POLITECNICO DI MILANO

Scuola di Ingegneria Industriale e dell'Informazione

Master of Science
Management Engineer

Smart water metering: analytical model computation for an estimated costs and benefits analysis

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ACADEMIC YEAR: 2019-2020

SUMMARY

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ABSTRACT

The water demand is increasing worldwide of around 1% per year since the 1980s, due to a combination of population growth, socio-economic development, and changing consumption patterns. The expectations foreseen an increase from 20% to 30% by 2050 over the current level. Considering the different water end-uses, the households consumptions account for 12% and the data show a growth of domestic water demand around 600% in the period 1960-2014. The climate change has worsened the situation. Indeed over 2 bln people in the world have lived water stress conditions, due to water scarcity or inadequate water infrastructure. In Italy, the water network is old: the 60% of the infrastructure has been installed more than 30 years ago. On average, the losses correspond to 43% of total water immitted, with peaks up to 70%. In addition, even if the water is less expensive than gas and electricity, it is the sector that registers highest shares of arrear customers and unauthorised consumption. The Internet of Things (IoT) has opened the opportunity of smart meters for utility. In this work, the authors have developed an analytical model to assess a cost-benefit analysis concerning both economic and environmental impacts of smart meters in Italy. It represents an innovative approach, though which are 7 benefits evaluated and quantified: remote meter reading, efficient maintenance (which includes identification and reduction of pipe leakages and faulty meters), demand management, arrear consumers control, fraud reduction and accurate billing. The authors have assumed a total meter park of 200’000 devices and supposed two cases for the simulation, distinguishing between ‘full costs’ and ‘delta costs’ for each one. ‘Full costs’ when the smart meters substitute working traditional meters, ‘delta costs’ when the new devices replace old meters that would be changed in any case in the near time. The two cases are rollouts of 10.000 and 50.000 meters. Each case has been declined in 6 scenarios, coming from the combination of 2 costs level (min, max) and 3 benefit level (min, avg, max). The results are evaluated considering 3 economic (NPV, IRR, PBT) and 3 environmental KPI’S (Absolute water saving, Relative water saving, Energy Efficiency) for each scenario. Finally, the authors have provided two curves (one for ‘full cost’, one for ‘delta costs’) that consider the NPV associated to several meters roll-out (from 10.000 to 200.000), to underline the presence of additional factors as economies of scale and smart water grid extended benefits.

Key words: Smart meter, Remote meter reading, Pipe leakages reduction, Faulty meters, Demand management, Arrear consumers control, Fraud reduction, Accurate billing, Cost – Benefit analysis, Analytical model

SOMMARIO

La domanda di acqua sta aumentando in tutto il mondo di circa l'1% all'anno dagli anni '80, a causa di una combinazione tra la crescita della popolazione, sviluppo socioeconomico e mutevoli modelli di consumo. Si prevede un aumento dal 20% al 30% entro il 2050 rispetto al livello attuale. Considerando i diversi usi dell'acqua, i consumi domestici rappresentano il 12% (AQUASTAT, n.a.). I dati mostrano una crescita della domanda di acqua domestica intorno al 600% nel periodo 1960-2014 (World Research Institute, 2020). Il cambiamento climatico ha peggiorato la situazione. Infatti, oltre 2 miliardi di persone hanno vissuto condizioni di stress idrico. In Italia la rete idrica è vecchia: il 60% delle infrastrutture è stato installato più di 30 anni fa. Mediamente le perdite corrispondono al 43% sul totale d'acqua immessa con punte fino al 70%. Inoltre, anche se l'acqua è meno costosa del gas e dell'elettricità, registra una quota maggiore di clienti morosi. L'Internet of Things (IoT) ha aperto l'opportunità dei contatori intelligenti per le utilities. In questa tesi, gli autori hanno sviluppato un modello analitico per valutare un'analisi costi-benefici riguardante gli impatti sia economici che ambientali dei contatori intelligenti in Italia. Rappresenta un approccio innovativo, per il quale vengono valutati sette vantaggi: lettura dei contatori a distanza, manutenzione efficiente (suddivisa in diminuzione perdite e riduzione dei contatori difettosi), gestione della domanda, controllo dei clienti morosi, riduzione delle frodi e fatturazione su consumi effettivi. Abbiamo ipotizzato un parco contatori di 200.000 dispositivi e ipotizzato due casi, distinguendo tra "costi completi" e "costi differenziali" per ciascuno. "Costi completi" quando i contatori intelligenti sostituiscono i contatori tradizionali funzionanti, "costi differenziali" quando i nuovi dispositivi sostituiscono i contatori difettosi. I due casi sono rollouts di 10 e 50 mila. Ogni caso ha 6 scenari, derivanti dalla combinazione di 2 livelli di costo (minimo, massimo) e 3 livelli di beneficio (minimo, medio, massimo). I risultati sono 3 KPI economici (NPV, IRR, PBT) e 3 ambientali (Risparmio idrico assoluto, Risparmio idrico relativo, Efficienza energetica) per ogni scenario. Infine, abbiamo fornito due curve intermedie (una per "costo pieno", una per "costi delta") che considerano il NPV di rollout con diverse quantità di contatori per calcolare i vantaggi aggiuntivi (come gestione della pressione, economie di scala).

EXECUTIVE SUMMARY

Introduction

The liberalization of the energy market, with the increasing attention towards sustainability and energy efficiency requirements, has made necessary for utilities the research of innovative tools that are more versatile and flexible. In particular, during the last years, new opportunities are rise with the development of Internet of Things (or IoT). It can be defined as “a network of physical objects that are connected to the Internet, equipped with a technology for interacting with the external environments”. In the utilities business, the IoT has allowed the introduction of smart meters. The metering systems are “devices and related instruments that can be installed to measure the volumes (e.g. quantity) of inputs and outputs that are being made available or delivered to a buyer at the interconnection point”. Below a technical perspective, the smart meters are digital electronic devices that collect information on use of electricity, water, or gas and sends it securely to the utility. The general features of a smart metering system have been summarised in the following list:

- Automatic processing, transfer, management, and utilization of metering data
- Automatic management of meters
- 2-way data communication with meters
- Meaningful and timely provision of consumption information to the relevant actors and their systems, including the consumer
- Effective support for services that improve the energy efficiency of the energy consumption and the energy system

Considering a broad perspective, the main benefits can be reconducted to three categories: prediction of consumption, detection of leakage and service customization. In this work, the analyses will be enlarged to additional advantages for a total of seven benefits.

In Italy, the main drivers that supports the progress of smart metering system are the regulatory framework and the standardization of technology. The legislative measures have been carried out gradually during the last decade. In particular, the European Union is having a leading role. Its first important action has been the Third Energy Package. It contains the directives of Internal Market for Electricity and Gas (Directive 2009/72/EC and Directive 2009/73/EC), that require at Member States the implementations of intelligent metering system to assist the active participation of consumers in the electricity and gas markets. The regulatory framework for the water sector is still less developed, however consistent laws have been launched in the last years. For example, in Italy the Decree 93/17 is now the most significative. It set criteria for periodic control on instruments of measure and their functions conformity with regulatory framework. Basically, the replacement of mechanical meters with smart meters. Looking at Italian scenario, the regulatory framework represents one of the most important drivers to install smart water meters.

The most recent reports about the IoT market shows a growing penetration rate of smart meters, but with huge differences among global regions. For that reasons, the authors have analysed the market dividing in four macro-areas: North America, Europe, Asia Pacific, and Rest of the world.

The first three, actually, are close to maturity, while on the last one, the authors have reported all the countries with no or only small-scale deployments.

Objective and methodology

The thesis has the aim of evaluating the actual benefits that smart devices can bring to the utility, to the final users and, on a larger scale, to the environment. In order to achieve this objective, the first step has been the analysis of the extant literature. Through this study, several gaps emerged. First, the utilities and producers provide a too simplistic assessment of smart water meter benefits for potential benefits of the smart solution by retrieving few information about the smart metering system characteristics and the impacts on the consumer's behavior, network efficiency and water resource savings. There is not a precise indicator for utilities intended to implement a smart water metering project about which are the aspects and the implication that could give the biggest savings in that particular circumstance.

Articles focused on comprehensive evaluations of benefits are in most of the cases qualitative or, if quantitative, do not provide any generalization of the results

obtained in a specific application, thus making difficult to separate the outcomes from that particular context.
The literature analysis makes clear that the roll-out of smart water meters could generate significant changes in water supply services, both from utility and consumer perspective. Moreover, a wide spectrum of possible benefits and costs emerges, making the cost-benefit analysis process complex and time-consuming.
Therefore, this dissertation tries to fill the hole left in between, aiming at giving to utility companies more precise information about the potential saving of smart metering, providing a general model for computation and quantification of the cost and benefits related to smart metering projects, yet keeping the model more accurate and close to reality as possible.
Moreover, the model has a double application. Since a large-scale application of smart technology could result in a considerable environmental positive impact, the model is also used to provide an estimation of the water resource consumption reduction, considering the application in the Italian scenario. This second purpose gives the dissertation an added value, providing the public institutions a mean for evaluating the possibility to establish incentives for smart metering projects.
The presented introduction led to the formulation of two research questions this dissertation aims at answering to.

RQ1: Do smart metering systems contribute to the improvement of utilities performances in the water sector? If yes, do they contribute significantly in terms of both economic and environmental terms?
RQ2: Which are the most important benefit and cost figures that utility companies need to consider when evaluating smart water metering projects?

Model Definition

To answer to the research questions, an innovative approach for the evaluation of potential economic gains and water savings reachable with smart meters for domestic application was developed. Starting from input variables characterizing both the network structure and the user's habits, an analytical model that quantifies the potential benefits of smart water metering solutions, both in terms of economic and environmental savings, has been built. Before explaining its structure, it is important to clarify which the starting situation is and which the considered scenarios are.

The authors have supposed 200’000 counters, and two reference cases of smart meter implementation at household level in Italy. The cases consist in the installation of 10.000 and 50.000 meters, with an average number of 3,3 inhabitants per device due to data gathered from ISTAT. Each case has two alternatives: “Full costs” or “Delta costs”. “Full costs” when smart meters substitute working mechanical meters, while “Delta costs” when the new devices replaced faulty meters. Other hypotheses regard the average length of network per inhabitants and the useful life. The average length is based on official Authority documents, but it might be very different among areas according with the density of population. The useful life has been estimated of 10 years due to a combination of actual regulatory framework and working smart water meter systems.
Once the starting case (10.000-meters installation) and the three possible "to be" have been clarified, it is necessary to explain how the model is structured, on which variables is based and how these might change. The model evaluates the savings on both economic and environmental perspectives. Its design started with the identification of benefits. Due to a deep investigation, the authors have selected seven most relevant benefits. They have been summarized in the following list:

- Remote meter reading
- Efficient maintenance – Pipe leakages reduction
- Efficient maintenance – Faulty meters
- Demand management
- Arrear consumers control
- Fraud reduction
- Accurate billing

Then they have been quantified through a mathematical framework, following the procedure showed below:

In the next paragraph it is provided a deeper insight on each benefit, in order to better understand how the quantification was done.

Remote meter reading benefit: traditional metering devices are able to collect measurements related to a specific application field, thus once the data has been gathered by the instrument it must be collected by the utility through the reading process. It is a procedure that nowadays, in many cases, is still done manually by

operators, and many times involves the address of remote areas, hazardous road conditions, poison ivy and bug bites. The meter reading is a routine activity for utilities. It involves different operators, that are forced to a constant travel around the city districts for addressing customers in order to access at their properties and do the measurements. The smart water metering could prevent these problems by instantaneously sending water use information directly to the utility company in charge of billing and administration. This would eliminate the need for company staff or property owners to take manual readings, thus reducing time and cost for this standard process. In order to better understand these aspects, it was necessary to make a distinction between walk-by remote reading and network based remote reading (e.g. LPWAN), developing two distinct formulas for the quantification.
In both cases, the benefit quantification was done by comparing the time required for traditional manual readings and the time required for smart meter reading activities. The value was then translated in economic terms by considering the cost of operators and cost for travelling.

Efficient Maintenance – Pipe Leakage benefit: One-third of the utilities around the world report a loss over the 40% of clean water, but many utilities currently manage the leaks with reactive mechanism, responding only to visible water losses. It is a costly and time-consuming process, due to the large field forces to address the problem after that it occurred. Moreover, it is also risky with water loss going on for weeks or months because leaks could lead to a stop of the service or flooding in a house. The introduction of intelligent meters is a concrete solution to reduce the expenditure for repairing operations, provide a more precise detection system, develop predictive modelling to estimate potential future leaks, minimize the time and the number of leakages. In order to quantify this relevant benefit, the authors developed a formula which computes the savings basing on the reduction of water losses achievable through a more efficient maintenance process, enabled by smart water meters. The value of water loss reduction was then converted in economic terms by considering the total amount of water saved, multiplied by the water tariff.

Efficient Maintenance – Faulty Meters benefit: another aspect related to maintenance operation is the detection and repair of faulty meters. This activity can be very complex because traditional meters do not have any mechanism that alerts the service provider of misfunctioning, and a failure in the meter can last for months undetected, leading to significant amount of water wasted or not properly billed.

Thanks to the increased amount of valuable data enabled by smart-metering technologies, there is space for a more accurate monitoring of meter performances. The smart solutions can help utilities on reducing the time needed to identify and fix failures, by flagging water losses and faulty meters earlier. In that way, they will also save costs, because the investment can be directed with more focus toward the proactive maintenance of water infrastructure, that remains a critical in a lot of world regions. The quantification of this benefit was done by considering the difference between the time required for detecting and repairing traditional meter failures, and the time required for spotting and resolving a failure in a smart water meter, focusing on the water loss (unbilled water) that would in these time intervals. The value was translated in economic terms multiplying the amount of unbilled water by the water tariff.

Demand Management benefit: demand management strategies are important for both consumers and utilities. The information generated by smart meter data might be sent back to customers to encourage consumers behavioural changes that cancel wasteful habits, modulating their daily water usage. At the same time the data retrieved with intelligent meter enables the extraction of end-user profiles for the utilities. These are the most evident advantages, but the demand management benefit has also other positive impacts, such as planning new greenfield investments as well as sizing the pumps and valves work conditions. The authors articulated the benefit in two components. The **efficient solutions** represent those demand management strategies where the smart meters cooperate with water efficient applications or fixtures at household level. The main advantage is the reduction of consumptions indoor and outdoor. The "**operational solutions**" concern the demand management strategies that have an impact on the network management. For example, potential advantages are: the reduction of chemicals cost and pumping costs consequent to water demand reduction; infrastructural the reduction of the size of new mains due to the joint effect of peak shifting and demand reduction, opening up opportunities in terms of capital efficiency investments. The quantification of the benefit was done by calculating the economic saving that comes from chemicals cost reduction and pumping cost reduction as result of demand management strategies that reduce the amount of water consumed and shift the demand peak.

Fraud Detection benefit: besides improved knowledge about the components of water losses and the noticeable efforts over the recent years to control this problem, excessive values persist in a significant part of water distribution systems worldwide. In particular, the attention over apparent losses, especially unauthorized water consumption i.e. water theft, metering inaccuracies and unbilled authorized consumption is growing among water utilities. New smart meters with remote reading may enable the detection in almost real time of any anomalous use of the system as well as the exact location of trouble in the network, resulting in significant savings for companies. The model quantifies this benefit by considering a reduction coefficient for the fraud rate, achievable through smart meters implementation. This reduction in frauds is translated in economic terms by considering the amount of water lost due to unauthorized consumption (non-revenue water)

Accurate billing benefit: the computation of water bills is a fundamental part of the service provision because it directly affects the relationship between the utility company and the customer. In this phase is absolutely necessary that the quantity of service billed is precisely equal to the actual service consumed by the client. However, in some cases this condition is not verified, and the customer finds inappropriate values for water consumption in the bill, resulting in complaints and juridical procedures to solve the contentious. This led to additional costs for the utility to solve the problem, including the generation of customer dissatisfaction. A smart water network solution that includes smart meters enables e-billing and e-payment options and allows consumers to interact with utilities via web portals for service requests and billing inquiries. Smart metering systems continuously collect data on consumption and eliminate the need of manual reads. On this way, they ensure that consumption is billed accurately and precisely

To complete the model, it was necessary to identify costs, in order to support a cost-benefit analysis.

The costs required for the realization of a smart metering project have been taken from different existing projects, and from the data available in the literature, together with contributions derived from interviews with utility managers.

The costs have been divided in CAPEX and OPEX.

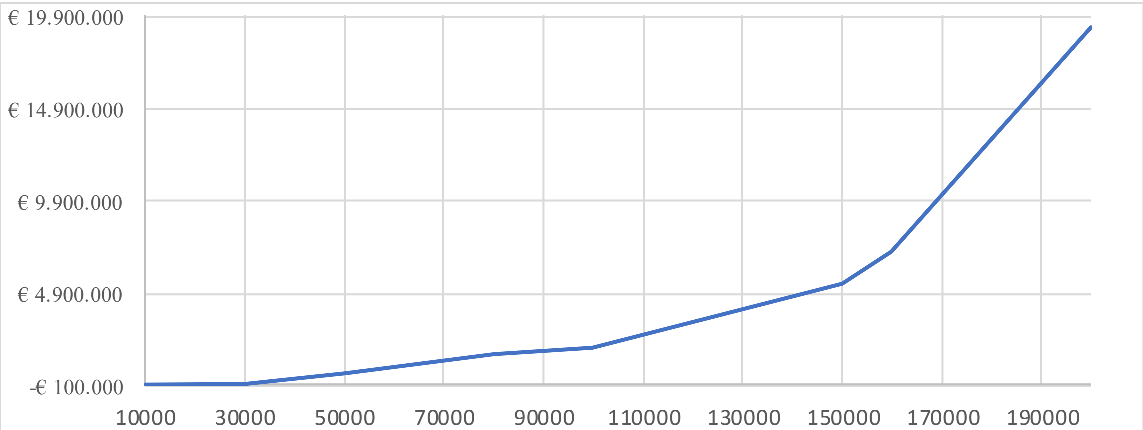
The **CAPEX** represents all the funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment. In the case of a smart metering project the CAPEX is represented by different items: cost for smart meters purchase, which represent the most important portion of total costs, the cost for meter installation, the cost for IT system integration, required to incorporate software and hardware elements of the system into the existing IT system of the organization, and finally, the cost for staff training.

The **OPEX** are those expenses a business incurs through its normal business operations. In the case of smart metering projects these costs include different components. The term that incorporates all the expenses for daily activities, network management and ordinary maintenance is the Cop, that has been estimated through comparison with similar projects, and evaluated around 2,50€/year for each meter. Another important component is represented by the extraordinary maintenance and meter replacement, which is due to battery damage or other causes. According to different sources, this cost figure is quite important and must be considered for all the duration of the project.

Model Application

After having computed all the formulas and identified all the variables required, the authors launched the model to get simulations of the 4 scenarios: 10.000-meters installation, 50.000-meters installations, 10-000-meters installations "delta case", 50.000-meters installations "delta case". The authors analysed the results according to 3 financial KPIs and 3 environmental KPIs. The financial KPIs selected were the: Net present Value (NPV), the Internal Rate of Return (IRR) and the Payback Time. The environmental KPIs selected were the Absolute Water Savings, Relative Water Savings and the Energy Efficiency Saving.

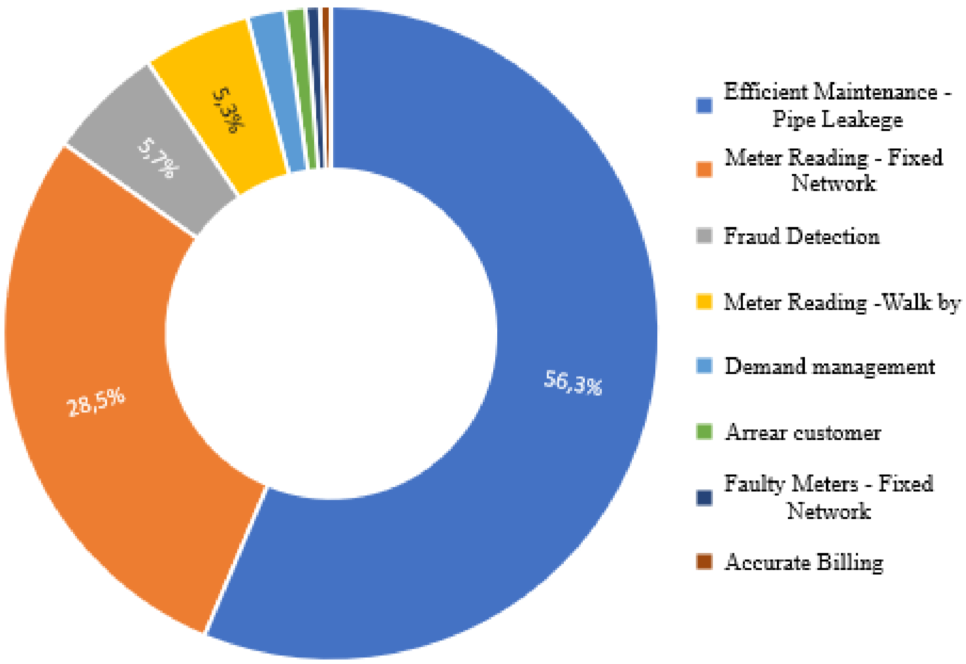
The curve below shows the returns curve (NPV) according different rollouts.



