determined the water-saving devices and water-saving habits that participants already have. The next part was dedicated to the respondents' beliefs and convictions regarding their water usage with questions like "Do you consider water conservation as an important issue?". Another section was focused on the interaction with water companies and finally the last part of the questionnaire contained questions related to daily or weekly water-related activities such as "How many baths are taken per day within your house?" or "On what daily activities do you use the most water?".

Our respondents appeared to have some common characteristics and most of them can be described as middle aged, educated and employed persons. The proportion of men and women was relatively similar, with just a slight majority of men (56.6%). Respondents were mainly over 50 years old (55.56%) or between 31 and 50 years old (40.91%). Most of them had a high level of education as a third had a postgraduate qualification (33.3%) and a bit less had a university degree (26.3%). Concerning their employment status, half of the participants were employed or self-employed (62.6%) and about a third were retired (31.3%). Only a minority of them were unemployed or studying (4%).

The results obtained from the questionnaire has given us indications about the environmental interest of our respondents but also attested the financial limit of their motivation to save water. On the one hand, results demonstrated that most of our respondents seemed to have an initial interest in water conservation. It appeared that the large majority of them consider water conservation as an important issue (92.4%) and that most of them feel that they could do more to save water (67.2%). When asked about the reasons leading them to conserve water, more than a third answered "helping the environment" (36.07%) along with "reducing wastage" (31.74%) and "reducing bills" (29.91%). Moreover, the respondents overall seemed inclined to change some of their habits to consume water in a more sustainable way (86.87%). Basic water-saving habits already seem to be part of most of the respondents' daily life as a majority of them make sure that there are no taps left running within the household (83.3%) or that they fully load the dish or clothes washers before using them (80.3%). The use of showers also seems to be preferred over baths since most of the respondents reported that no baths were taken within their household on a daily basis (77.3%). Moreover, more than half of the participants reported having short showers (57.6%). This was verified by the fact that the average duration of a shower appears to be approximately less than five minutes (24.7%) or five minutes (27.8%) for a majority of respondents. This initial interest could be explained by the fact that respondents to this survey were volunteers as they had agreed to be consulted again. However, despite this environmental awareness, economic and

utilitarian beliefs appeared to limit the respondents' motivation to consume water in a sustainable way. This seemed to prevent them from investing in water-saving devices. When asked if they would be willing to buy and install water saving devices within their houses, slightly more than a third answered positively (39.39%). Nevertheless, when asked if they would use water-saving devices if they were provided for them, almost all the participants agreed (93.43%). To the question "would you be willing to install a device to help you save water?" about a third of the participants responded they would install it (35.4%) but the majority answered that they would do it only if the device was free (60.6%). This shows that people are indeed motivated to introduce water savings habits within their households but only to a certain extent. This is coherent with the findings of Randolph and Troy [20] that came to the conclusions that consumers are often willing to use water saving devices but do not go as far as buying them. These results are also in line with the Rational Choice Theory that states that individuals anticipate the outcomes of different courses of action and choose the one that will "give them the greatest satisfaction" [43]. Before deciding to invest in new devices, consumers will therefore tend to assess the costs and the benefits of each choice to determine which decision will be the most beneficial to them [44]. In the context of our study, we can assume that consumers do not consider buying water-saving devices as profitable enough for them. That leads us to think that, despite having an interest in water conservation, consumers' utilitarian and economic beliefs take over environmental convictions.

In terms of water pricing, a previous study conducted by Randolph and Troy found that some people are willing to pay more for water, but that they are usually only inclined to pay a maximum of 10% more [25]. Participants of our study mainly think that water pricing should depend on the amount of water people use (74.2%) or that their water bill should vary depending on their consumption (80.8%). However, the responses given demonstrated that they do not always know the amount of water they use. In spite of a large number of respondents reporting being aware of the quantity of water used within their households (49.5%), half of them did not seem to have this information or were not sure about it (50.5%). Participants indeed appear to check the amount of water they use at different frequencies. Only a few checked daily (3.5%), weekly (1%) or monthly (7.6%) while most of them affirmed checking quarterly (32.3%), annually (48%) with a minority reporting that they never checked (7.6%). Likewise, a quarter of our respondents stated that they were not sure of the current price of their monthly water use (26.50%) and, among them, a majority agreed to say that they would be more careful of their usage if they were aware of its costs (74.6%). This is questionable as the cost of water can be perceived as negligible cost for some water consumers and may not motivate them enough to induce a reduction of their consumption [22]. Displaying costs related to consumers' consumption is delicate as it can lead them to focus on the financial aspect of their water usage. However, showing them

the savings they could achieve by reducing their consumption in the long term, for a year for instance, could help them maintaining water-saving habits [45]. Gathering the yearly savings could also allow the in-home device to display more significant financial savings and trick consumers into thinking that they can save a larger amount of money.

V. FUTURE WORK

The results of the initial survey have provided us with information about the main reasons driving participants to save water. It was demonstrated that people's intention to conserve water is led by a desire to help the environment but is also limited by economic and utilitarian beliefs. Thus, it appears necessary to combine various strategies in order to have more impact on participants' water consumption.

Future work includes further consultations to be carried out with volunteers, the objectives of which are to gather more information about their water use and to build an understanding of the household's consumption. However, as the results of the initial survey demonstrated it, it is difficult to determine the level of influence of economic and environmental beliefs on people's water use. Most of the participants indeed considered water conservation as an important issue (92.4%) and perceived it as being "very important" or "important" in their daily life (71.7%). They also seemed to be willing to use water-saving devices (93.43%). Yet, when asked about investing in those devices, less than half of them answered positively (39.39%). Therefore, after being consulted a second time, households will be scored, by attributing a certain amount of points to each answer given by the respondents, on their true interests in water conservation. That way, without being aware of it, participants will get a final score that will give us an indication of the degree of their environmental involvement.

