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Smart metering use cases to increase water and energy efficiency in water supply systems

D. Loureiro*, P. Vieira*, C.Makropoulos**, P.Kossieris**, R. Ribeiro*, J. Barateiro*, E. Katsiri***

* Laboratório Nacional de Engenharia Civil, Av. do Brasil 101, 1700-066 Lisboa, Portugal, dloureiro@lnec.pt, pvieira@lnec.pt, rribeiro@lnec.pt, jbarateiro@lnec.pt
** School of Civil Engineering, National Technical Univ. of Athens, Heroon Polytechneiou 5, Athens GR-157 80, Greece, cmakro@chi.civil.ntua.gr, pkossier@central.ntua.gr
*** Institute for the Management of Information Systems, Research Center “Athena”, Artemidos 6 and Epidavrou, Marousi 15125, Greece, eli@imis.athena-innovation.gr

Abstract
The efficient water and energy use in water distribution systems is being limited by the lack of sufficient data about water and related energy consumption. Therefore, it is crucial to provide updated and continuous feedback information to water users. This paper describes relevant use cases to improve efficient water use and related energy consumption in water utilities and consumers through the use of smart metering technologies. A systematic approach was established to obtain a comprehensive list of possible functionalities, using the concept of use case. For the consumer domain, 6 high-level and 18 detailed-level use cases were obtained. For the water utility domain, 7 high-level and 20 detailed-level use cases were described. The high-level with higher priority to be implemented in the iWIDGET system were also identified based on the contribution of different target audiences. The list of use cases covers a comprehensive range of possible usages that can be built upon the exploitation of data related to water and energy use in water distribution systems and in the households, which may be of further use as a guide for similar studies.

Keywords
Information and communication technology, smart metering, use cases, water-energy efficiency, water supply system

INTRODUCTION

The water-energy nexus concept recognizes a strong interaction between these two resources. This relationship is not limited by the demand of one resource on the other, but includes many shared challenges and opens new opportunities for collaboration between water and energy utilities and consumers. The aging infrastructure, that impacts reliability and dependability of services, and increased consumer demands for resource adequacy and improved quality are challenges that requires to be addressed in the near future (GEI, 2013).

Nowadays, the efficient water and energy use in water distribution systems is being limited by the lack of sufficient data about water and related energy consumption (Water in the West, 2013). Therefore, it is crucial to provide updated and continuous feedback information to water users (consumers and water utilities) in order to promote efficient water and associated energy uses. Smart meter technologies provide access to real-time data related to water and related energy consumption. They also provide opportunities for efficiency improvements, namely efficient water use in the household and utility-level control of water losses and cost-benefit water planning.

To take advantage of such valuable information, and improve water and related energy efficiency in water supply systems, using smart metering technologies, several Information and Communication Technologies (ICT) can be developed. This opportunity must be addressed in a systematic way, taking advantage of current ICT knowledge to support an efficient communication tool between system architects/analysts and stakeholders (*e.g.,* water-energy consumer, utility, services regulators). The concept of Use Case is recognized as one of the most powerful tools to model system's requirements and desired functionalities, using formalisms that all stakeholders can understand. In fact, use cases are part of the behaviour diagrams and are "means for specifying required usages of a system" (OMG, 2011). In general, use cases are used as a basis to capture the requirements of a system (i.e., what a system is supposed to do). The use cases will also inform and determine the technological solution(s) (*e.g.*, data types and characteristics) and will clearly shape the solution to be developed.

Use cases are based on three main concepts:

- Actor – specifies a role played by a user or any other system that interacts with the system;
- Use Case – specification of a set of actions performed by a system, which yields an observable result that is, typically, of value for one or more actors or other stakeholders;
- Subject – system under consideration to which use cases apply.

The semantics and concepts behind use cases are intentionally simple, as their main goal is to establish a communication tool, providing an overall view of the system behaviour. As a consequence, they should mainly focus on business goals rather than system goals.

However, in the water-energy domain, there is a lack of studies where the concept of use case is used to capture appropriately the main functionalities to be incorporated in an ICT system. This concept was adopted successfully in the iWIDGET Project to identify the major processes to improve urban water demand management in households across Europe. iWIDGET is a collaborative ICT research project (http://www.i-widget.eu/), co-funded by the EU's 7th Framework Programme, with R&D and water utility partners from Portugal, UK, Germany, Greece, Ireland and Switzerland.

