the smartH2O project
A European project on water sustainability

TECHNOLOGY WATCH REPORT

Exploring the market dimensions

SmartH2O

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SEVENTH FRAMEWORK PROGRAMME

Table of Contents

Executive Summary

This document is the Deliverable **D8.2 – Technology Watch Report**, which, according to the DoW has the following goals:

D8.2) Technology watch report: This deliverable is a report of the technology areas involved in the project (e.g., water modelling and management IT solutions, smart water management appliances, social and persuasive games and applications), with a focus on both the scientific and the industrial progress. Each area is analysed and its potential is assessed to provide an adequate input to the exploitation plan. [month 12]

The present document represents the second achievement of the Business Development work package (WP8). WP8 aims at the identification and involvement of early adopters in order to ensure post-project exploitation and long-term sustainability and impact of results.

This document focuses on the review and the critical analysis of the state-of-the-art in the different areas involved in the project, namely smart meters sensors (Section 2), water customers modelling (Section 3), water utilities and water market (Section 4), gamification and serious games applications (Section 5).

In particular, for each area analysed, the current status, the scientific and industrial challenges, and the future directions are discussed in order to identify the most promising directions for the exploitation of the SmartH2O project results.

The document also connects the opportunities identified by the review of the current status with the assets and actions defined in the Deliverable D8.1 – Early exploitation plan, ultimately providing inputs for the exploitation plan that will be formulated in the next deliverables of WP8 (i.e., D8.4 – Intermediate exploitation plan; D8.6 – Final exploitation plan).

1. Introduction

This deliverable contains a review and a critical analysis of the state-of-the-art in the different areas involved in the project (i.e., smart meters sensors, water customers modelling, water utilities and water market, gamification and serious games applications). The deliverable is part of the activity of WP8 (Business development).

The document includes the results of the active tasks of WP8:

- T8.1 Technology and market watch, for the analysis of the current status of the technology and the market.
- T 8.2 Regulation watch, for the identification of the regulatory frameworks in the countries that are direct target of the Consortium.

This deliverable will also influence the prosecution of work in WP8 as it will identify the most promising directions for the exploitation of the SmartH2O project results. The combination of the opportunities identified in this document with the assets and actions defined in the Deliverable D8.1 – Early exploitation plan, will represent the initial directions for the construction of an effective SmartH2O exploitation plan, which will be formulated in the next deliverables of WP8 (i.e., D8.4 – Intermediate exploitation plan; D8.6 – Final exploitation plan).

The deliverable is organized as shown in Figure 1:

1. **Review and critical analysis** of the current status, the scientific and industrial challenges, and the future directions for each technology area involved in the project, namely **smart meters sensors** (Section 2), **water customers modelling** (Section 3), **water utilities and water market** (Section 4), **gamification and serious games applications** (Section 5).
2. **Identification of the** input for the future exploitation plan by connecting the most promising areas resulting from the results of the review of the current status with the assets and actions defined in the Deliverable D8.1 – Early exploitation plan.

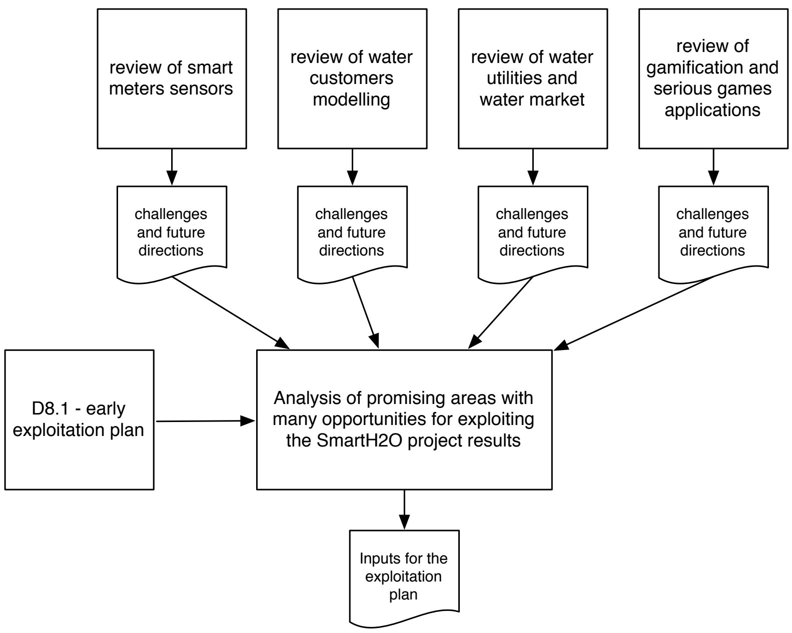

Figure 1: Overview of the technology watch methodology for the identification of the inputs for the exploitation plan.

2. Smart-meter sensors

The role of digital water metering technologies, i.e. smart metering (SM) including information/communications technology (ICT), to improve operational efficiency, and inform demand management and customer services, is becoming increasingly recognised by water utilities, research institutes and governments [Stew2013]. Traditional metering technology is a pre-condition for customers to know how much water they consume and, subsequently, only pay for amount of water actually consumed. Smart meters provide further benefits for water utilities and customers as they offer the opportunity to improve visibility of network and operation efficiency, to effectively and timely schedule renovation works, and to obtain qualified daily water consumptions, which are the basis for prompting water demand management strategies.

So far, the systematic deployment of smart meter networks is still slow due to the high technological and communication cost. As these are expected to decrease over the next decade, the cost-benefit equation for utilities should soon suggest new investments in intelligent metering [Boyl2013]. Other barriers include security and privacy, and the management of big data by water utilities. The collection and distribution of user behavioural patterns will introduce also the need for new regulatory framework to protect privacy of customer information and data [Boyl2013].

Several water companies in Europe are steadily exploring the benefits of smart meters. In UK, even if metering was left out from the Water Act, a number of water and sewerage and water only companies, including Anglian, Northumbrian (with Essex & Suffolk), South West, Southern, Thames, Wessex, Bournemouth & West Hampshire, Cambridge, Folkestone & Dover, South East, Sutton & East Surrey, Tendring Hundred and Three Valleys, launched intensive metering programmes involving smart meter installation over the next 25-year [Ofwa2008]. Smart metering penetration rates have considerably been growing in countries outside UK such as in France. Among all major countries worldwide France is the fastest-expanding market in intelligent metering, with smart meter penetration approaching the 50 percent mark [Mete2014]. For example, in the city of Beaune, 6,200 smart water meters were installed by Veolia water to improve network efficiency (initial level of 68%) by reducing leaks. After the installation of smart meters network efficiency increased to 78% leading to substantial water savings amounted to 300,000 m^3 (13%) [Lafu2014]. Other water companies in France invest in smart meter technology such as Sedif in the Paris suburban area (550'000), GeandLyon in the city of Lyon and suburban (400'000 - beginning of January, 2015), Eaux de Marseille in the city of Marseille and suburb (300'000 – beginning of July, 2014) [Lafu2014]. Moreover, smart meter in the water sector is growing worldwide such as in US and Australia and a recent report by the StatPlan Energy consultancy estimates that the 2014 global water meter market to be worth \$2.6 billion and by 2018 it will have increased by 13.2% to just over \$3 billion. In Switzerland the market for smart water meters is, on the contrary, slower to start, despite some early tests in 2009 and the fact that some well known smart meter producers are based in Switzerland, such as Landis+Gyr and Aquametro. Energy utilities are making massive investments in the deployment of energy smart meters, but water utilities only recently are showing timid interest in the water sector. This is probably due to the abundance of water in this alpine country and its consequently low price.

2.1 Current status

2.1.1 Metering sensors available on the market

Conventional metering techniques traditionally rely on mechanical water meters based on a spinning turbine, which reports the volume of water flow directly in an impeller rotation. In recent years, several types of sensors have been developed by exploiting different technologies and physical properties of the water flow (for a review see [Arre2011] and references therein):

- **Accelerometers** [Evan2004], which analyze vibrations in a pipe induced by the turbulence of the water flow. A sampling frequency of 100 Hz of the pipe's vibrations allows reconstructing the average flow within the pipe with a resolution of 0.5 liters [Kim2008].
- **Ultrasonic sensors** [Mori04], which estimate the flow velocity, and then determine the flow rate knowing the pipe section, by measuring the difference in time between ultrasonic beams generated by piezoelectric devices and transmitted within the water flow. The transducers are generally operated in the range 0.5-2 MHz and allow attaining an average resolution around 0.0018 liters [Sanderson02].
- **Pressure sensors** [Froe2009, Froe2011], which consist in steel devices, equipped with an analog-digital converter and a micro-controller, continuously sampling pressure with a theoretical maximum resolution of 2 kHZ. Flow rate is related to the pressure change generated by the opening/close of the water devices' valves via Poiseuille's Law.
- **High resolution flow meters** [Maye1999], which exploit the water flow to spin either pistons (mechanic flow meters) or magnets (magnetic meters) and correlate the number of revolutions or pulse to the water volume passing through the pipe. Sensing resolution spans between 34.2 and 72 pulses per liter (i.e., 1 pulse every 0.029 and 0.014 liters, respectively) associated to a logging frequency in the range of 1 to 10 seconds.

So far, only flow meters and pressure sensors have been employed in smart meters applications because ultrasonic sensors are too costly and the use of accelerometers requires an intrusive calibration phase with the placement of multiple meters distributed on the pipe network for each single device of interest [Kim2008]. It is worth noting that the "smartness" of these sensors is related both to their high sampling resolution and to their integration in efficient systems combining data collection, transfer, storage, and analysis.

A typical example is Aquametro's domestic water meter system dubbed *aquaconcept©,* which is based on the mechanical Aquametro meter *PMK-aquabasic©* (see Figure 2). This latter acts as a base element upon which to fix different electronic devices, such as *aquareader© M–Bus* or *aquareader© CS* (Figure 3).

Figure 2: PMK-aquabasic.

Another element of *acquaconcept©* is *aquadata© M–Bus*, which is powered by a 3V Li battery to allow full autonomous operation automatic readout and generates meter pulses to control visualization panels for local operation and includes also a M Bus interface (EN 13757 ENN 1434-300/2400 baud).

Figure 3: aquareader CS.

A similar component is *aquapuls©* which also provides pulse for controlling instruments, remote display and transmission and filling control units. Metering resolution (pulse weighting) is up to 1 Litre per pulse. This system can be controlled wirelessly by means of the *aquaradio©* module, which connects the meter to the reader through M Bus. For off line operation and storage of consumption data over longer periods (e.g. reading once a year) the *aquatarif©* module allows storing of metering information of the previous 400 days and 15 months as well as days with downtimes and leakage. Reading can be done either by CS interface or Optical interface (IEC 62056-21). Wireless reading is implemented by means of the *acquaradio©* module based on the "walk or drive-by" operations. It works on RF 868 MHz and is equipped with a battery ensuring 12 years of operation, connected to the meter through M-Bus (or Pulse) input. Integration with other domestic metering requirements, such as gas meters, is foreseen through *aquainfo©,* a system module allowing remote and on-site reading of CS interface values connected to gas or water meters.

An alternative to the combination of different modules is offered by **integrated metering systems**. These electronic devices integrate metering and communication functions in a single tool by adopting electronic metering techniques such as ultrasonic meters.

Since Aquametro has a solid presence in Swiss waterworks, in the Swiss SmartH2O test case the Aquametro Topas ultrasonic meter (Figure 4) has been selected and employed.

Figure 4: Aquametro Topas ultrasonic meter.

2.1.2 Data reading and transfer technology options

Several options for water consumption data reading and transfer are available to water utilities for implementation. Thames Water identified in 2013 the following three data reading and transfer options, conditioned to the metering technology installed:

- **Dumb Meter Reading** – a conventional meter is installed with a register dial. Meter reading is undertaken by a meter reader gaining physical access to the meter and visually recording the meter reading into an electronic meter reading data capture devices.
- **Automatic Meter Reading (AMR)** – a meter with a short range radio is installed at each property. The meter reader equipped with a meter reading device is required to walk-by the meter in order to take a meter reading but does not require physical access to the meter. This process can also be achieved in certain circumstances in a vehicle application – known as drive-by reading. The data is captured electronically. Additional data may be stored in the meter and collected, such as a small number of historic meter readings, minimum and maximum flows and alarms for tamper, low battery and potential leakage found.
- **Advanced Metering Infrastructure (AMI)** – using a fixed network meter reading system (usually radio based), meters are read electronically and do not require a meter reader. Electronic readings are passed from the meter through to utility offices for billing and network management purposes. With these systems it is possible to collect more frequent data on consumption and alarm conditions, which can be used to provide additional benefits.

A cost-benefit analysis performed by Thames Water (detailed cost-benefit analysis reported in APPENDIX A) on the three options allowed identifying AMI solutions as the most promising and suitable one, when considering potential for customer consumption reduction, leakage detection, reading frequency intervals and data quality.
As for data transfer from customers' houses to water utilities, Advanced Metering Infrastructure can alternatively rely on wired connections (e.g., power line communications, telephone line) or wireless connections (usually through radio spectrum (RF)) for data transfer from. However, the latter wireless option appears to be more suitable than the previous ones, especially in cases of externally located water meters. Four viable configurations of RF-based AMI can be identified:

- mobile phone technology;
- low power radio;
- medium range radio;
- long range radio.

Such configurations are presented in the following paragraphs (for more information on the specifications of each infrastructure option, see A.1.5).

RF-AMI configuration 1: Mobile phone technology only.

The meter uses the mobile phone network system as the only RF data transfer component. This implies a one to one relationship between meter and mobile phone system, thus the coverage range depends on the mobile phone coverage. Figure 5 shows the AMI system configuration for such option.

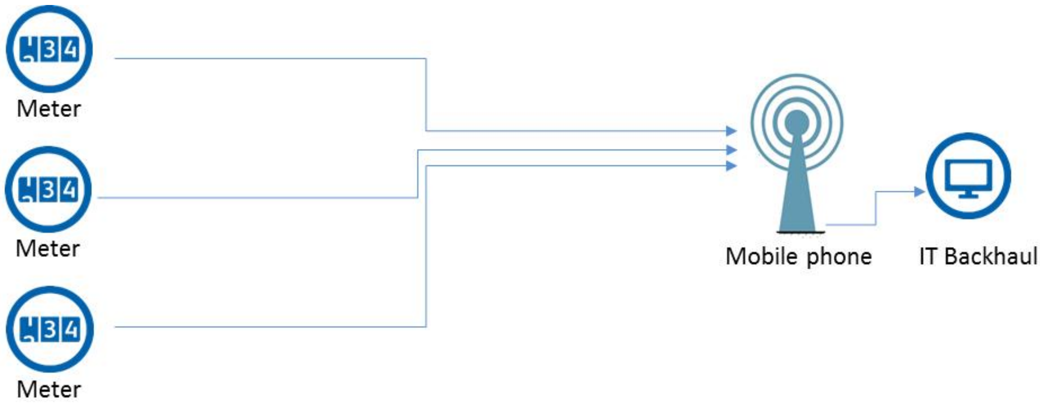

Figure 5: Mobile phone data transfer.