As described previously, a subset of the households that will have smart meters installed will be part of a further trial group and will have access to an in-home display whereas the remainder will work as a control group, where their water use is monitored but no additional engagement takes place. In order to obtain significant and interesting results, a single trial group, gathering volunteers, will be created. This group will experience different features included in the in-home display instead of being divided into smaller groups and testing only one aspect of the device. [19], [23], [24]. Those having access to the in-home display will receive information about their consumption. Nevertheless, in order to obtain behavioural changes, it becomes crucial to use smart meters in accordance to a specific social strategy and to provide information given in line with the consumers' needs and behaviours [8], [22]. As our survey demonstrated, although participants seem to have a significant interest in water conservation, their motivation to act in a more sustainable way is limited by economic beliefs. The implementation of the device will allow us to get information about the influence of different factors on domestic water usage in order to identify the most appropriate measures to obtain significant reduction in water consumption. Likewise, by testing different types of features at once, we

will be able to determine those that are the most used and the most appealing to consumers of a same trial group.

The display will include four different aspects that can influence water consumption;

- It will remind consumers of the economic aspects of water saving and especially of the potential financial savings that could be achieved in spite of the low price of this resource in the United-Kingdom. Graphs and bar charts will show them the evolution of their consumption and the money saved proportionally to the amount of water conserved. As it is crucial to ease consumers' use of the device, implementing a system of notifications, such as sound alarms to inform them of important feedback, appears useful [9], [46], [47].
- It will inform participants about the environmental impact of their consumption to increase or maintain their interest in water conservation. The display will present them with the bigger picture of the global challenge that is water scarcity. Pictures of drought or signs of environmental distress will be shown to get their attention and highlight the importance of water conservation [35].
- Participants will be able to compare their past consumption to their current consumption. A graph displaying the evolution of the household's consumption in both the long and short term will allow them to observe the consequences of their conservative efforts. Additionally, the display will give consumers access to a breakdown of the households' consumption by appliances to determine the devices that require the more water on a daily basis. Social comparisons will also be included as participants will have the opportunity to compare their average consumption to the consumption of other participants and similar households. This will install a sense of competition that can encourage them to reduce their consumption [9], [19], [23].
- The display will give participants access to a virtual game taking the form of an aquarium. Previous studies have shown the benefits of gaming in shaping and influencing environmentally responsible behaviours. Pervasive technologies can indeed have a natural persuasive power encouraging sustainable behaviours and can increase consumers' knowledge and motivation especially by incorporating competitive and social elements [38], [45]. Moreover, creating virtual pets increases the involvement of participants in the game as it usually leads to them developing an emotional attachment to the animal [41]. The aim of the game will be to take care of an aquarium by making sure the level of water remains high, by nurturing the fish or by adding decoration items. To do so, participants will need to achieve different objectives by accomplishing water-saving tasks within the household in order to gain points. They will be ranked according to the points gained and will be able to share their results on social networks such as Facebook or Twitter.

The in-home device will be removed from the house after a few months. In order to determine whether or not they have adopted more sustainable habits regarding their water

consumption, the consumer's perceptions of their water usage, their views on water related issues as well as their motivation to reduce their consumption will be assessed in follow-up surveys. Water use will be continually monitored to assess fall off from the behavioural change and further follow-up surveys will determine whether or not they have adopted long-lasting and more sustainable habits regarding their water consumption.

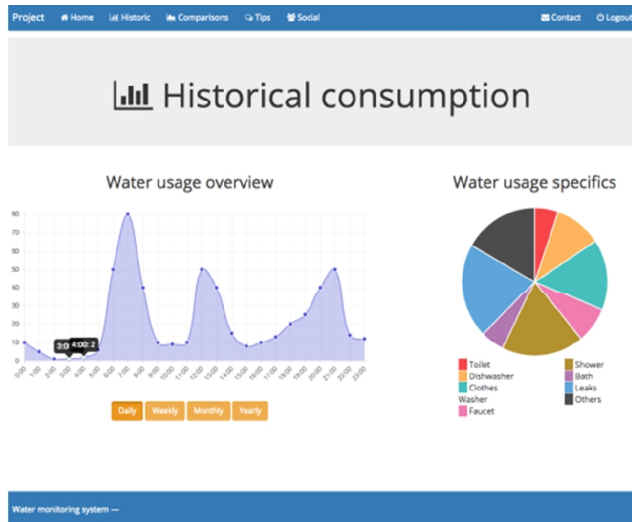


Fig. 1 Early screenshot of the display

VI. CONCLUSION

By improving the way water is consumed in urban areas, new technologies can be used as a solution to current water-related issues. Educating and informing people about their consumption becomes a priority. It is equally important to guide consumers towards reducing their water usage. This paper has described our study, which aims at determining how to obtain water savings and peak demand changes by taking into account the influence of social and cultural factors. This paper has reported the results of our first step; carrying out an initial survey. This has demonstrated that, overall, people are interested in water conservation and in helping the environment. They are also willing to change some of their habits and to implement and use water-saving devices within their households. However, it appeared that their motivation to achieve water savings can sometimes be limited by economic and utilitarian beliefs. Future work, including the implementation of smart meters and in-home displays within trial households, will help us assess the concrete impact of (a) financial savings, (b) environmentally friendly actions, (c) social competition and (d) water games on people's consumption. Based on these findings, appropriate behavioural strategies will be identified and will participate in efficiently changing the way people consume water. Determining the environmental, financial, and social factors that most influence water consumption will make it easier to implement adequate measures that can encourage conservation.

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