This paper describes relevant use cases to improve efficient water use and related energy consumption in water utilities and consumers through the use of smart metering technologies. A systematic approach was established to obtain a comprehensive list of possible use cases.

METHODOLOGY

To describe, validate and rank use cases a list of high-level use cases was firstly compiled, described and harmonized (Step 1). Then, for each high-level use case, a list of detailed-level use cases was obtained using the same procedure (Step 2). Finally, the use cases were validated and ranked (Step 3). A complete description of the methodology, presented in Figure 1, can be found in Loureiro *et al*., (2013).

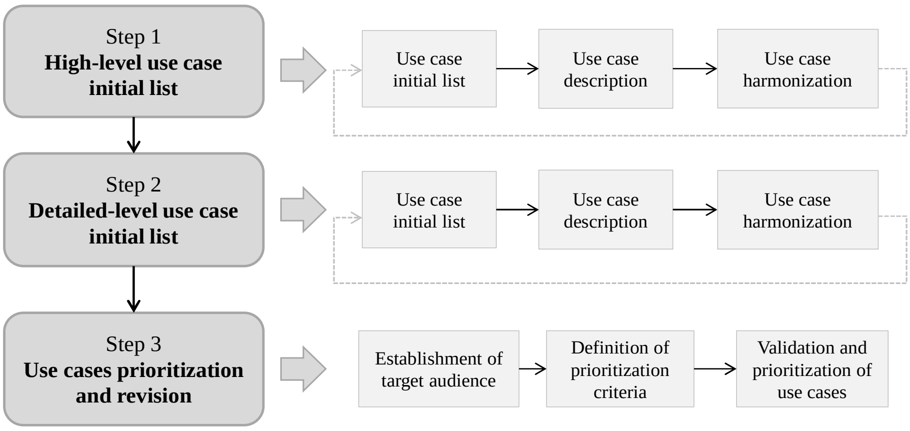

Figure 1 - Methodology for use case description

In Step 1, an initial list of high-level use cases was compiled. These high-level use cases describe major processes in the system and are largely business-oriented and in line with the objectives of the iWIDGET project, the stakeholders' concerns, and with the business areas of the stakeholders/actors. All use cases included in the list were described using a common template (Table 2 and Table 4). This template aims at providing use case descriptions, and the initial information to support further analysis of functional and non-functional requirements. Functional requirements specify functions and/or behaviour, while non-functional requirements specify criteria to evaluate the quality of the execution of such functional requirements (Pohl, 2010). Finally, harmonization of high-level use cases was made in order to find a good balance in terms of level of detail between use cases, finding overlapping use cases and finding use cases with conflicting objectives.

In Step 2, an initial list of detailed-level use cases was compiled for each high-level use case. Next, each detailed-level use case was described. Similarly to Step 1, harmonization of use cases was made with the aim of ensuring a good connection and a structured work in subsequent tasks, namely in the specification of requirements.

In Step 3, the use cases were prioritized for relevance to potential end-users of the iWIDGET system (i.e., water utilities and consumers). Prioritization was carried out with the contributions from two different target audiences: *i*) the project partners and *ii*) the stakeholders that attended a workshop yielded in Portugal. The group of stakeholders that attended the workshop included experts from water utilities, consumer's organizations, technology providers, water services regulators, professional associations, government organizations, research institutions and associations for environment protection. The prioritization criteria for the project partners were based on the relevance of the use cases for the project case studies and for the users outside the project. For the workshop stakeholders, the prioritization criteria were based on the drivers for smart metering use, both in the water utility domain (water loss control, networks water-energy efficiency, management of information systems, services to the consumer, billing systems, pricing schemes and sustainable planning) and in the consumer domain (leak detection, increase water-energy efficiency, benefit from better service or from new services, decrease the water-energy bill). All experts rated the relevance by assigning a priority to each use case using a 3-point Likert scale (3-highly relevant, 2-relevant, 1-not relevant).