Findings

The different outputs of the model associated to each scenario, were analysed in detail. from the results shown in the tables, the returns of these smart metering projects significantly change according to the scenario. In particular, the main difference emerges considering the 10.000 and 50.000 “delta cases”, in which, the reduced cost considered for meter purchase makes the investment considerably profitable compared to the other two scenarios, with an average payback time of 4 years against 8 years of the “non-delta” case. This favourable condition of course is not always feasible in real applications, but it is an interesting opportunity that in the next years could drive the investment. In fact, the existing water infrastructure (including meters) is considerably aged, especially in Italy, and a fair share of meters is near to its end-of-life. This condition, together with the Decree 93/17, which introduces the obligation for meters substitution creates space, for promising investment conditions. Since aged meters have to be substituted, the opportunity to get additional advantagessand benefit choosing smart meters will become certainly a fundamental driver for utility companies operating in this sector.

Additionally, the analytical model also allowed us to clarify which is the contribution of each benefit over the total returns in economic terms and supports the comprehension of what are the most important factors that characterize these projects for obtaining the optimal results. In parallel, this analysis facilitates the understanding of benefit that do not represent significant levers, avoiding too much attention and resources. In this way it is possible to develop an investment plan that focus on the most convenient benefit and neglects the ones without significant contributions neither in economic terms nor in environmental terms.



We found that the most important benefit in terms of economic and environmental importance is the "Efficient Maintenance – Pipe Leakage" benefit, together with the "Remote Reading" benefit, which represent the two main drivers that make this investments profitable.

The analysis of the return curves developed by increasing the size of the roll-out progressively, starting from 10.000-meters and reaching 200.000-meters., allowed us to get additional information. In particular the relevance of economies of scale and their economic value, for installation above 30.000-meters, is a fundamental driver for wider installations. The increase of smart meters penetration, opens up new opportunities and increases the advantages coming from leakage reduction benefit and demand management, underlining the importance of developing these projects in perspective of smart water grids.

Conclusions

The presented dissertation has the aim of quantifying a cost-benefit benchmark between traditional and smart meters, achievable through the installation of the latter. Although in Italy we are at the early stage of their deployments, the literature shows a growing interest around the topic. In particular, the analysis of several papers has underlined different gaps that authors have tried to fulfil. First of all, the models presented in literature are case studies focused on just one or two potential benefits. Secondly, most of the times, they are small-scale experimentations. This represents a barrier, because the models are tailored on specific context and their findings are not adaptable to various scenario. Thirdly, only few papers investigate both environmental and economic aspects. Lastly, the scientific research studies the results in the short term, excluding potential benefits that are more profitable in the long run.

The dissertation seeks to bridge those gaps, with an analytical model that evaluates the economic and environmental dimensions, including all the possible benefit and cost into a comprehensive analytical model. The model has a flexible structure that allow to adjust itself at different inputs value for a series of characteristics. The model gathers information for example about tariff price, user habits, population density or level of leakages and it is able to provide the relative results. The model adopts the utilities point of view, for this reason, the benefits have been selected considering their importance for the service providers.

Thanks to the analysis and validations performed, it is possible to answer the formulated research questions.

RQ1: Do smart metering systems contribute to the improvement of utilities performances in the water sector? If yes, do they contribute significantly in terms of both economic and environmental terms?

Actually, the changes of regulatory framework represent the most significative drivers in Italy for companies: in particular the recent standardization of technology among the wide range available and the Decree 93/2017 which pushes the substitution of traditional meters that have more than 10 working years with smart solutions. The model has confirmed the importance of regulatory framework for supporting the transition toward smart meters, but in the meanwhile, it has also demonstrated the opportunity to catch positive economic returns in some of the different conditions analysed. Moreover, it highlights a positive correlation between the number of meters installed and financial KPI's considered (i.e. NPV, PBT, IRR), which supports wider installation in the next years. In addition, the model reports 3 environmental indicators. Especially when the scenario has negative economic results, they are significant to justify the initial investment. Moreover, the model made possible to highlight the most important variables that influence returns, and other factors which are fundamental to make the investment more profitable, for example the presence of scale economies.

RQ2: Which are the most important benefit and cost figures that utility companies need to consider when evaluating smart water metering projects?

The analytical model clarifies which is the contribution of each benefit over the total returns in economic terms and supports the comprehension of what are the most important factors that characterize these projects for obtaining the optimal results. In parallel, this analysis facilitates the understanding of benefit that do not represent significant levers, avoiding too much attention and resources. In this way it is possible to develop an investment plan that focus on the most convenient benefit and neglects the ones without significant contributions neither in economic terms nor in environmental terms. The model highlights that the most important benefits in terms of economic and environmental importance are the "Efficient Maintenance – Pipe Leakage" benefit, together with the "Remote Reading" benefit, which represent the two main drivers that make this investments profitable.

The model has been developed from scratch, so it has large potential for further improvements and modifications. It is versatile, and it is opened to adaptations according to circumstances, adding specific variables or formulas. For example, the model could simulate a wider roll outs in a metropolitan city, considering a higher population density, and a specific coexistence of traditional and smart meters. It has been though also for including new categories of benefits that actually are still not present. The authors have just provided the example of "pressure management" that is emerged during different interviews with utilities managers, but in general, further benefits may not affect directly the service providers: like the quantification of sociological factors in monetary terms could be an interesting topic for pushing the smart meter technologies. More informed customers could reduce their demand, avoid the wastes, and improve their satisfaction. A customer responsible consumption restores a positive feedback to environment and society at large. They could lead a higher water resource preservation, diminish the water basins stress. Those factors, included into a comprehensive evaluation, could favourite a more equal access to water resources or an improved equity tariff.

1 Smart metering overview

The Chapter 1 is an introduction of the smart metering topic. It has been divided in four sections. The firsts two contain the definition, the architecture, and the potential applications of smart metering technologies. The third section reports an overview of the market conditions and the expected trend in the next years. The last one includes a description of in force laws among selected geographical areas.

1.1 Smart Metering System: definition and features

The metering systems can be defined as devices and related instruments that can be installed to measure the volumes (e.g. quantity) of inputs and outputs that are being made available or delivered to a buyer at the interconnection point.

Determining the amount of energy or resource delivered to each customer has always been at the basis of utilities business in order to get a fair remuneration for the service offered: consumption meters allow to measure flow of different commodities, (e.g. gallons of water, cubic feet of gas, or kilowatt-hours of electricity) while more advanced meters can even quantify how fast such commodities are being consumed, thereby determining peak demand (e.g. kilowatts).

The liberalization of the energy market, together with increasing sustainability and energy efficiency requirements, made necessary the introduction of more versatile and flexible either equipment or systems, as well as to standardise the processing of the associated data in order to bill the service more efficiently and to keep users informed. Evolving energy markets have brought many changes, among them an expanded willingness for tracking energy use on a real-time (or near real time) basis, and the necessity for water, electric, and gas utilities to continuously read and record consumption in shorter time intervals, or at least provide daily reporting, monitoring, and billing. In this context, the introduction of smart metering was considered a pre-requisite step to achieve the desired market competitiveness (NYSERDA, 2003).

Meters have been called smart since the introduction of static meters that included one or more microprocessors. (European Smart Metering Alliance, 2010). A common understanding of SM considers it as a combination of an electronic meter and a communication link. An electronic meter computes how much energy or water is consumed based on electronic signals and sends this information to other devices. Smart meters are predominantly based on wireless technologies to allow a two-way communication between a user and a utility supplier. It permits at customers to become aware of individual energy or water consumption and enables them to undertake appropriate actions directly, aiming at consumption reduction, cost minimization, environmental goals achievement, local energy and water security increase (Kochański, Korczak, and Skoczkowski 2020). From a technical perspective, SM can be considered as a control system with the role of providing feedback to the energy system participants.

More precisely, smart metering infrastructure (SMI) is an electronic system that is capable of measuring energy consumption whilst providing more information than a conventional meter and that can transmit and receive data using a form of electronic communication (Leiva, Palacios, and Aguado 2016).

ESMA defines a set of features that characterize smart metering systems:

- Automatic processing, transfer, management, and utilization of metering data
- Automatic management of meters
- 2-way data communication with meters
- Meaningful and timely provision of consumption information to the relevant actors and their systems, including the consumer
- Effective support for services that improve the energy efficiency of the energy consumption and the energy system (generation, transmission, distribution and especially the end-use)

Smart meters should not be intended as simple electronic meters. The novelty of smart meter technology lies in the functionalities that are added to conventional electronic meters.

Advanced Metering Reading (AMR) enables data acquisition from long distances and can be regarded as the predecessor of smart meters. The new functions of smart meters to older metering solutions, including AMR, can be summarized in advanced data collection (using physical and wireless connection, end-to-end communication), advanced data processing (detection and diagnosis of system faults, data storage and management) and advanced data use (interactive display, bi-directional metering and billing).

1.2 Smart Metering Systems, IoT and Smart City paradigm

Smart metering systems can be considered as part of the IoT and fundamental enabler for Smart City paradigm.

IoT is a network of physical objects or things connected to the Internet, equipped with embedded technology to interact with their internal and external environments. These objects sense, analyse, control and decide individually or in collaboration with other objects through high speed and two-way digital communications in a distributed and autonomous manner (Saleem et al. 2019).

The integration of intelligent measuring devices in a city using the Internet of Things (IoT) allows the collection of all the data necessary to become a smart city. In this sense, smart meters have a fundamental role of keeping the city connected, informed, and ensure that each subsystem performs its function. The installation of these technologies facilitates the development of the city, achieving better management of the electric energy, water, and gas providing networks, and an efficient balance between demand and consumption (Zanella et al. 2014).

Monitoring energy and resource consumption of the whole city is a fundamental pillar of the future smart cities (smart energy), thus enabling authorities and citizens to get a clear and detailed view of the amount of energy required by the different services (public lighting, transportation, heating/ cooling of public buildings). In turn, this will make it possible to identify the main energy and water consumption sources and to set priorities for optimizing their behaviour. The process goes in the direction indicated by the European directive for energy efficiency improvement in the next years. In order to obtain such a service, smart monitoring devices need to be integrated in the power and water infrastructure, to build smart infrastructure able to perform fault localization, isolation and service restoration, resulting in an increased level of service for users and lower costs for the service provider.

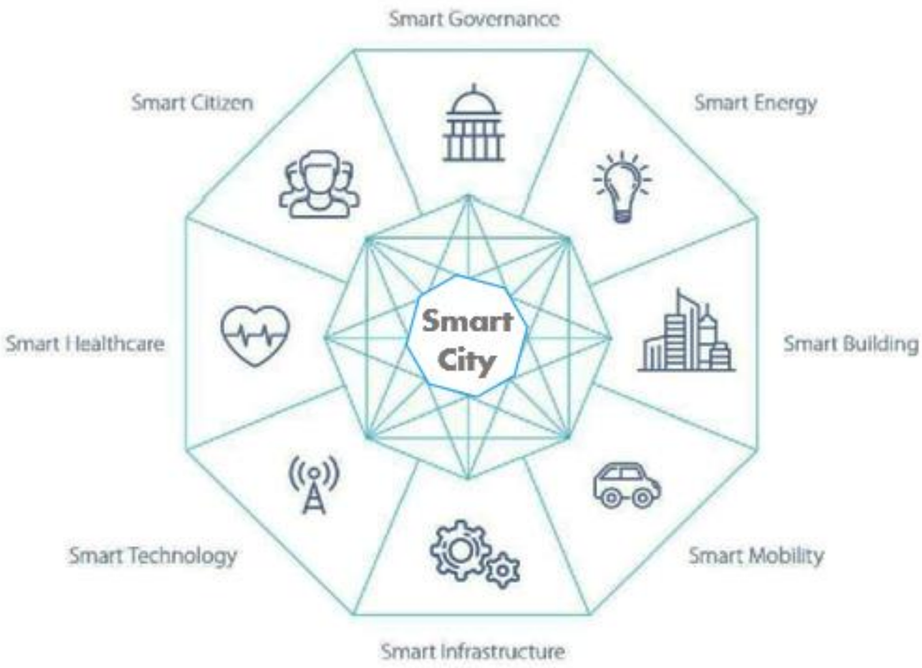


Figure 1.1 - Smart city diamond

The figure 1.1 represents the smart city diamond (Mathew, 2013). It is a visual portrayal of the smart city pillars. We can notice that smart metering is a fundamental enabler, supporting at least three out of the seven pillars of the smart city: smart energy, smart infrastructure, and smart building.

1.2.1 Smart Metering Systems: architecture and purposes

In the next paragraph it is provided a model for smart metering architectures, that describes the main features of smart meter technology, understanding how these systems are part of the IoT paradigm.
Since smart metering can be applied in different sectors, according to the type of utility considered (water, electricity, gas) there can be significant differences, in particular related to the specific typology of measurement device (smart meter for water, electricity or gas), the operating parameters (frequency of collection, transmission delay, location above ground or underground) and data transmission technologies. For these reasons, the authors will try to provide a description of the general architecture that is common to all different types of smart meter for utility application, defining a generic Smart Metering System.

The smart metering systems include sensors, hardware, software, communication protocol, consumption displays and controllers, customer systems, software for data mining, software for meter data management, and business systems.

Lloret et al. (2016) proposed a layered architecture to classify all components and interfaces according to their features and purpose. This architecture is articulated in 3 layers:

- Layer 1 includes smart meters, network devices and communication protocols
- Layer 2 includes the devices in charge of receiving data at the utility side
- Layer 3 includes artificial intelligent systems to manage data and billing systems

Smart meters are digital electronic devices that collect information on use of electricity, water, or gas and sends it securely to the utility. There are different solutions and possibilities, therefore it is important to emphasize some functional aspects related to these devices. First of all, smart meters often require autonomous energy supply systems, for this reason the battery lifetime of the meters is a crucial factor, that many times can limit the quantity and frequency of sending data, requires energy saving and optimization techniques. At the same time, another important aspect that has to be considered is the frequency of data collection and their relative sending rate. A high data reading frequency opens a new spectrum of possibilities for understanding the electricity/water/gas demand network and for services management, but at the same time increases the energy consumption of the meter thus reducing battery lifetime. Moreover, the location of meters often limits the signal transmission, which can negatively affect the possibility of gathering real-time data. An adequate transmission technology, together with precise requirements in term of transmission delay are key features considering the smart metering activities.

Once the information has been collected by the smart meter, data must be transmitted to the receiver. The lack of a common communication standard makes the interoperability of smart meters produced by different manufacturers very difficult and give rise to a wide range of different possibilities. The communication technologies for collecting and transporting data can be wired, wireless mobile, wireless fixed network, or a combination of them. The choice of technology depends on multiple factors such as the challenges the utilities face, the configuration of the deployment field, the benefits of using the data and the information. Lloret et al. (2016) have classified communication protocols according to three categories:

- First category: standardized and open meter access protocols (M-bus, CzBus, Wavenis, LonTalk, KNX)
- Second category: general purpose standardized communication protocols (IEEE 802.15.1 (Bluetooth), IEEE 802.15.4, 6LoWPAN, and IEEE 802.11)
- Third category: well established proprietary systems (Plextek)

Moreover, there is another classification that basically distinguish between wired and wireless technologies for transmission. The most used wired technologies including public switched telephone network (PSTN), asymmetric digital subscriber line (ADSL), and fibre to the buildings or homes (FTTx). In the wireless group, we can find a wide range of solutions: Terrestrial Trunked Radio (TETRA), second generation (2G, including Global System for Mobile Communications, GSM; General Packet Radio Service, GPRS; and Enhanced GPRS, EGPRS), 3G (Universal Mobile Telecommunication) IEEE 802.16, Long Term Evolution (LTE), and mobile satellite communication.

The PLC has been the leading technology for SM communication in the first wave of SM deployments. However, various other types of communication technologies for SM are still used currently. They offer different types of advantages and entail several disadvantages depending on various circumstances of SM deployment, such as the location. The wireless communication technologies (e.g. mesh radio, NB-IoT) are becoming more and more advanced, offering broader bandwidth, shorter response times, improved security, as well as wide coverage even in problematic locations, such as rural areas or cellars (Kochański, Korczak, and Skoczkowski 2020).

The table 1.1 shows the main wired and wireless communication technologies used for SM application.

Connection Type	Technology Category	Technology Name	Examples of Deployments in SM Systems in the EU
Wireless	RF-Mesh	-	InovGrid (PT)
	Cellular	3G-4G	HEDNO (GR)
		GSM	Telegestore (IT)
		GPRS	PRICE-GEN (ES), Eandis and Infrax (BE), Linky (FR)
	IEEE 802.15 Group	ZigBee	Energy Demand Research Project, EDRP (UK) National Smart Metering Programme, NSMP (IRL)
		6LoWPAN	
		Bluetooth	
	IEEE 802.11 Group	Wi-Fi	National Smart Metering Programme (IRL)
		Enhanced Wi-Fi	
		IEEE 802.11 n	
	IEEE 802.16	WiMAX	Smartcity Malaga (ES)
Wired	Power Line Communication (PLC)	NB-PLC	Telegestore (IT), PRICE-GEN, Iberdrola (ES) Eandis and Infrax (BE), Linky (FR)
		BB-PLC	
	xDSL	ADSL	Demand Research Project, EDRP (UK), PRICE-GEN (ES), Eandis and Infrax (BE), Stadtwerke Emden by Deutsche Telekom (DE)
		HDSL	
		VHDSL	
	Euridis	IEC 62056-31	SMs in France
	PON	-	PRICE-GEN (ES)

Table 1.1 - Common wired and wireless communication technologies on Smart Meters application

Once the data coming from the intelligent meters are gathered, there are different techniques that allow the treatment of large information volumes for extracting the maximum value. The most common are within the category of big data system, for example Hadoop and Spark. Apache Hadoop is a platform that handles large datasets in a distributed fashion. The framework uses MapReduce to split the data into blocks and assign the chunks to nodes across a cluster. MapReduce then processes the data in parallel on each node to produce a unique output. Apache Spark is an open-source tool. This framework can run in a standalone mode or on a cloud and it is designed for fast performance and uses RAM for caching and processing data.

The data are collected from electricity, water, and gas smart meters using IoT. They can be used for many purposes, but broadly they can be reconducted to three categories: prediction of future consumption, detection of incident, customization, which will be further examined in this thesis.

Most of these benefits are common to all smart metering systems, but additional advantages can be found considering the specific application. For example, smart metering applied to electricity allows the implementation of demand-response systems that can bring additional benefit for user and utilities.

1.3 Global market for Smart Metering Systems

The 2019-2024 report of IoT Analytics shows the global market penetration of smart meter (electricity, water, and gas). It has surpassed 14% in 2019, however with significant differences among regions and countries.
By the report emerges that the total number of intelligent meters installed (considering all the sectors: electricity, gas, and water) is expected to overcome the 150 million mark within the next 2 years. In 2018, more than 132 million of smart meters have been shipped worldwide and their number is constantly increasing as witnessed by the Compound Annual Growth Rate (CAGR) estimated around 7%. The report foreseen the achievement of 200 million units by 2024.

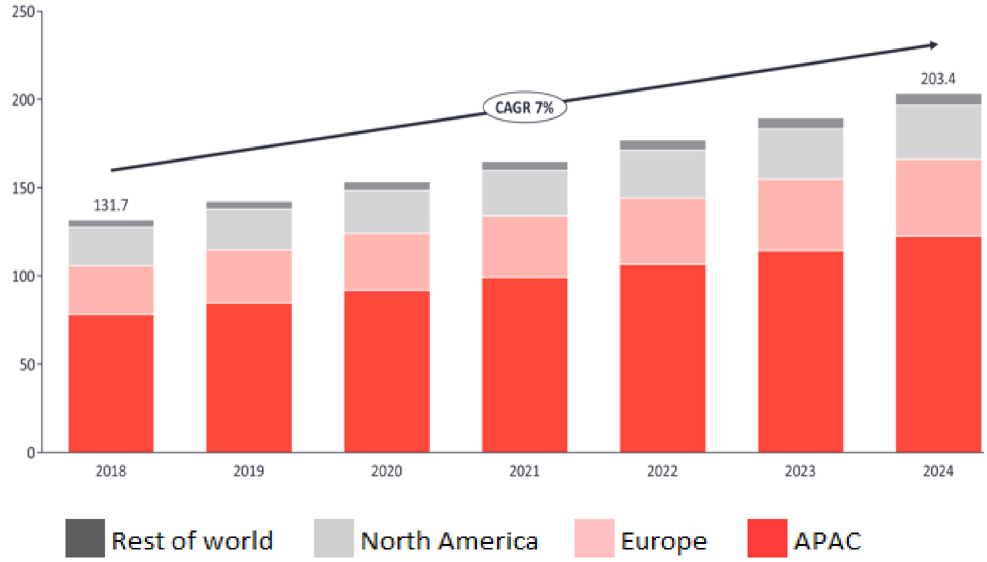


Figure 1.2 - Global volume of smart meter shipment by region (in millions of units)

The analysis underlines a high level of heterogeneity and fragmentation in the smart meter market, mainly because at regional or country level, the institutions support a not well-defined regulatory frameworks without considering the various needs of utilities in different geographical areas worldwide. In the next section it is provided a global overview of smart metering market according to four different macro-regions.