RF-AMI configuration 2: Low power radio systems.

In this second AMI option (see Figure 6), the meter uses a low power RF transmitter to send meter reading to a 'repeater' a short distance away. From the repeater the data is transferred over a longer range (1 to 5 km) to a concentrator. Data transfer from the concentrator is via the mobile phone system or landlines.

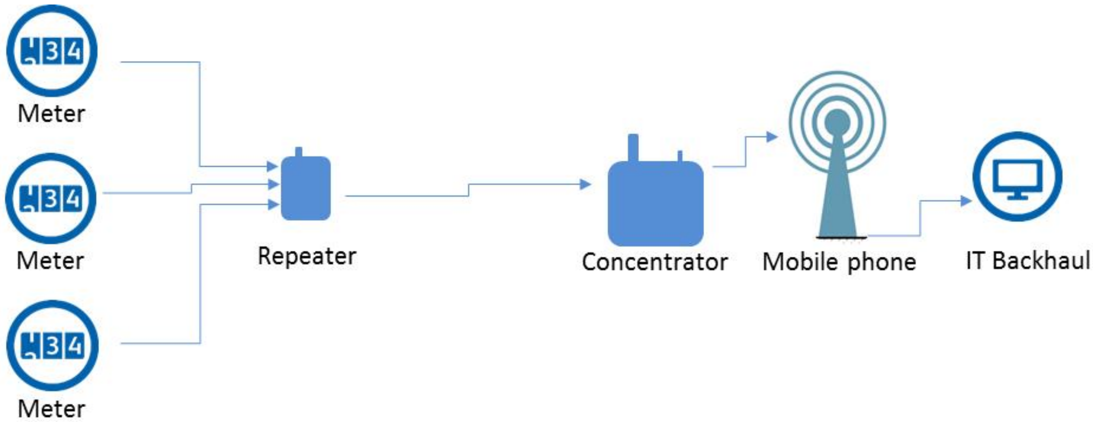

Figure 6: Lower power radio systems.

RF-AMI configuration 3: Medium range radio

These systems (see Figure 7) discard the repeater and make use of multiple (battery powered) concentrators. From the concentrator, data is returned via the mobile phone system.

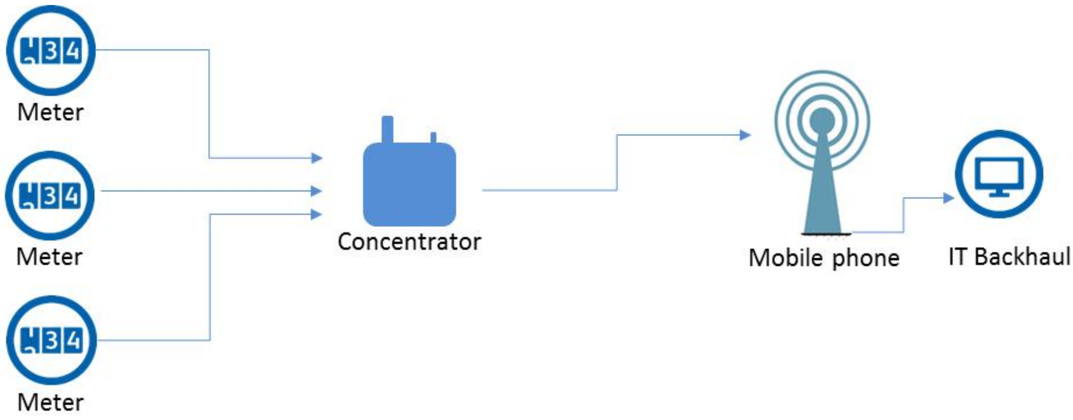

Figure 7: Medium range radio data transfer.

RF-AMI configuration 4: Long-range radio

A long-range radio system (Figure 8) places the emphasis on a limited number of high quality concentrators and relatively powerful meter transmitters. Power outputs are at least 10 times higher than the low power radio systems. When implementing the system, frequencies spectrum and power output limits allowed in the considered country must be kept into account.

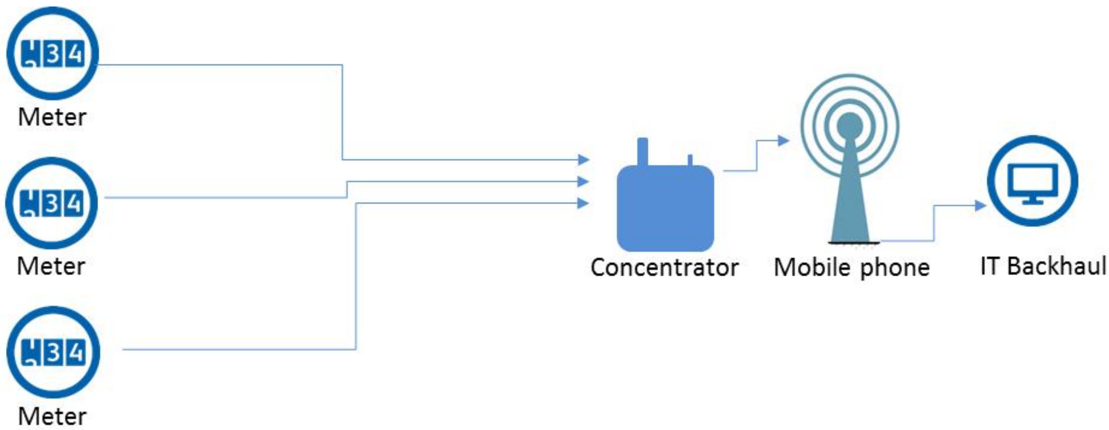

Figure 8: Long-range radio data transfer.

2.2 Scientific and industrial challenges and exploitation potential

Some general comments, challenges and exploitation potential of the different data metering and communication solutions identified in the previous paragraph can be drawn from a trial performed by Thames Water. Between 2011 and 2013, Thames Water conducted a Fixed Network Trial (FNT) that provided experience of two different AMI solutions: a low power radio solution and a long-range radio installation (medium range solutions were not evaluated). Such FNT consisted of more than 4000 AMI enabled meters providing daily data at a 15-minute resolution.

2.2.1 Challenges and findings from a Fixed Network Trial

The knowledge gained from the FNT allowed identifying the following practical issues and challenges:

- Low power radio technologies are more difficult to deploy; principally because of the number of sites required for repeaters (typically lampposts) and concentrators. The need to access street furniture effectively gives local government a veto over the deployment of low power radio systems.
- The availability of concentrator sites is limited or can be very expensive.
- Achieving close to 100% data returns from AMI is difficult due to local radio dead spots, even in areas that would be expected to be within the radio range.
- The number of meters returning data varies due to changing conditions (weather, vehicles on pits and new construction etc.).
- Repeaters installed on lamp-posts require the use of a mobile platform. A single failure is therefore relatively expensive compared to the number of meters affected.

A two-fold strategy can be adopted, in order to minimise these issues:

- a first option would be deploying equipment with a very long range between the meter and the receiver;
- a second option would be having shorter range equipment with multiple receivers.

In simplistic terms, the greater the range between the meter and the concentrator, the fewer concentrators will be required. The required number of concentrators will decrease as a square root of the equipment range, (doubling the radio range, quadruples the area covered). As a fundamental finding of the FNT trials, data transmission range between meter and concentrator is seen as a major factor in determining equipment suitability. Figure 9 shows a sample simulation of concentrator coverage with equipment ranges of 100m, 200m and 400m.

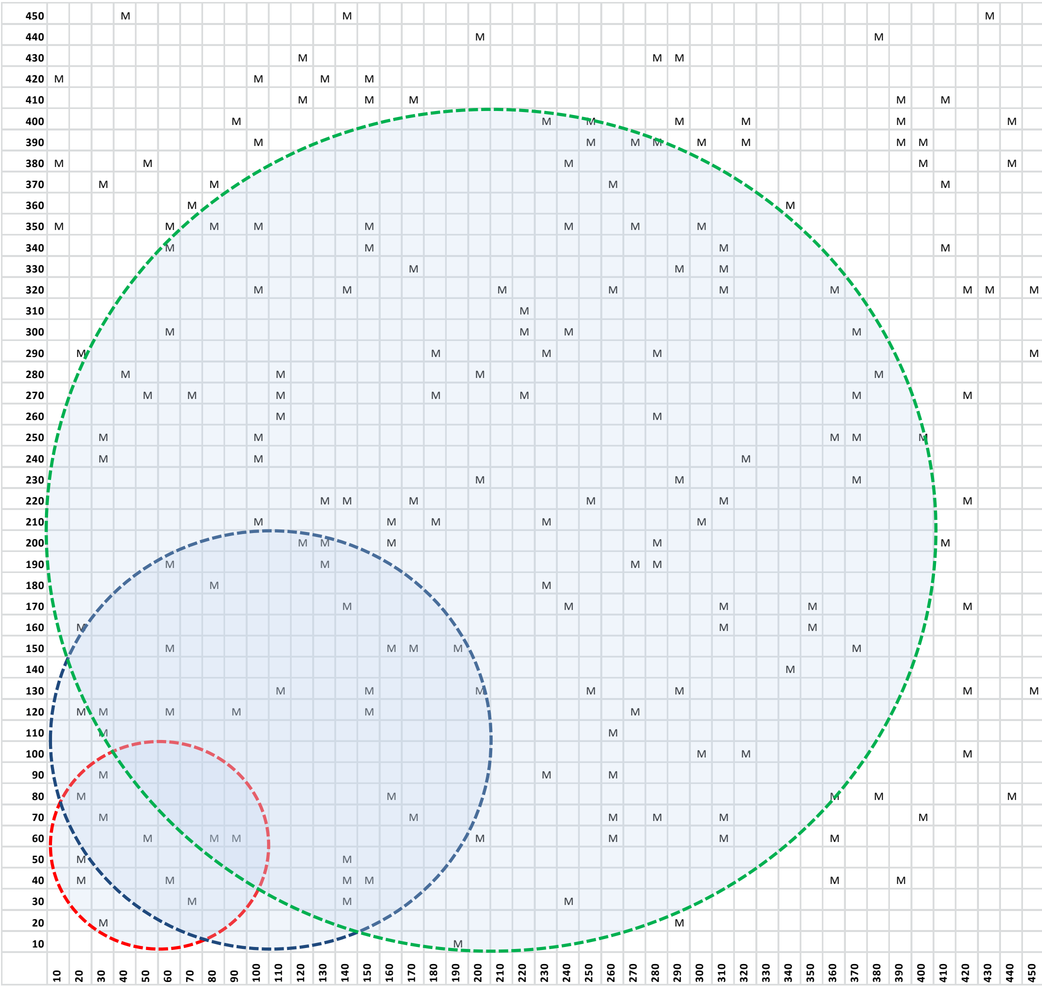

Figure 9: Simulation of coverage at 100, 200 and 400m radio ranges.

2.2.2 Opportunities for the development of AMIs

The deployment of an AMI system offers other opportunities for the water sector. Currently several business critical systems make use of RF technologies (principally mobile phone) to transmit data. The AMI infrastructure may provide a more cost effective alternative. The use of a two-way system in particular offers control functionality as opposed to just a monitoring function. The development opportunities identified for AMI networks are summarized in Table 1.

Table 1: Future potential benefits of AMI networks.

Equipment	Notes
Meters into supply, zonal metering and district metering applications	These (large) meters measure flow from the water treatment works and within the network. Currently these meters are data logged using mobile phone technology. Data resolution varies from live to 15 minute. Some meters are bi-directional. There are few obstacles in moving from mobile phone data logging to its AMI equivalent.
Pressure loggers	Within the network the pressure is recorded. This information is used to minimise pressure (and therefore leakage) within the network. Pressure data is transferred using mobile phone data loggers.
Noise loggers and noise correlators	Noise loggers are used to identify leakage on the network. The amount of data requiring transferring ranges from minimal to megabits requiring dedicated landlines. Local noise correlators frequently make use of walkby data collection systems. Noise loggers are available to connect to some existing AMI systems.
Level monitors and alarms	Level monitors are used to check the flow of water or wastewater (sewage) in open or unpressurised systems. Equipment may need to be ATEX (gas safe) in some conditions
SCADA (supervisory control and data acquisition) equipment	Water treatment works, sewage treatment works and water and waste water networks make extensive use of SCADA systems. Examples include remote pumping and valve controls. An AMI network offers an alternative to control methods.

3. Water customers modelling

Despite the increasing pressure on water resources posed by growing population as well as climate and land use change, water customers modelling has received less attention than studies focused on the water supply expansion.

Traditionally, customers' models focus on describing the water demand at different temporal and spatial scales. At the lowest resolution, studies have been developed, mostly in the 1990's, to model water demand at the urban or block group scale, using low time resolution (i.e., above daily) consumption data retrieved through billing databases or experimental measurement campaigns on a quarterly or monthly basis. The main goal of these works is to inform regional water systems planning and management on the basis of estimated relationships between water consumption patterns and socio-economic or climatic drivers [Hous2011]. The advent of smart meters [Maye1999] in the late 1990's made available new water consumption data at very high spatial (household) and temporal (from several minutes up to few seconds) resolution, enabling the application of novel data analytics tools to develop accurate characterizations of end-use consumption behaviours of the water customers.

From a review of 131 scientific papers and project reports [Comi2015], we defined a general 4-step procedure (see Figure 10) to study residential water demand modelling and management relying on the high-resolution data nowadays available: (*i*) ***data gathering***, (*ii*) ***end-use characterization***, (*iii*) ***user modeling***, (*iv*) ***design and implementation of personalized water demand management strategies***. In particular, water customers modelling refers to steps 2 and 3 of this procedure, which are extensively discussed in the next two sections. It is worth noting that so far the water customers modelling has been mainly explored within academic research, as confirmed by the count of the publications reviewed (Figure 11).

