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Framework for technical evaluation of decision support systems based on water smart metering: the iWIDGET case

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Abstract

Water smart metering enables the measurement and reporting of water consumption at sub-daily intervals. However, assuming that increased availability of consumption information will necessarily result in changed behaviour is simplistic. The main scientific challenges for iWIDGET project are the management and extraction of useful information from vast amounts of high-resolution consumption data, the development of customized information to influence awareness and support behavioral change, and the integration of iWIDGET concepts into a set of decision-support tools for water utilities and consumers. In this paper, it is described the evaluation general framework, the iWIDGET system's technical evaluation system and stakeholders involved.

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1. Introduction

Similarly to the energy sector, the water sector is facing new challenges in the sustainable management of water systems. Four key drivers are influencing the entire sector and promoting business transformation: increase in

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infrastructure costs; regulations and compliance; consumer expectation changes and new technologies [1]. An efficient communication with the consumers is essential to improve public understanding about drinking water availability and real service costs, to achieve sustainability in this sector. Additionally, consumers need to understand better their water consumption behaviors to improve control over its use. Water smart metering enables the measurement and reporting of water consumption at sub-daily intervals. However, assuming that increased availability of consumption information will necessarily result in changed behaviors is simplistic [2]. It is necessary to support decision making by consumers and utilities regarding the use of water in the urban context. If this issue is not addressed, the benefits associated with the use of data from smart meters to improve the management of urban water systems can be distorted.

The Water Framework Directive and the European Union carbon emission reduction target by 2020 set out the strategic context for the EU FP7 iWIDGET ((Improved Water efficiency through ICT for integrated supply-Demand side manaGEmenT)) project (http://www.i-widget.eu/) deployment. The goal of this project is to provide a web-based platform – the iWIDGET system, targeting both the household and water utilities end-users, capable of offering near real-time (at sub-daily intervals) information about water consumption (and energy use, in specific conditions) and a set decision-support tools aimed to promote water and related energy efficient use behaviors.

The main scientific challenges of the iWIDGET system are the management and extraction of useful information from vast amounts of high-resolution consumption data, the development of customized interventions to influence behavioral change, and the integration of iWIDGET concepts into a set of decision-support tools for water utilities and consumers, applicable in differing local conditions. This project is integrated in the "ICT for Water Management" cluster (http://ict4water.eu/), sharing the common goal of promoting an increased efficiency in water management and enabling greater cooperation among water regulators, operators and users by deploying solutions provided by ICT.

The iWIDGET system collects data from smart water meters, analyze it, and use a variety of techniques – usage graphs, alerts and usage advices – to encourage water conservation among householders and water utilities. This paper offers an in-depth evaluation of the system. It presents the iWIDGET system's technical evaluation framework, the evaluation system (criteria and metrics) and stakeholders involved, along with the design evaluation adapted to three case studies.

2. Defining the technical evaluation framework

2.1. Contextualization of iWIDGET system

Boyle *et al*. (2013) [2] defined "intelligent metering system" as an assortment of components and procedures configured for the continuous monitoring and evaluation of water use, according to four processes (Figure 1 (A)):

- Measurement - focus on network flow meters, household water meters to collect water consumption data and main technical requirements that ensure that appropriate data is measured.
- Data transfer - focus on the means by which data is transferred from meters to utilities, customers and back, and main technical requirements that ensure that appropriate data is collected and stored.
- Processing and analysis – involves the establishment of a robust architecture and the definition of a set of algorithms and software implementation to process and analyse large volumes of data.
- Feedback of water use data – focus on the methods by which data is provided to customers for interpretation.

The iWIDGET system is primarily focused on the last two processes of the intelligent metering systems: "processing and analysis" and "feedback of water use data", as illustrated in Figure 1 (B).