1.3.1.1 North America

The smart meter market in North America is fairly mature with a penetration rate estimated around 30-40% of total utility consumers for electricity, gas, and water. Both USA and Canada have been early adopters of smart meters. Today many of the utility operators in the region have deployed a large-scale smart meter solution or they are currently working in progress.
In the USA, the smart meter deployments took off during the Obama presidency, when the government financed projects with public support, making the country the early leader in the market. At that time, many utilities opted for turn-key solutions based on proprietary technologies from well-established meter vendors such as Itron or Sensus.
In the next 5 years, for the region is expected a stable growth driven by planned large-scale rollouts of the remaining utility operators, in particular the private-owned ones and by smaller deployments promoted through cooperative and municipal utilities. In addition to new deployments, a large share of smart meters will be replaced because they have been installed during the first implementations and actually, they are reaching the end of their lifecycle.

1.3.1.2 Europe

In Europe, the smart meter market has still not reached maturity. Its penetration rate is estimated around 30% of utility customers. The adoption is comparable to North America; however, their presence is much more heterogeneous with consistent variations between countries in terms of regulations, disparity of the local utility markets, and the willingness arising with the adoption of smart meter solutions.
Over the past decade the adoption of smart meters in the region has been driven by the roll-out target of 80% market penetration for electricity by 2020, established by the EU with the 2009 Third Energy Package plan. However, the roll-out progress is not proceeding as fast as planned, and there are consistent differences between Member States degree of adoption. The European countries can be distinguished in 4 groups according to the smart meter penetration rate:

- Leading countries: Italy, Sweden, Finland, and the Netherlands have already hit the 80% target and expect to reach more than 95% penetration by 2020

- On-schedule: France, Spain, Greece, and Denmark rollouts are proceeding at a steady pace and they are expected to reach the 80% target by 2020
- Behind schedule: Progress in other countries has been slower, and the 80% target will not be reached by 2020. UK is the most noticeable example, where various technical and consumer-related challenges have delayed the roll-out and recently convinced the government to extend the deadline by 2024.
- Not following the EU plan: A few countries, including Germany, Belgium and Portugal have opted not to follow EU's smart meter plan due to a negative cost-benefits analysis and they are planning or implementing selective rollouts instead.

In terms of gas and water meter, the level of adoption remains lower than electricity, but growing faster. Only a few countries in the EU have already started or are planning large scale rollouts (e.g. Italy, France, UK, Netherlands). Specifically, the estimations foreseen that the 40% of households and commercial buildings in EU will have a smart gas meter by 2020.

1.3.1.3 Asia Pacific

Asia Pacific represents the largest region in the global smart meter market, with estimated 78.1 million smart meters shipped in the region in 2018, more than 60% of total market. The overall penetration of smart meters in the region remains lower than North America and Europe however, with less than 20% of utility customers equipped with smart meters. In general, electricity meters have been the primary focus in most leading countries, while gas and water meters have only recently witnessed increasing traction, although the rate of adoption grows slowly due to the general lack of capital for these projects in many countries.

China is the leading country in the Smart Meter market. In 2011 "The State Grid Corporation of China" began the deployment of smart electricity meters in various areas of the country, installing a total of 476 million meters that represent more than half of the worldwide installed base today. Japan and South Korea also put in place large scale deployments of smart energy meters currently ongoing.

India is expected to play an increasingly important role in the smart meter market, following the recent introduction of a centralized AMI procurement and financing process that will drive adoption of smart meters in the country over the next 5 years. One of the major drivers that is sustaining the deployments in India is the entrance of the government-owned energy services company EESL (Energy Efficiency Service Limited). Through its demand aggregation and procurement model, EESL is effectively addressing the cost issue of smart metering investments, currently the main barrier for Indian utilities to launch standalone deployments.

Indonesia, Malaysia, Philippines, Singapore, and Thailand are still in embryonal stage of adoption, but they are expected to become key markets after 2020.

Australia was the first country to complete a large-scale rollout in 2013 in the State of Victoria, installing 2.8 million meters to cover 93% of households and small businesses. Various other states (e.g. Western Australia) are currently either planning or launching large-scale smart meter deployments in the country. The region is also the leader in terms of smart water meters installation.

1.3.1.4 Rest of the World

In the rest of the world, the smart meter market is largely still at an early stage. Most countries in Africa, Latin America or the Middle East are either still in a pilot stage or have not started yet introducing smart meters. To date, market penetration rates in these regions are below than 5% of total utility customers, with electricity meters being the most adopted, followed by water and then gas.

In general, the main barrier to the adoption of smart meters in these regions is the lack of funding and government initiatives. Moreover, in many cases there are also problems related with an inadequate infrastructure, based on obsolete technologies, and often covering only urban areas, which makes the deployment of smart meters prohibitive for many utilities.

In Africa most of the projects are still in a pilot phase with the major implementation occurring in Nigeria and South Africa, while Egypt recently announced its plan to deploy 30 million smart meters in the next 10 years.

In the Middle East, the major deployments are happening in countries like UAE, Saudi Arabia, and Qatar, but the majority are pilot projects and only one utility in Abu Dhabi has completed the roll-out of smart electricity and water meters for its customers.

In Latin America, the market is led by Mexico and Brazil where various smart meter projects were launched in the past decade, from pilot-phase to large-scale deployments. In Mexico, the state-owned utility CFE is currently installing smart meters with the objective of 30 million units by 2025. In this moment, the contributions from other countries are small, but a future market growth has been foreseen in Colombia, Peru, Chile, Uruguay, and Costa Rica where the major utilities have announced plans for large-scale rollouts in the next decade.

1.3.2 A dive in the European Smart Metering (electricity and gas)

The European Union has already started the modernization and transformation towards a climate neutral economy. In this context, the Commission has proposed a strategic long-term vision for Europe to become the world's first major economy and achieve the climate neutral by 2050.

With digitalization being a main enabler for the rise of a resilient and secure grid of the future, the recently updated European Union regulatory instruments stress more than ever the need of large-scale rollouts of intelligent energy meters. Despite the current advanced stage of smart electricity and gas meter the deployment in some Member States, in other ones they are still at the beginning of this process.

The adoption of the 2009/72/EC Electricity Directive and the 2009/73/EC Gas Directive has triggered the necessity to foster the deployment of smart metering systems in each Member States for both electricity and gas utility.

However, the picture appears quite different among gas and electricity markets. Indeed, the three quarters of Member States have adopted specific legal provisions for the roll-out of electricity smart meters against only a quarter of them that has also done a specific roll-out for gas smart meters.

As July 2018, all less than two Member States have conducted at least one CBA for a large-scale rollout of electricity smart meters involving the 80% or more of total users by 2020, with the results for most of these being positive.

In the next paragraph it is provided an overview of the current European condition in terms of Smart Metering current deployment and future installations. The analysis is conducted for electricity and gas smart meters, focusing on data found on the Report “Benchmarking smart metering deployment in the EU-28” published by the European Commission in March 2020. Unfortunately, the report does not provide any data regarding Smart water metering, but this theme will be widely and deeply discussed later on this work.

1.3.2.1 Smart Meters for electricity

In 2018, the 34% of electricity metering points were equipped with a smart meter (99 million of units). The electricity metering points of household and the ones of SMEs taken separately were equipped at 35% and 28%, respectively.
According with the Benchmarking Smart Metering Deployment in the EU-28 report, the weighted average cost per metering point is € 172, that means the deployment of these 123 million electricity smart meters would require an aggregated investment of over €21 billion.
Considering that Member States will proceed with the rollout according to their updated planning and new target periods, it is expected that totally between households and SMEs will be installed 223 million smart meters by 2024.
By 2030, it is estimated that 266 million smart meters will be installed (the 92% out of the total number), which will represent a total aggregated investment of €46 billion. Currently, more than half of the Member States have reached at least 10% of installation rate for electricity smart meters. It means a first important step in their large-scale roll-out programs. Seven countries have already reached the 80% penetration for example Denmark, or even finished their large-scale electricity smart metering roll-out like Estonia (98% in 2017), Finland (100% by 2013), Italy (95%, by 2011), Malta (85% by 2014), Spain (100% by 2018) and Sweden (100% by 2009). Some of them are already proceeding with the second-generation rollout, like Italy, or planning this (for instance Finland, Sweden).
Nevertheless, only few from those remaining Member States that had committed to do so are still on track to reach the 80% deployment target rate by 2020; some of them are now setting this target as late as 2030. One of the main reasons for these deployment delays concerns the low level of consumer acceptance, an issue that still needs to be further investigated.

1.3.2.2 Smart Meters for gas

For what concerns smart gas meters, the situation appears trickier and the complete large-scale roll-out is still far from become reality
In January 2018, according to the available data, only 14% of all gas metering points were equipped with smart meters, which represents around 16 million of intelligent meters. Actually, just 6 Member States have provided an implementation strategy for large-scale rollout of gas smart metering. They are France, Ireland, Italy, Luxembourg, Netherland, and United Kingdom, but apparently only

Luxembourg and Netherlands seem for being on track with their objectives, that have been originally intended for a roll-out of 80% by 2020.

By 2024, based on the original announcements of previous 6 Member States, the penetration rate could reach 51% with 60 million gas smart meters installed in 5 years. Considering a weighted average cost per gas metering point of €171, this would represent an aggregated investment of €10 billion.

Nevertheless, at the current slow pace of deployment, it is estimated that in 2020, 31 million of smart gas meters will be in place, accounting for 27% of all gas metering points. It represents an aggregated investment of over €5 billion. By 2024, it is expected that 51 million smart meters will be in place, corresponding to the 44% penetration rate EU-wide and a total investment of almost €9 billion. By 2024 only Italy, Luxembourg and the Netherland would have completed their large-scale rollout of gas smart meters considering the actual premises.

1.4 Smart metering directive

The development of smart metering systems has been carried out gradually through the adoption of numerous legislative measures during the last decade. In this section is reported a complete description of regulatory framework milestones among selected geographical area. In details, we will discuss the norms for smart water metering on USA, Australia, and Europe with a dedicated insight about the legislation in Italy.

1.4.1 USA

The regulation of the water sector reflects the federal nature of United States, with the responsibility for governance shared between national and State governments. It makes difficult and very complicated a complete overview of existing laws. For that reason, the authors focused on most important national norms, providing a discussion at low level of details. The first legislation milestone has been the “Safe Drinking Water Act” of 1974, even today the water utilities are subjected to that law. In general, each water system has to meet at least the federal standards, however further requirements could be imposed by the States as well as the interstate and regional authorities might exert a relevant influence. The municipalities are the major responsible for proper daily operations such as guarantee an acceptable quantity and quality of water supplied, under a constant pressure. The utilities must set a fair price, offer customer service, avoid public health issues, and offer opportunities of training for their employees. The economic regulations are focused on control of the prices and profit of utilities. They are valid mostly for the private company, while the public utilities are largely self-controlled. The economic regulations could be managed by local commissions or States ones. For the local commission, the theory states that accountability is assured for publicly owned monopolies through electoral and other public channels (namely municipal governance).

EPA's Clean Water and Drinking Water Infrastructure Sustainability Policy promotes sustainable infrastructure within the water sector. Federal state and local officials collaborated with EPA to develop the policy. The policy's objective is to ensure that federal investments and actions support water infrastructure in efficient and sustainable locations to aid existing communities, enhance economic competitiveness and promote affordable neighborhoods.

The regulation emphasizes the need to build on existing efforts to promote sustainable water infrastructure, working with states and water systems to employ robust, comprehensive planning processes to deliver projects that are cost effective over their life cycle, resource efficient and consistent with community sustainability goals. Moreover, EPA offers tools and information to help water sector utilities manage water for optimum water and energy efficiency (EPA, 2020).

1.4.2 Australia

The water sector is critical in Australia because of three factors: water shortage, periodic droughts, and the high rate of population in urban areas. In the last years, the situation is worsening, e.g. in 2009 in South Queensland the population is growth of 33% over the previous twelve years.

The local government is providing a series of incentives to subsidize the water utilities. However, it is important to stress that Australia is a federal country where the States are responsible of policymaking on water sector. Although some authorities are under the federal control like the "Ministry for Climate Change and Water" and even some issues are treated at national level as the Murray-Darwin Basin that crosscut several States. The procedure has been formalized in 2004, after an agreement between the regional, interregional, and federal authorities thought the CoAG. The agreement also created the National Water Initiative (NWI), a national forum for discussing about water issues. The NWI is a compatible national system between the market and the legislation requirements. In particular, the NWI aims at:

- Prepare water plans with provision for the environment
- Deal with overallocated or stressed water systems
- Introduce registers of water rights and standards for water accounting
- Expand the trade in water
- Improve pricing for water storage and delivery
- Meet and manage urban water demands

The National Water Commission administers the NWI, after the National Water Commission Act of 2004 and strengthened in 2011. The National Water Commission has to use the NWI for fostering the progress toward the sustainable management. It advises the Australian government and CoAG about water issues. NWI was established, even, for creating independent bodies to set or review prices. The Water Act of 2007 assigned the commission to audit the effectiveness of the implementation of the Murray-Darling Basin Plan and associated water resource plans.

The economic regulation of the water sector is different among the Australian states and territories. For example, within Queensland and Tasmania, the water services are provided by the local governments, while several municipal service providers and state bulk service providers cover large portions of South Wales, Victoria, and South East Queensland.

In South Australia, Western Australia, and the Northern Territory, integrated state-level utilities are in charge of both bulk and retail water supply. There is very little competition in the water sector, and the providers generally act as monopolies. This makes the regulatory framework very important in Australia. A growing movement is underway to bring economic regulation of utilities to a national level (or at least an eastern seaboard level). The Water Services Association of Australia has called for independent price regulation at a national level using nationally consistent approaches and common principles (WSAA, 2009), such as already is the case in the energy sector with the Australian Energy Regulator. Whether such reforms will be implemented is unclear.

1.4.3 Europe

1.4.3.1 Electricity and Gas

The Directive 2006/32/EC has been the first institutional paper where was prescribed the use of innovative technological solutions as “electronic metering” for achieving an energy saving. The directive represents the initial step to make customers active through the usage of metering devices. It sets a level of 9% energy savings using as a baseline the consumption in 2006, that had to be achieved in 9 years.

Then, it has been launched the Third Energy Package. It contains the directives of Internal Market for Electricity and Gas (Directive 2009/72/EC and Directive 2009/73/EC). They require at Member States the implementations of intelligent metering system to assist the active participation of consumers in the electricity and gas markets. Moreover, the smart meter implementation is subjected at a cost-benefit analysis (CBA), but with distinctions between the two sectors. (Benchmarking smart metering deployment in the EU-28, 2020).

As concerns the electricity market, if the results of a long-term analysis of costs and benefits is positive, at least 80% of those consumers who have been assessed positively have to be equipped with intelligent metering system by 2020. Where no long-term CBA is made, at least 80% of all the consumers have to be equipped with smart metering systems by 2020. While for the gas sector has not been set a deadline, but it was required at each Member States of providing a detailed timetable for scheduling the deployment of smart meters. The directives have obliged the countries to produce a CBA for the rollout of intelligent meters before 3 September 2012 with a timetable in the electricity sector up to 10 years for their introductions.

The European Commission has provided a report in July 2018 in which was described the results of CBA for the electricity market in all the 28 countries of the community (European Smart Metering Landscape Report, 2016).

With the Directive 2012/27/EU has been updated the energy saving target to 20% by 2020. The directive regards the energy efficiency and underlines the importance of energy saving, as mentioned in its following note “it is important that the requirements of Union law in this area be made clearer” (Benchmarking smart metering deployment in the EU-28, 2020).

Furthermore, for complementing the provision of Third Energy Package, it has been introduced the Energy Efficiency Directive (EED). It was published in the Official Journal on 14 November 2012 and entered in force on 4 December 2012. Member States had to transpose it by June 2014. EED supports the development of energy services based on data from smart meter. The article 9 of the EED contains the rules on what devices, invoices and information should be provided to end users. In details, it "requires that final customer for electricity, natural gas, district heating, district cooling and hot water should have a competitively priced individual meter that accurately reflects their energy consumption and provides information on the time of their energy use (with exceptions based on technical and financial grounds). This is mandatory for connections in a new building and major reservation." In addition, the EED ensures for internal energy market the protection of consumer privacy when providing access to data for running business processes as guaranteed by Article 8 of Charter of Fundamental Rights of European Union. The Members States should empower programmes for intelligent meters deployments through specific measures. The EED identifies five main elements which could be present in the measures: fiscal incentives, grants, information provision, exemplary projects, and workplace activities (European Smart Metering Landscape Report, 2016).

The Recommendation 2012/148/EU was a guidance for the Member States on the design of smart metering systems, in particular it concerned the protection of personal data and recommend Member States to include an impact evaluation. It defines 10 minimum functionalities for smart metering systems, mainly applicable for electricity, which are relevant for different market actors. Finally, the Recommendation set a methodology for the economic assessment of the roll-out of smart metering, in accordance with Annex I of Directives 2009/72/EC and 2009/73/EC.

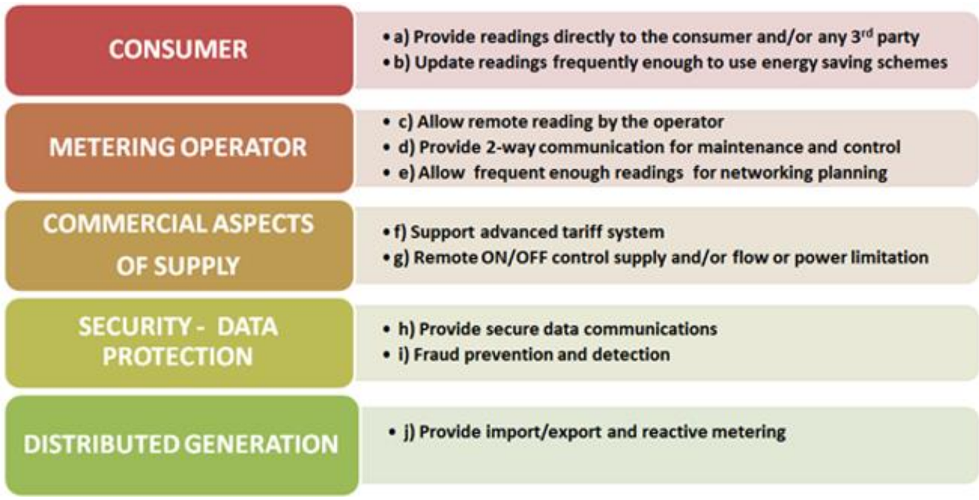


Figure 1.3 - 10 functionalities identified by Commission Recommendation

A subsequent improvement was Commission Recommendation 2014/724/EU that introduced procedures for the promotion of the Data Protection Impact Assessment Template (called the “DPIA Template”). It was developed at EU-level, with the aim to ensure the fundamental rights of protection of personal data and to safe the customers privacy in the deployment of smart grid applications and systems and smart metering roll-out”.

The Directive 2014/32/EU defines a methodological control on measurement instruments. It harmonises their parameters on different national law. The parameter are essential requirements that must be satisfied for making available the instruments on the market.

The ‘Electricity Directive’ (or Directive 2019/944/EU) has changed the conditions on deployment of smart metering in the electricity market. When the CBA results have a positive outcome “at least 80 % of final customers shall be equipped with smart meters either within seven years of the date of the positive assessment or by 2024 for those Member States that have initiated the systematic deployment of smart metering systems before 4 July 2019. When the deployment is negatively assessed, Member States shall revise their CBA at least every four years. (Benchmarking Smart Metering Deployment in EU-28, 2019)

The capital investment linked to smart meters, IT infrastructure, network management, operations and maintenance are emerged as the most common cost figures considered by Member States. The benefits are divided in direct and indirect for the consumers. The direct benefits concern a bill reduction, thanks to a higher energy efficiency with smart meters that allow a deep understanding of the energy

consumptions and the dynamic price. The indirect benefits regard the potential cost reductions that other market actors could access, such as the smart meters will allow automated meter reading with a consequent reduction of operational savings.
The timeline below shows the most relevant reforms introduced on the Member States about Smart Metering for electricity and gas meters.