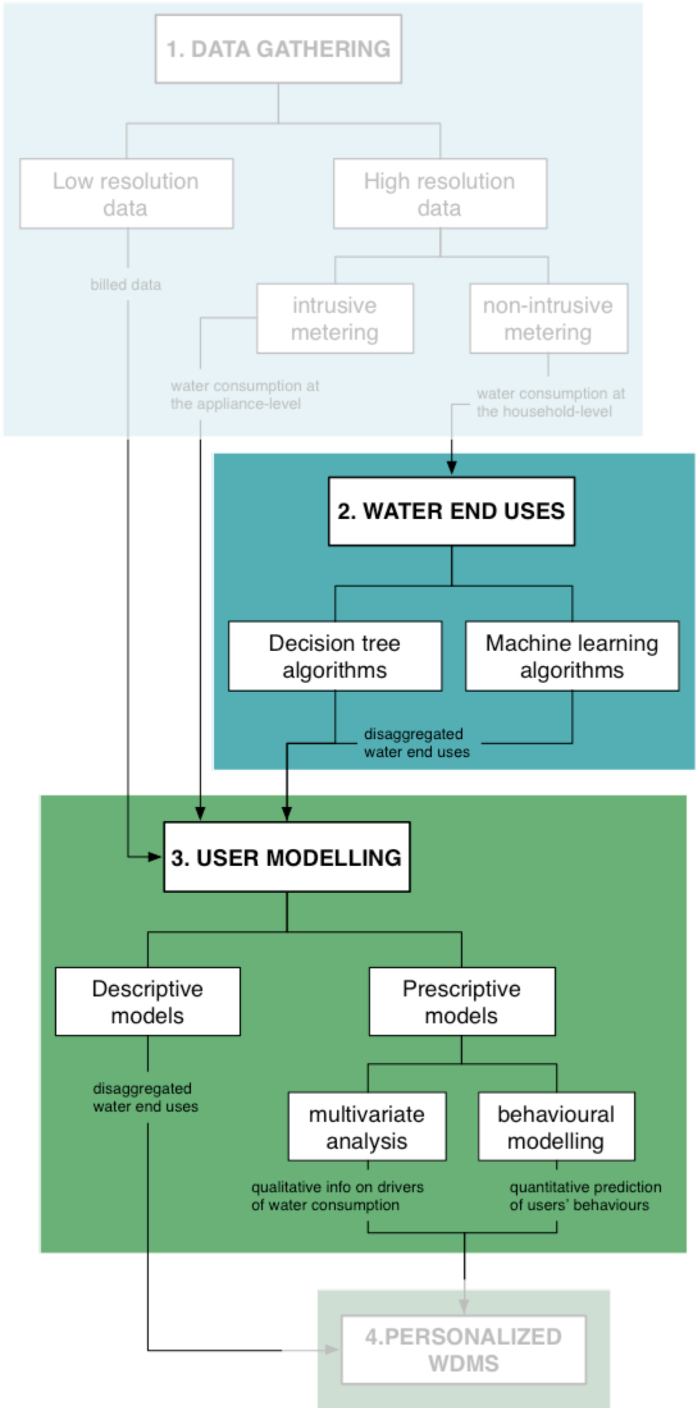

Figure 10: Flowchart of the general procedure for studying residential water demand modelling and management.

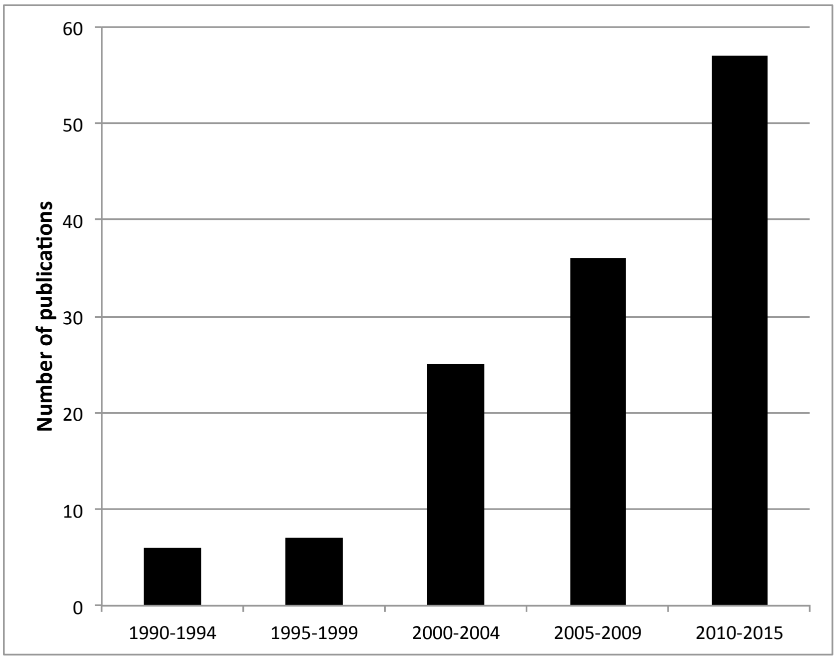

Figure 11: Five-years count of the 131 publications reviewed in [Comi2015].

3.1 End-use characterization

Non-intrusive metering requires disaggregation algorithms to breakdown the total consumption data registered at the household level into the different end-use categories. In the water research literature, several studies have been conducted in the last two decades using a variety of single or mixed disaggregation methods, such as household auditing, diaries, high resolution flow meters and pressure sensors (see Table 2).

According to the methodology adopted, we can identify two main approaches: ***decision tree algorithms***, namely Trace Wizard® [DeOr1996] and Identiflow® [Kowa2003], and ***machine learning algorithms***, namely HydroSense [Froe11] and SEQREUS [Beal2011]. Recently, the disaggregation of medium resolution water data (i.e., hourly data) has been explored by means of the water use signature patterns method [Card2013a,b], namely a combination of feature selection, unsupervised learning, and cluster evaluation.

Table 2. List of scientific publications contributing to the end-use charaterization.

Reference	Location	Disaggregation algorithm	Number of households
Froe2011	NA	HydoSense	5
Hein2007	New Zeland	Trace Wizard	12
Maye2004	USA	Trace Wizard	33
DeOr1996	USA	Trace Wizard	NA
Kowa2003	UK	Identiflow	250
Kowa2005	UK	Identiflow	NA
Beal2011a	Australia	SEQREUS	1500
DeOr1994	USA	Trace Wizard	16
Maye1995	USA	Trace Wizard	16

DeOr2000	USA	Trace Wizard	10
Loh2003	Australia	Trace Wizard	720
Robe2005	Australia	Trace Wizard	100
Mead2009	Australia	Trace Wizard	10
Will2009a	Australia	Trace Wizard	200
Will2009b	Australia	Trace Wizard	151
Aqua2011	USA	Trace Wizard	209
Nguy2014	Australia	SEQREUS	3
Nguy2013a	Australia	SEQREUS	252
Nguy2013b	Australia	SEQREUS	3 (out of 252)
Maye2000	USA	Trace Wizard	37 (out of 1188)
Maye2003	USA	Trace Wizard	33
DeOr2011	USA	Trace Wizard	1000
Card2013a	Australia	water use signature patterns	11,000
Card2013b	Australia	water use signature patterns	187

3.1.1 Trace Wizard

Trace Wizard® [DeOr1996] is a commercial software (recently replaced by an on-demand service developed and managed by Aquacraft Inc) which applies a decision tree algorithm to interpret magnetic metered flow data based on some basic flow boundary conditions (e.g., minimum/maximum volume, peak flow rate, duration range, etc.).

The disaggregation process is structured in the following steps:

1. Conduct a detailed water device stock inventory audit for each household to determine the efficiency rating of each household appliance/fixture;
2. Household's occupants should complete a diary of water use events over a one-week period to gain information on their water use habits;
3. Analysts use water audits, diaries, and sample flow trace data for each household to create specific templates that serve to match water end-use patterns depending on some basic flow boundary conditions.
4. Based on the developed templates, stock survey audit, diary information and analysts' experience, the individual water end-uses are disaggregated.

It is worth noting that the human resource effort required by Trace Wizard makes the overall process extremely time and resource intensive, with the quality of the results that is strongly dependent on the experience of the analyst in understanding flow signatures. It has been estimated that the classification of two weeks of data approximately requires two hours of works by the analyst and attain an average classification accuracy of 70% [Nguy2013a]. In addition, the prediction accuracy of Trace Wizard is significantly reduced when more than two events occur concurrently [Maye1999]. However, Trace Wizard still has an edge on disaggregation techniques and has been used in several research works and projects [DeOr1994; Maye1995; DeOr1996; Maye1999; DeOr2000; Loh2003; May2004; Robe2005; Hein2007; Mead2009; Will2009a; Will2009b; Aqua2011; DeOr2011a].

3.1.2 Identiflow

Similar to Trace Wizard, Identiflow® [Kowa2003] relies on a decision tree algorithm to perform a semi-automatic disaggregation of the total water consumption at the household level. Identiflow uses fixed physical features of various water-use devices (e.g., volume, flow rate, duration, etc.) to classify the different end-use events. Although Identiflow has shown better performance than Trace Wizard (i.e., 74.8% accuracy in terms of the correctly classified volume over 3,870 events [Nguy2013a]), its classification accuracy strongly depends on the physical features used to describe each fixture/appliance. Two different water events are likely classified into the same category if they exhibit similar physical characteristics. Moreover, it fails to classify events when the customers replace old devices with modern ones, since the physical characteristics of these latter might be completely different compared to the old ones.

3.1.3 HydroSense

HydroSense [Froe2011] is a probabilistic-based classification approach, which relies on data collected through pressure sensors. Water end-use events are classified with respect to the unique pressure waves that propagate to the sensors when valves are opened or closed. Specifically, when a valve is opened or closed, a pressure change occurs and a pressure wave is generated in the plumbing system. Based on the pressure wave (which depends on the valve type and its location), water end-use events are classified by using advanced pattern matching algorithms and Bayesian probabilistic models.

HydroSense has been demonstrated to attain very high levels of classification accuracy, namely 90% and 94% with one or two pressure sensors, respectively [Froe2011]. However, the calibration of the algorithm requires an intrusive monitoring period with the installation of a much larger number of pressure sensors connected to each water device (i.e., Froeh2011 used 33 sensors in a single household). This requirement significantly constrains the portability of this approach to a wide urban context, as it would entail large costs and privacy issues.

3.1.4 SEQREUS

The SEQREUS approach [Beal2011a] proposes a combination of Hidden Markov Models (HMMs), Dynamic Time Warping (DTW), and time-of-day probability to automatically categorize the collected data at the household level into particular water end-use categories. To minimize the intrusiveness of the approach, the ground truth for the calibration (i.e., a set of disaggregated end-use events) is obtained using Trace Wizard. Then, the SEQREUS approach works as follows:

1. The disaggregated data are used for training multiple HMMs, one for each end-use category (excluding the inconclusive event);
2. The physical characteristics of each end-use category are used to refine the estimate given by the HHMs (e.g., any shower event with a volume less than 7 litres or any bathtub event with duration less than 4 minutes is placed in the inconclusive event for future analysis);
3. A DTW algorithm determines if any event in the inconclusive dataset is similar to an event in categories having clearly defined consumption patterns, namely the clothes washer and dishwasher cycles;
4. Time of day probability is used to assign inconclusive events to an end-use category.

Testing on three independent households located in Melbourne (Australia) demonstrated a high prediction accuracy, namely between 80% and 90% for the major end-use categories [Nguy2014]. However, the method still requires human input to achieve such levels of recognition accuracy, such as for the classification of inconclusive events supported by DTW and for manually classifying combine events [Nguy2013a; Nguy2013b].

3.2 Customers modelling

The customers modelling phase aims at representing the water demand at the individual (household) level, possibly as determined by natural and socio-psychographic factors as well as by the users' response to different water demand management strategies (WDMS). When the households are equipped with smart meters, the disaggregated end-uses replace the consumption at the household level.

In the literature, two distinctive approaches exist (see Table 3): ***descriptive models***, which focus on the analysis of observed water consumption patterns, and ***predictive models***, which provides estimate of the water demand as determined by natural and socio-psychographic factors, and in response to different WDMS.

Table 3: list of scientific publications contributing to the water customers modelling. The multivariate analysis is classified in E=economic-driven studies, GS=geo-spatial studies, P=psychographic studies).

Authors	Location	Modelling approach	Multivariate analysis	Behavioural model	Spatial scale
Loh2003	Australia	descriptive	-	-	household
Gato2011	Australia	descriptive	-	-	household
SDU2011	USA	descriptive	-	-	household
SJES2011	USA	descriptive	-	-	household
Card2013c	Australia	descriptive	-	-	household
Beal2013	Australia	descriptive	-	-	household
Beal2014	Australia	descriptive	-	-	household
Guru2015	Australia	descriptive	-	-	household
Guru2014	Australia	descriptive	-	-	household
Beal2014	Australia	descriptive	-	-	household
Cole2013	Australia	descriptive	-	-	household
Willis2011	Australia	descriptive	-	-	household
Beal2011	Australia	descriptive	-	-	household
Magg2015	USA	predictive	E+GS+P	single	household
Makk2015	Australia	predictive	E+P	single	household
Hous2011	NA	predictive	E+GS+P	single+multi	NA
Schn1991	USA	predictive	E	-	district
Lyma1992	USA	predictive	E+GS+P	single	household
Espe1997	NA	predictive	E	-	NA
Dalh2003	NA	predictive	E	-	NA
Miao90	USA	predictive	GS	-	urban
Pole2010	USA	predictive	GS	-	census tracts
Lee2011	USA	predictive	GS	-	household
Olms2007	USA	predictive	E	-	household
Will2013	Australia	predictive	P	-	household
Homw1994	USA	predictive	AR	-	urban
Moli1996	Italy	predictive	AR	-	urban
Altu2005	Turkey	predictive	AR	-	urban
Alvi2007	Italy	predictive	AR	-	household
Nass2011	Iran	predictive	AR	-	urban
Broo2002	NA	predictive	E	-	NA

Olms2009	NA	predictive	E	-	NA
Rose2010	Jordan	predictive	E	-	household
Qi2011	USA	predictive	E	-	urban
Griff1991	USA	predictive	GS	-	district
Zhou2000	Australia	predictive	GS	-	urban
Zhou2002	Australia	predictive	GS	-	district
Full2004	USA	predictive	GS	-	urban
Aly2004	USA	predictive	GS	-	urban
Gato2007	Australia	predictive	GS	-	urban
Ball2007	USA	predictive	GS	-	urban
Ball2008	USA	predictive	GS	-	census tracts
Lee2008	USA	predictive	GS	-	census tracts
Pras2009	Korea	predictive	GS	-	urban
Corb2009	NA	predictive	GS	-	NA
Chan2010	USA	predictive	GS	-	household
Lee2010	USA	predictive	GS	-	urban
Syme2004	Australia	predictive	P	-	household
Went2007	USA	predictive	P	-	household
Fox2009	UK	predictive	P	-	household
Russ2010	NA	predictive	P	-	NA
Graf2011	10 OECD countries	predictive	P	-	household
Suer2012	USA	predictive	P	-	household
Mato2014	Portugal	predictive	P	-	household
Tale2014	Australia	predictive	P	-	household
Roma2014	Italy	predictive	P	-	water utility
Gato2006	Australia	predictive	GS	single	urban
Rose2007	Jordan	predictive	GS+P	single	household
Blok2010	Nederland	predictive	P	single	household
Cahi2013	USA	predictive	P	single	household
Benn2013	Australia	predictive	GS+E+P	single	household
Rixo2007	Australia	predictive	E+P	multi	household
Gala2009	Spain	predictive	P	multi	household
Chu2009	China	predictive	E+P	multi	household
Kant2014	NA	predictive	GS+P	multi	household
Jorg2009	NA	predictive	P	-	household
Kenn2008	USA	predictive	E+GS+P	single	household
Makk2013	Australia	predictive	E+P	single	household

3.2.1 Descriptive models

The first class of models, namely descriptive models, aims at analysing the observed water consumption behaviours of water customers. Depending on the resolution of the data available, the analysis can focus on identifying aggregated consumption patterns or on defining customers' profiles on the basis of the disaggregated end-uses (e.g., [Loh2003; SDU2011; SJES2011; Gato2011; Willis2011; Beal2011b; Beal2013; Card2013c; Cole2013; Beal2014a; Beal2014b; Guru2014; Guru2015]).