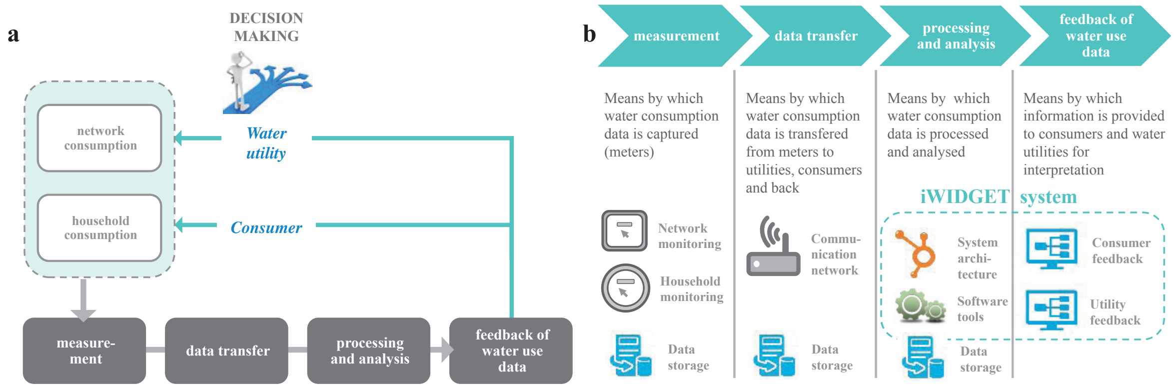

Figure 1. (a) Intelligent water metering system (adapted from [2]; (b) Integration of iWIDGET system in the intelligent water metering system process.

The iWIDGET system is developed with a distributed and open architecture that allows the analysis on demand of sub-daily measurements of water consumption. Components in this architecture include a centralized server and client systems for data acquisition, analysis, and visualization. The centralized server provides a set of functions which client applications use to retrieve information, and optionally, to return information for future use. The current development deployment of the iWIDGET system provides user interfaces through an on-line portal platform, with two alternatives: household level and water utility level. More information about the iWIDGET architecture, system design, storage mechanism, and communication techniques can be found in [3].

2.2. Objectives of technical evaluation

Evaluation is a core component of the efforts done in the iWIDGET project to improve the quality of evidence upon the impact of the iWIDGET system in decisions made by households and water utilities technicians regarding the use and management of water in the urban context. The developed framework outlines the requirements for evaluation planning and clarifies the articulation with the on-line testing of the iWIDGET system.

To guide consistency in evaluation, it is important the framework emphasizes a strategic approach and outlines iWIDGET project and system features that should be considered when prioritizing evaluation efforts. In parallel, it is essential to include in the framework key principles of good evaluation practice (e.g., by using the experience on evaluation the implementation of energy saving programs) in a way that may be applied in different types of programs or research projects. Finally, the framework should facilitate the explanation of findings generated by evaluation and their use for learning and better decision making.

The technical evaluation of the iWIDGET system takes in consideration different viewpoints and has as a key purpose the assessment of its potential benefits to consumers and water utilities. The overall purpose is to inform about the potential of the iWIDGET system implementation in a real case basis, by collecting credible insights about its functionalities. The current technical evaluation has two primary objectives, as shown in Figure 2.

A. To determine the value proposition associated with the iWIDGET system. "Value" is defined as capabilities, options, assets or knowledge not available prior to the project that can potentially deliver benefits [4]. The object of this particular evaluation will be iWIDGET's capabilities regarding data processing and analysis and feedback information production about water consumption data.
B. To understand the behavior change experienced by consumers and decision support systems adopted by the water utilities technicians as a consequence of the interaction with iWIDGET on-line platform.

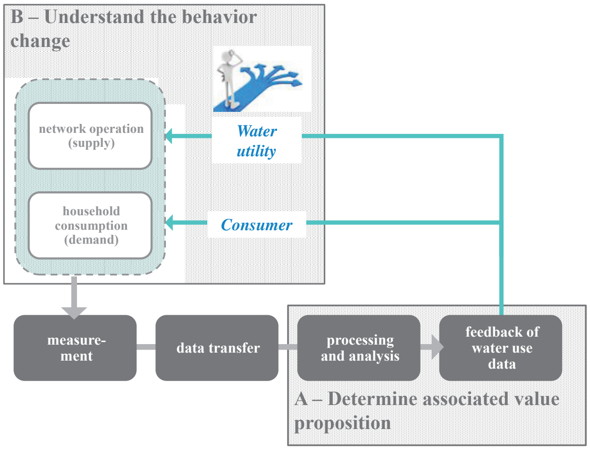

Figure 2. Objectives of the technical evaluation

2.3. Benefits associated with the iWIDGET system

The exploitation of water consumption data enhanced by the iWIDGET system is supposed to create significant and specific value to consumers and water utilities. The developed technical evaluation system aims at identifying and determining this value creation to both target audiences. From the society perspective, evaluation also address if the developed on-line platform the potential to reach project´s goals in areas such as the efficient use of water and energy, consumer adoption rate, demand-side reshaping, user empowerment and user awareness.

It is expected that the implementation of iWIDGET system will create value on both sides of the water smart meters (*i.e.*, household – water use efficiency, and water utility – network operation). Potential benefits potentially enhanced by the use of the iWIDGET system can be related to economic aspects, to environment, to water distribution system operability and to consumer satisfaction. It is assumed that iWIDGET high-level use cases can express the value creation enabled by the use of water smart metering data (Table 1). More information about the iWIDGET use cases can be found in [5].