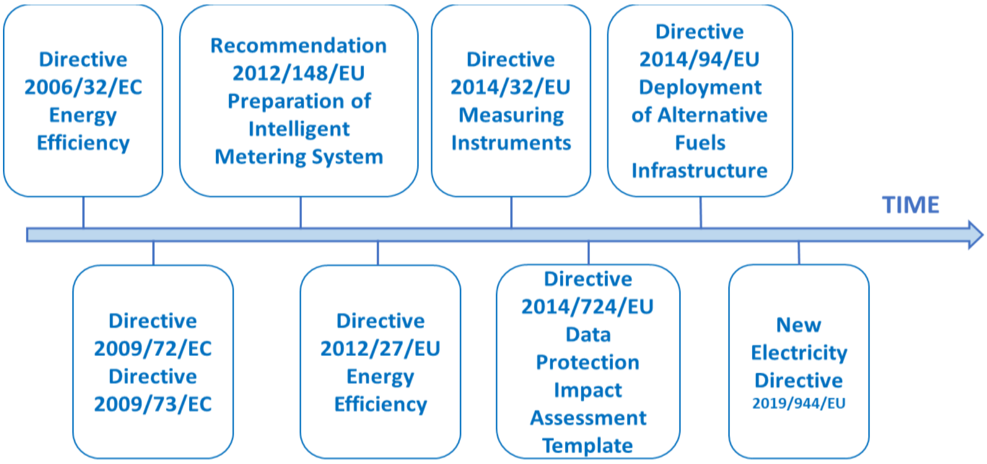


Figure 1.4 - Timeline of European regulatory framework for smart meters

To conclude the section dedicated at European regulatory framework, the authors have provided a panel with all the most relevant laws of each country on electricity and gas market. In the analysis, it is excluded only Italy by the list of European nations because it has a detailed description in the next paragraph.

Country	Relevant legislation for electricity smart metering
Austria	The ‘ElWOG 2010’ has been the first law in the country. It has been followed by delegated legislation which further implement the smart metering deployment as ‘IME-VO’ for implementation plan, “IMA-VO” for the functional scope, and ‘DAVID-VO’ concerning the data availability and presentation to the customer.
Belgium	The primary law enabling the smart meters for electricity in the Brussels Capital Region has been in 2001, called ‘Ordonnance du 19 juillet 2001 relative à l'organisation du marché de l'électricité en Région de Bruxelles-Capitale’. In the rest of countries specific laws were introduced later: 2009 in Flanders and 2018 in Wallonia.

Bulgaria	No specific laws have been adopted to frame the deployment of smart metering.
Croatia	The ‘Energy Act’ allowed both smart electricity and gas metering.
Cyprus	The country first law has been ‘Regulation of the Electricity Market Act 2003’.
Czech Republic	The Act No. 458/2000, Coll. on Business Conditions and Public Administration in the Energy Sectors and on Amendment Other Laws (Energy Act)
Denmark	The ‘Danish Electricity Supply Act’ enables the smart metering on the country. It has been revised in 2019.
Estonia	The primary law that enables smart metering for electricity is the ‘Grid code under Electricity Market Act’, which was revised in July 2010.
Finland	The primary law that enables smart metering for electricity is ‘Decree of the State Council (66/2009)’.
France	The primary law that enables smart metering for electricity is the ‘Law n° 2005-781’. It provided the energy policy guidelines, that has been incorporated into the ‘Energy Code (art. L.341-4)’.
Germany	The primary law that enables smart metering for both electricity and gas is ‘Gesetz zur Digitailiserung der Energiwende’ introducing the 'Metering Point Operation Act'.
Greece	The primary law that enables smart metering for electricity is ‘Law 3855/2010’. It is in line with the purpose of European directive to replace 80% of the conventional meters with smart meters until 2020.
Hungary	The primary laws that enable smart metering for electricity is the ‘Electricity Act LXXXVI’ of 2007. The ‘Government Decree No. 26/2016’ is currently the delegated law that further implements smart metering deployment for both smart electricity and gas meters.
Ireland	The primary law has been ‘Climate Action and Environment' in 2014. It enables smart metering for

	electricity and gas meters and belongs at 'Statutory Instrument 426'.
Latvia	There is no specific law framing the smart metering deployment for electricity
Lithuania	The general principles of implementation of the Lithuanian energy sector vision are approved in the National Strategy for Energy Independence. The latest version of the strategy was approved by national parliament in 2018, called NENS. The approved NENS envisages that the development of the Lithuanian energy sector must be based on smart technologies and digitalization of energy (Article 19.8). They are set out in the General Regulations for the Installation of Electrical Equipment, approved in 2017. These requirements are based on the implementation of the Directive 2012/27/EU.
Luxembourg	The primary law that enables smart metering for electricity is 'Loi modifiée du 1er août 2007 relative à l'organisation du marché de l'électricité'. This law was last revised in 2015. This revision introduced the mandate to roll out Smart Meters.
Malta	The primary laws that enable smart metering for electricity are the Subsidiary 'Legislation 545.13 on Electricity Market Regulations' and the 'Subsidiary Legislation 545.01 on Electricity Supply Regulations'.
Netherlands	The primary laws that enables smart metering for electricity and gas are: • 'Wet implementatie EG-richtlijnen energie-efficiëntie' • 'Wijziging van de Elektriciteitswet 1998' • 'Gaswet ter verbetering van de werking van de elektriciteits- en gasmarkt (31374)' A delegated law that further implements smart metering deployment for electricity is the 'Besluit op afstand uitleesbare meetinrichtingen ten behoeve van de grootschalige uitrol van de slimme meter'.

Poland	The Primary law that enables smart metering for electricity is under legislative process. The draft provisions were presented for public consultation in October 2018
Portugal	The primary laws that enable smart metering for electricity and gas are 'Decreto-Lei n° 215-A/2012' (October 8) and 'Decreto-Lei n° 231/2012' (October 26), which have been both revised. The delegated law that further implements smart metering deployment for electricity is 'Portaria n° 231/2013' (July 22).
Romania	The primary law that enabled smart metering for electricity is the 'Law on Electricity and Natural Gas No. 123/2012', put in place in 2012 and revised in 2018 with 'Law no. 167/2018'.
Slovakia	The Slovak primary law that enables smart metering is 'Act on Energy No. 251/2012'. The 'Decree No. 358/2013' of the Ministry of Economy of the Slovak Republic is currently the delegated law laying down the procedure and conditions for the introduction and operation of smart metering systems in the electricity sector.
Slovenia	The 'Energy Act' is currently the primary law that enables electricity and gas smart metering in Slovenia, as it includes Articles 49 addressing "Intelligent metering systems" for the electricity sector. In 2015, as set out by the Energy Act, the "Decree on Measures and Procedures for the Establishment and Connectivity of Advanced Measuring Systems for Electricity" was adopted.
Spain	The primary law that enables smart metering for electricity is the 'Royal Decree 1110/2007'. The order 'ITC/3860/2007' reviews the electricity tariffs and further sets the implementation of smart metering deployment for electricity.
Sweden	The primary law that enables smart metering for electricity is the 'Electricity Act 2012' which has been revised.

United Kingdom	The primary law that enables smart metering for electricity is the 'Energy Act 2008', as amended by the Energy Act 2011 and the Smart Meters Act 2018.

Table 1.2 - Relevant laws smart metering electricity in each European country

Country	Relevant legislation for gas smart metering
Austria	The primary law is 'GWG2011'. The status of this law is also nearly unchanged since implementation. A delegated law that further implement smart metering deployment is 'IGMA-VO 2012' which contains functional requirements for Gas Meters.
Belgium	The primary law that enables smart metering for gas in the Brussels Capital Region is the 'l'ordonnance du 1er avril 2004 relative à l'organisation du marché du gaz en Région de Bruxelles-Capitale' At this stage there are no laws that enable smart metering for gas in Wallonia. In Flanders, the primary law that enables smart metering for electricity and gas is the 'Decreet van 8 mei 2009 houdende algemene bepalingen betreffende het energiebeleid
Bulgaria	No specific laws have been adopted to frame the deployment of smart metering.
Croatia	The Croatian primary law that enables both smart electricity and gas metering is the 'Energy Act'.
Cyprus	The 'Regulation of the Gas Market Act2004' enables the CERA to ensure the implementation of smart meters.
Czech Republic	'Act No. 458/2000, Coll. on Business Conditions and Public Administration in the Energy Sectors and on Amendment Other Laws (Energy Act).'
Denmark	No specific laws have been adopted to frame the deployment of smart metering.
Estonia	The primary law that enables smart metering for gas is the 'Natural Gas Act', which was revised and valid as of June 2017.
Finland	Information regarding national law relevant for gas smart metering has not been provided by the NRA
France	A framework similar to that of the electricity market has been adopted.

Germany	The primary law that enables smart metering for both electricity and gas is ‘Gesetz zur Digitaliserung der Energiwende’.
Greece	Information regarding national law relevant for gas smart metering has not been provided by the NRA
Hungary	The primary laws that enable smart metering for gas is the ‘Natural Gas Act XL of 2008’. The ‘Government Decree No. 26/2016’ is currently the delegated law that further implements smart metering deployment for both smart electricity and gas meters.
Ireland	The primary law introduced by the Department of Communications, Climate Action and Environment in 2014 that enables smart metering for electricity and gas meters is the ‘Statutory Instrument 426’, transposed into Irish law by way of secondary legislation based on the obligations under the Third Directive.
Latvia	There is no specific law framing the deployment of smart metering for natural gas.
Lithuania	No specific laws have been adopted to frame the deployment of smart metering.
Luxembourg	The primary law that enables smart metering for gas is ‘Loi modifiée du 1er août 2007 relative à l'organisation du marché du gaz naturel’. The last revision of this law was in 2015.
Malta	There is no gas market in Malta
Netherlands	The primary laws that enables smart metering for electricity and gas are: • ‘Wet implementatie EG-richtlijnen energie-efficiëntie’ • ‘Wijziging van de Elektriciteitswet 1998’ • ‘Gaswet ter verbetering van de werking van de elektriciteits- en gasmarkt (31374)’ These laws are currently under revision.
Poland	There is no specific law framing the deployment of smart metering for natural gas.
Portugal	The primary laws that enable smart metering for electricity and gas are ‘Decreto-Lei n° 215-A/2012’ (October 8) and ‘Decreto-Lei n° 231/2012’ (October 26), which have been both revised. Concerning gas smart metering, at present, there is no delegated law to further implement its deployment.

Romania	There is currently no specific law framing the deployment of smart metering for natural gas.
Slovakia	No Decree is in place for the implementation of gas smart meters.
Slovenia	The 'Energy Act' is currently the primary law that enables electricity and gas smart metering in Slovenia, as it includes Articles 174 addressing "Intelligent metering systems" for the gas sector.
Spain	Following the negative outcome of the CBA for gas smart meters deployment, no specific law framing the deployment of smart metering for gas has been implemented. Nonetheless, Orden ETU/1283/2017 on natural gas activities have prepare a new CBA on gas smart meter rollout by 2019.
Sweden	Information regarding national law relevant for gas smart metering has not been provided by the NRA
United Kingdom	The same framework to that of the electricity market applies.

Table 1.3 - Relevant laws smart metering gas in each European country

1.4.3.2 Water

In Europe, an important development on smart meter for water has been an initiative carried out in 2009 to build a standardize structure of devices in line with the mandate M/441 of European Commission. The initiative was named European Open Public Extended Network (OPEN) meter project and was directed to electricity, gas, and water markets, but it was not mandatory for water sector. The OPEN meter project was the result of a collaboration within the 7th Framework Program for creating a coherent set of well-established standards on AMI sector. It involved 19 major players within utilities, meters manufacturers, and research institutes (Festival dell'acqua, 2019). The project last 30 months with a budget of € 4 million, of which 60% are granted by the EU (Smart energy, n.a.).

1.4.4 Italian landscape

1.4.4.1 Electricity

Italy has been the first country in the world on adopting intelligent metering systems for the electricity sector. They were installed thanks to a massive project in the period between 2001 and 2006 by Enel. They were named smart meter of first generation (1G). The requirements for the smart meter of 1G where defined with the resolution ARG/elt292/06. In the next years, the legislative decree 102/2014 transposed the European Directive 2012/27/EU on energy efficiency in the national regulatory framework. The decree allows at the entity responsible for the electricity, water and gas management named “Autorità per l’energia elettrica il gas ed il sistema idrico” (AEEGSI) (now has been included ARERA) to define an operative plan called “Quadro Strategico” for the period 2015-2018. “Quadro Strategico” included as a strategic target for 2016, the definition of specific requirements for smart meters of second generation (2G). Therefore, AEEGSI with the resolution 87/2016/R/eel of 8th March 2016 has established the functional requirements of 2G smart metering systems and has launched the substitution of smart meters of 1G, but it did not set a deadline to complete the process. The resolution 87/2016/R/eel has the primary aim to guarantee a progressive and effective exploitation of intelligent metering benefits. Moreover, the resolution analysed a wide range of inherent themes, such as the estimation of costs for either utilities or DSO, the treatment and collection of consumers information. The decree 60/2015 has defined the criteria for the periodic controls on intelligent electricity meters. The decree states that they are mandatory every 15 years since the installation, and the controls must be provided by a third party.
The resolution 306/2019/R/eel updates the guidelines for the period 2020-2022 on 2G smart meter equipment and roll out. It defines the costs of installation and eventually, the fee for the utilities which do not respect the functional requirements.

1.4.4.2 Gas

ARERA with the resolution 631/2013/R/gas has set out the requirements for the roll out of smart gas meters. The first norm on intelligent gas meters has been the decree 102/2014. It has been cited in the previous paragraph; among the other things it set the requirements and enabled the deployment of smart meters for the

national gas market. Subsequently, with the resolution 554/2015/R/gas approved by AEEGSI, the requirements have been updated.
It revised the mandatory requirements for the roll-out and established new fines in case of fraud behaviours. In addition, the resolution set a substitution target level of 50% for smart gas meter on households. The target had to be achieved by 2018, but no furthers information are available in literature for understanding if it has been reached or not.

1.4.4.3 Water

In Italy as well as in the other European countries, the regulatory framework for the smart meter in the water sector is still less developed than electricity and gas sector (Festival dell'acqua, 2019). The first step has been the resolution AEEG 393/2013/R/GAS that launched the deployment of multiservice telemetering. The roll out ended in July 2018, but the results were published only on September 2019 (Festival dell'acqua, 2019).
The next stage has been the directive 536/2013/R/eel which defined an important analysis for assessing the minimum level of efficiency, the service quality, the potential benefits, and criticalities for consumers. The analysis lasts one year, and it mainly tried to classify the drivers underpinning the water demand such as eventual losses in the network or the users' attitude to sustainable consumption. Moreover, AEEGSI provided the resolution 42/2016/IDR. It established the requirements for integrated water system, in Italian "Sistema Idrico Integrato".
The discussed themes have been partially considered even within the resolution 218/2016/R/IDR, that defines the responsibilities of the water utilities for the installation of meters, maintenance, and meter verification, as well as meter reading (including self-reading) and bill validation. It represented an important policy development because it was dedicated specifically for intelligent water system (Festival dell'acqua, 2019). In 2017, the national government emended the decree number 93, which defined the criteria for periodic control on instruments of measure and their functions conformity with both Italian and European regulatory framework. If the meter is not working properly or it has more than 10 years, the comma 5 of decree 93/2017 imposes the substitution threshold within 3 years. The comma 7 provides a derogation due to plan for improving the measurement system with replacement of existing meters and consequently, to coordinate the following

obligation, to avoid disproportionate burden for utilities and negative effect on price mechanism.

According with ISTAT data, the threshold has had a huge impact on utilities business because at least 54% of meter did not respect the legislation requirements. The total cost of replacement has been estimated around € 170-250 mln. In the same year AEEGSI introduced the resolution 917/2017/R/IDR that imposed, as a technical requirement on smart water systems, strict parameters on precision of measures.

In 2018, every utility of the SII has defined a strategic plan for meter replacement, of which the relative investment and time-lapse has been shared with ARERA. Through, the resolution 311/2019/R/IDR (also called RESI), the Authority has regulated the arrear customers of the water service.

Finally, ARERA has defined the criteria of water bill tariff through the resolution 665/2017/R/idr. It defines the considerations within the bills for the water services used by consumers, i.e. aqueduct, sewer, purification, and treatment of wastewater. The resolution is articulated in consumption bands and it distinguishes among a variable and a fixed component. On residential level, the consumption bands are five. The first one is called "Tariffa agevolata" in Italian, and it is applied to the essential quantity of water established for meeting the people needs (for each user 50 l/day).

"Tariffa Base" is the second one and it has a variable maximum threshold according with the contractual agreement. It is not standardized due to several factors, as investments, operating expenditures, number of clients served, percentage of arrear consumers, or morphological and geographic conditions. The other three consumption bands are named "Tariffa di Eccedenza":

- "Tariffa di 1° Eccedenza": applied on consumptions that overcome "Tariffa Base", until the 50% more of the contractual agreement.
- "Tariffa di 2° Eccedenza": applied for consumptions from 50% to 100% more than the contractual agreement
- "Tariffa di 3° Eccedenza" for higher consumptions

The fixed component is independent by consumption and it covers the fixed charges for guaranteeing sufficient quantity and an adequate quality, whatever the effective consumptions. It is divided according with the yearly number of bills. In general, users receive a bill every three months, therefore the fixed component will be the 25% of the total amount in each one.

On the opposite, the variable component is dependent by consumptions and is measured in euros per cubic meter (€/mc). It keeps the same value for sewer and purification, but it changes for aqueduct in line with the consumption band.

The fixed quota represents around 40% of total annual expenditure, instead the variable component is the remaining 60%. (Apkappa, n.a.) Nonetheless, the authors have reported only the general principle of how the water bills are computed. The complex regulatory system is the reasons why the water service has not a constant price among utilities. For example, in 2019 the price varied from 0.82 €/mc till 3.89 €/mc, reporting an average value around 1.94 €/mc (ISTAT, 2019). However, Italy is the country with lowest price associated for water in Europe.

1.5 Global Water Scenario

1.5.1 Water demand, water availability and water accessibility

Water use has been increasing worldwide by about 1% per year since the 1980s, driven by a combination of population growth, socio-economic development and changing consumption patterns. Global water demand is expected to continue increasing at a similar rate until 2050, accounting for an increase of 20% to 30% above the current level of water use (around 4 trillion m^3/year), mainly due to rising demand in the industrial and domestic sectors (Statista, n.a.).

Currently, over 2 billion people live in countries experiencing high water stress, and about 4 billion people experience severe water scarcity during at least one month of the year. Three out of ten people do not have access to safe drinking water. Almost half of people drinking water from unprotected sources live in Sub-Saharan Africa. Six out of ten people do not have access to safely managed sanitation service. However, these global figures mask significant inequities between and within regions, countries, communities and even neighbourhoods.

Considering different water end-uses, the agriculture (including irrigation, livestock, and aquaculture) is by far the largest water consumer, accounting for 69% of annual water withdrawals globally. Industry (including power generation) accounts for 19% and households for 12% (AQUASTAT, n.a.). Global water demand is expected to continue increasing, however specific projections can somewhat vary. The current analyses suggest that much of this growth will be attributed to increases in demand by the industrial and domestic sectors (OECD, 2012; IEA, 2016). Agriculture's share of total water use is therefore likely to fall in comparison with other sectors, but it will remain the largest user in the coming decades considering both water withdrawal and water consumption. The figure below shows the projections for global water demand by sector until 2040.

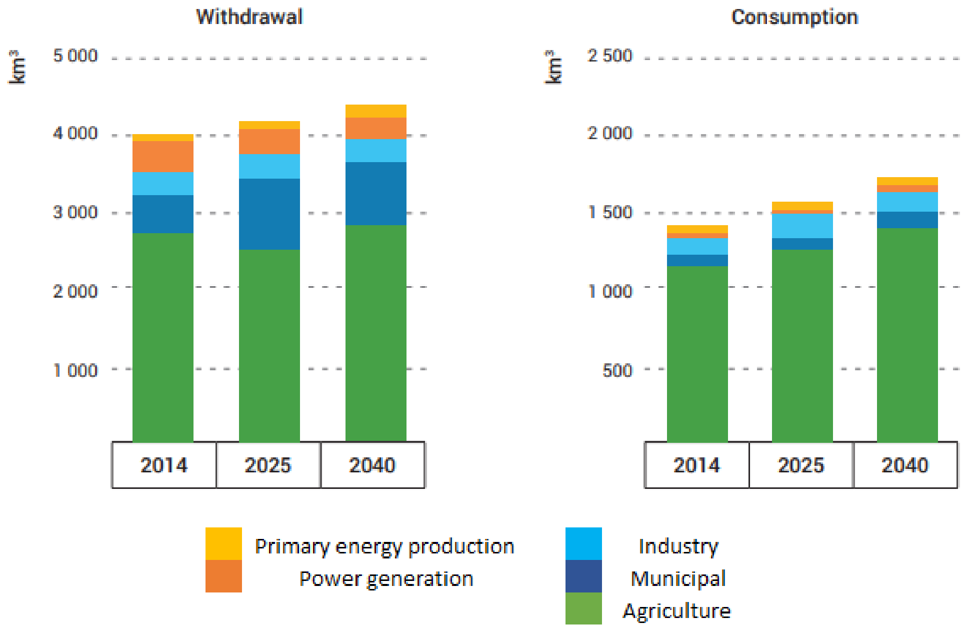


Figure 1.5 - Expected water demand until 2040

Water consumption of a region is the amount of water consumed by each sector operating in that specific region, while water availability depends upon the amount of water physically available, and how it is stored, managed, and allocated to various users. It includes aspects related to the management of surface water, groundwater, as well as water recycling and reuse. The balance between water consumption and water availability is crucial for preventing extreme water stress conditions. Physical water stress is defined as the ratio of total freshwater withdrawn annually by all major sectors, including environmental water requirements, to the total amount of renewable freshwater resources, expressed as a percentage. Currently, over 2 billion people live in countries experiencing high water stress. Although the global average water stress is only 11%, 31 countries experience water stress between 25% (which is defined as the minimum threshold) and 70%, while 22 countries are above 70% and therefore, they are under serious water stress conditions. A growing water stress indicates substantial use of water resources with greater impacts on resource sustainability and a rising potential for conflicts among users. (United Nations World Water Development Report, 2019)

Several other important aspects of water stress need to be highlighted. Firstly, since water availability can be highly variable from season to season, data averaged over the entire year do not show periods of water scarcity. It has been estimated that about 4 billion people, representing nearly two-thirds of the world population, experience severe water scarcity during at least one month of the year (United Nations World Water Development Report, 2019).