RESULTS

Overview

The subject of the use cases subject comprised urban water distribution systems and residential systems. Use cases were grouped according to the viewpoints of two actors (entities that interact with the system): water utility and consumer. They focus on water-energy efficiency using consumption data collected from smart meters (installed in the households and in the distribution networks). A broad list of stakeholders, which might be involved in the system, was also identified in this study (*e.g.*, associations for consumers' protection, market data providers, service regulators (water, energy), standardization committees, technology providers).

Use cases for consumer domain

The major processes of the iWIDGET system for consumers are described through the following six high-level use cases. Each high level use case comprises a series of detailed-level use cases, which provide detailed information on specific system services.

- **C_UC01: Obtain water consumption data -** This high-level use case is devoted to the detailed monitoring of consumption of the household, on a real-time basis. It includes all the appropriate functionalities that enable householders to monitor the progress of their consumption and how it is disaggregated into various uses and appliances. The information is presented through an advanced visual environment that displays consumption statistics using charts and tables. Householders are able to explore their consumption using the available functionalities and options, such as the selection of the time interval, the time resolution, and the units of the presented information.

- **C_UC02: Obtain energy data associated with water consumption -** This high-level use case comprises the functionalities for monitoring and presentation of information concerning the energy consumption of household which is derived from water uses. These functionalities concern the total energy consumption and the corresponding cost, as well as the breakdown into appliances that consume water and energy simultaneously. The system also provides information about the related carbon emissions. For the efficient presentation of information related to energy, the system provides several options that are similar to those concerning water.

- **C_UC03: Understand water consumption -** This high-level use case comprises all functionalities, which support householders to better understand the water consumption profile of their household. Through an advanced visual environment, the users can compare the current consumption of their household with: (*i*) other neighbouring consumers; (*ii*) consumers of similar characteristics; (*iii*) the efficient households; (*iv*) the past consumptions of the same household. This process aims to motivate users to change their wasteful behaviour and reduce their consumption. Towards this direction, information for wasteful behaviour and inefficient appliances is also presented. Finally, the system has the ability to detect, on a real-time basis, various faults related to water, such as bursts and leakages. The long-term water consumption trends of the household are also monitored for the detection of abnormal situations, which could be linked with other factors, such as health.

- **C_UC04: Understand energy associated with water consumption -** This high-level use case enable householders to monitor and understand better the energy consumption profile of their household, associated with the various water uses. The system provides comparative statistics about past energy consumption and the breakdown of total energy consumption into various uses.

- **C_UC05: Get assistance to increase water use efficiency -** The services of this high-level use case aim at supporting householders to improve the water efficiency of their household. Towards this direction, the system provides customised and alternative suggestions that include practices, tips and interventions. Apart from general water-saving tips, the system, based on the specific needs and characteristics of the household, is able to compose and perform different hypothetical but realistic scenarios, using various combinations of innovative technologies, such as water-efficient appliances, rainwater harvesting systems, greywater treatment systems, advanced gardening systems etc. The results are presented in the form of comparative information that highlights the profit and the cost of each intervention.

- **C_UC06: Control water use -** This use case comprises some advanced functions that assist the users to schedule their water related activities, to improve efficiency. The user can choose the appliances that are going to operate during the day, and the system uses customised scenarios that try to schedule these appliances in a way that water/energy bills will be optimised. Additionally, the system also comprises advanced functionalities for smart appliances with remote communication abilities. The system can also operate as a mean to control the source of water supply and thus the advanced water saving technologies.

In order to support the efficient development of analytic functionalities within iWIDGET, a list of detailed use cases has been composed for each of the six high-level use cases. For example, for the first high-level use case, two detailed-level use cases were derived and for the second one, three detailed-level were derived (Table 1).

Table 1 – Example of the list of detailed-level use case for the consumer domain

High-level use case	Detailed-level use case
C_UC01: Obtain water consumption data	C_UC01.1: Obtain total water consumption and costs using real-time data from smart meters C_UC01.2: Obtain per appliance water consumption and costs using real-time data from smart meters
C_UC02: Obtain energy data associated with water consumption	C_UC02.1: Obtain total energy consumption and costs associated with water consumption using real-time data from smart meters C_UC02.2: Obtain per appliance energy consumption and costs associated with water consumption using real-time data from smart meters C_UC02.3: Display carbon emissions related to water consumption (carbon footprint of water)

The detailed use cases describe the targets, functions, possible constraints and sequence of steps for a specific process of the platform (Table 2). These use cases will be implemented in the iWIDGET system and this complete description is fundamental to model system's requirements. A total of 18 detailed use cases were described for the consumer domain.