The construction of descriptive models allows studying historical trends to build a user consumption profile that constitutes the baseline for identifying the most promising areas where conservation efforts may be polarized (e.g., restriction on irrigation practices in case gardening represents the dominant end-use). However, the majority of these models cannot be used to predict the water savings potential of alternative WDMS, unless combined with control group experiments to observe users responses [Cahi2013].

3.2.2 Predictive models

The second class of models, namely predictive models, aims at estimating the water demand at the individual (household) level or the corresponding disaggregated end-uses. Some works developed predictive models that mostly provide short-term forecast of the water demand on the basis of time series analyses (e.g., [Homw1994; Moli1996; Altu2005; Alvi2007; Nass2011]). Yet, these approaches are ineffective in supporting the design and implementation of WDMS as the predicted water consumption of a user is not related to his socio-psychographic factors or his response to different WDMS.

An alternative approach can be structured in the following two sub-steps: (*i*) ***multivariate analysis***, which consists in the identification and selection of the most relevant inputs to explain the pre-selected output (i.e., individual water consumption), and (*ii*) ***behavioural modelling***, which means model structure identification, parameter calibration and validation.

The multivariate analysis phase (i.e., variable selection as called in data-driven modelling [Geor2000]) is a fundamental step to build predictive models of urban water demand variability in space and time. In most of the works, the identification of the most relevant drivers relies on the results of correlation analysis between a pre-defined set of variables (candidate drivers) and the water consumption data. Depending on the specific domains from which the candidate drivers are extracted, we can distinguish three main approaches:

- ***economic-driven studies***, which focus on studying the correlation between water consumption and purely economic drivers, such as water tariff structures or water price elasticity (e.g., [Schn1991; Espe1997; Broo2002; Dalh2003; Olms2007; Olms2009; Rose2010; Qi2011]);
- ***geo-spatial studies***, which assess the correlation between hydro-climatic variables and seasonality with water consumption (e.g., [Miao1990; Griff1991; Zhou2000; Zhou2002; Full2004; Aly2004; Gato2007; Ball2007; Ball2008; Lee2008; Pras2009; Corb2009; Chan2010; Pole2010; Hous2010; Lee2011]);
- ***psychographic-driven studies***, which infer the influence of users' personal attributes on their water consumption, including income, family composition, lifestyle, and households' physical characteristics, such as number of rooms, type, presence of garden (e.g., [Syme2004; Went2007; Fox2009; Jorg2009; Russ2010; Graf2011; Will2011; Sue2012; Mato2014; Tale2014; Roma2014]).

In most of the literature, the customers modelling is limited to the multivariate analysis, which however provides only qualitative information to water managers, water utilities, and decision makers. Only few works completed the second phase (i.e., behavioural modelling) and provide a quantitative prediction of the water demand at the household level, thus representing better decision-aiding tools as they can use these models to develop what-if analysis as well as scenario simulation and analysis.

The construction of behavioural models aims at the identification, calibration, and validation of mathematical models, which describe the water demand (i.e., output variable) as a function of the drivers identified in the multivariate analysis. In the behavioural modelling literature, we can identify a first class of models, named ***single-user models***, which describe the consumption behaviour of individual customer considered as isolated entities. These works (e.g., [Lyma1992; Gato2006; Rose2007; Kenn2008; Blok2010; Cahi2013; Magg2015]) generally rely on dynamic models or Monte Carlo techniques based on sampling of statistical distributions describing users and end-uses (e.g., number of people per household and their ages, the frequency of use, flow duration and event occurrence likelihood). Water demand patterns can be then estimated via model simulation and comparison of the results with the observed data. Yet, sampling a probability distribution often reduces the heterogeneity of the water users. Recently, different approaches (e.g., [Benn2013; Makk2013; Makk2015]) combining non-parametric statistical tests and advanced regression models to identify key water consumption drivers and forecast urban water consumption have been demonstrated to successfully identify the main drivers of water consumption and to attain good forecast accuracy levels.

A second class of behavioural models, named ***multi-user models***, instead focus on studying the social interactions and influence/mimicking mechanisms among the water customers. The majority of these works rely on multiagent systems [Shoh2009], where each water customer (agent) is defined as a computer system situated in some environment and capable of autonomous actions to meet its design objectives, but also able to exchange information with the neighbour agents and change its behaviour accordingly [Wool2009]. The adoption of agent-based modelling offers several advantages with respect to other approaches [Bona2002; Bous2004]: (1) it provides a more natural description of a system, especially when it is composed of multiple, distributed, and autonomous agents, (2) it relaxes the hypothesis of homogeneity in a population of actually heterogeneous individuals, (3) it allows an explicit representation of spatial variability, and (4) it captures emergent global behaviours resulting from local interactions. As a consequence, multiagent systems can be employed to study the role of social network structures and mechanisms of mutual interaction and mimicking on the behaviours of water customers (e.g., [Rixo2007; Gala2009]), to estimate market penetration of water-saving technologies (e.g., [Chu2009]), and to simulate the feedbacks between water consumers and policy makers (e.g., [Kant2014]).

3.3 Scientific and industrial challenges and exploitation potential

3.3.1 End-use characterization

Given the small number of algorithms for managing water flow data, there is still a large room for developing new methods addressing the major limitations of the existing approaches:

1. First, most of the approaches used in the water sector requires time consuming expert manual processing and intensive human interactions via surveys, audits and water event diaries, while the development of automatic procedures is fundamental to further extend the application of these methods beyond experimental trials and research projects [Stew2010]. Moreover, the existing methods have limited accuracy in identifying overlapping events.
   The disaggregation problem has been addressed in other research fields as a general problem of ***blind identification***, or output-only system identification [Reyn2012]. The real state of the system (i.e., the set of the working states and water consumption of each single fixture in the household) is unknown and only observations of the system's output (i.e., the total water consumption) are available. Starting from the 1990's, several techniques have been proposed to address blind identification problems in different research field, such as signal processing, data communication, speech recognition, image restoration, seismic signal processing (see [Abe1997] and references therein).
   Recently, this problem has been largely studied in the energy sector to develop automatic disaggregation methods, also known as Non Intrusive Load Monitoring algorithms, which aim at decomposing the aggregate household energy consumption data collected from a single measurement point into device-level consumption data

(for a review, see [Zeif2011; Zoha2012; Carrie2013] and references therein). These methods show promising results and seem effective also up to 6-10 appliances [Figu2014; Mako2013]. Yet, the portability of such techniques in the water field has not been assessed. Some additional challenges in characterizing water end-use events might be introduced by the larger human dependency than the one of electric appliances, which are generally more automatic. These concerns primarily involve manually controlled fixtures (e.g., bathtubs, showers, faucets), which can be used not at the maximum capacity [Froh2009].

2. The second main open question relates to the acquisition of the ground truth for initial calibration. All the algorithms used for disaggregating water data, but also the majority of the ones used for energy data, need an intrusive period to collect a dataset of disaggregated end-use events, which incurs extra cost and human effort, ultimately challenging their large-scale application. Researchers are actively looking to devise completely unsupervised or semi-supervised methods that avoid the effort of acquiring the training data (e.g., [Gonc2011; Pars2014]).
3. Finally, most of the approaches are currently focused on correctly characterizing the on/off status of the devices and, possibly, the fraction of total energy assigned correctly, while their performance in reproducing the timings and frequencies of each device are lower [Batr2014]. Yet, timings and frequencies represent key information to understand customers' behaviours and design personalized demand management strategies (e.g., deferring the use of some appliances to peak-off hours).

3.3.2 Customer modelling

Given the current status of the customers modelling studies and the room for improvement given by the use of high resolution, smart metered data, several open challenges and future directions emerge:

1. The first open question in terms of descriptive models concerns matching the analysis of the water consumption patterns with the potential drivers generating the observed customers behaviours. This would allow validating the results of the classification of the users on the basis of their consumption and understanding if this latter is a good proxy representing different characteristics of the users.
2. The use of spatially explicit models to take advantage of the high temporal and spatial resolution of smart metered data is often hindered by the aggregation of individual household data to a larger spatial scale to protect customers' privacy as well as by the difficulties in collecting and sharing data coming across multiple water authorities and administrative institutions [Hous2011].
3. The second major challenge relates to the validation of the agent-based behavioural models. As in the construction of complex process-based models, accurately describing the single customer (agent) behaviour and connecting multiple customers within an agent-based model does not ensure the validity of the results, although these latter are contrasted with observed data. In addition, given the large number of assumption and parameters, the problem of equifinality (i.e., the potential existence of multiple, alternative parameterization leading to same simulation outcomes) has to be addressed [Ligt2010].
4. Finally, it is worth noting that the type of candidate drivers considered in the customers modelling process impacts the statistical representativeness of the results. The construction of sufficiently large datasets to estimate the relationships between water consumption data and the uncontrolled drivers (i.e., hydro-climatic and psychographic variables) is generally easy, provided that the time period is long enough and the number of involved users is sufficiently high. On the contrary, in most of the cases there is a single historical realization of the controllable drivers, namely the ones subject to human decisions (e.g., the existing pricing scheme). In such cases, the response of the customers to different options is generally estimated via economics principles or surveys. Yet, economic principles introduce a priori general rules that might be inaccurate in characterizing the specific customers under study, and the surveys provide only a static snapshot of the system conditions. The

potential for using experimental trials (e.g., [Gilg2006; Bori2013; Fiel2013]) and gamification platforms [Muhl2008] to validate behavioural models results by retrieving information to the real customers in large-scale applications has not been tested yet.

4. Water utilities and water market

This section reviews status and prospects of a specific segment of the broader water market, that is, investment undertaken by water utilities in smart metering, and more generally in smart water systems. To this aim, it leans upon empirical evidence and the conceptual framework that were illustrated by an early exploitation plan for the SmartH2O project [SH2O2014] and surveys available information on smart meter market and regulation.

4.1 Current status

Water market concerns equipment, plants, works, services and materials that are offered by manufacturers, contractors, consultants, technology vendors and other suppliers to water utilities. A widely cited estimate of the global expenditures in water market reaches 557 USD billion in 2013 [UKWR2014]. The same source reports a narrower estimate, which is obtained by focusing on global capital expenditures of utilities only. Under this definition, the global market size is worth 195 USD billion in 2013. Nevertheless large variation can be expected in utilities' investment conducts, as water resource endowment, institutions and industry organization vary highly between countries [SH2O2014].

For instance, both Italy and Switzerland exhibit substantial fragmentation of utility industry, dominance of municipal ownership, very low water tariffs, and high levels of per-capita water consumption. At the same time, investment is by far more intense in Swiss utilities than in Italian utilities owing to the adoption and enforcement of stricter environmental regulation. In this respect Swiss and German water industries are more similar, even though the latter shows higher tariffs and lower levels of water consumption. By contrast medium levels of tariffs and consumption are reported for both France and UK, whose water industries are organized in quite different ways. Private ownership and a national regulatory authority are the most salient treats of the UK water and sewerage industry, while public-private partnership and local authorities are common in France.

4.1.1 Smart metering market: investment assessment and estimates

More particularly European utilities are likely to vary greatly with respect to their investment potential towards smart meters and smart water systems. A taxonomy of water utilities as possible targets users of SmartH2O platform was developed by a previous report of SmartH2O project (see [SH2O2014] for further details). Availability of financial resources, i.e. internal financial health and compliance with binding investment requirements (e.g. concerning urban wastewater treatment), and predictability of management behavior, that is civil-servant or business-like attitude v. managerial discretion, are critical dimensions for a preliminary decision that the utility is worth being analyzed as a possible target user (Table 4).

Table 4: First step: Is the utility worth analyzing further?

	Financial resources (Utility)	
Management style (Utility)	***Fair or good***	***Poor***
Business-like or Civil servant	**Further analysis**	~~**Financially constrained**~~
Discretionary	~~**Unpredictable**~~	~~**Unpredictable**~~

Source: [SH2O2014]

Once the utility is acknowledged to be worth an in-depth analysis, Table 5 illustrates how to combine management style and external dimensions in order to assess the utility's significance as a target user. So-called external dimensions include operational needs for water conservation (water scarcity, topology of the network, maintenance costs, energy costs, water treatment costs), economic sustainability (economic regulation in terms of delivery mode, presence of incentive regulation, or public subsidies), utilities' quest for legitimacy and reputation (institutional and social pressures from various stakeholders).

Table 5: Second step: May the utility be a target user?

	External dimensions		
Management style	***Operational needs (Local area)***	***Economic sustainability (Country)***	***Quest for legitimacy & reputation (Country)***
Business-like	**+**	**++**	**++**
Civil servant	**++**	**+**	**+**

Source: [SH2O2014]

The utility taxonomy indicates that adoption of smart water systems depends on drivers that are highly specific to individual utilities. Thus quantification is not trivial, and it does not come as a surprise that macro-level figures for smart metering investments in global water industry vary greatly, with estimates for 2010 ranging from $214 to $525 million [UKWR2014]. Metering market includes different technologies; smart meters were estimated to cover around 6% out of global water metering markets in 2009. The global smart water market, including automation and control, design and engineering services, ICT, software and analytics, besides smart meters, is estimated to reach almost to $6 billion in 2010 [Fros2012].

4.1.2 Organization of smart metering activities in network industries

A fruitful perspective to analyze the smart metering business in the water industry is an account of the way in which smart metering activities are developing and organizing in other network industries, mainly electricity and gas. Prior to liberalization reforms, the electricity and gas industries were organized as vertically-integrated monopolies and metering activities were regarded as part of the monopoly supply business. Metering quality, mainly measurement frequency and precision, was subject to regulation and metering costs were passed on users via regulated metering tariffs.

Over the liberalization of energy markets, the metering activities have been kept bundled to the distribution segment, a regulated local monopoly both in electricity and gas industries. Bundling distribution and metering was coherent with some antecedents of energy markets. First of all, physical interconnection of metering equipment to the distribution network made a model in which meters were considered as a network component rational and effective. Second, the prevalent model in Europe, both in electricity and gas, entailed bundling of downstream activities, i.e. distribution and retail. In this context, the downstream vertically-integrated utility was the only user of meter data and became naturally entitled to take charge of meter responsibility as well. Third, the traditional meters did not provide services besides supplying data necessary for billing. This narrowed the scope for specialized metering operations.