The figure below shows water stress levels in different regions of the world.

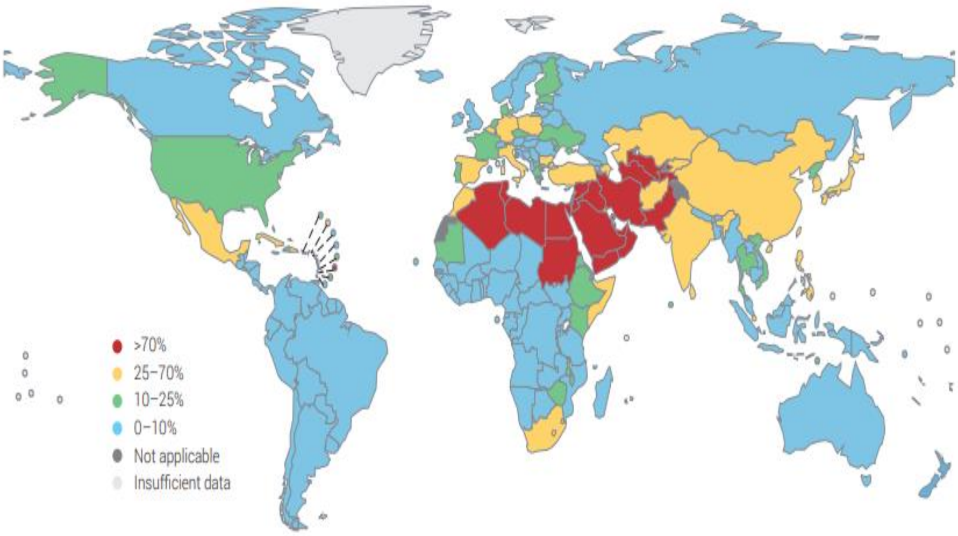


Figure 1.6 - Level of water stress in each country

The levels of physical water stress are likely to increase as populations and their demands for water grow, and the effects of climate change intensify. The climate change is determining a higher variability on local and basin scales over different seasons. However, in general, the dry areas will tend to become drier and wet areas wetter, such that climate change will likely worsen water stress in areas that are already the most affected. The estimates suggest that if the degradation of the natural environment and the unsustainable pressures on global water resources continue, 45% of the global gross domestic product (GDP), 52% of the world's population and 40% of global grain production will be at risk by 2050 (United Nations World Water Development Report, 2019).

The progressive reduction of water availability has obvious implications in terms of water accessibility. Water accessibility refers to how water is physically delivered or obtained. Piped water is the least costly method to transport water in densely populated areas. Where piped networks are unavailable, people mostly rely on wells or community water supply systems (e.g. water delivery through kiosks and vendors, or water trucks). In the latter case, they often pay prices several times higher for water of lesser quality, further aggravating inequities.

The water treatment concerns the processes used to purify, disinfect, and protect water against recontamination. The most common methods of water treatment depend upon energy (usually electricity) and its availability along all day, which is often a problem in most of developing countries.

Currently, the 29% of the global population did not use a safely managed drinking water service in 2015, whereas 844 million people still lacked even a basic drinking water service. Of all the people using safely managed drinking water services, only one out of three (1.9 billion) lives in rural areas (World Health Organization - Water Sanitation and Health 2017). Coverage of safely managed water services varies considerably across regions (from only 24% in Sub-Saharan Africa to 94% in Europe and Northern America). There can also be significant variability within countries between rural and urban areas, wealth quintiles and subnational regions.

Water availability, distribution, and quality affect dramatically the socio-economic dimension of many regions of the world. Many people around the world, typically not connected to piped systems, suffer disproportionately from inadequate access to safe drinking water and sanitation services and often pay more for their water supply services than their connected counterparts. The human rights to water and sanitation place obligations on states and utilities to regulate payments for services and to ensure that all members of the population can afford access to basic services. Ensuring that water is affordable to all requires policy recommendations tailored to specific target groups. Expenditure on drinking water and sanitation typically includes infrequent, large capital investments, including the cost of infrastructure and connections as well as recurrent spending on operation and maintenance. One way of increasing affordability is to lower the costs of providing the service. Technological innovation and the enhancement of management through good governance and increased transparency practices, and the implementation of cost-effective interventions can improve production efficiency and thus lower service costs.

1.5.2 Water network scenario

A water supply system is a system for the collection, transmission, treatment, storage, and distribution of water from source to consumers, for example homes,

commercial establishments, industry, irrigation facilities and public agencies for water-related activities. (Glossary of Environment Statistics United Nations, 1997)
As said before, water accessibility is strictly dependent on water availability but also on the infrastructure: the existence of an efficient water supply system is fundamental to ensure fair living conditions and economic prosperity.
Actually, economic water scarcity is normally caused by a lack of water infrastructure that can ensure access to water (Comprehensive Assessment of Water Management in Agriculture, 2007), and occurs typically in Africa and some parts of South America and South Asia. Developing more water infrastructure in these regions is the only way to alleviate scarcity, but it should take into account the impacts of climate change that are already observed. Climate change elevates risks to water infrastructure. More intense and more frequent floods increase the risks of damage to water treatment and supply infrastructures, which can lead to service disruptions.
Another globally emerging issue is the ageing of the water infrastructure. The pattern of ageing differs between regions; indeed, many developed countries are dependent on old water infrastructure, designed and constructed on the assumption of stationary hydrological time series, and many water networks are nearing the end of their design lives. For example, in the United Kingdom, 75% of the urban water networks are more than 100 years old (WaterUK n.d.). The American Society of Civil Engineers estimates $3.6 trillion would need to be invested into U.S. infrastructure by 2020 just to raise the country's support systems to acceptable levels. Capital investment needs for the nation’s wastewater and stormwater systems are estimated to total $298 billion over the next twenty years. Most of the U.S. drinking water infrastructure is nearing the end of its useful life. There are an estimated 240,000 water main breaks per year in the United States that, according to the American Water Works Association (AWWA, n.a.), would require a replacement cost that accounts for $1 trillion in the next decade.
According to the report “Blue Book” published by Utilitalia in 2019, also the Italian water infrastructure is significantly aged: the 60% of the infrastructures were installed over 30 years ago (a percentage that rises to 70% in large urban centres); 25% of these are over 50 years old (reaching 40% in large urban centres), which makes these systems near to their end-of-life.
In water storage infrastructure, the aging issue reflects into sedimentation, increased operation and maintenance costs, structural changes, increasing risks of

breakage, and overall operational efficiency decline as a structure approaches its design life. Moreover, ageing is also influenced by the changing river inflow variability associated with climate change. Increased uncertainty in stationarity of hydrology due to climate change makes it necessary to reassess the safety and sustainability of water systems. Overall, conventional water infrastructure is becoming more vulnerable to climate change and may incur increasingly high costs or adverse societal and environmental impacts.

The serious issue that comes together with ageing is the problem of water losses: water infrastructure in service decades is subject to many breaks and pipe leakages which, together with overflow from transmission and distribution mains and metering errors, makes up the major part of the non-revenue water (NRW).

According to the U.S. Environmental Protection Agency (EPA), the volume of water lost through distribution systems in the U.S. is 1.7 trillion gallons per year, which correspond to a loss equal to 16%.

Considering the Italian water network, the average percentage of losses is 43%, with peaks of 70% in the southern regions, thus confirming the poor condition of the water infrastructure, with a network efficiency considerably lower that European average (Utilitalia, 2019). The mean value of water losses in the European countries' network is around 23% and the graph below shows differences among countries (EurEau, 2017).

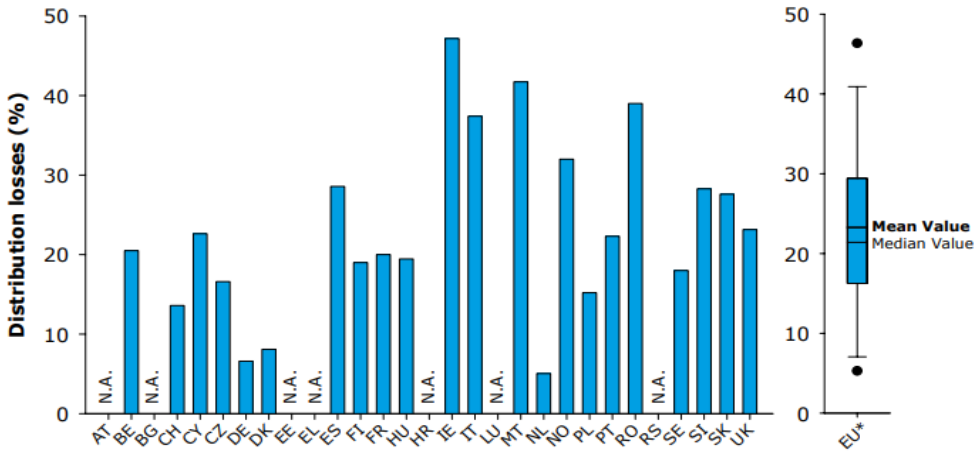


Figure 1.7 - Average percentage of water losses, EU-28

In countries with economic water scarcity, more water infrastructure, like water storage and reliable water supply and sanitation systems, needs to be developed in an accelerated way, but with a clear consideration of future climate uncertainty and increasing variability. In the next years, the investments are needed not only in new infrastructure but also in the maintenance and operations of the existing stock, in order to improve their efficiency and reduce the water losses. The climate change generates additional risks to water-related infrastructure, requiring an ever-increasing focus on the inclusion of adaptation measures. Investment need to be directed into creating the appropriate water infrastructure in developing countries and targeted at upgrading existing infrastructure in advanced economies, exploiting new technologies and opportunities.

1.6 Residential water consumptions

Humanity request for freshwater has more than doubled since the 1960s, keeping pace with growing populations and economies. As analysed in the previous sections, while agriculture and industry withdraw the overwhelming majority of the world's freshwater (70% and 19%, respectively), demand from households is also rising precipitously. Data from WRI's Aqueduct platform show that domestic water demand grew 600% from 1960-2014, at a significantly faster rate than any other sector (World Research Institute, 2020).
The graph below shows the percentage increase in water withdrawals by sectors, highlighting how water withdrawals from industrial and agricultural sectors have grown at slower rate compared to the domestic one.

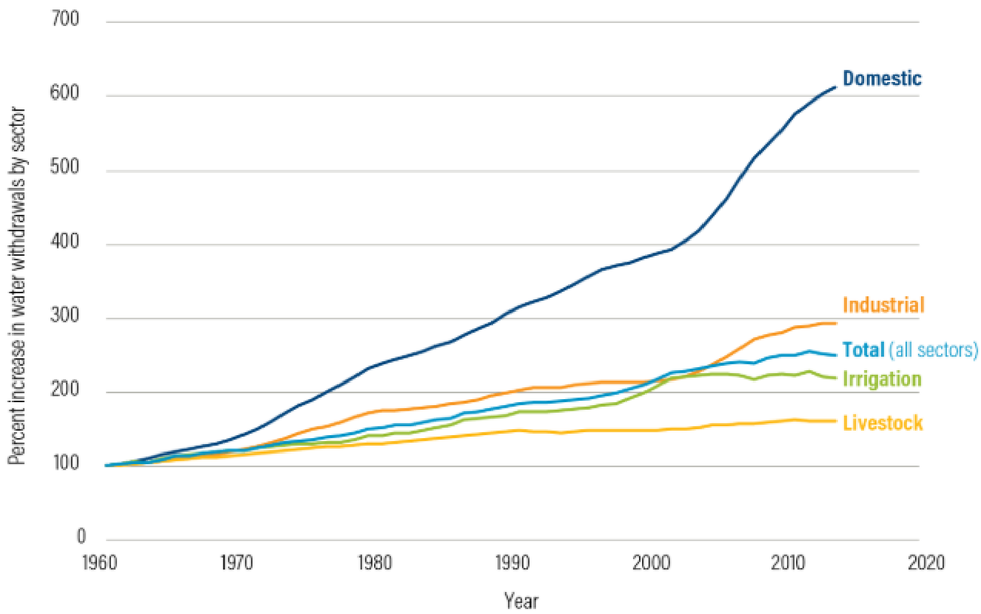


Figure 1.8 - Percent increase of water withdrawals by sectors, World (1960 - 2020)

During the period from 1960 till today, the world's population grew by more than 4 billion, contributing to the rapid growth in municipal water use. More people, more homes and growing cities require more water than ever before. Since our work is focused on the application of new smart water metering technologies at residential level, it is quite interesting to understand how water is used and what are the main components of residential water consumption. For this reason, in the next paragraph it is provided a more detailed examination of how residential water consumption is shaped and what are its determinant factors.

In its Guidelines for Drinking-Water Quality, WHO defines domestic water as being 'water used for all usual domestic purposes including consumption, bathing and food preparation' (WHO, 1993; 2002).

Sub-dividing uses of domestic water is useful in understanding minimum quantities of domestic water required and to inform management options. It is possible to find that three types of use could be defined in relation to normal domestic supply:

- Consumption (drinking and cooking)
- Hygiene (including basic needs for personal and domestic cleanliness)
- Amenity use (for instance car washing, lawn watering)

Gleick (1996) developed a measurement of the ability to meet all water requirements for basic human needs: drinking water for survival, water for human hygiene, water for sanitation services, and modest household needs for preparing food. The proposed minimum amount needed to sustain each is as follows:

- Minimum Drinking Water Requirement: 5 litres per person per day.
- Basic Requirements for Sanitation: 20 litres per person per day is recommended.
- Basic Water Requirements for Bathing: 15 litres per person per day.
- Basic Requirement for Food Preparation: 10 litres per person per day.

The proposed water requirements for meeting basic human needs gives a total demand of 50 litres per person per day. However, as we can see in the figure below, domestic water consumption per capita is way different from this level in many countries of the world, with high inequalities among developed and developing countries. For example, on average, a U.S. citizen consumes 586 L/day, more than ten times the basic human water requirements, while an Ethiopian citizen cannot get a 20 L/day consumption (de Simone Souza, Loureiro Paulo, and Árpad Boncz 2017).

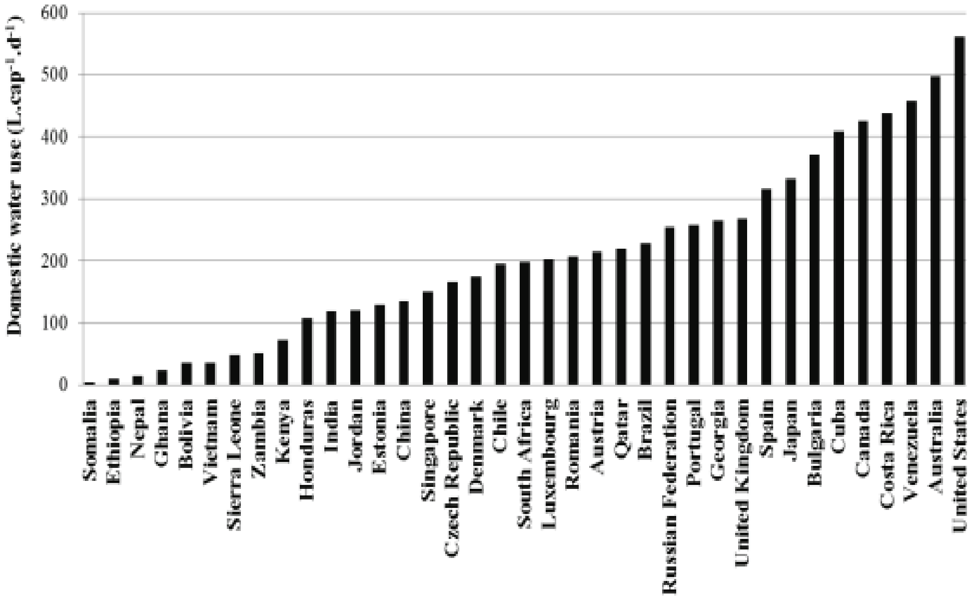


Figure 1.9 – Average daily water consumptions per citizen in different countries

Moreover, household water use and per capita water consumption are not directly related to water availability. For instance, in Australia, the driest populated continent, the average water consumption of 497 L/ capita per day, is amongst the highest in the world (World Bank, 2016). Thus, even though water consumption differs depending on region, many studies demonstrated that it mainly depends on a number of sociodemographic factors, like residents' age, income level, family size, education level, consumption habits, and ecological awareness, as well as it depends on characteristics of the household-like size of the building and appliances fitted.

Moreover, a study conducted on different towns of every Italian province, investigated the determinants of residential water demand by using the linear mixed-effects model. The empirical findings demonstrated that increasing the tariff levied to customers caused a reduction in residential water consumption, while an increase of the income per capita increased consumption. In addition, considering climatic and geographical features, data demonstrated that both altitude and precipitation exerted a strongly significant negative effect on consumption. Further, population size, has a positive effect on consumption, so that bigger towns showed a higher residential water demand per capita, compared to small towns (Romano, Salvati, and Guerrini 2014).

Once highlighted the determinants of residential water consumption, is interesting to understand what its components are, and what are the behaviours and the applications that require more water at domestic level.

According to the study of (Carragher, Stewart, and Beal 2012) conducted on 191 Australian households, it is possible to break down domestic water consumption, identifying 8 main components: tap, toilet, shower, washing machine, bathtub, dishwasher, irrigation, and leakages. The graph below shows the specific portion of consumption for each component, highlighting 4 most relevant ones as: shower, washing machine, tap and toilet. Understanding what are the most relevant water consuming activities and behaviours is fundamental to allow efficiency improvements and behavioural changes by users.

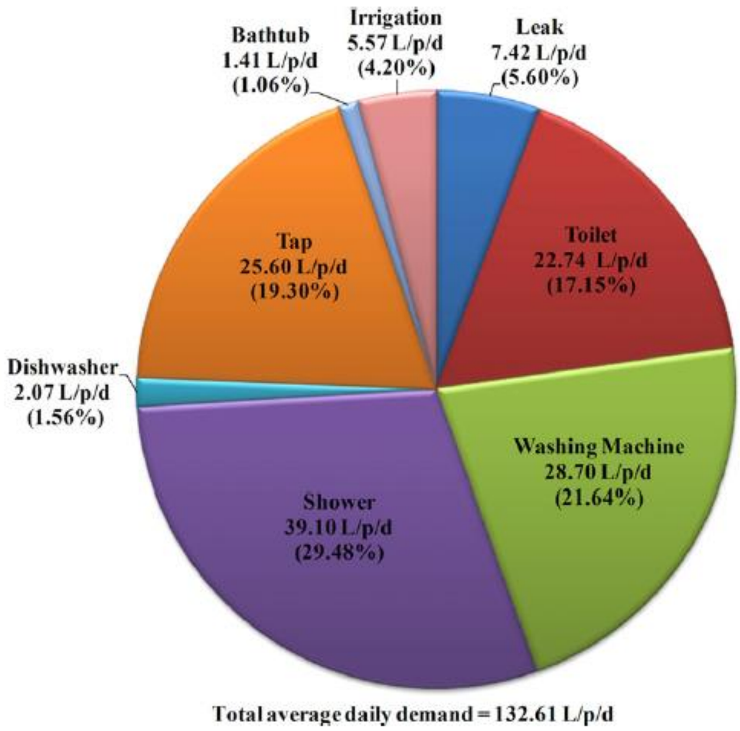


Figure 1.10 – Absolute and percentage water consuming activities at residential level

It is relevant to mention that this analysis was conducted using smart water meters, which emerge as enabler for disaggregated water consumption analysis, which opens up many opportunity in terms of consumption reduction, demand management, water efficiency, thus contributing to improve the water resource conservation.

In the next section we will go deeper in the description of smart water meters and their functioning.