Table 2 – Use Case C_UC01.1: Obtain total water consumption and costs using real-time data from smart meters

Unique ID and use case name	C_UC01.1: Obtain total water consumption and costs using real-time data from smart meters
Domain	Consumer (residential)
Goals	Promote an easier, faster, flexible and appealing way to display the total water consumption and the corresponding cost using real-time data.
Actors	Householder
Description	This use case aims at monitoring the total water consumption at the household, on real-time basis using data from smart meters. The iWIDGET portal enables householders to follow the consumption of their household through an advanced visual environment that incorporates many graphical abilities and features (e.g. interactive graphs, pie charts and plots). The users can monitor: • The current total consumption of their household, based on real-time data collected from smart meters, and the corresponding cost. • The accumulated consumption of the current day, week, month or year, and the corresponding cost. • How the total or seasonal consumption is allocated throughout the day (night flow consumption, day flow consumption) and the corresponding cost. • How the total consumption is allocated throughout the year (winter and summer consumption) and the corresponding cost. The system provides options for the selection of time interval, through a calendar, and the time resolution of the presented information. The user can also obtain water consumption as volume (e.g. litres), per capita volume (e.g. litres per person), cost, per capita cost, etc.
Pre-conditions	Availability of water consumption data from smart metering systems and database. Availability of information about the implemented water pricing schemes/tariff structure. Information about the characteristics of the household (household profile).
Post-conditions	Householder receives information about the current water consumption of his/her house.
Trigger	Householder requests access to information about the current water consumption of his/her household.
Constraints	Availability of accurate real-time data.
Main flow	• Householder logs on to his personal profile using a private password • iWIDGET portal displays the facilities available to the user • Householder selects the options related to the visualization of real-time and accumulated water consumption of the household. • iWIDGET presents a report with the obtained information and data • Householder can print the report, save data or escape the application
Alternative flow	n.a
Issues	Nature/specificity of data that can be obtained from smart meter systems.
Relationship with other use cases	n.a.

Use cases for water utility domain

The major processes of the iWIDGET system for water utilities are described through the following seven high-level use cases. Each high-level use case comprises a series of detailed-level use cases, which provide detailed information on specific system services.

- **WU_UC01: Obtain water consumption and related energy consumption data** – This use case aims at promoting an easier, faster and more flexible access to accurate data. The utility has access to near real-time data about metered water and associated energy consumption. Water consumption data comes from SCADA, smart metering and includes network inflow, total metered consumption and total metered consumption per category of consumer. Associated energy consumption data comes from SCADA and is related to network pumping (if existing).

- **WU_UC02: Understand water consumption** – It improves the understanding about metered water consumption and water losses. In this high-level use case, the utility gets near real-time information on the different components of metered consumption and water losses (real losses, apparent losses, unmetered consumption). The utility can also benchmark water losses against reference values and obtain valuable information on consumption profiling to improve for network operation and planning.

- **WU_UC03: Understand energy associated with water consumption –** The utilities will improve understanding about metered energy consumption and identify inefficiencies. The utility gets near real-time information on the different components of metered energy consumption associated with network pumping. It also allows obtaining energy costs associated with pump inefficiency (*e.g.*, operating outside of the optimal range).

- **WU_UC04: Get support to increasing operational efficiency –** This use case optimizes real-time operation in terms of water-energy efficiency. The water utility gets real-time information on the effects of pressure control on consumption components, adaptive pumping scheduling regarding energy costs and consumption profiles and optimal placement of valves and flow meters on pipes in the network.

- **WU_UC05: Get support to increasing the quality of service –** This high-level use case enables the utility to improve the quality of service provided to the consumers in terms of billing, complaints and warnings of residential leaks. These functionalities help the utility to resolve consumers' problems faster and more efficiently, with higher first call resolution rates and a corresponding decrease in follow-up calls.