In the last years, the above described scenario has evolved considerably. Energy markets and the water industry have been subjected to significant changes. Technological progress and the introduction of smart metering have transformed the way we look at the metering business. As reforms of energy markets have been going on all over the European Union, unbundling and retail liberalization have broadened the set of market participants that rely on meter data to settle economic transactions. Suppliers (often new entrants) need meter data to design price options as well as to invoice customers and to assess each customers' potential for demand management; transmission and distribution system operators need meter data to invoice retailers for network services; the system operator needs meter data to assess imbalances.

From a technological point of view, smart metering relies on telecommunication systems and requires communication network operation, a highly specialized activity, traditionally beyond the core businesses of electricity, gas and water suppliers. Moreover, telecommunications bring potentially significant scale and scope economies, as the same communication infrastructure can serve multiple metering purpose, e.g. electricity, gas, water, heat, as well as additional services (home security and safety monitoring, public lighting, street security, etc.).

As a consequence, electricity, gas and/or water suppliers cannot be regarded any more as the obvious candidate to deploy and operate communication infrastructures shared by multiple purpose metering systems.

4.1.3 Multiservice smart metering in Italy

Recently the Italian Energy and Water Regulatory Authority (AEEGSI) has launched an initiative aimed at trialing multiservice smart meters targeted at electricity, gas, water and district-heating sectors. The project involves approximately 60,000 customers in 9 large and medium-sized cities (Turin, Reggio-Emilia, Parma, Modena, Genoa, Verona, Bari, Salerno and Catania). The initiative is funded by a 10 cents *una tantum* contribution charged to all Italian natural gas customers. As a result, the involved customers will be able to check their energy, gas and water consumption by connecting to a single web portal and, depending on the city, they will enjoy trials of other related services (noise sensors, garbage bin sensors to detect and forecast fill-levels, leakages sensors on the water pipelines, etc.). For reasons that will be discussed in the remaining part of Section 4, deployment and operation of smart metering systems are required to be contracted to third-party operators completely independent from network operators.

4.2 Scientific and industrial challenges and exploitation potential

4.2.1 Market forecasts

Market research supports a positive expectation toward the growth of global market for smart metering. Forecasts for smart metering investments in global water industry by 2020 range from $3 to $10 billion [UKWR2014]. Smart water meters are expected to cover a 29% share of total metering investment worldwide by 2020 [Fros2012]. The widely-defined smart metering business can be split into two broad groups of activities: *meter availability services*, consisting in making the metering infrastructure and functionalities available to the party in charge of collecting data, and *data management services*, consisting in ensuring that the entitled parties have access to data, when requested, in the correct format. The global smart water market, i.e. availability and data management services, is estimated to reach $23 billion by 2020, with Europe amounting to a 24% share of the global market [Fros2012].

4.2.2 Smart metering in European countries: Cost-benefit assessment

At EU level, Member States have been pushed to provide cost-benefit analyses for the purpose of assessing the economic sustainability of smart metering systems deployment. The following table reports summary information on the results of the cost benefit assessments performed in Great Britain, France, Germany and the Netherlands. Figures are sourced by [Cerv2014].

It should be emphasized that cost-benefit analyses performed in different countries are not directly comparable because of differences in: targeted sectors (electricity, gas); smart metering systems architectures (single purpose vs. multi-utilities, single customer vs. neighborhood data level concentrators); smart meters features (data collection, remote generation control); project size (share of smart meters on total customers).

Table 5: Cost-benefit analysis in selected European countries (source [Cerv2014]).

Cost-benefit Assessment of Smart Metering Systems Deployment in some EU countries					
	Great Britain	**France**		**Germany**	**The Netherlands**
Sector	Electricity&Gas	Electricity	Gas	Electricity	Electricity&Gas
Deployment	2014-2019	2013-2018	2011-2022	2012-2022	2014-2020
#Meters(Mln)	49	35	11	38.5	14.6
Overall costs (€ Bln)	14.4	3.8	1.2	20.8	2.8
- Rollout investment costs	8.3	3.8	1.0	8.5	-
- Operating costs	6.2	-	0.2	12.3	-
Investment cost/meter	€ 168.5	€ 108.6	€ 94.8	€ 220.8	€ 192.1
Expected benefits (€ Bln)	22.3	3.9	1.28	20.7	3.6
- Lower customer care cost	13.2	3.9	0.5		2.1
- Energy conservation	7.7		0.2		1.5
- Others	1.4		0.58		
Net Present Value (€ Bln)	7.9	0.1	0.07	-0.1	0.8

Anyway, cost-benefit analyses carried out in different countries provide different conclusions and results seem to be very sensitive to potential energy savings. This is crucial when results of cost-benefit analyses carried out in electricity and gas sectors have to be generalized with respect to the water sector. Despite the room for water savings is considerable, the resource cost in the water sector is far more difficult to assess.

4.2.3 Challenges for the organization of smart metering activities

The organization of smart metering business must be assessed for the two groups of metering-related activities separately, both from economic and legal perspectives. The economic assessment must focus on the relative merits of competition as compared to monopoly. The legal assessment must analyze how and to what extent general EU law and sector-specific regulation (energy, water, electronic communications) can have an impact on both the smart metering business regulation in the Member States and the behavior of market actors.

From an economic point of view, the relevant dimensions are: the need for standardization, service and transaction costs and expected competitive dynamics. On the one hand, meter availability and data management services share the reliance on standardization both for design and technology solutions. On the other hand, cost structures are very different for the two kind of services. Meter availability services are characterized by relevant sunk costs, unlike data management services, which exhibit a cost structure similar to any other information technology service. In case of energy and/or water supplier's switch, transaction costs are expected to arise for both groups of services because of transactions and information exchanges, when different energy and water suppliers procure smart metering services from different meter companies.

To sum up, the economic assessment seems to suggest distinct forms of expected market organization for the two groups of activities. Meter availability services can be organized as a regulated monopoly because of the relevant sunk costs and the limited scope for benefits coming from competition. Data management services, instead, are suitable for competition for the market, i.e. a periodic selection of the provider through some form of competitive process.

4.2.4 Regulatory challenges: Mandatory roll-out and legal monopoly granting

From a legal point of view, the two issues on the table are: *mandatory roll-out* and *legal monopoly granting*. Mandatory roll-out implies that one or more operators are obliged to install metering infrastructures for all customers in a given territory. This may be rational to reach the critical mass and to address network externalities.

The legal monopoly granting both on meter availability and data management services may be introduced in the Member States pursuant to Article 106(1) of the TFEU (Treaty on the Functioning of the European Union), as long as it is shown to be necessary for the fulfillment of a Service of General Economic Interest. Of course, the legal monopoly would be less exposed to attacks if bounded in some way. For instance, it would be more acceptable on meter availability than on data management services; it would be more justifiable if combined with mandatory roll-out; it should be of limited duration and awarded via a competitive process which creates competition for the market; it should be awarded to a third-party operator without any other role in the sector.

The legal monopoly granting will entail some forms of regulation to be put in place. In this case, aside from tariffs and quality, the most relevant issue to be regulated is the third-party access. Such regulation should include mainly obligations of transparency and non-discrimination.

As far as the legal framework is concerned, privacy and data protection law deserve a separate discussion, which will be provided in the next section.

4.2.5 Regulatory challenges: privacy and data protection

When we talk about privacy and data protection in the EU, the two pillars to be taken into account are the Data Protection Directive (Directive 95/46) and the e-Privacy Directive (Directive 2002/58). However, on the one hand, the first one will supposedly be replaced by a forthcoming comprehensive regulatory framework, directly applicable in all Member States (see Commission Communication "Safeguarding Privacy in a Connected World – A European Data Protection Framework for the 21st Century"). On the other hand, the e-Privacy Directive is specific to electronic communications and it is accordingly not always relevant for the smart metering systems (smart metering systems do not constitute fully electronic communications services, but only the data transfer from meters to the head-end does so).

At EU level, privacy and data protection issues have been ubiquitous in the policy discussions on the introduction of smart metering systems, within a more comprehensive discussion on the new smart grid paradigm. Within the Smart Grids Task Force created in 2009, one expert group was specifically established to produce "Regulatory Recommendations for Privacy, Data Protection and cyber-security in the Smart Grid

Environment”.

Privacy and data protection legislation is applicable when data constitutes *personal data*. Article 2 of the Data Protection Directive defines *personal data* as “any information relating to an identified or identifiable natural person”. Therefore, what makes data personal is not so much the possibility to get insight into the life of private persons, but rather their direct link to a well-defined person. According to this definition, data collected and processed through smart metering systems are personal data when linked to an individual identifier.

When personal data have to be dealt with, two kinds of entities should be identified: the *data controllers* and the *data processors*. A *data controller* is a natural or legal person, public authority or agency which determines the purposes and means of the processing of personal data (Article 2(d) of the Data Protection Directive). Factually, the data controller ensures that data protection legislation is met and protects the rights of users whose data have been collected, i.e. *data subjects*. The *data processors* are the entities which use personal data in their operations pursuant to a list of legitimate grounds, such as consent, contractual obligations, performance of public tasks, legal obligations and the legitimate interests of the data controller. The Working Party of Data Protection authorities set up under Article 29 of the Data Protection Directive (WP29) has suggested that the entity in charge of installing and operating smart metering systems should be the data controller in any event. Even National Regulatory Authorities (NRAs) may be identified as data controllers if they use personal data for policy and research purposes.

The need to consider privacy and data protection issues has encouraged policy makers in the EU to recommend that Member States pay great attention to information security in the smart metering systems since the very early stages of their deployment.

Firstly, the European Commission has recommended that a Data Protection Impact Assessment (DPIA) should be carried out prior to the roll-out of smart metering systems. A DPIA assesses the risks that may arise from the breach of privacy and data protection laws. Actually, the Data Protection Directive does not make DPIAs compulsory, but it is to be applied voluntarily by relevant actors in the markets.

Secondly, considering that smart metering systems are being conceived and deployed once privacy and data protection is already well established, the WP29 has pushed for the Member States following Data Protection by Design (DPbD), an integrated approach whereby information security features should be included into the smart metering systems before they are rolled-out. DPbD seeks to embed data protection at every level of the smart metering system development, from conception to deployment.

5. Gamification and serious games applications

In this Section, we overview the recently emerged sectors of gamification of business applications and of digital games applied to non-entertainment tasks from a technical and design point of view.

These technologies and approaches exploit social and persuasive factors in order to promote the change of behaviour with respect to a target issue, and have been recently applied to behavioural change for sustainability.

The Deliverable D8.1 already introduced they key elements of Gamification, "the use of game mechanics and experience design to digitally engage and motivate people to achieve their goals" [Gart2014] and its market trends and segmentation; Games with a Purpose and serious games were also analysed. The document concluded the section by describing case studies related to the public administration and utility sectors. In the following an overview of the current status of both Gamification and Serious games is detailed, along with insights on the challenges and possible commercial use from scientific and industrial points of view.

5.1 Current status

5.1.1 Serious Games

Environmental education for sustainable development, one of the goals of the SmartH2O project, is a relevant area in which serious games have been applied. Fostering education towards sustainability is *“critical for promoting sustainable development and improving the capacity of people to address environment and development issues”* [UNES1992]. Moreover, some Digital Learning Games (DLGs) produced in the academic field have been launched commercially and achieved some popularity, such as Super Energy Apocalypse [Douc2010] and Math Blaster[1].

In the sustainability field, the DLGs are a promising tool, as they can provide content learning on an actual and growing topic. In order to provide insights on the technologies used to develop and distribute them, we carried out a research for the terms ”serious”, ”games”, and ”sustainability”, in the portals IEEE Xplore and ACM, between 2010 and 2014.

We found six DLGs proposed for environment protection and sustainability: Alberto’s Gravimente Toys [Ferr2010], Super Energy Apocalypse [Douc2010], Heroes of Koskenniska [Lain2010], Irrigania [Pier2013], Futura [Antl2011] and LifeTree [WaiS2013].

Table 6 shows the results of a comparative analysis performed on them.

[1] http://www.mathblaster.com/

Table 6: Summary of DLGs for sustainability features. Games analyzed: Alberto's Gravimente Toys [Ferr2010], Super Energy Apocalypse [Douc2010], Heroes of Koskenniska [Lain2010], Irrigania [Pier2013], Futura [Antl2011] and LifeTree [WaiS2013].

	Alberto's Gravimente Toys	Super Energy Apocalypse	Heroes of Kosken-niska	Irrigania	Futura	LifeTree
Technology	N/A	Flash	MUPE	Visual Basic ASP.NET 4.0	C# Breezy	Microsoft XNA
Assessment	Prototype	Briefly Evaluated (survey + quantita-tive)	Briefly Evaluated (survey)	Briefly Evaluated (quantita-tive)	Briefly Evaluated (survey)	Briefly Evaluated (survey)
Mechanics	Puzzle	Real Time Strategy	N/A	Turn based	Turn based	Puzzle
Players	Single	Single	Single	Single	2-6 players	Single
Focus	Diverse sus-tainab. top-ics	Energy use	Diverse sus-tainab. top-ics	Common pool re-sources use	Urban area de-velopment planning	Diverse sus-tainab. top-ics
Target Au-dience	Primary school chil-dren	N/A	Visitors of Kosken-niska Mill	Engineering graduation students	7 years and above	Students
Platform	Electronic board and 'toys'	Web	Nokia N95	Web	Bar height tabletop	Mobile

From **Table 6** we can observe the principal dimensions that characterize the development of serious games in the sustainability sector:

- **Technology**: The technologies used to develop the DLGs were very diverse, since the games were developed for different platforms. Interestingly enough, all the authors decided to rely on ad-hoc solutions instead of developing their games on consolidated game engines; the analyzed examples do not permit to identify a clear tendency in the technology employed for serious games in the sustainability sector.
- **Assessment**: Although only one game is just a prototype and some of them have been played by a large audience - Super Energy Apocalypse by November of 2009 had 3 million plays [Douc2010] - none of the analyzed DLGs were evaluated formally with an established methodology to assess their playability, impact on users' behavior, and pedagogical value. The use of control groups was not declared and also the number of testers was limited. This situation underlines that although qualitative studies help to extend the understanding of the nature of engagement in games, studies on games for learning are lagging behind on the use of randomized control group tests, which could provide a rigorous evidence of the impact of gaming on sustainability behavior.
- **Target Audiences**: The DLGs were designed with a wide range of target audiences in mind. Some of them have specific age restrictions, like primary school children on Jose Alberto Gravimente's Toys, or engineering college students on Irrigania. On the other hand, others had few restrictions on age, like students in general in Futura and 7 years old or plus on LifeTree. Super Energy Apocalypse and Heroes of Koskenniska had no age restriction at all.
- **Platforms**: In an attempt to achieve a wide range of audiences, the authors used also diverse platforms to deploy the games. The games designed for audiences that include children (Alberto's Gravimente Toys, Futura, LifeTree and Heroes of Koskenniska) seem to invest on platforms more attractive to this audience, like mobile or innovative interfaces. Irrigania, which has an older audience, is web based. Also Super Energy Apocalypse, that does not make statements about its target

audience, is web based too. The tendency seems to be investing on more simple (mobile) or attractive platform for younger audiences and more established and accessible platforms (Web) for older audiences.