Table 1. Potential benefits and related value propositions represented by the iWIDGET high-level use cases

Domains	iWIDGET high-level use cases	Benefits			
		Economic	Environ-mental	Distribution system operability	Consumer satisfaction
Consumer	C_UC01: Obtain water consumption data			X	
	C_UC02: Obtain energy data associated with water consumption			X	
	C_UC03: Understand water consumption		X	X	
	C_UC04: Understand energy associated with water consumption		X		
	C_UC05: Get assistance to increase water use efficiency	X	X		X
	C_UC06: Control water use	X	X		
Water utility	WU_UC01: Obtain water consumption & related energy consumption data			X	
	WU_UC02 - Understand water consumption		X	X	
	WU_UC03 - Understand energy associated with water consumption		X	X	
	WU_UC04 - Get support to increase operational efficiency	X			
	WU_UC05 - Get support to increase the quality of service		X		X
	WU_UC06 - Get support to improve consumer efficient water use		X		X
	WU_UC07 - Get support for system planning and design	X		X	

3. The iWIDGET technical evaluation system

The technical evaluation of the iWIDGET system's capabilities has as main focus the value creation possibilities which are deeply related with to the iWIDGET high-level use cases. The evaluation of these is achieved by using a coherent system composed of evaluation criteria and metrics, and considering different evaluation perspectives. First, main stakeholder groups (*i.e.*, consumers, water utilities, software developers, infrastructure providers, vendors/service providers) were identified, followed by the clarification of roles and responsibilities using the responsibility assignment matrix (RAM) or the RACI matrix [6].

Software-intensive computer systems, such as the iWIDGET system, have several functional and non-functional requirements. Comprehensive specification and evaluation of the quality of the iWIDGET system is thus a key factor in ensuring value to stakeholders. Based on [7] in the definition of some criteria, Table 2 presents the list of evaluation criteria and related metrics used in the evaluation of iWIDGET system, considering the product quality model (*i.e.*, a model that relates to static properties of software and dynamic properties of the computer system). The Part A of the evaluation system is strongly related with the project efforts in testing the iWIDGET system, namely with functional and non-functional on-line tests and non-functional on-line test. It also considers the input of case studies' participants.

Table 2. List of criteria and measures: evaluation system – Part A

Criteria group	**Sub-criteria**	**Metric / Measure**	**Evaluation method**	**Target audience**	
				Project team	**Case studies**
Functional suitability	Functional completeness	Functional implementation completeness	Functional on-line tests	X	
	Functional correctness	Functional implementation correctness	Functional on-line tests	X	
Performance efficiency	Time behaviour	Response time perception	On-line survey		X
		Response time with multiple users	Non-functional on-line tests	X	
		Response time variable data volume	Non-functional on-line tests	X	
Compatibility	Interoperability	Interoperability with different browsers	Non-functional on-line tests	X	
		Interoperability with mobile devices	Non-functional on-line tests	X	
Usability	Data visualization	Visualization perception	On-line survey		X
	Operability	User operation capability	Non-functional on-line tests + Usability enquiries	X	
		Operability perception	On-line survey		X
	Appropriateness recognisability	Attractive interaction	Usability enquiries		
		Appropriateness recognisability perception	On-line survey		X
	Learnability	Completeness of user documentation	User documentation Non-functional on-line tests Usability enquiries	X	
			On-line survey		X
		Learnability perception	On-line survey		X
Reliability	Availability	System web availability perception	On-line survey		X
Security	Confidentiality	Non-authorized accesses	Non-functional on-line tests	X	
	Integrity	Protection to Injection attacks	Non-functional on-line tests	X	
Portability	Adaptability	Hardware adaptability	Non-functional on-line tests	X	

Table 3 presents the list of evaluation criteria and related metrics used in the evaluation of iWIDGET system, from the perspective of behaviour changing assessment. The Part B of the evaluation system is strongly related with the three case studies. It also aims to integrate the view of society (through a focus group input).

Table 3. List of criteria and measures: evaluation system - Part B.