- **WU_UC06: Get support to improve consumer efficient water use –** Using this use case, the utility will improve domestic demand management. The utility receives customized suggestions on adaptive pricing schemes and awareness campaigns. Awareness campaigns might be used to reduce peak demand (*e.g.*, through shifting outdoor uses along the day) or total demand in order to achieve a more efficient operation of the network. Thus, iWIDGET may enable the following functionalities: i) suggests which target groups need to be addressed by campaigns, ii) provides a set of pre-defined messages designed to different target groups and iii) sends messages to consumers proposing efficiency measures to be adopted and associated potential gains.

- **WU_UC07: Get support for system planning and design –** This use case improves operational planning and long term asset management. The utility may specify possible scenarios (*e.g.*, long-term: low-level of economic growth and customers more active towards efficient water use practices), regarding the different time horizons, where the assessment of consumption trends is important. Afterwards, these reliable scenarios are used to support decisions on network expansions and on optimal replacement period of equipment's.

Table 3 lists the detailed-level use cases established for the high-level use cases WU_UC01 and WU_UC02, respectively. A total of 20 detailed use cases were described for the consumer domain.

Table 3 – Example of the list of detailed-level use case for the water utility domain

High-level use case	Detailed-level use case
WU_UC01: Obtain water and related energy consumption data	WU_UC01.1: Obtain inflow (and associated energy consumption) and total water consumption per network sector using real-time data WU_UC01.2: Obtain water consumption data per category of consumer using real-time data
WU_UC02: Understand water consumption	WU_UC02.1: Obtain water balance data WU_UC02.2: Benchmark water losses against reference values WU_UC02.3: Obtain information on consumption profiling WU_UC02.4: Obtain detailed information on operational inefficiency

Table 4 presents a complete description for the detailed-level use case WU_UC02.1: Obtain water balance data. This use case combines data from supervisory control and data acquisition (SCADA) and smart metering systems and represents an evolution relatively to the well-established IWA standard international water balance (Lambert and Hirner, 2000), since it will enable more accurate and frequent analysis to control water losses. This use case exploits data analysed in the use case WU_UC01.1.

Table 4 – Use Case WU_UC02.1: Obtain water balance data

Unique ID and use case name	WU_UC02.1: Obtain water balance
Domain	Water utility
Goals	Improve understanding about consumption and water losses through more accurate and frequent balances.
Actors	Network operation staff
Description	Obtain more accurate and frequent information on the different components of the water balance using data from SCADA and smart meters. The user may select the data processing options – time interval, frequency to perform water balances (*e.g.*, hourly, daily, weekly, monthly, quarterly, annually) and desired disaggregation level of water balance components (*e.g.*, real losses vs background losses and pipe bursts). The utility's operational staff accesses data through a variety of technology devices (*e.g.*, personal computer, mobile phone). Use case output enables different ways of data visualization (time series charts, pie charts, tables). This use case involves: i) data processing of raw data series, ii) combination of large amounts of consumption data for a specific time interval.
Pre-conditions	Consumption data from SCADA and smart meters systems
Post-conditions	Network operation staff gets information on water balance
Trigger	Network operation staff requests access to information on water balance
Constraints	Desired disaggregation level of water balance components is dependent of the frequency of raw data (*e.g.*, hourly data allows splitting water losses into real losses and apparent losses, whereas daily data do not allow) and availability of other estimated data (*e.g.*, unmetered consumption).
Main flow	• Network operation staff logs on to iWIDGET • Network operation staff selects data processing options • Network operation staff selects data visualisation options • iWIDGET processes data according to selected options • Network operation staff accesses to data • iWIDGET presents a report with the obtained data • Network operation staff can print the report, save data or escape the application
Alternative flow	n.a.
Issues	n.a.
Relationship with other use cases	WU_UC01.1

Prioritization of use cases

Results of the prioritization of use cases by workshop stakeholders are presented in Table 5 for the consumer domain and for the water utility domain.

For the consumer domain, workshop stakeholders considered the use case C_UC01 related to obtaining water consumption data as the most useful (priority 2.6). Lowest priorities (1.5-1.9) were given to energy related use cases (C_UC02 and C_UC04). A limited awareness about the importance of energy consumption related with water use (water-energy nexus) might be a possible explanation for this low priority energy use cases. Use cases C_UC03, C_UC05 and C_UC06 related to understand water consumption, get assistance to increase water use efficiency and control water use were respectively considered to have an intermediate priority.