With respect to exploitation factors that may drive the development of novel serious games for sustainability, we focus primarily on the Technology and Platform dimensions.

The most relevant companies in the field are described, along with insights on the technology they have used and the reasons behind it, in order to support a principled decision of the choice of specific engines to be used in the SmartH2O project and, more in general, for serious games for sustainability.

Virtual Heroes[2]

Virtual Heroes is one of the most successful serious games developer company in the world. Virtual Heroes' initial projects focused on creating new technology and content for the official, high-profile U.S. Army game *America's Army*, leading to the concept of the America's Army Platform now being used for a number of DOD computer based learning applications[3]. More recently, the company has expanded its Serious Games projects to include space exploration, Medical training and DVHT, "Dynamic Virtual Human Technology". This expansion reflects the Company's greater emphasis on its **HumanSim** product, a human physiology engine meant to emulate actual medical physics and response to medications. Powering the technologies of these serious games is **Epic Games' Unreal Engine 3**[4], which Virtual Heroes has been using since 2004 and the company is planning to switch to the newest version of the engine, Unreal Engine 4, by the end of 2015. The **ARA-Virtual Heroes' Go platform** is a **browser-based** single/multi-player immersive training and education platform based on the Epic' Unreal Engine and relies on a back-end server infrastructure. Content released on the Go platform is accessed via a web server that provides pages containing content plugins as well as an interface to access specific training applications, when authorized. A sample plugin is available to allow visitors to meet and converse in a 3D lounge/showcase environment and provides a way for users to allow users to navigate to other training environments.
The **ARA Unreal Engine 3 Web Player** is a PC browser plug-in that, for the first time ever, allows content created with the Unreal Engine 3 (UE3) to be streamed to and run within a web browser, supporting single and multiplayer gameplay. It was initially developed for the Air Force, to serve as a foundation for delivering realistic 3D simulations and training courses to AF service members with the strength of full Unreal Engine content and the simplicity of a one-time browser plug-in install. The Web Player allows users to access immersive, real-time, 3D content at any time, from anywhere in the world, and supports a wide range of PC browsers, including Internet Explorer, Chrome, and Firefox.

BreakAway Ltd.[5]

BreakAway Ltd. is a leading developer of entertainment games and game-based technology products. The company creates entertainment experiences that enable people to master skills and concepts in virtual worlds, and transfer this expertise to develop tools that provide game-based solutions for real world problems. Their leading tool for the development of serious games is **Mōsbē**, an engine that offers a powerful suite of tools and models based on game technology to generate results rapidly and more affordably than through traditional simulation models and eases the customization of the solutions. Based on the expertise derived from BreakAway's ten years of development experience in creating commercial

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[2] http://www.virtualheroes.com/

[3] http://en.wikipedia.org/wiki/Virtual_Heroes,_Inc. - cite_note-VHabout-1

[4] https://www.unrealengine.com

[5] http://www.breakawaygames.com/about/overview/

entertainment games and building military, first-responder, and medical simulations, Mōsbē provides the end user the freedom to build worlds, create scenarios, and assess new capabilities in a fully interactive 2D/4D environment, independent of contractor support; the scripting capabilities allows customization of the product in real time and the engine also offers the possibility to expose the functionalities of the games through a set of API to allow an easier integration of the platform.

***Unity Technologies*[6]**

Unity Technologies is the company that develops **Unity**, a cross-platform game creation system that includes a game engine and integrated development environment (IDE). It is used to develop video games for web sites, desktop platforms, consoles, and mobile devices and it is mostly known for the focus on "fun and games." But over the years the use of the platform has truly matured in the development of industry-defining game changers for serious games and virtual environments, from the military to education to medical and were recently reissued certifications by both the US Army and US Air Force. NASA's Mars Rover, NASA Jet Propulsion and the National Oceanic and Atmospheric Administration (NOAA) all took advantage of Unity for a variety of projects. For example, NOAA leverages the power of Unity to create powerful data visualizations of their big data for science analysis, education and outreach. One of their products named TerraViz is a multi-platform interactive visualization tool that accepts information in formats like KML or data provided through web map services (WMS) and displays the results in a 3D environment. They can seamlessly display millions of points of information at game-level frame rates, as NOAA produces thousands of gigabytes of information every day. Serious games projects made with Unity also swept the majority of the category awards at the recent Serious Games Showcase and Challenge at the recent Interservice/Industry Training, Simulation and Education Conference (I/ITSEC). Four of the six category winners were made with Unity and approximately 40 percent of both the overall submissions and finalists for SGS&C were Unity projects. The judging included more than 100 people from academia, government and industries around the globe for the official awards of the I/ITSEC conference that attracts 20,000 attendees each year. The top, award-winning projects using Unity technology were: Government: Cross-Competency Cultural Trainer by JKO-J7, Student: Machineers by IT University of Copenhagen, Mobile: DragonBox+ by WeWantToKnow AS, People's Choice: C-ID Combat Vehicle Detection & Identification by AEgis Technologies. Organizations including Booz Hamilton Allen, CliniSpace, Daden for BAE Systems, Designing Digitally Inc., E-Semble, Heartwood, Real Visual, Serious Games, Vienna University, VIZERRA, and more, have chosen and implemented incredible new experiences, simulations, and 3D content and serious games with Unity.

Given the benefits derived from multi-platform deployment as native applications, the possibility to extend the platform with several plugins to adapt the engine to specific needs and the active support community, the choice for the development of the SmartH2O Serious Games applications, namely the Quiz and Single Player version of Drop!, has been the **Unity** game engine, which has been adopted also by commercial companies for creating mass-scale gaming titles.

5.1.2 Gamification

Even though the importance of Gamification has grown considerably in the past years, applied research in Gamification Technology is still lacking. Research the terms "gamification platform" in the portals IEEE Xplore and ACM, between 2010 and 2015 yielded only to 24 results, of which just two papers, namely [Herz12] and [Herz13], describe approaches useful for describing generic gamification platforms, while the other articles are describing proprietary ad-hoc solutions.

Gamification techniques have been applied in several scenarios related to Environmental sustainability. Nissan, a famous car manufacturer, has produced a well know example of

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6 www.unity3d.com/sim

gamification in their Leaf line of electric vehicles. The 'Eco Mode' software keeps track of a number of variables (which are explained below) including speed and power usage and then provides constant feedback so drivers can improve upon efficiency. This feedback is provided by a display behind the steering wheel, which shows you your achievements through symbols which resemble needle trees. The car even provides online profiles so people can compete with other drivers, but there's no real benefit in collecting these trees other than saving battery charge. Recently, the Moldovan Environmental Governance Academy (MEGA[7]) created an online gamified platform to connect young people from both traditional and unprivileged schools in developing countries, with the design and mechanics of a Massively Multiplayer Online Game. The platform offers interactive trainings on achieving social and environmental goals, a virtual space for networking, collaboration and peer-to-peer learning, tools for monitoring players' performance, measuring and displaying their impact.

Companies such OPower[8] utilize gamification to encourage people to use less energy. OPower works with utility companies to provide households with data on how much energy they are consuming, how they match up with neighbors, and if they are close to any new milestones. Compellingly, people are consuming on average 2% less energy, which in 2012 led to over 1 Terawatt of energy savings in the world. This equates to $120,000,000 in utility bill savings, and decreased pollutions equivalent of keeping 100,000 cars off the road. Several are the gamification services and platforms provided by commercial companies (identified as [PROP]) and open source providers (identified as [OS]). They aim to meet the increasing needs of gamifying non-game applications; in the following the most prominent ones are described, along with their main features.

Badgeville[9] [PROP]

Badgeville brands itself to be the world's leading Social Loyalty Platform. Its products include "Dynamic Game Engine", providing an easy and flexible way to setup behaviors, rewards, missions; "Gamification Widget Studio", offering a collection of skinnable and configurable game mechanics widgets; and "Social Fabric", integrating social graph, social notification, relevant activity streams for better social engagement.

Bunchball[10] [PROP]

Bunchball's Nitro Platform provides a comprehensive set of game mechanics, besides the normal points and badges levels, it provides Actions, Groups, Virtual Goods, Social networks, Trivia, Poker, Comments etc. It is a fully integrated platform for engineers, designers, and marketers. Another product that Bunchball introduced is the Nitro Elements, which is a suite of cloud-based, simple plug and play applications, which is aimed for quick implementation of gamification. The current elements includes "FanBox" (a reward system) and "GameBox" (hosted poker game).

BigDoor[11] [PROP]

BigDoor also provides a platform with flexible API and customizable widgets to add game mechanics to web sites, to reward users with points, badges, achievements and leader boards. The javascript based "MiniBar" widget is a quick way to add game layer to the web site.

Webratio Community [PROP]

Webratio Community is a Gamified community for Enterprise Business scenarios that fosters users contribution and participation through game mechanics able to reward meaningful actions performed in the platform through credits, points, achievement and badges. Monthly and General leaderboards provide incentives to the players to perform at the best of their

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7 http://www.changemakers.com/project/mega-moldovan-environmental-governance-academy

8 http://www.opower.com/

9 http://badgeville.com/

10 http://www.bunchball.com/

11 http://bigdoor.com/

possibility in order to claim virtual or physical goods. The application allows full customization of the community and the mechanics with a Model Driven development approach.

Mozilla's Open Badges* [12]*[OS]

Offered by Mozilla, the Open Badges project makes it easy for anyone to issue, earn, and display gameplay badges through a shared infrastructure that's free and open to everyone. Badges are portable — that is, those who earn badges can display them on, say, their personal resume, Web site, social networking profile, or on employment sites.

CloudCaptive's User Infuser* [13]*[OS]

From the makers of AppScale, UserInfuser, a scalable, open-source gamification platform, provides customizable gamification elements for badging, points, live notifications, and leaderboards. The platform, which is scalable, also includes analytics for tracking user participation. The result: increased user interaction.

NGA's Gamification Server* [14]*[OS]

The NGA's Gamification-server provides a framework for providing awards/points to users or teams and can be operated either standalone or integrated with other web-based applications. Based on the notion of badges used within other gamification systems, gamification-server also provides a customizable web interface for displaying badges as well as a configurable rules engine to translate actions performed by users into awards. User awards can be exported into an Open Badges Backpack, allowing users to present expertise gained within other social frameworks or applications. The gamification-server is implemented as a django python web service and associated web application.

In SmartH2O we have decided to exploit Webratio Community as our platform of choice, given the fact that it was developed internally at Politecnico's Research group for a previous project and provides commercial grade gamification features along with full customization of all the components.

5.2 Scientific and industrial challenges and exploitation potential

5.2.1 Serious Games

Serious games are a growing market as well as an interesting area for inter and multidisciplinary academic research. While the majority of the games labelled serious are used in educational settings of various kinds, serious games may have purposes other than learning and education. Modern life is characterized by daily interactions with complex systems that affect almost every aspect of our lives, from economy to environmental problems; even if they could gain benefits and revenues out of it, companies struggle at understanding the vast amounts of potentially meaningful data these systems produce. In Games with a Purpose (GWAP) the players' actions in the game contribute to a real-world purpose outside of the game like sorting and understanding real data, analysing the possible outcomes and testing potential solutions. Persuasive games can monitor players' interactions among themselves and the environment in order to change their behaviour toward specific objectives to be reached.

1. An open issue, relevant both in scientific and industrial domain is related to the necessity of finding suitable techniques to evaluate Serious Games applications and be able to compare them among each other. While validation techniques are being consolidated for Serious Games involving computational tasks resolution, as described in [Gall2014], the topic is still an open problem for what concerns learning

12 http://openbadges.org/

13 https://code.google.com/p/userinfuser/

14 https://github.com/ngageoint/gamification-server

based games; effective research should take into account the content-dependency of its results (e.g. relating to educational settings or target groups). To achieve this, effective and unobtrusive assessment methods for digital game-based learning need to be developed and evaluated to monitor not only the learning outcomes, but also the learning process [Bent2009][Shut2009]. Here, it is important that not only the final outcomes are assessed, but also that the learning and training process itself is monitored continuously without impairing the playing/learning experiences (e.g. via psycho physiological measurements or automated logs/recordings of player behaviour). This is especially beneficial as it can inform new ways to make learning games more adaptive so that they can always offer help or additional information when the players need it (e.g. when they get stuck at a certain point of a game). For this reason, objective and quantitative evaluation of Serious Games could greatly improve their adoption and the possibility to improve the design and the achieved results.

2. As it has been described before, Serious Games are often developed with proprietary game engines tailored over the specific needs of the problem they are trying to solve. Given the increased interest towards this particular genre of games, designing and implementing tools and frameworks able to deal with the most common data collection and refinement tasks, along with ready to use pluggable game elements typically used in this genre of games could have a meaningful economic impact both in terms of tools licencing and development costs savings. The extensions created for the Unity Game Engine during the SmartH2O project will fill the gap of tools for the development of Serious Games for Environmental Sustainability, in particular in the Water sector.
3. Another emerging research challenge regards the adoption of the forthcoming virtual reality wearable devices, expected to hit the mass market from 2015, as a novel device for even more engaging serious game experiences. Devices such as Oculus Rift[15], Microsoft HoloLens[16], Samsung Gear[17], and the announced Magic Leap technology acquired by Google promise to bring Virtual Reality/Augmented Reality applications to the mass market, offering an enormous potential to serious game developers, thanks to the possibility of overlaying real and virtual elements in the same experience, a feature that could be extremely valuable, e.g., for augmenting the real experience of water consumers with in-context, activity-dependent sustainability tips delivered on the wearable device when necessary and most useful.

5.2.2 Gamification

Gamified applications have gained a considerable market share in the past years but this trend has not brought the same growth in technology and academic research. Most of the platforms that are used in real world scenarios derive from commercial and closed solution in which data, the most valuable resource gathered through a gamified approach, is often kept on the premises of the company offering the services. Since these platforms need to tailor most of the applications of their customer, customization is often limited or not present. Surprisingly, reports on the effectiveness of these platform is often overlooked, with no statistical relevant analysis of the improvements claims.

The potential benefits of using gamified systems and games for research are manifold: their engaging nature can increase participation; as computational environments, they allow automatic fine-grained tracking and manipulation; they can generate large-scale data sets; and deployed on personal tracking devices, smart phones, or through the browser at home, they can collect ecologically valid behaviour data. As it has been described, exploitation potential for gamified application is high, even though it has reached the “Trough of Disillusionment”, as stated in a recent Gartner’s report shown in Figure 12 Gartner's Hype

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15 https://www.oculus.com/

16 http://www.microsoft.com/microsoft-hololens/en-us

17 http://www.samsung.com/global/microsite/gearvr/gearvr_features.html

Cycle, but the possibility to achieve meaningful results in research is even higher.