1.7 Comparing smart and traditional water meters

A smart water meter is a water meter connected to a data logger that allows for the continuous monitoring of water consumption. As opposed to conventional systems in which users get the information on water usage after months since the events occurred, a smart metering system can provide real-time water consumption or sufficient data points to determine usage patterns. When a water event occurs, such as a person taking a shower or using a washing machine, the event creates several pulses in a water meter that are logged by a data logger in a pre-determined frequency. Then, the pulses can be analysed manually or using special purpose software that can disaggregate the water events and associate them to specific water uses, according to various parameters as flow rate, volume, and time. In the next paragraph the authors will illustrate the main technical characteristics of smart water meters compared to the traditional "dumb" water meters.

In terms of metering process the contrast between traditional "dumb" meters and smart meters is that traditional meters produce a simple transfer of data that relies on manual collection and processing, with customers only being able to access this data through a bill issued at a specific interval e.g. three or six months. In contrast, smart metering systems can facilitate a transfer of more disaggregated data, giving households or businesses (and water providers) direct access to this real-time (or near-real time) data (Foundation of Water Research, 2015)

As shown in the figure below, the metering process can be distinguished in four main steps:

- data collection: measurement of the water volume consumed in a specific interval of time through the meter
- data transfer: transmission of the data collected to a central location for analysis (this transfer can be a manual reading in traditional meters, or automated data transfer using one-way or two-way communication between the smart meter data collector, logger and the final data storage point)
- data processing: for traditional metering systems consists in the simple processing of data for billing consumption, while in smart metering systems

also incorporates the interpretation of raw data into meaningful information about end-uses and water consumption characterization

- data storage: loading of data into a digital repository (e.g. database)

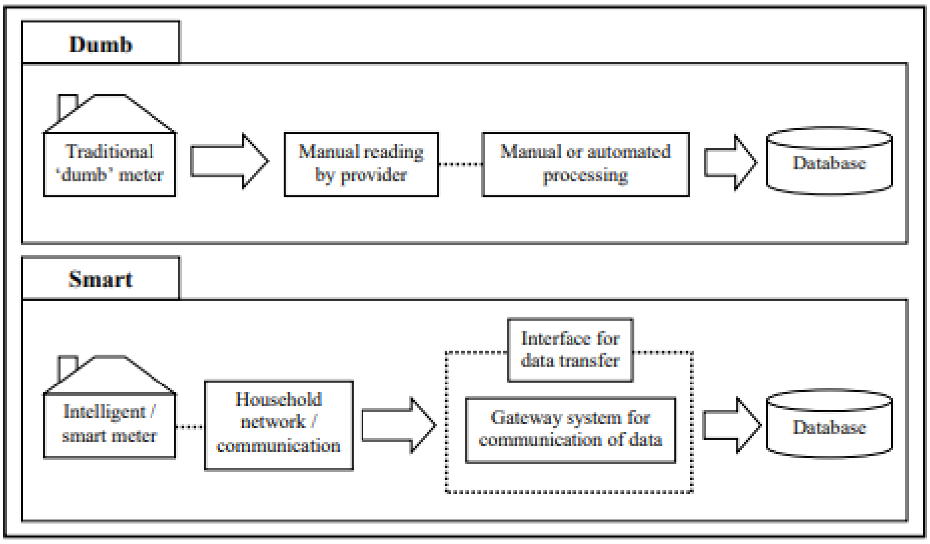


Figure 1.11 – Steps of smart metering process

The data collection process starts from the water meter, that is located at the user premises. For many decades, water meter manufactures have used only basic physical principles of measurement in the design of water meters. This allowed, together with the low manufacturing costs, the diffusion of a particular type of meters (traditional water meters with turbine and mechanical gears), which lead to water metering parks mainly composed of traditional "dumb" measuring instruments. Most of the time, this instrumentation is composed of a turbine and mechanical gears. The water passing through the meter makes move the turbine, which is connected to mechanical gears that transform the rotational speed of the turbine in a flow measurement. This measure is then expressed in cubic meters (m^3), or fractions of m^3, on the consumption wheel of the water meter's dial. Therefore, this information must be read on the water meter's dial and it refers to the total volume (cumulative consumption) of water transited since the installation of the water meter. These meters are designed to determine the volume of water that has flowed through the meter based on the speed of the flow, and for this reason, are also known as velocity water meters. Another type of mechanical water meter are the displacement meters, that can be divided into two subcategories: oscillating piston and nutating disk meters. Regardless of the subcategory, each displacement water meter measures the rate of flow based on the movement of a specific element within the meters construction. The amount of movement recorded correlates to the amount of water that has flowed through that portion of the system. In the past two decades, electronic circuit components were progressively integrated into mechanical water meters to provide automatic functionalities, such as AMR. These are known as the electromechanical water meters; whose measurement basis is still mechanical. Recently, fully electronic water meters were designed using new measurement principles, such as electromagnetic (operating principle based on Faraday induction law), fluidic (operating principle based on the Coanda Effect) and ultrasonic meters (operating principle based on soundwaves and Doppler Effect) (X. J. Li and Chong 2019a).

Figure 1.12 – Visual comparison among mechanical and smart water meter

Apart from the technical differences and physical principles beyond the functioning of each type of meter, what is important to remark is the fact that traditional meter record consumption on the rotating wheel incorporated in their dial, which requires to be manually read by an operator. On the contrary, smart meters incorporate circuitry elements that allow to convert the measurement into electronic signals to be sent automatically through the communication network, thus requiring electricity to power the electronic circuits adopting fixed wired power supply or replaceable batteries.

As already said, once the data has been collected by the smart meter it must be transferred in real time in order to deliver data from the meter/logger to a site where processing and analysis can occur. To do so, there are different possibilities both in terms of communication technology and communication protocols.

There are wire-based systems that range from simple systems utilizing RS232 or USB cabling, to more advanced systems using power-line communication or telephone line network. More frequently, the communication system is based on wireless communication technologies, due to the fact that majority of the meters are located underground and cannot to be connected by cabling.

The first generation of smart water meters adopted low power short-range wireless protocols, such as Wireless M-Bus, that operates over the unlicensed spectrum (169 or 868 MHz in Europe). These meters were designed to operate in Remote Meter Reading (RMR) systems, in which data collection can be performed without a dedicated networking infrastructure: the operators equipped with portable receivers collect data in the proximity of the smart meters either in walk-by or drive-by mode. RMR systems eliminate the need for physical access or visual inspection of smart meters, but they do not allow either real-time or automated consumption monitoring (Alvisi et al. 2019).

More recently, a second generation of smart water meters that leverage on low-power long-range wireless protocols, such as LoRa (Long Range), which is designed for a wider communication range both in urban and extra-urban environments, hit the market. Smart water meters periodically transmit their consumption information towards gateway devices which gather the data from the in-range smart meters. Then, they retransmit it to the utility management typically using mobile communications (3G/LTE/4G).

In addition to the already mentioned Wireless M-Bus and LoRa protocols, which are being increasingly adopted by smart water metering manufacturers, there are a range of wireless IoT protocols that might be relevant for smart metering applications. Among these, the IEEE 802.15.4, and its full stack proprietary extension ZigBee, is widely adopted in low power networks and provides transmissions capabilities over a limited range (10–50 m) and it supports different network topologies: star, peer-to-peer, and cluster. Bluetooth LE is a relatively recent version of Bluetooth specification, featuring increased communication range (up to 100 m) and lower power consumption, albeit at the expense of a lower maximum bitrate (1 Mbps). (Alvisi et al. 2019).

Another interesting wireless IoT protocol is Sigfox, a proprietary communication technology. Unlike LoRa, which is also proprietary but free to use, Sigfox adopters need to leverage on a communication infrastructure provided by Sigfox and pay corresponding licensing fees. Another LPWAN technology which is increasing popularity is the NB-IoT, a narrowband radio technology designed for the IoT, which has been standardized by the Third-Generation Partnership Project (3GPP) body. It can be deployed in the GSM spectrum and it can support a big number of low throughput devices (Andreadou, Guardiola, and Fulli 2016).

An interesting example is the one of Italy, where the Amendment 38.22 of the "Articolo 38" introduces administrative simplification in the Internet of Things sector in relation to Low Power Wide Area Network (LPWAN) technological solutions that insist on the 863-870 and 915-921 MHz frequency ranges. The planned simplification would be able to determine greater legal certainty for investments in LPWAN technologies, which represents a potential volume of economic relaunch and development of the country.

The table below summarizes the main technologies adopted for transmitting data in smart water metering application.

Connection Type	Technology Category	Technology Name	
Wireless	RF-Mesh	-	
	Cellular	3G-4G	
		GSM	
		GPRS	PR
	IEEE 802.15 Group	ZigBee, Sigfox, NB-IoT	
		6LoWPAN	N
		Bluetooth	
	IEEE 802.11 Group	Wi-Fi	
		Enhanced Wi-Fi	
		IEEE 802.11 n	
	IEEE 802.16	WiMAX	
Wired	Power Line Communication (PLC)	NB-PLC	
		BB-PLC	
	xDSL	ADSL	
		HDSL	
		VHDSL	

Table 1.4 – Main technology used for smart water meters

The central unit receives data and starts data processing, to extract information useful for the water provider (e.g. demand peak quantity) and for the user (e.g. daily consumption). Data analysis tools include software packages such as Aquacrafts's TraceWizard© and WRc's Identiflow®.

Finally, data are stored in a digital repository that contains all the historical data on consumption and all the associated information.

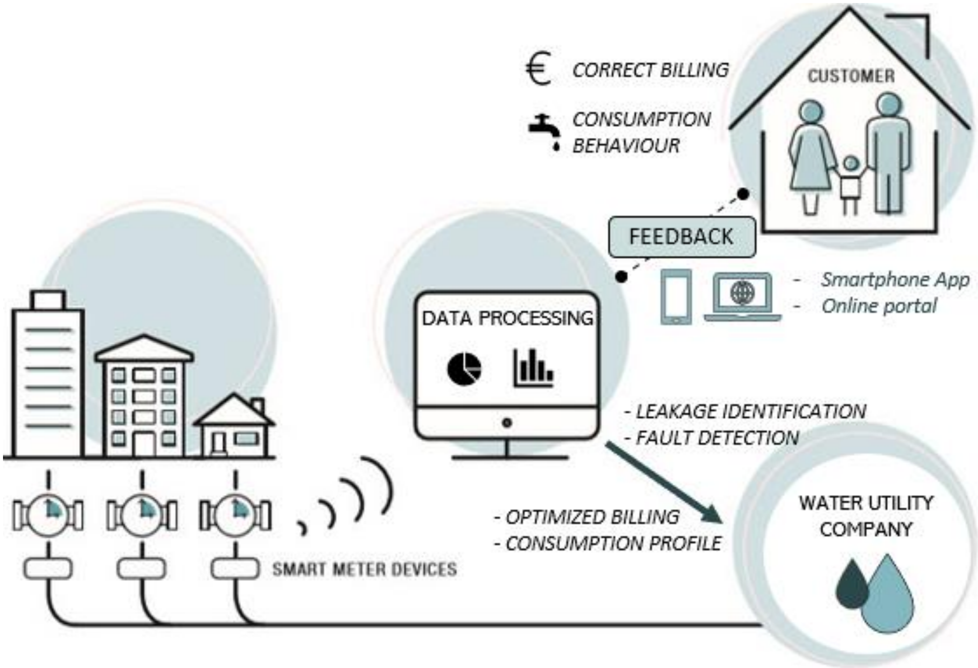


Figure 1.13 – Smart meter communication process to users

It is important to remark that smart metering enables a completely new interaction between utility service provider and customer: real-time data exchange enables a bidirectional flow of information. On the one hand, the water service provider gets updated measurements of the daily consumption profiles of the user, becoming able to detected anomalies and to optimize the billing process, reducing errors and costs; on the other hand, water usage data can be provided through different "feedback channels" such as online portal, in-house display or smartphone application, thus offering customer accessible information and potentially helping to adjust behavior, limit expenditure and fix problems.

Indeed, feedback channels together with water efficiency devices are becoming more popular among people and will be illustrated in the next paragraph.

1.8 Water efficient devices

The sustainability of water supply in urban setting represents an important concern under social, economic, and environmental perspective and it is feasible only with the adoption of water conservation and water efficiency practices. The two concepts are different; therefore, it is firstly necessary to report their definitions. The water conservation is a "beneficial reduction in water loss, waste or use" (Water Footprint, 2018, while the water efficiency is the "minimization of the amount of water used to accomplish a function, task or result." (Water Footprint, 2018). The smart meters act on both sides, but they are not the only solution existent for promoting a sustainable approach. Indeed, according with the theme of the discussion, at household level for pursuing water efficient practices there are the efficiency devices (e.g. appliances). Several studies have been undertaken to determine the relative water savings attributed to the installation of engineering water conservation fixtures and appliances. In literature, the most positive results show that the replacement of high-water consuming devices with more efficient resulted in indoor water consumption savings between 35% and 50%. (Stewart et al. 2013a).

For example, in Miami-Dade County (MDC) on USA, it has been launched a program by Miami-Dade Water and Sewer Department (MDWASD) for assisting the users to implement efficiency measures to reduce water demand. During the 3-years period, the smart meters monitored the demand from January 2006 to December 2009. The program has been divided in three projects, each one concern a different appliance. The scope was the computation of water saving arising through a progressive substitution of old appliances with new ones. The program involved three types of devices: high efficiency showerhead (SH), high efficiency toilet (HET), and high efficiency clothes washer (HEW). The data shown water saving among 6% and 14%, without any distinction between high and low users. On the same way, the participants to HEW reported a demand saving in a range between 6.5% and 14.2%. It is a consistent reduction, considering an average number of laundries washing cycle of 289. (Lee, Tansel, and Balbin 2011) Moreover, the program results suggest that the incentives for switching to water efficient units (i.e., rebates or unit exchange programs) are more acceptable by the public in comparison to other water management policies such as price increase or water restrictions. (Lee, Tansel, and Balbin 2011). Sometimes the water-efficient solutions together with smart meters measurement are not sufficient to achieve a resource saving, because there are evidences of how a wrong user behaviour could reduce the positive impact.

In order to overcome this issue, there is a second type of sustainable practices: the water conservation ones. During the last years, they have been based on display technologies. Essentially, the display technologies consist in visual alarm systems for providing instantaneous or at least frequent feedbacks about the level of consumers water demand. (Stewart et al. 2013a) A common category of technological display tool is the In-Home Display (IHD).(Stewart et al. 2013) The IHD made an alert signal when the consumer reach a pre-defined level of consumption. For example, Davies et al. (2014) provide a 5 years study (2008-2013) that considers how change the consumer behaviour during a shower after the installation of an IHD. The IHD was basically composed by an LCD monitor which warn for 1 minute the consumer when he reached the 40 L of water per shower. The study considers three sample: 161 household were provided with IHD plus AMR, 307 with just AMR and 162 did not receive any equipment. In 2010, the IHD were removed to check if their change the user behaviours. In 2013, the users with IHD reduced their water demand of 6.4% compared with the pre-trial period instead the others increase their usage of 1.3%. In the next years, it is expected a wider penetration of both water efficient appliances and consumption monitoring devices.

1.9 Projects

The authors have reported in this section the most important projects concerning the introduction of smart water meters. In order to be in line with the theme of thesis, the authors have considered only the project at household level. They started with a general overview of interesting international projects, and then they will conduct a deep analysis specifically for the Italian scenario.

1.9.1 International projects

1.9.1.1 SmartH20

The SmartH20 has been a European project, which has developed an ICT platform to leverage on Social Computing for an efficient urban water demand management. (SmartH2O: an ICT Platform to leverage on Social Computing for the efficient management of Water Consumption 2017) The SmartH20 has been tested in the city of Valencia (Spain) and Canton Ticino (Switzerland). The project last from 1st April 2014 till 31st March 2017. The total capital invested was € 3.573.368 of which € 2.508.842 were financed with public European funds. Totally, it involved 11 organizations among Italy, Spain, Switzerland, Romania, Germany, and United Kingdom divided in private centre for research and public institutes (such as "Politecnico of Milan"). The platform has been designed thanks to the integrated use of smart meter, social computation, and dynamic water pricing. (SmartH2O: an ICT Platform to leverage on Social Computing for the efficient management of

Water Consumption 2017) The project aimed to provide at water utilities and municipalities all the information for improving the demand management, increase the resource security, implement better new policies and practices leading towards a reduction in water consumption without compromising the quality of service offered at consumers. (SmartH2O: an ICT Platform to leverage on Social Computing for the efficient management of Water Consumption 2017) The ICT platform solution was able to:

- Understand and model the consumer behaviour
- Predict how the consumer behaviour can be influenced by various water demand management policies as water savings campaigns
- Raise the awareness of water consumers on their current water usage habits and their lifestyle implications for stimulating lower consumptions

SmartH20 created a bi-directional communication stream between citizens and utilities. On one side, the data about consumer behaviour are gathered through smart meters and send towards utilities, while on the other, the awareness campaigns and new policies are launched by utilities toward customers (SmartH2O: an ICT Platform to leverage on Social Computing for the efficient management of Water Consumption 2017). The ICT infrastructure has made possible the collection of feedbacks about consumer response in front of new situations (e.g. new regulations, appeals to water during droughts). (SmartH2O: an ICT Platform to leverage on Social Computing for the efficient management of Water Consumption 2017) The utilities used the feedbacks for maximising the energy and water saving goals, in particular they searched what were the factors that determine the gap between the actual consumptions level and the desired targets.

1.9.1.2 ICT4Water

ICT4water cluster faces the water challenges on Europe in line with the target set by Paris agreement, Sustainable Development Goals (SDG), and United Nations climate conferences. ICT4Water proposes an action plan for a single digital market for water services (European Commission Environment, n.a.). The action plan considers the period 2018-2030. It is based on two roadmaps: the first has been published in 2015, while the second in 2016. They are briefly summarized in the next table.

Roadmap 2015 Focused on Water Management	Roadmap 2016 Focused in Water Management
Technological, social and organisational challenges:	Main Gaps and technological challenges to be addressed:
• Cost/Benefit analysis of ICT • Synergies across sectors • Data sharing • Interoperability • Standardisation • Indicators	• Big Data • Data infrastructures • Link with Smart Cities • Nexus, Water–Food-Energy • Standardisation • Lack of reliable field trials

Table 1.5 – Roadmaps leaded by the European Commission focused in emerging topics and technologies for water management (ICT4Water Action Plan)

Despite a promising technological scenario, the European countries are still recording a low level of maturity concerning the standardization of ICT solutions and their implementation in the legislative framework. The leaders among water utilities are digitalising their processes, however they noted that just introducing ICT systems was not sufficient for accomplishing their objectives. The ICT4Water action plan outlines and details necessary steps that water actors are taking towards a complete value chain transformation, as well as change of the market dynamics (European Commission Environment, n.a.).

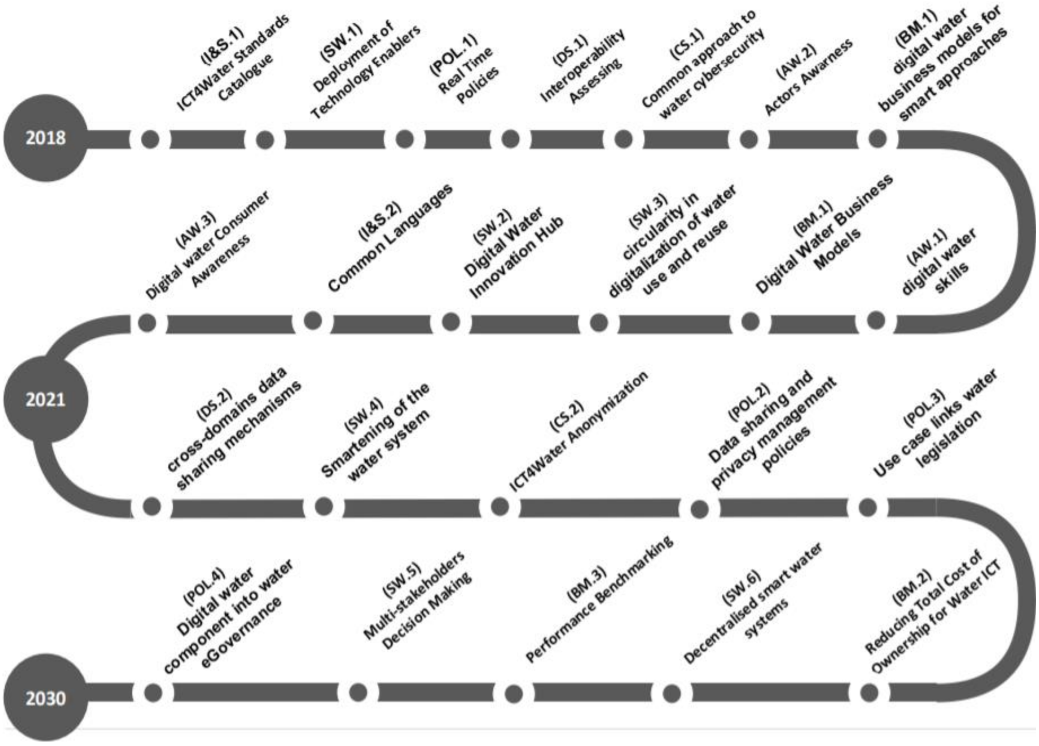


Figure 1.14 - Timeline of the Action Plan (ICT4Water Action Plan)

It is divided in the following categories on interoperability and standardisation (I&S), data sharing (DS), smart water (SW), cyber security (CS), actor security-water & digital (AW) and policy (P). Each category has a series of dedicated initiatives, through which the most important are defined as "Immediate". Every initiative has a specific timetable with the relative instruments for the implementation. The actions seek to achieve their targets in maximum 5 years, except for those that required a more extended and constant time evolution. The other European tools as EU Framework Programmes, the European Structural Funds and European Funds for Strategic Investments could be used for faster reaching the objectives.