For the utility domain, the use cases regarding the access and understanding of water consumption data, getting support to increase operational efficiency and getting support to system planning (WU_UC01, WU_UC02, WU_UC04, WU_UC07) were assigned by workshop stakeholders with higher priorities (2.6-2.9). The stakeholders considered that the use case intended to give utilities support to improve their customers water use efficiency (WU_UC06) as having the lowest mean level of priority (1.8).

Besides this prioritization of use cases, another important result from the workshop was that all suggested use cases were validated by the stakeholders. Results of the prioritization of use cases by project partners are also presented in Table 5.

For the consumer domain, higher overall ratings (2.6-2.8) were obtained by use cases C_UC01, C_UC03 and C_UC05 related to the access and understanding of water consumption data and also to getting assistance to increase water use efficiency. Use case C_UC02 related to obtaining data on the energy associated with water use was considered to be the less relevant (priority 1.9) by project partners. Use cases C_UC04 and C_UC06 related to understand energy associated with water consumption and control water use were considered to have an intermediate priority.

Table 5 – Prioritization of high-level use cases for consumer and water utility domains.

		Prioritization by stakeholders at PT workshop			Prioritization by project partners
Domain	**Use cases**	Water utilities	Consumers and other stakeholders	Overall rating	Overall rating
Consumer	C_UC01: Obtain water consumption data	2.8	2.6	2.6	2.7
	C_UC02: Obtain energy data associated with water consumption	1.8	1.9	1.9	1.9
	C_UC03: Understand water consumption	2.1	2.2	2.2	2.6
	C_UC04: Understand energy associated with water consumption	1.8	1.5	1.5	2.0
	C_UC05: Get assistance to increase water use efficiency	2.7	2.4	2.4	2.8
	C_UC06: Control water use	2.6	2.3	2.3	2.1
Water utility	WU_UC01: Obtain water consumption and related energy consumption data	2.8	2.7	2.7	2.8
	WU_UC02: Understand water consumption	2.3	3.0	2.9	2.8
	WU_UC03: Understand energy associated with water consumption	2.6	2.2	2.3	2.0
	WU_UC04: Get support to increasing operational efficiency	3.0	2.9	2.9	2.8
	WU_UC05: Get support to increasing the quality of service	2.6	2.1	2.2	2.3
	WU_UC06: Get support to improve consumer efficient water use	1.9	1.8	1.8	2.4
	WU_UC07: Get support for system planning and design	2.6	2.6	2.6	2.3

For the water utility domain and in a similar way, Table 5 shows that use cases related to the access and understanding of water and energy consumption data and also to getting support to increasing operational efficiency (WU_UC01, WU_UC02 and WU_UC04) were assigned with higher priorities (2.8). The remaining use cases, related to the understanding of energy consumption, to getting support to increase the quality of service, to getting support to improve consumer efficient water use, and to getting support for system planning, were considered as having intermediate priority (2.0-2.4). There were no low priority use cases in this domain.

CONCLUSIONS

This paper identifies and characterises a range of relevant use cases to improve efficient water and related energy consumption in water utilities and consumers using smart metering technologies. The comprehensive list of high-level use cases and corresponding detailed-level use cases was compiled for two domains: consumer and water utility.

For the consumer domain, 6 high-level and 13 detailed-level use cases (from an initial 6 and 18, respectively) were given a high priority; for the water utility domain, 7 high-level and 18 detailed-level use cases (from an initial list of 7 and 20, respectively) were ranked with higher priority to be implemented in the iWIDGET system.

The list of use cases covers a comprehensive range of possible usages that can be built upon the exploitation of data related to water and energy use in water distribution systems and in the households. The list of the most relevant use cases should drive the subsequent tasks of the project, at least on a first approach. The complete list of detailed-level use cases may be of further use as a guide for similar studies. The methodology used in iWIDGET project for use case description proved to be adequate to identify functionalities useful for efficient water and energy use in distribution systems and in the households, using smart metering systems.

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