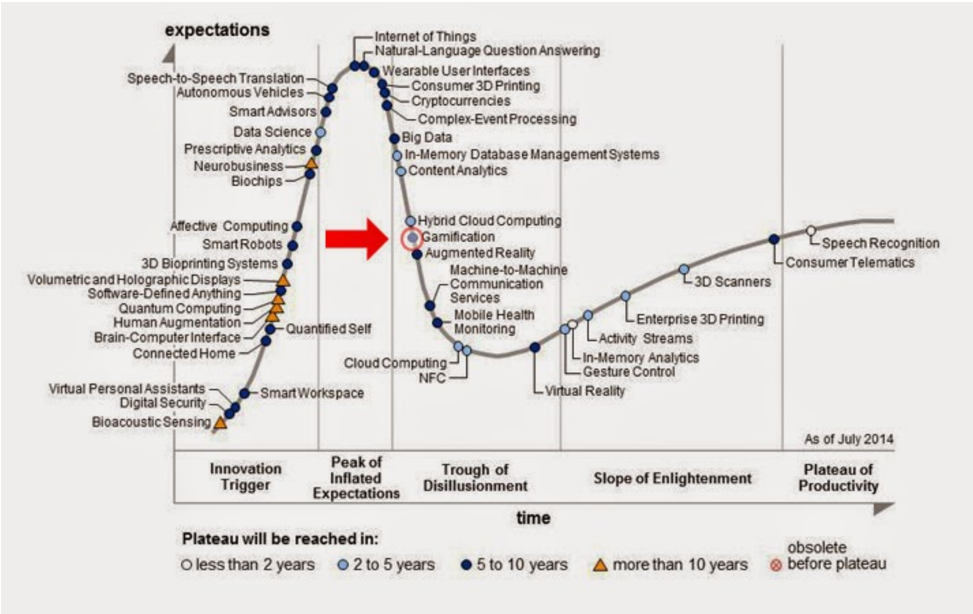

Figure 12 Gartner's Hype Cycle

1. Many empirical studies involving gamified systems show significant methodological shortcomings since there are no established best practices so far. Collecting the approaches, concepts, tools, and methods that are currently used in creating gameful experience and in particular analysing and describing the features and the architectural choices of existing commercial solution is a necessary step for improving the current technologies used in Gamification.
2. Empirical, statistically relevant evidence on the effectiveness and efficiency of the currently employed gamification approaches is currently lacking. The reports on the results derived from the adoption of gamified applications usually do not take into consideration how their choices over the game mechanics introduced affect the obtained results. Providing objective and quantitative evaluation techniques would allow the definition of a thorough comparison strategy to choose the most efficient gamification platform for a specific purpose or improve existing designs.
3. Understanding to what extent design elements of one design practice can be isolated and transplanted into another, along with the definition of gameful system design process and methods that could be borrowed from game design will lower the risks of introducing costly failures, while speeding up the development process of the platform.
4. Most gamification approaches are developed ad-hoc, as standalone projects. This makes it difficult to “inject” gamification features into existing business applications, which are already deployed and in use. Studying methods and tools to “weave” gamification aspects seamlessly and with low effort to existing business applications would greatly reduce development times and costs and make this type of engagement solution more affordable to SMEs.

6. Discussion and Conclusions

This deliverable has presented and critically analysed the current status, the scientific and industrial challenges, and the future directions for each technology area involved in the project. The results of this review identifies the gamification and serious games applications and the water customer modelling as the two main technology areas where the SmartH2O Project can potentially provide relevant contributions.

On one side, the SmartH2O Project is expected to contribute in the gamification and serious games applications area through the **gamified online water bill**, the **board game & customer loyalty relations**, and the **digital game** assets identified in D8.1 – Early exploitation plan (see Sections 7.1-7.2-7.3) show the potential for representing relevant contributions with respect to the current status described in Section 5.2. In particular, the gamified water bill will introduce a better relationship with the customers, also providing customers with direct access to their water consumption data and raising customers' individual and collective environmental awareness. The board game and the digital extension will convey the difference between virtuous and wasteful water actions and also promote the image of the water utilities, by customising the packaging based on the visual identity and brand guidelines of the company.

On the other side, the SmartH2O Project is expected to contribute in the water customers' modelling area through the development of the **Dashboard for customer behaviour analysis and water demand planning** (see Section 7.5 of D8.1 – Early Exploitation Plan), which aims at supporting water utilities in designing and testing alternative water demand management strategies. The dashboard will indeed provide the following tools: disaggregation algorithms for the identification of end use patterns, which produce key information for providing feedbacks to the users through the gamified online water bill and for the classification of user behaviours; monitoring customer behaviour and consumption data provided by smart meters and the gamified online water bill platform; agent-based user behavioural models, which allows predicting water demand at the household level while also considering social dynamic interactions among the water users.

Future work of WP8 will rely on the results provided by this deliverable and D8.1 in order to construct an effective exploitation plan and substantiate the marketing strategy of the SmartH2O assets.

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APPENDIX A Cost-benefit analysis of data reading and transfer infrastructures by Thames Water

In this appendix we report the outcomes of a study performed by Thames Water prior to the decision on the investment of 3 billion UK Pounds in the purchase and deployment of 8 million smart meters over the period 2015-2030. A similar study has not yet been conducted by SES for the Swiss case study, but this is justified by the fact that the Swiss case study is a small trial (400 meters) where the initial focus is on technical feasibility.

A.1 Cost benefit analysis of high level options

In 2013 a cost benefit analysis was undertaken by Thames Water (TM) to identify the best metering solution to adopt. The analysis consisted of modelling the 3 metering technology options against 4 potential benefits and 6 different property types. Table 7 shows the scenario inputs for the analysis.

Table 7: Business case scenarios.

Meter Technology Options	Potential Benefits	Property Scenarios
'Dumb' metering	Customer demand reduction (usage)	Detached
'Automatic meter reading' (AMR)	Customer side leakage (CSL) reduction	Semi Detached
'Advanced metering infrastructure' (AMI)	Mains rehabilitation reduction efficiency	Terraced
	Customer calls reduction	Flats small block
		Flats large block
		Bulk

The three metering technologies considered are:

- **Dumb Meter Reading** – a conventional meter is installed with a register dial. Meter reading is undertaken by a meter reader gaining physical access to the meter and visually recording the meter reading into an electronic meter reading data capture devices.
- **Automatic Meter Reading (AMR)** – a meter with a short range radio is installed at each property. The meter reader equipped with a meter reading device is required to walk-by the meter in order to take a meter reading but does not require physical access to the meter. This process can also be achieved in certain circumstances in a vehicle application – known as drive-by reading. The data is captured electronically. Additional data may be stored in the meter and collected, such as a small number of historic meter readings, minimum and maximum flows and alarms for tamper, low battery and potential leakage found.
- **Advanced Metering Infrastructure (AMI)** – using a fixed network meter reading system (usually radio based), meters are read electronically and do not require a meter reader. Electronic readings are passed from the meter through to utility offices for billing and network management purposes. With these systems it is possible to collect more frequent data on consumption and alarm conditions which can be used to provide additional benefits.

The policy drivers made it likely that conventional dumb metering would not be adequate to fulfil TW's requirements. The choice was more likely between AMR and AMI systems. The potential benefits of each system were compared to highlight differences between the two systems. The key distinguishing features between AMR and AMI systems are listed below in Table 8.

Table 8: Distinguishing features between AMR and AMI.

Component	Distinguishing feature	AMR	AMI
Customer consumption	1. Accurate meter readings with no estimated data	Y	Y
	2. No access required to property	Y	Y
	3. On demand meter readings	N	Y
	4. Data suitable for rapid online display	N	Y
Customer side leakage	1. Ability to identify that a property has a leak.	Y	Y
	2. Flow rate of the leak, (the lowest non-zero flow rate)	Y	Y
	3. Start, stop and duration of leak	N	Y
	4. Rapid notification of leak onset	N	Y
Customer wastage	1. Ability to distinguish between 'wastage' and 'leakage'	N	?
Network leakage and water balance	2. Data compatible with data used by DMA meters	N	Y
	3. Near real time data	N	Y

The potential benefits considered for the analysis are:

- **Customer Demand Reduction (Usage)** – this covers the reduction in use by the household found from being billed on a metered basis. The installation of a dumb meter will tend to reduce customer demand without further automation of meter reading.
- **Customer Side Leakage (CSL) Reduction** - this covers the losses within the customer's pipework. This is dependent on the type of meter reading technology allowing accurate targeting of the existing losses.
- **Mains Rehabilitation Targeting Efficiency** – meters provide an understanding of the water balance within DMAs. This ensures accurate target where the leakage exists, either within our network or within the customer's boundary. The benefit is the reduction in mains rehabilitation required to achieve the same leakage target.
- **Customer Calls Reduction** – The three metering technologies offer different capabilities in providing accurate data to customers. Increased confidence in meter reading accuracy leads to a reduction in customer calls. This will occur with AMR and AMI, although it is expected dumb meters will lead to an increasing trend in calls. The benefit is the improved customer satisfaction and reduced complaints.

Finally, the property types considered were: Detached, Semi-detached, Terraced, Flats small block, Flats large block, Bulk metered. These property definitions are used within Thames Water and for which TW currently estimates a consumption value. ‘Bulk’ properties include properties that cannot have separate supplies.

A.1.1 Usage Assumptions and Information from Fixed Network Trials

Thames Water based its modelling assumptions on information gathered from a number of sources including a Fixed Network Trial (FNT), a Domestic Water Use Study (DWUS) and consumption estimates of consumers moving from unmeasured to measured tariffs. From these sources it was possible to demonstrate that AMI technology could identify leaks more quickly than AMR due to more frequent read intervals (daily versus 6 monthly) and to be better able to identify leakage because of the quality of data available, (hourly or 15 minute data). Table 9 shows the expected percentage of customer side leakage that could be detected by different metering technologies.

Table 9: % CSL detectable by different systems.

	Dumb	AMR	AMI
% of customer side leakage reduction detected	24%	56%	76%

The reduction in usage per metering technology by property type is shown in Table 10. These values refer to a customer moving from an unmeasured tariff to a measured tariff. TW has estimated an overall reduction in domestic customer usage of 9.2% for a property fitted with a dumb meter, 10.7% for AMR and 13.2% for AMI metering technologies.

Table 10: Reduction in usage by property and technology type.

Property Type	Thames Water		
	Dumb	AMR	AMI
Detached	10.9%	12.4%	14.9%
Semi-Detached	14.8%	16.3%	18.8%
Terraced	8.8%	10.3%	12.8%
Flats – Small Block	9.1%	10.6%	13.1%
Flats – Large Block	4.3%	5.8%	8.3%
Unknown	11.1%	12.6%	15.1%
All metered	**9.2%**	**10.7%**	**13.2%**

A.1.2 Outputs from the Cost Benefit Model

While AMI can be shown to reduce customer consumption in comparison to other meter technologies, this comes at a considerable additional cost. The cost benefit model used a net present value (NPV) method for identifying the best option. The variables included a 4.5% discount rate and a 60 year time frame. An example of the calculations carried out a property level show the varying return by property type. Figure 13 shows the output of the NPV estimate for AMI against different property types. Similar calculations were carried out for dumb and AMR technologies.

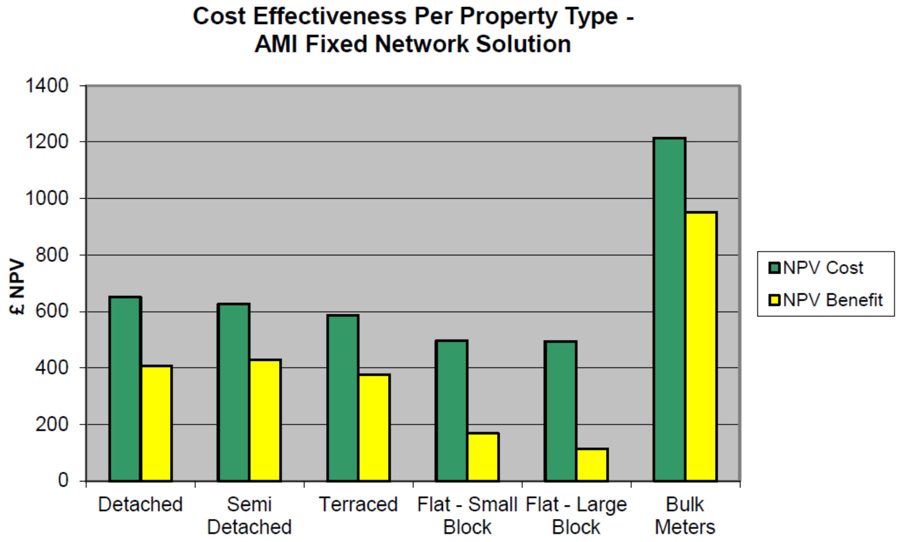

Figure 13: Cost effectiveness of AMI solution per property type.

Thames Water's cost benefit analysis selected advanced metering infrastructure (AMI) as the best metering technology solution.

The comparative benefit of AMI largely accrued from its enhanced ability to detect leakage.

Moderating customer demand further by means such as intelligent, targeted feedback to the customer would improve the benefit case for AMI further. This is the space in which the SmartH2O project operates.

A.2 Technology Options for Metering

A variety of meter reading technologies are available. These can be split into three categories: (i) excluded by the cost benefit analysis; (ii) excluded by TW meter location policy (iii) potentially suitable technologies.

A.1.3 Excluded technologies based on the cost benefit analysis

The cost benefit case effectively eliminated all metering technology choices other than AMI. The excluded technologies included a range of options widely used within the water industry in the UK. Table 11 shows the technologies excluded by the cost benefit analysis.

Table 11: Metering technologies excluded by the CBA.

Technology choice	Description	Notes
Dumb metering	Visual reading of meters only	For several UK water companies this will remain the dominant metering technology for the medium term.
Inductive 'touch-pads'	Meter readings returned via an inductive 'touch pad' connected to the meter with a cable. The meter reading is returned by touching a	Provides increases in meter reading productivity. Limited by requirement for cable connection between pad and

	reader gun against the pad. Examples include Sensus Touch-Read system.	meter. This technology is no-longer being deployed in the UK
Automatic meter reading (AMR) <u>Basic</u> systems	Systems that provide a meter reading and little or no other data.	Early versions of AMR systems provided limited functionality although almost all systems will return a leak alert of some form.
Automatic meter reading (AMR) <u>Advanced</u> systems	AMR systems that provide multiple data fields for meter reading, leakage detection, and consumption patterns. Examples include the Homerider system in walk-by mode	Extensive metering data (historic consumption, flow profiles etc) can be returned depending on the systems, however this may reduce meter reading productivity. These systems are now widely deployed in the UK. At least one UK company (United Utilities) has a large scale successful drive-by implementation of AMR

A.1.4 Excluded AMI Technologies Based on TW Metering Policy

The cost benefit model identified AMI as the best solution for Thames Water, however not all AMI technologies are entirely based on RF communications. The AMI options below (Table 12) are not considered viable due to Thames Water's policy of externally locating water meters. These solutions rely on wired connections or cooperation with other utilities to collect data.