1.9.1.3 iWIDGET

iWidget was a European project for improving the water efficiencies through the adoption of the novel ICT technologies. It has been founded by European Commission under the 7th Framework Programme (iWIDGET, 2013).
iWIDGET was built on a partnership among 9 organisations divided in technology developers, utilities leader in water sector, universities, and specific research lab of several European countries. Moreover, it availed of experts' judgments creating a Project Advisory Panel. It was launched with the aim of providing experts opinion to organisations involved, through seminars, workshop, and lectures. The execution of the project has been coordinated by the University of Exeter, in UK. It started in November 2012 and run three years (iWIDGET, 2013).
It aimed at an integrated supply-demand management system. The iWIDGET project was based on ICT system of techniques and technologies that enable the householders to reduce the water consumptions. The object was a more integrated approach to water resource management, fostering the achievement of Europe 2020 objectives. The iWIDGET results have been discussed during the ICT 2015 conference in Lisbon (Portugal), when was presented the ICT4Water cluster. The conference has been an opportunity for analysing the role of smart water as integral part of smart city and the IoT linked to smart energy. It occurred from 20 to 22 October 2015, with more than 6000 visitors (European Commission Environment, n.a.).
iWIDGET provided a clear report of the state-of-art, a precise understanding of the market, and ideas for new project. They main fields identified for developing

projects were data mining, analytics, decision support, data management and scenario modelling (iWIDGET, 2013).

1.9.1.4 Smart Water Meters

The Australian government invests every year $50 million on “Smart Cities and Suburbs Program” (abbreviated as “Program”) for innovative technology-based solution to face with urban challenges. Nowadays, one of the most critical issue on urban context is the reduction of water losses. In Australia, the water losses have been estimated around 150 million litres during 2015-2016 financial year (Australian Government, 2019). The “Smart Water Meters” is a project that receive funding under the “Program” for saving water through early leaks detection and identifying pattern in its usage. The total capital invested is of $ 2.805.518 of which $ 1.262.218 financed by Australian government (Australian Government, 2019).
The results shown that the application of smart meters enables the cooperation among consumers, municipalities, and utilities. The smart water meters enhance modelling schemes to manage losses and treatment of wastewater. In addition, they help a fair education of consumer with a raising awareness over their consumptions. (Australian Government, 2019)
The rectification of water leaks has decreased the level of consumptions; however, it has not been possible a proper evaluation of total savings and effects because of a drought that has naturally reduced the water demand (Australian Government, 2019).

1.9.1.5 SMART.MET

SMART.MET is a project led by a group of 7 European water utilities, which work together for the development of new technologies to deal with collection and management of smart meters data. (Smart met, 2017) Their collaboration is based on a joint Pre-Commercial Procurement (PCP), that is a multiple sourcing procedure for procuring research and development services. It allows at public services to share solutions and it is a chance for companies in Europe of taking the market leadership. Moreover, the smart meters are an opportunity for the utilities to substitute an aged infrastructure and for solving their needs in terms of battery lifetime, readability, interoperability, and costs.

SMART.MET is under the European program “Horizon 2020”. (Smart met, 2017) The “Horizon 2020” is the biggest research and innovation program, with nearly € 7 bln of public funds in 2014-2020 period. It has been approved by the European Parliament for sustaining investments which help the progress and development of the European countries. It is open to everyone, it reduces the red tape and time, therefore it makes sure that new projects could get off the ground quickly. (European Commission Environment, n.a.)

1.9.1.6 Lancaster project

The U.S. city of Lancaster has conducted a campaign for the introduction of smart water meters. (Analysis: California smart water meter landscape, 2016) According with the US Census Bureau, it is a large city that counts about 159’000 habitants. (Census Bureau, 2019) Lancaster is in California, one of the States more affected by water issues, as in 2009 when the region was affected by a long drought period. The State promulgated a temporal new tariff system to discourage the excessive consumptions and forbidden the water usage during the hottest hours of the day. (Mini, Hogue, and Pincetl 2015) In 2015, a survey of US Drought Monitor shown that 60% of State was still in severe drought conditions, down from about 95% of the previous year. It is the reason why, in the same year on Lancaster started the roll-out of smart water meters. (Analysis: California smart water meter landscape, 2016) The city council signed an agreement with Itron; an American service company dedicated to the resourceful use of energy and water. (Itron, 2016) The project foreseen the progressive substitution of old manual meters (more than 14 years) with new smart system. (City of Lancaster, 2019) The scope was the enhancing of a better consumer service, improve the operational analysis and better understand the consumers’ demand. (Itron, 2016) Moreover, the smart meters have allowed an improvement on water efficiency thanks to a detection system of residential plumbing leaks. (Itron, 2016) The economic results have been very positive; indeed, the Lancaster city’s Public Works Department has estimated a total bill savings around $ 130.000 – 220.000 per year. (Analysis: California smart water meter landscape, 2016, Itron 2016).

1.9.2 Italian pilot projects

1.9.2.1 GST4Water

The “Green-Smart Technology project for the sustainable use of water resources in buildings and urban areas” (GST4Water) is an Italian project financed with fund of sponsorship earmarked for Emilia Romagna and reported on POS – FESR. (GST4Water: presentazione dei risultati 2018) The POS -FESR is a six years’ programming document that explains where each region invests its own available European funds for supporting the local development and for promoting targeted interventions.

Actually, the document considers the period from 2014 to 2020 (GST4Water: presentazione dei risultati 2018). In Emilia-Romagna, the program favourites the deployment of intelligent solutions in line with research and development strategies described on “Strategia regionale di specializzazione intelligente”.

The project lasts two years from 1st May 2016 till 31st May 2018 and it has achieved all the initial 4 objectives that are briefly summarised below:

- Create a smart technology for a constant monitoring of water consumptions indoor and outdoor. It has been possible thanks to a central unit that receive data from meters in real-time and based on open protocol of Wireless M-Bus technology
- A virtual platform to either inform or elaborates data for utilities and consumers about the level of consumptions. They developed a cloud system where the data of each client were collected, validated, and stored. Then the data were sent from smart meters to utilities for providing a precise insight over the water demand of each residency and to users for offering a feedback about their consumptions (e.g. eventual leakages with subsequently the necessary repair interventions)
- Use the intelligent meters for monitoring the quantity of grey water produced by clients. It allows the building of a storage system, where the rainwater is collected. The adoption of smart solution is important for a proper sizing of the tanks, thanks to demand management systems that provide insights about users’ behaviour
- Develop a software to evaluate the financial and environmental sustainability. Its scope has been the identification of key performance parameters (KPI)

through a Life-Cycle Assessment (LCA) approach in order to evaluate the social impact of consumers' demand.

GST4Water has been the result of joint efforts provided by 5 laboratories, 2 universities, 1 national institute for research and 5 companies. (Regione Emilia-Romagna, 2015)

1.9.2.2 Progetto CAP

Gruppo CAP is an Italian society that provides the water service at 286.968 users, with more than 800 employees. They have planned investments for € 524.105.091 in the period 2020-2024, of which € 53 mln specifically for sustainability. Just in 2016, they launched CAP21 (Gruppo CAP, n.a.). They are 21 actions for facing the most important climate challenges. In that context, Gruppo CAP has launched a program for introducing new smart meters to substitute the manual ones. In 2016, they run a pilot project in Magenta, near Milan. At the beginning, it involves 243 meters out of 5000 that are served in the town. (Gruppo CAP, n.a.)
The new smart meters allowed the remote gathering of data in a defined area, called in Italian "Distretto", and they acquire information about relative improvement on efficiency and energy saving. In 2017, other 10000 smart meters have been installed in the metropolitan area of Milan, precisely on the municipalities of Cinisello Balsamo, Bareggio, and Pioltello. In 2019, the smart meters installed were more than 170.000 introduced in 3 years. (Gruppo CAP, n.a.)

1.9.2.3 Acquedotto Pugliese

In 2018, Acquedotto Pugliese (AQP) has found a deal with "Autorità Idrica Pugliese" for the replacement of mechanical water meters with new smart devices. (Festival dell'acqua, 2019) The project has been formalized in "Gazzetta Ufficiale" on 26 September 2018. In the same year, AQP has moreover launched a market research in order to understand which are the most mature technologies to be implemented into a telemetry system based on IoT solution. AQP S.p.a is water utility operating in Puglia region that manages around 1 mln of meters and provides the water service at 3 million of customers. The company has foreseen the substitution of 400 thousand meters in the period 2020-2023, with a replacement rate of 100 thousand meters per year. The budget cost is 15 € million, with a cost

for each replacement of 150 € that comprehend the physical devices and the cost of installation. In order to substitute the actual entire park meter, AQP has estimated a time required of 10 years for a total investment of 150 € million.
The authors have had the opportunity to interview the Dott. Gianfredi Mazzolani; responsible of water service for Acquedotto Pugliese (AQP). Thanks to his individual willingness and professional experience, the authors have gained important insights about smart water metering in the Italian scenario. In particular, Dott. Mazzolani has provided both important hints for a deeper knowledge of smart water metering sector and useful information for completing and improving the analytical model of this work.
Firstly, one of the most important aspect discussed during the interview has been the “VRG” (Vincolo Ricavi Garantiti). Dott. Mazzolani explained that VRG represents the actual regulatory schemes used for setting the utilities returns on water sector. The returns have to be equal at VRG value for a quadrennium. Since 2012, every 4 years the authority redefined the entire regulatory framework of water sector. The VRG has been defined with the resolution 664/2015/R/IDR and according with the tariff preparation, it has been updated with the resolution 918/2017/R/IDR. Therefore, in October 2019, ARERA has established the rules for the third period that started in 2020 and will last until 2023. In general, it has confirmed the structure of VRG that is computed as:

$$VRG = CAPEX + OPEX + FoNI + ERC + Rc_{TOT}$$

where FoNI is the component for supporting specific objects, ERC considered the coverage of environmental costs, and finally Rc_{TOT} is the component for tariff adjustment of VRG referred to two years before.
The VRG has important implications on our model, especially referring to the “demand management” benefit. The authors divided the benefit in “efficient solutions” and “operating solutions”. In the first computation of the model, the “efficient solutions” defined as the set of practices and technologies that might be coupled with smart water meters, can provide a reduction of water demand. Theoretically, they allow to achieve resource savings and they would imply lower revenues for the utility (less water consumed; less water billed). It results in the negative contribution of the first part of the formula (see Chapter 4 - Demand Management). Then, due to important hint of Dott. Mazzolani about VRG

constraint, that basically ensures fixed remuneration for the water services provider companies, the authors have modified the computation of the benefit. The authors have considered null the effect of the "efficient solutions" and only looking at the "operational efficiency" part, the positive value of benefit is increased (see Chapter 5 – Demand Management).

Secondly, he offered valuable insights on the upcoming development and future provisions of intelligent meters which Acquedotto Pugliese is planning since 2021. In particular, he talks about the critical deadline that has been set with the subparagraph 5 of the article 18 of ministerial Decree 93/17 or also called "Transitional Provisions". As argued in "Chapter 1 – Regulatory framework", it imposes to SII (Servizio Idrico Integrato) managers a transient period of 3 years till September 2020 for the replacement of all the meters that have 10 or more years of life and proceed to keep the installed park up to date in the following period. This decision has been taken by the authority for renovating the aged Italian water metering system. Nonetheless, Dott. Mazzolani said that according with the subparagraph 7 of article 18, the deadline of 3 years may be extended if there is a meter substitution with "more efficient systems". In detail, the text of the subparagraph says that "the deadline for meter replacement can be waived, within the regulatory measures adopted by competent administrative authority, also as a function of any improvement plans of measurement services with replacement of instruments existing measures to avoid disproportionate burdens for the operators and negative effects on price levels."

Dott. Mazzolani has sustained that the mandatory replacement imposed by the authority, together with the imminent expiration of the deadline (September 2020), represents the main driver for smart water meter rollout plan. The smart or intelligent water meters are considered as the "more efficient systems" that would allow the waiving of the deadline. In addition, they avoid of incurring in penalties for service providers and, at the same time, they improve the operational performance of water companies.

Considering the huge quantity of installed meter which are managed by Acquedotto Pugliese, the compliance with the Decree 93/2017 has been assumed as critical by the company, and for this reason, the corporation decided to put in place a massive 10-years substitution plan of traditional meter with smart ones which involves around 100.000 meters/year.

Moreover, the interview has been important for talking about the several technological alternatives. AQP has issued many market consultations in order to find out which is the best solution for their project according with technical factors. Thanks to the consultation, they have analysed a series of different transmission protocols: 169 MHz W-Mbus, WIZE (169 MHz), Sigfox (868 MHz), LoRaWAN (868 MHz) among radio protocols on non-licensed band, NB-IoT on licensed band. The LoRaWAN (Long Range Wide Area Network) communication protocol is the only one that responds to company requirements, especially considering the lock-in risk and the fixed network as meter reading system. The company has also installed a W-Mbus for around 5 – 10 % of meters that can be read only through the walk-by mode due to specific criticalities of relative installation sites.

This insight has been very useful for this work because it highlights a possible leading technology for smart water meters application in Italy, among the plethora of possible ones.

The interview was extremely valuable and beneficial because showed us all the practical concerns that Italian water utilities are challenging to move toward the smart metering development.

1.9.2.4 IRETI S.p.a

IRETI is a private company owned by IREN Group with headquarter in Genova, that manages more than 1 mln of water meters among Piemonte, Liguria and Emilia-Romagna. The authors have interviewed Dott. Michele Zanichelli, responsible of water and gas measurements for IRETI S.p.a.

The interview has been important for gaining more information about the actual regulatory frameworks and for implementing some lacking data in the analytical model due to the IREN project on smart water and gas meters in the cities of Genova, Parma and Reggio Emilia.

The project uses the standard technology PLC and the frequency of 169 MHz provided by a single supplier. However, IRETI has signed an agreement for an interoperable IT system that could work with different data recording technologies and providers. He has underlined how this feature has made the costs sustained for the software implementation very consistent (around 18 mln). Actually, the project is based on walk-by mode, but in the next experiments, the utility aims at the co-adoption of walk-by and fixed network mode. of It supports the benefit of “Meter reading” explained in a dedicated section on Chapter 4. The results of IRETI project shows a 16 times higher meter reading rate compare to traditional solutions, with 98% of efficiency. In addition, also the cost for meter reading agents is lower. Nonetheless, he has reported some criticalities about batteries. The regulatory framework sustains that their useful life has to be at least 13 years, in practice they have just faced some cases of excessive battery deterioration or breaks. The lower performances have a direct economic impact for utilities, because in case of battery break, it is necessary the substitution of the entire device.

Then, Dott. Zanichelli said that the Italian 2020 Budget Law has a significant impact on the problem of arrear customers. Indeed, the law states after two years since the unpaid bill the utility could not require the backlog payments. It represents a consistent economic loss for service providers, especially it concerns those meters that are hardly accessible and difficult to be closed. The introduction of smart metering system that allow the remote control of devices is an opportunity for reducing the impact of this problem.

Moreover, he has talked about a document provided by the authority and entitled "Regolamento Qualità Tecnica" in Italian. The document ranks the utilities in a scale from A till C according with their leakage levels, where A is the highest value and C the lowest one. The classification on this standard rating as an impact on the utility image. IRETI with the introduction of smart meters has reduced the operating expenditure for pipe leakages from 2 mln to 1 mln (-50%), and it is improving the service quality in many areas from B to upper category A.

Dott. Zanichelli highlights how the smart meters could sent to utility a series of feedbacks that are not possible with mechanical meters. For example, the smart meter might improve the fraud detection systems, because they are able to transmit immediate alarms in case of negative consumptions or tampering.

Finally, Dott. Zanichelli considers the Decree 93/17, that imposes the substitution of meter with more than 10 years, as a chance for renovating the older water infrastructure.

1.9.2.5 Gruppo Hera – Modena multiutility smart metering pilot project

One of the most interesting projects carried puts by the company is related to multiutility smart metering pilot project launched in 2015.

Resolution 631/13 required utilities with more than 200,000 gas point of deliver, to implement a meter roll out plan. With a view to seizing the opportunity of the roll out as an engine of innovation and improvement of customer service Hera has

decided to participate in the trial proposed by AAEGSI with Resolution 393/13 in order to verify the extent of possible synergies towards other services such as water, electricity and district heating.
The project presented concerns about 13,000 users involved in the replacement of gas meters, water meters and district heating meters, with the goal of verifying possible synergies between different services, testing the organizational model in the field management of the mass market roll out plan and experimenting value added services for the final customer.
The project disposes the substitution of 3.800 meters with smart meters that adopt 169 MHz or 868 MHz transmission module. These devices allow the provision of additional services, which include monitoring of night-time consumption and the ability to set on a given period an alert for consumption on average higher than the historical consumption and unexpected/abnormal consumption (service designed to identify hidden leaks during periods of absence from home). The consumption data will be returned to the user also in graphic form, with a comparison with the data of national average consumption, based on the number of family members. Goal of this service is to increase users' awareness of their water consumption and push them towards virtuous behavior.
Moreover, the project includes the realization of a Smart Water Grid, consisting of a smart meter system and a software platform that allow a daily measurement of the water use and water consumption of a specific portion of the network enclosed within an analysis perimeter, in order to detect hidden leaks. It also provides for the setting of consumption thresholds by type of user, thus allowing to identify any losses downstream of the meter.

1.9.2.6 MM Spa - Interview

MM Spa is developing the plan for the massive replacement of smart metering meters on the fixed network in the city of Milan. The company offers water service to more than 50,000 consumers, through more than 2200 km of network, with a yearly volume of billed water that reaches 190 million/m3. The project will be completed by 2021 and, already today, remote reading reaches more than 30% of end users, but there are still many challenges to be addressed, due to the complexity of the city area which is characterised by high urban density, difficult meter installations, manholes with heavy covers which disturb signal transmission, high radiofrequency noise.

The final objective of the mission is the improvement of the aqueduct service offered by focusing on the new technologies enabling the paradigm of industry 4.0 such as the Internet of things and Big Data Analytics solutions and by integrating plant supervision systems (DSS-SCADA) with the acquired data daily by smart meters.

The project is configured as a complex system consisting of the different components. First of all, the smart meters installed are of two types: MID mechanical smart meter equipped with pulse emitter and electronic control unit for data acquisition and transmission in radio frequency 169 MHz, and MID electromagnetic static smart meter equipped with electronic control unit for data acquisition and transmission in GPRS (for large users).

The smart meters allow the detection of the daily and monthly volumes supplied to users, of the hourly flows, the management of alarms and alerts in the event of tampering or failure, presumed loss downstream of the meter and detection of the battery status.

Moreover, there are pressure sensors installed in the critical points of the network and are of two types pressure transducer complete with control unit equipped with power supply and connection to the corporate optic fibre network and pressure transducer complete with battery-powered data logger and UMTS (3G/4G) communication to the company database;

The first type of sensors allows a continuous measurement of the network pressure and is directly interfaced with the company SCADA system. The second type of sensors provides a sampling of the pressure measurement with a configurable frequency (up to a minimum of one minute) and a daily communication with the company database of the daily maximum-minimum-average pressure data and sampled pressure with georeferencing of the point of measure.

In addition to the geographic view, a daily volume chart is available for each city area. The generation of consumption trends is automatic, with the possibility to choose the required time window and the panel also allows the management of alarms by modifying and customizing the thresholds and limits for each selected zone.

The company identifies the main purposes of the project as:

- Tracing the quality of the service offered in a documented manner in terms of constant monitoring of the flow rates and pressures of the aqueduct distribution network
- Identification of losses, abusive withdrawals, breakdowns, fraud and other problems also in order to improve the timeliness of interventions
- Automated analysis of the water balance with consequent analysis of the losses and optimization of the hydraulic management of the network

Optimized management of pumping stations in order to minimize energy consumption and comply with the necessary levels of service quality

1.10 Drivers and barriers

This section reports a review of main drivers and barriers for urban meters on water sector. The authors have provided a brief overview to deeper explain what are the factors that foster or obstacle the deployment of intelligent solution for water utilities. It represents an important step to define which benefits will be implemented in the final model and what variables could affect its results.

The wide range of benefit that smart meters brings to utilities, consumers, and municipalities, represents the most interesting driver for the adoption of these systems.