Criteria group	Sub-criteria	Metric / Measure	Evaluation method: On-line survey	Evaluation method: Focus group	Evaluation method: Objective data	Target audience
Awareness	Knowledge of own water consumption	Knowledge	X			CONSUMERS
	Awareness of the importance of water saving	Water conservation awareness	X			
		Usage of the iWIDGET e-learning platform	X			
					X	
Water saving	Reduction in volume of water consumed	Volume of water consumed			X	
	Reduction in water bills	Water bill	X			
Energy saving (1)	Reduction in energy consumed	kW of energy consumed			X	
	Reduction in energy bills	Energy bill	X			
Satisfaction	Consumer satisfaction	Levels of consumer satisfaction with WU	X			
		Number of billing queries/complaints			X	
	Consumer trust	Levels of consumer trust in their water utility	X			
Usage	Frequency	Frequency of usage of the iWIDGET system			X	
			X			
	Quality	Levels of consumer satisfaction (*e.g.*, usability/utility and data format/type)	X			
			X			
Management	Day-to-day network operations	Improvements on network operations (*e.g.*, pumping and storage optimization)	X			WATER UTILITY
			X			
					X	
	Water and energy balances	Improvements on water and energy balance (*e.g.*, leakage reduction and energy balance)	X			
					X	
Planning	Short and medium term planning	Improvements on short and medium term planning (*e.g.*, procedural information and decision-making)	X			
			X			
	Long term planning	Improvements on long term planning(*e.g.*, procedural information and decision-making)	X			
			X			
Acceptance	Usage	Employees' engagement with iWIDGET system	X			
	Satisfaction	Employees' satisfaction with the iWIDGET system	X			
Uptake	Interest - consumers	Community members' interest in using the iWIDGET system		X		SOCIETY
	Interest – water utilities	Water utilities' purchase of iWIDGET system		X		
Changing demand	Awareness	Level of awareness of importance of water conservation among the wider community		X		
	Water saving	Community members' willingness to conserve water		X		
Diffusion of innovation	Visibility	Degree to which the results of an innovation are visible to potential adopters		X		
	Relative advantage	Degree to which an innovation is perceived as better than similar others		X		
	Compatibility	Degree to which an innovation is perceived as consistent with the needs of the potential adopters		X		
	Trialability	The degree to which an innovation may be experimented with a limited basis		X		
	Problem solver	The desirability of adopting an innovation depends on the problem the innovation promises to solve for the adopter		X		

(1) Energy consumption data only available in the Greek case study and in a sub-sample of the UK and PT case studies.

4. Evaluation design and implementation

To evaluate the impact of iWIDGET system on consumers and water utility stakeholders, the iWIDGET project implement three case studies (in Portugal, in the UK and in Greece) testing, in order to carry out real life, full scale testing of the on-line platform. Each of the three case study sites presents particular characteristics that lead to the necessity of adjusting the evaluation design. This is because of differences in the number of participants in the pilot at each site, differences in recruitment methods, and differences in the metering available at each site. However, this is a strength, rather than a limitation, of the proposed evaluation; that is, each case study evaluation reflects the real constraints of implementing ICT and smart metering technologies in different EU nations.

The Portuguese case study is located in the north of Portugal, in Barcelos. All customers were invited (by letter and telephone) to participate in the project as volunteers, to share their water consumption data with the project and access the iWIDGET portal. In the Portuguese case study, participants were recruited on an opt-in basis from a sample of consumers in three DMAs. The sample size from the household side is 82, with 10 participants in the full trial. This case study also envisaged the assessment of the contribution of telemetry systems to successful water loss control and improved operation at network level.

In the Greek case study, participants were recruited on a voluntary basis from a convenience sample (i.e., people with a connection to NTUA) and have both water and energy meters installed. The sample size for the Greek case study is 20, and 10 participated in the full trial. The sample comprises households with different socio-demographic characteristics and consumption profiles, distributed inside the wider metropolitan area of Athens city.

In the UK case study, participants are recruited on an opt-out basis. For these participants, data will be recorded on a daily basis only via AMR readings. In addition, further participants were recruited on a voluntary basis to have 15-minute interval water loggers installed to act as a small trial on the effects of providing near real-time data.

5. Conclusions

Smart metering will play an important role in supporting these policies, by directly helping consumers to understand their water consumption and make savings, providing utilities with a more integrated demand-supply side management and enabling new services aimed at an increased consumer focused business.

The iWIDGET system explores the data from smart meters as an enabling factor for increased collaboration between consumers and water utilities, allowing a more sustainable approach to supply-demand management (promoting increased network awareness). A combination of evaluation approaches was selected for iWIDGET system technical evaluation, namely system architecture analysis, system quality and user-centered feedback evaluation, as well as a real case concept end-user validation in the three case studies (in Portugal, UK and Greece).

The proposed framework has two primary objectives: to determine the value proposition associated with the iWIDGET system and to understand the behavior change experienced by consumers and decision support systems adopted by the water utilities technicians as a consequence of the interaction with iWIDGET on-line platform. It is based on a coherent system composed of evaluation criteria and metrics, and considering different evaluation perspectives – consumer, water utility and society. This approach is currently under implementation in three case studies (in Portugal, in the UK and in Greece).

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