Table 12: AMI solutions considered not viable for water.

Name	Description	Notes
Power Line Communications (PLC)	The electricity meter uses the incoming mains power cable to transmit meter readings were they are decoded by local communications endpoint/	Italy has completed a roll-out of PLC for electricity meters across the entire country.
Asymmetric Digital Subscriber Line (ADSL)	A conventional telephone line is used for data communications from the meter, currently used for internet provision	No obvious usage in the UK for metering.

Energy Home Area Network	The electricity meter provides a transmission hub to which gas or (potentially) water meters connect via a low power radio solution (such as Zigbee) for onward transmission via PLC, mobile phone technologies or long-range radio. The UK has selected two companies using mobile phone based systems (Telefonica) and long-range dedicated RF (Arqiva)	This is one of the proposed solutions for the energy sector in the UK. Gas and water meters are similar in that both systems are reliant on battery power transmitter connecting to the mains hub. This option remains an option for future deployments of AMI

A.1.5 Viable AMI Solutions for Thames Water

In 2013 TW placed a notice in the Official Journal of the European Union (OJEU) seeking an AMI solution. The pre-qualification questionnaire returned 16 potential providers. Some providers relied on technology provided on of the other suppliers so the list included some duplication in the technology returned. Nonetheless this procurement operation provides a realistic survey of the current options for AMI for water. All systems relied on radio spectrum (RF) technologies to transmit data from the meter to the utility, with the last stage data transfer being provided over the internet. The systems were chiefly distinguished by the range of the RF equipment involved and the number of repeaters or concentrators used within the system. Four viable technologies were identified:

1. Mobile phone technology
2. Low power radio
3. Medium range radio
4. Long range radio

System 1: Mobile phone technology only.

The meter uses the mobile phone network system as the only RF data transfer component.

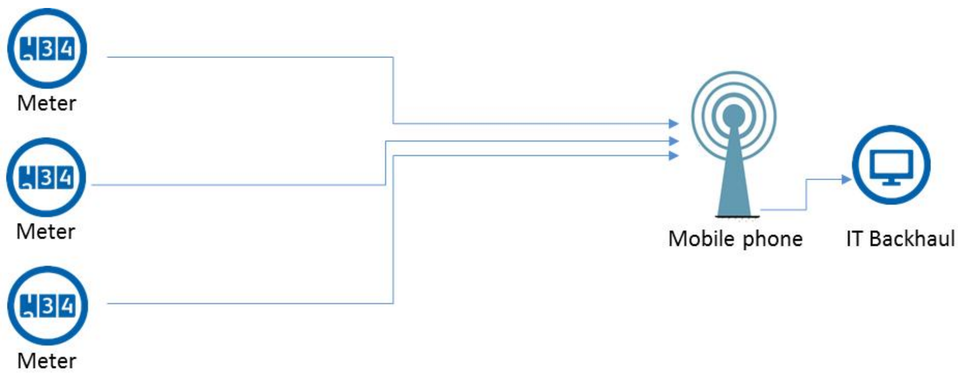

Figure 14: Mobile phone data transfer.

- One to one relationship between meter and mobile phone system.
- Range equivalent to mobile phone coverage.

Table 13: Mobile phone AMI advantages and disadvantages.

Advantages	Disadvantages
Long range	Battery life is relatively short, less than 10 years.
Massive investment in mobile phone infrastructure provides existing network	Equipment is relatively large due to battery considerations
Extensive use in water industry on larger customers for data logger purposes	Cost per unit is high

One company offered this option as the primary data mechanism and two others offered it as an option if coverage was not otherwise available.

System 2: Low power radio systems.

The meter uses a low power RF transmitter to send meter reading to a 'repeater' a short distance away. From the repeater the data is transferred over a longer range to a concentrator. Data transfer from the concentrator is via the mobile phone system or landlines.

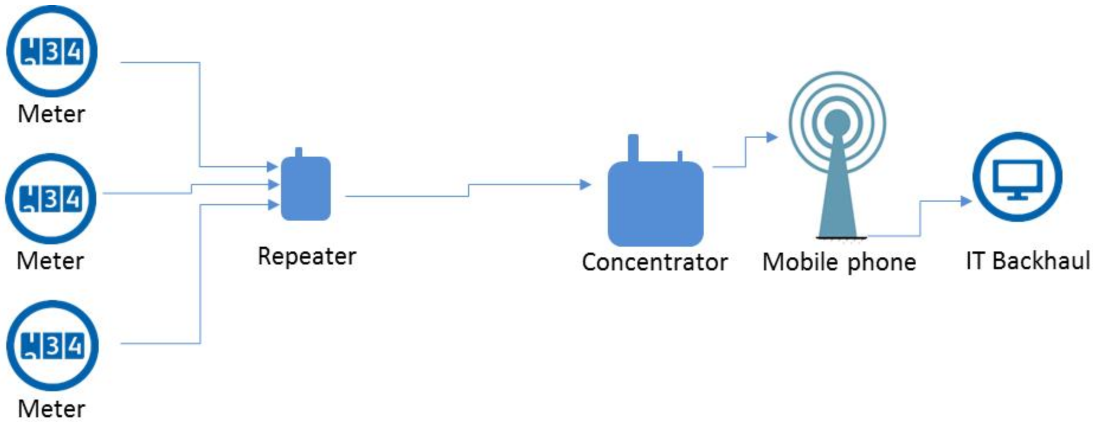

Figure 15: Lower power radio systems.

- Systems typically use 868 Mhz or 434 Mhz with power outputs not exceeding 25 Mw.
- Range from the meter to the repeater varies from 10s of meters to low hundreds.
- Ratio of meters to repeater is typically 10 to 1.
- Meters can also transmit direct to the concentrator.
- Concentrators able to collect data from 1000's of end points.
- Concentrators are normally mains powered.
- Range from repeater to concentrator typically be 1km – 5km.

Table 14: Low power radio advantages and disadvantages.

Advantages	Disadvantages
Systems generally allow transfer from walkby / driveby to a fixed network system.	Multiple components: repeaters and concentrators need to be maintained.

Systems have been specifically developed for water and contain suitable alarms within the equipment.	Sites for repeaters and concentrators may not be available
Millions of endpoints deployed in apartment metering.	Successful deployment is not straightforward in urban environments due to short range of equipment involved.
Battery life is relatively long depending on configuration. 15 years + is viable.	

4 of 16 systems in the TW procurement exercise could be considered to be of this type

System 3: Medium range radio

These systems discard the repeater and make use of multiple (battery powered) concentrators. From the concentrator, data is returned via the mobile phone system.

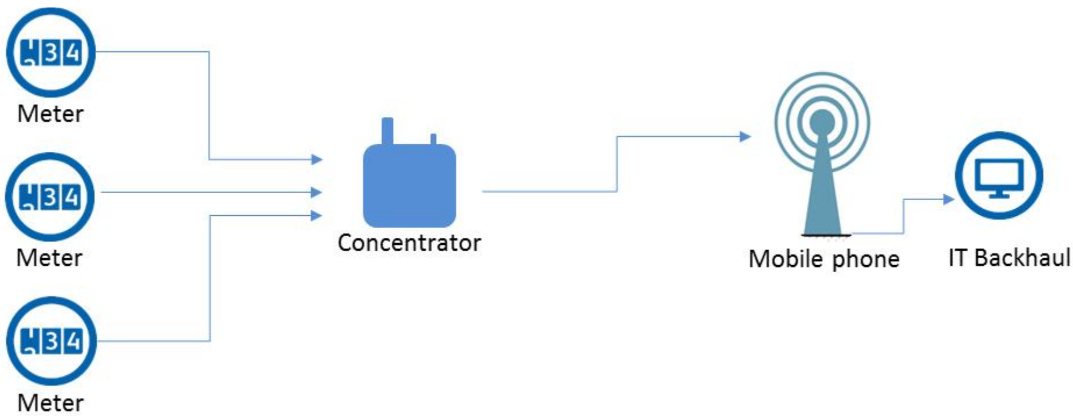

Figure 16: Medium range radio data transfer.

- Systems include 434 MHz and 169 MHz systems
- Ranges 500m to 4km from meter to concentrator
- 1 systems was one-way only

Table 15: Long range radio advantages and disadvantages.

Advantages	Disadvantages
Removes the need for intermediate repeaters which have no direct link to the mobile phone network.	Battery powered concentrators still require lampposts or other street furniture
Concentrators can handle hundreds of meters.	Concentrators will need maintenance due to battery life less than 10 years and dependent on the number of meters and transmission requirements
Concentrators have some data storage capacity, if the mobile phone network is temporarily unavailable.	

2 of 16 systems identified by TW could be considered medium range systems.

System 4: Long-range radio

A long range radio system places the emphasis on a limited number of high quality concentrators and relatively powerful meter transmitters. Power outputs are at least 10 times higher than the low power radio systems.

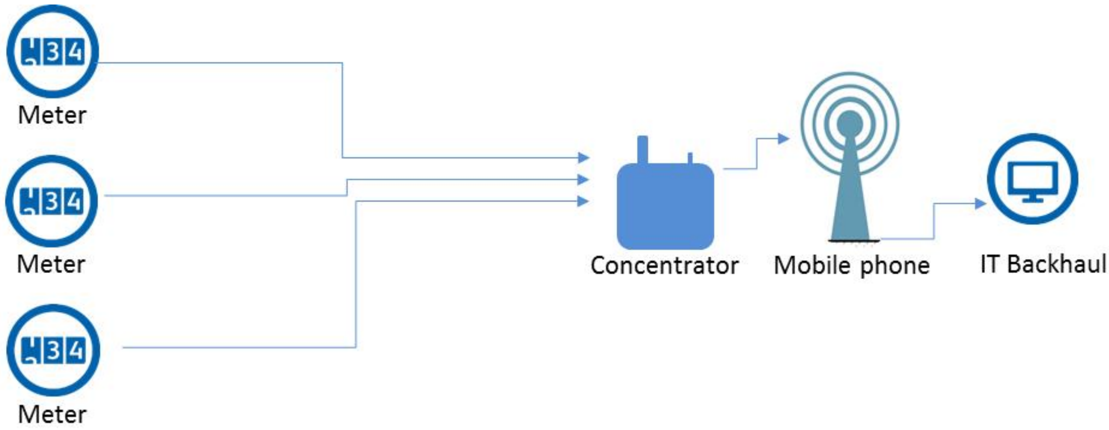

Figure 17: Longe-range radio data transfer.

- Solutions include a 413 MHz 300 mw system (from meter to concentrator)
- Other proposed systems operate at ~900 MHz, and 450 MHz with 500 mw outputs
- Two way and one way systems are available.
- One system made use of the dedicated frequencies used by the police, fire and ambulance serves. This system has an existing infrastructure equivalent to the mobile phone network.

Table 16: Long-range radio (dedicated) advantages and disadvantages.

Advantages	**Disadvantages**
Ranges can exceed 5km, concentrators can potentially receive data from 10s of thousands of meters.	Reception black spots can still exist.
Minimal number of concentrators reduces potential maintenance issues.	Single concentrators tend to be very expensive making small deployments uneconomic.
Concentrators unconstrained by battery life.	Meters will be more expensive compared to competing systems.
Widespread use in the US	Limited number of systems are immediately UK ready.
Meters may be able to communicate with multiple concentrators providing redundancy	

Some proposed solutions were based on US technologies currently employing frequencies around 900 MHz, these would need further development to remain within UK spectrum and power output limits.

A.3 Scientific and industrial challenges and exploitation potential

Thames Water procurement process aimed to identify an AMI provider and did not require a specific technology, however the expectations of the AMI supplier reflected knowledge gained from previous trials. Between 2011 and 2013 TW conducted a Fixed Network Trial that provided experience of 2 different AMI solutions: a low power radio solution and a long-range radio installation. (Medium range solutions were not evaluated.) The FNT consisted of more than 4000 AMI enabled meters providing daily data at a 15 minute resolution. The knowledge gained from the FNT helped to inform the procurement process. Key findings are:

- Low power radio technologies are more difficult to deploy; principally because of the number of sites required for repeaters (typically lampposts) and concentrators. The need to access street furniture effectively gives local government a veto over the deployment of low power radio systems.
- The availability of concentrator sites is limited or can be very expensive.
- Achieving close to 100% data returns from AMI is difficult due to local radio dead-spots, even in areas that would be expected to be within the radio range.
- The number of meters returning data varies due to changing conditions (weather, vehicles on pits and new construction etc)
- Repeaters installed on lamp-posts require the use of a mobile platform. A single failure is therefore relatively expensive compared to the number of meters affected.

Minimising these issues can be achieved by either deploying equipment with a very long range between the meter and the receiver or having shorter range equipment with multiple receivers. In simplistic terms the greater the range between the meter and the concentrator the fewer concentrators will be required. The required number of concentrators will decrease as a square root of the equipment range, (doubling the radio range, quadruples the area covered). Based on experience in the FNT trials, data transmission range, between meter and concentrator is seen as a major factor in determining equipment suitability. Figure 9 on page 2 shows a simulation of concentrator coverage with equipment ranges of 100m, 200m and 400m.

The procurement process did not specify any particular technology as a data service was stipulated. The supplier would take the risk providing the equipment and maintaining the system. The prices offered would reflect these factors. After consideration TW has selected a long range system (Sensus Flexnet in collaboration with Arqiva).

The deployment of an AMI system offers other opportunities for the water sector. Currently several business critical systems make use of RF technologies (principally mobile phone) to transmit data. The AMI infrastructure may provide a more cost effective alternative. The use of a two-way system in particular offers control functionality as opposed to just a monitoring function.

Table 17: Future potential benefits of an AMI network.

Equipment	**Notes**
Meters into supply, zonal metering and district metering applications	These (large) meters measure flow from the water treatment works and within the network. Currently these meters are data logged using mobile phone technology. Data resolution varies from live to 15 minute. Some meters are bi-directional. There are few obstacles in moving from mobile phone data logging to its AMI equivalent.
Pressure loggers	Within the network the pressure is recorded. This information is used to minimise pressure (and therefore leakage) within the network. Pressure data is transferred using mobile phone data loggers.
Noise loggers and noise correlators	Noise loggers are used to identify leakage on the network. The amount of data requiring transferring ranges from minimal to megabits requiring dedicated landlines. Local noise correlators frequently make use of walkby data collection systems. Noise loggers are available to connect to some existing AMI systems.
Level monitors and alarms	Level monitors are used to check the flow of water or wastewater (sewage) in open or unpressurised systems. Equipment may need to be ATEX (gas safe) in some conditions
SCADA (supervisory control and data acquisition) equipment	Water treatment works, sewage treatment works and water and waste water networks make extensive use of SCADA systems. Examples include remote pumping and valve controls. An AMI network offers an alternative to control methods.