The intelligent solutions have favourited strategies of supply-demand management, as well documented in the Chapter 2 about Literature Review where a lot of studies have analysed the importance of an effective demand management solutions. The smart meters allow the adoption of management strategies through a process of reverse back of data. Starting from the acquired information, the utilities search one or more patterns on water consumption at both individual and group levels in order to elaborate targeted educational campaigns and introduce price mechanisms to discourage the demand during peak hours (Gurung et al. 2014) or drought periods. (de Sousa and Dias Fouto 2019). All these aspects can be important drivers for utility companies, enhancing their competitiveness on the market and opening-up opportunities for cost savings and improved customer service.

Smart water systems have existed for years only as a theoretical idea, but they had a lot of barriers which have constrained their deployments. Nonetheless the potential savings arising with the installation of intelligent systems, the economic sustainability represents one of the most complex challenge that is limiting the migration towards smart water meters.

A smart meter technology has several tasks to support from a data management software to real-time communication systems. For that reason, it is difficult to develop an economic and efficient solution, especially for small utilities which have a lack of in-house IT competences and they do not take advantage of large-scale economies. (SWAN, 2016) In addition, the resource has a very low price, especially in developed countries, and it is vital for consumers. Therefore, they are not always interested at substitute the manual meters with digital ones for achieving an uncertain and very limited personal profit, because it is difficult that they will cut the demand after their installation.

Then, there are non-financial barriers which have a heavy weight on lower intelligent water meters adoption. The most important is the lack of political and regulatory framework support.

Actually, the water utilities are not receiving rewards or incentives for improvements in operational efficiency (as opposed to energy utilities, which are encouraged to pursuit efficiency year by year, due to the well deployed regulatory framework e.g. white certificates) and this fact do not favour the implementation of intelligent solutions.

Another issue is the lack of an international standard among the technologies available on the market. In some cases, the utilities and consumers have concern also on quality of integrated solutions, mainly because they are not clear and easy to implement.

Moreover, the introduction of intelligent solutions is raising concerns about the respect of consumers privacy associated with who have access to consumptions information and what is the level of detail. (Giurco, White, and Stewart 2010) It is a complex barrier to overcome for utilities that underlines the need of including the social factors in the future technology deployments, in order to achieve sufficient levels of customer acceptance.

The drivers and barriers are mutually dependents. The Table 2.3 has been developed in order to depict an ordered and clear representation. The authors have divided them in two common categories: economic and organizational, depending on the nature of the driver/barrier.

	DRIVERS	BARRIERS
ECONOMIC	• Utility company competitiveness • Utility company cost savings • International financing	• Economic sustainability • High cost of the technologies • Low cost of the water resource • Lack of capital availability
ORGANIZATIONAL	• Environmental consciousness • Water resource savings • Competence availability • Low organizational inertia	• Project complexity • Lack of competences (SMEs) • Lack of international standard and regulation • Privacy issues • Customer acceptance

Table 1.6 - Drivers and barriers of smart water meters

2 Literature review

The literature review should provide a synthesis of the knowledge on a specific topic, illustrating the existing theories. “Selecting, reading and evaluating literature is an ongoing core activity of researchers that is usually carried out routinely and intuitively” (Seuring and Gold, 2012). It is an important tool for a dissertation to critically analyse the researched problem. It highlights the limits of actual alternatives, suggests further investigations and work on new directions.

The smart metering is a wide topic, that involves several essential utilities such as electricity, gas, and water. The term smart is “quite ambiguous, as it includes a plethora of different technologies” (March et al., 2013). For that reason, the dissertation is specifically focused on identifying what are the solutions that leverage the use of Internet of Things (IoT) within the water sector.

The literature around this topic is fragmented, and it is difficult to expose a single definition which completely embody the meaning of smart water meter. In order to provide an in-depth study, the dissertation considers the main aspects below the social, environmental, and technical perspectives. Special insights are necessary to explain in detail the technologies adopted, the economic benefits and change in the relationship that it could bring to both users and utilities.

The literature review considers the scientific research for discovering the possible gaps within the literature. A careful selection of articles has been conducted to achieve the objective. The first step was a general research to find the papers related with the argument, and then a selection of the most interesting.

Finally, the articles have been classified considering the most relevant variables emerging in the papers and further dimensions specific for the theme analysed.

The literature review follows a multi-steps approach to expose in a clear way the method used. The first part is dedicated to article research method, then it shows deeper how the articles were selected.

2.1 Paper collection and selection

In this section are reported the researched papers and their relative selections according with the criteria planned.

2.1.1 Paper research

The paper research needs, as initial step, to filter the possible results defining a unit of analysis. There were chosen exclusively articles published on international journals, with only the exception of a conference paper, that was added to the list because it contains general knowledges about the topic. It was not defined a threshold for the year of publication to offer a more comprehensive overview about the topic. However, due to the particular features of the theme, the relative studies are all recent. The older paper inserts in the literature has been published in 2008. The sources of literature were Scopus and Web of Science. Scopus was the main source due to the higher number of articles available. The search was conducted through key words following a meticulous method. At the beginning, it was carried out a general research using only general keywords about the topic for giving a broad definition of the theme and analyse the main sector trends (e.g. “smart metering”, “intelligent metering”, “smart water”, “smart water grid”).
Then, according to the results, keywords were also combined to find out all the most interesting papers and ensure a detailed coverage of the argument.

2.1.2 Article Selection

In order to proceed with a reliable collection of valuable papers, it has been necessary to delimit the field and select only the consistent papers in line with the focus of our thesis, which aims to explore different applications, benefits and opportunities that smart water metering offers. For this reason, the analysis has been based on keywords that investigate specific fields of interest and restrict the researches: together with the aforementioned keywords, more specific ones like “water saving”, “water efficiency”, “leakage detection”, “demand management”, “fraud detection”, “dynamic pricing”, “user behaviour”, “water consumption” have been added.
It is important to specify one issue: smart metering embraces different sectors (i.e. electricity, water, gas) for this reason some of the keywords used (e.g. “smart-metering”, “intelligent metering”, “smart network”) lead us to face a consistent list of articles which however, where not useful for our research. In order to identify possible economic consideration regarding the smart metering system adoption the search was refined adding other keywords like “cost”, “investment” and “cost-benefit”, which lead to a considerable reduction in number of articles.

The analysis of the articles make evident that smart-metering embraces two distinct elements: meters based on a new technology to capture water use information, and communication systems that can capture and transmit water use information as it happens or almost as it happens (NYSERDA, 2003). Indeed, it is possible to identify a first classification of the articles, according to the element and process on which focus their attention. Some articles present a deeper insight on the sensor technology, the way how it emits signals or it is powered, finding useful insights on communication protocols (Augustin et al. 2016) and interesting energy harvesting techniques (Alrowaijeh and Hajj 2018), while other articles provide a more detailed knowledge of the process of data collection and analysis, investigating innovative technologies like fog computing (Amaxilatis et al. 2020). An important aspect that emerged from the analysis is the possibility to include the research of applications and opportunities of smart metering into the more general framework of smart water systems: structured combinations of water management technologies and ICT distinguished from traditional water management technologies.(J. Li, Yang, and Sitzenfrei 2020). These systems are structured in 5 layers: physical layer, sensing and control layer, collection and communication layer, data management and display layer, and data fusion and analysis.(J. Li, Yang, and Sitzenfrei 2020); the composition of these different layers allows smart-meters to communicate the captured data to a broad audience, e.g. utility managers, consumers and facility authorities, opening-up to a wide range of opportunities and benefits, shared between customers and water service providers (e.g. utilities). The analysis then was carried out trying to find more detailed information and insights about the benefit and opportunities. Mainly, benefits are linked to the fact that smart-meters provide new data about account-level demands at hourly or sub-hourly frequencies, and this allows a disaggregation of demand and consumption patterns that cannot be achieved with traditional water meters (Pesantez, Berglund, and Kaza 2020a). The availability of disaggregated data represents the possibility for utility companies to spot leakages in more systematic way (Britton, Stewart, and O'Halloran 2013a), identify and detect frauds or flawed meters (Dália Loureiro et al. 2016a), save labour-cost about meters reading and maintenance of infrastructure with the emerging opportunity to set dynamic tariff for water consumption and enable a demand-response system (Vašak et al. 2014).

Opportunities arise also from the consumer side, starting from the possibility to identify residential water consumption patterns (Aisa and Larramona 2012) and opening-up to potential water savings (Stewart et al. 2013), and more in general to increase the water-consumption consciousness.

The wide range of possible benefit allows a second classification of the articles according to the one that they investigated more in depth. Summarizing, the initial paper collection sample account 90 studies: all those papers were found thanks to the above-mentioned key words and through the reference snowballing technique. Nevertheless, many of them were discarded because they did not meet some requirements. For example, Thneibat M. (2019) provided an interesting survey about people perception about water-efficient devices, nonetheless its scope was too broad and do not considered smart-metering between the water-efficient technologies, and for this reason was not added to the final list. Augustin A. et al (2019) proposed an in-depth review of the Lora network, a technology which is largely adopted in the smart-metering field, but the study was about merely technical aspects which were not useful for our purpose. In the same way the authors choose to discard some articles which investigated other issues about water-efficiency but do not completely focus on smart-metering, for example general studies about hybrid systems or the effect of dynamic pricing for utilities.

Since the initial sample, according to the previous mentioned criteria of selection, 82 papers were ready for an in-depth review. After having read the abstract, a deeper look at the content was given, entering in details of the articles that showed potential for our research. These papers were published between 2008 and 2020, moreover they were classified according to different criteria. The final number of papers was not established a priori, but it is the result of iterations and combined research.

2.2 Paper analysis

2.2.1 Characteristics of papers

Concerning the *year of publication*, the majority of the selected papers belong to the past four years; indeed, 48 of the 82 papers were published from 2017 on. Figure 2.1 summarizes the just exposed trend.

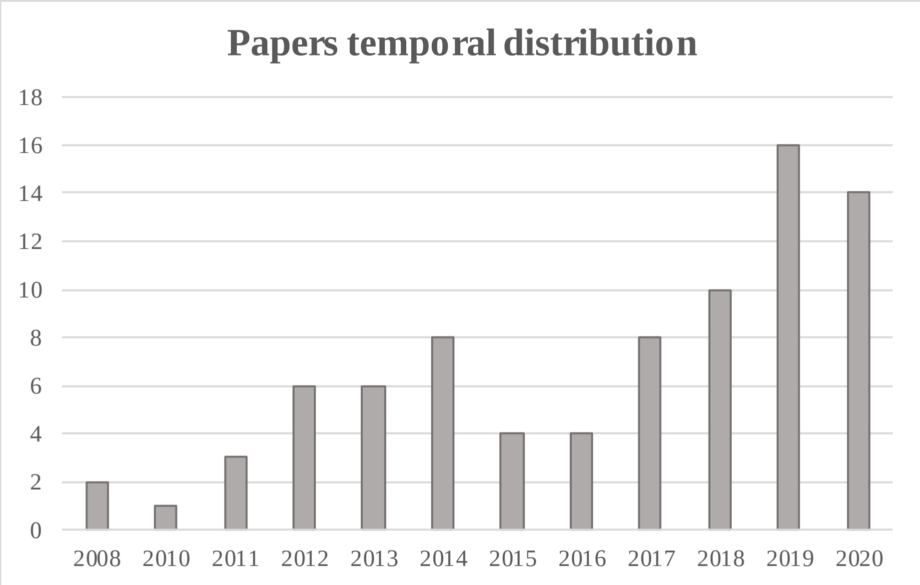


Figure 2.1 - Temporal distribution of papers

Overall, the collected papers cover a time span of 12 years, with the oldest published in 2008 and the most recent during this year (2020).

The reason why there are few papers during the years between 2008 and 2011 is mainly associated to the relative low attention about the topic of the smart water metering. With reference to this time span, many of papers concern projects made in Australia in those years. They are based on programs such as Water Savings Action Plans in New South and Water Efficiency Management Plans in Queensland. They have been implemented to ensure that large water consumers in urban settings attempt for reducing their water consumptions and thus gives a contribution towards securing whole-of-city water supply (Hauber-Davidson G., 2008). These projects entailed smart- and sub-metering of the water supply and a detailed analysis of site activities to produce a site water balance. For the first time the application of smart metering to water sector began to generate attention.

Although the concept of Smart Metering has been around for longer time, indeed the smart metering for electricity and gas are consolidated themes, only in the last 10 years smart water metering topic has increased its popularity.

In the period from 2011 to 2016, the contribution to the literature was pretty constant with an average of 5 articles published per year, another symptom that the interest for the technology was slowly increasing importance among researchers. Otherwise is important to notice that many of the articles published among that time span are referred to experimentation done in the previous years. For example, Davis K. et al (2014) published an interesting empirical study on the impact of smart-water metering on water conservation, collecting data samples about water consumption of citizens groups in Sidney for a period of 5 years starting from 2009. The increasing importance of smart metering applied to the water sector becomes even more evident in the last 4 years. Between 2017 and 2020 there has been a radical increase in the number of publications, with a peak of 16 papers published during 2019. There are possible explanations behind this trend. First of all, just considering the overseas market as example, the smart-water metering market has touched the value of USD 1,38 billion in 2018 and it's expected to reach USD 3,07 billion by 2026 (Fortune Business Insight). (Fortune Business Insight s.d.) This significant market growth automatically drives the interest of academic and research works as well. Moreover, the gradual realization of the true value of potable water to society has made water metering a critical activity for many water utilities, offering the opportunity to improve the balance between providing access to potable water joint with the responsibility of people to preserve scarce water resources (Boyle T. et al, 2013).

Focusing on the *region of origin* of the published papers, the biggest contribution is given by Australia with 18 papers, followed by Italy with 9 papers, UK with 8 papers, Switzerland with 7 papers and USA with 6 papers.

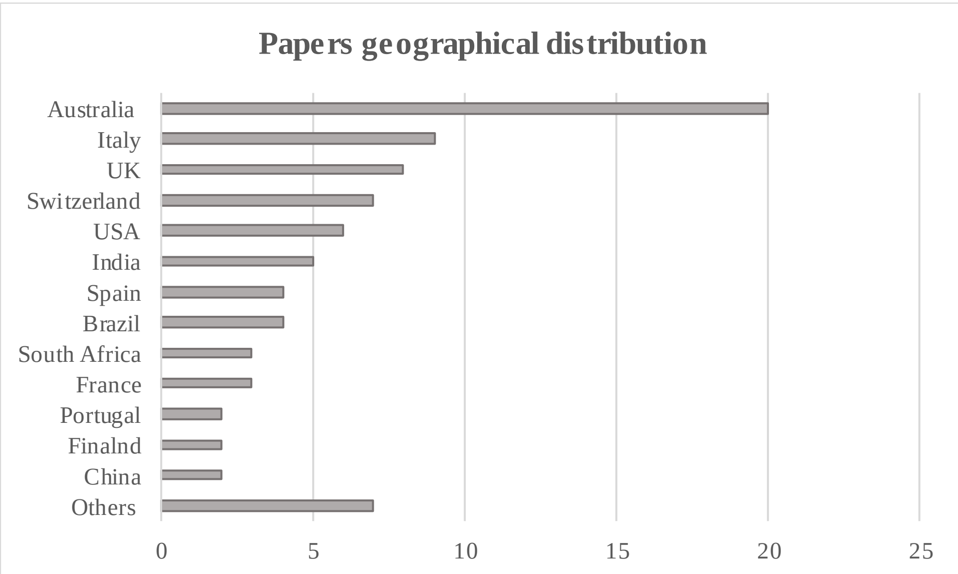


Figure 2.2 - Geographical distribution of papers

Through the analyses conducted so far, the impact of the Australian contribution immediately emerges, not only for the number of studies, but also for being the first country to deal with the topic through scientific studies and publications. This mainly due to the water scarcity that affects many parts of the country and that make the water resource planning extremely critical, fostering the experimentation and the adoption of smart technologies to guarantee the balance between supply and water demand.

9 papers out of 82 belong to Italy, which is the first European country that at the beginning of the new millennium introduced smart meters for electricity on massive scale and witnesses a growing interest towards the issue of Smart Water Metering.

A consistent contribution to the literature is provided by 8 articles published in UK, and this is interesting because the country deals with a particular condition in which metering is not mandatory for utility companies apart from specific water-stressed areas; however the National Infrastructure Commission (NIC), the body set up to make recommendations to government about the country's long-term infrastructure needs, issued a report in April 2018 in which it recommended that Defra (Department of Environmental and Rural Affairs) should enable all companies, including those outside water-stressed areas, to implement compulsory metering by the 2030s (from WWT June Issue). It also recommended that all water companies be required to consider the systematic roll-out of smart meters, explaining the increasing interest of the literature studies toward this theme.

7 papers out of 82 belong to Switzerland, which represent a hinge for scientific publications panorama, thanks to the wide number of notorious scientific journals as Water in which many of the articles founded (4 out of 7) were published.

A consistent number of articles (6) belongs to USA, country which is showing an increasing interest for smart-water metering, in order to ensure water security to many rural areas that, differently form metropolitan ones, are still experiencing difficulties in managing the water resource.

Moreover, North America is expected to hold a major share of the global market for smart water meters between 2018 and 2026, according to research agency EuroPlat, primarily attributable to the strong presence of well-established players in the US.

The US Government is investing heavily in deploying innovative smart water meters in place of older water meters across the country.

Finally, we can see that also India contributes to the literature with a fair number of articles, the country is facing impressive development in industrialization, urbanization and population growth that led to water demand unbalance and water pollution. India challenges the high to extremely high-water stress risk that put approximately almost 600 million people in condition of surface-water supply disruptions (Kalimuthu and Ponraj 2020).

The remaining part of the articles are distributed among several countries, with major contribution coming from: India, Brazil, Spain, France, and South Africa.

2.2.2 Research method used

The research method is an instrument for the authors to classify the papers. The categories are objectives, and they are defined according with the way the papers answer to research questions. The categories are literature review, conceptual framework, analytical model, simulation, case study, survey, and benchmarking. These categories have been defined and explained in the next paragraph:

- **Survey** is a statistical analysis based on a sample for understanding the opinions of a larger group, their preferences, and behaviours about a research topic. Survey might be structured, semi-structured and non-structured, according with the level of discretion concede to the interviewed

- **Case study** is an empirical analysis that investigates a contemporary phenomenon in its real contest

- **Benchmarking** is a paper that uses a model based on data collected by various sources.

- **Analytical Method** is a research methodology based on a scientific approach which allows to achieve the solution of a problem via a clear and well-defined mathematical procedure

- **Conceptual Framework** models an event through the adoption of causal map, matrixes, and diagrams

- **Literature Review** when the paper conducts an analysis over articles and studies beforehand published on a determined argument

- **Simulation** is a model of the reality that allows to assess and foresee the dynamic occurring of a series of events or subsequent process after the imposition of certain conditions by an analyst or user

Two or more categories can be used within the same paper. The presence of multi-categories occurs when different contributions help to answer at research questions which are not correlated. Therefore, they are not mutual exclusively as the example of literature review and simulation (Jin et al. 2019). The paper explains the existing technologies through a literature review, and then proceed with a test of a new solution using a simulation program.

The articles are mainly empirical, with the aim to demonstrate practically which are either potential benefits or weakness of technologies for smart water metering and how does the customer behaviour change after their introduction. The empirical papers consist in the case studies and the surveys.

The surveys are 6 out of 82 papers selected, including two cases of multi-categories. The surveys are used as a tool to address the influence of several factors on water consumption. The study of Aisa and Larramona (2012) analysed the behaviour of Spanish households covering attitudinal, socioeconomic, and demographic characteristics. The result was a matrix with the correlation among the set of factors considered. Nonetheless the mixed nature of data make difficult to provide quantitative values, the authors find that "those individuals most committed to the adoption of water-saving equipment and, at the same time, less committed to water-saving habits tend to have higher incomes". The study of Ramsey, Berglund, and Goyal (2017) consider the non-price policies (NPPs), which include educational campaigns and rebate programs for water-efficient technology. The paper shows that NPPs such as public messaging campaigns, may be effective in encouraging water-conservation behaviour. Moreover, the study finds through a questionnaire that "if the citizens believe that others are doing their part to save water, they are more interested to engage saving behaviours as well".

On the opposite, the survey of Bollinger and Hartmann (2020) studies the impact of price policies (PP). It tests, over a control group, the effectiveness of short-run price for several technologies (i.e. digital and automated). The computations are based on a specific non-parametric function and the results state that the short-run price is sustainable just for automated technologies because they are the only ones that lead toward a sufficient elasticity to justify it.

The survey of Britton, Stewart, and O'Halloran (2013) consider the network management. Its primary aim was to provide "fit-for-purpose post meter leakage rectification policy and program". The researchers provided questionnaires to design customised solutions according with socio-demographic features of a sample group.

The case studies are 48 out of the total papers selected, of which the 62% concern the household level. They mainly discussed about the water losses identification and the demand management issues. Both problems have a large set of potential solutions present in literature and moreover, they are really fragmented. Therefore, the huge presence of case study is mainly due to the absence of standard solutions within the market and the necessity to assess in practice the efficiency of the different alternatives. For example, the most common tool for solving the leakage detection issue is the Minimum Night Flow (MNF). It is basically the measure of water consumption during the non-peak hours of the night to find out potential losses (Alkasseh et al., 2013). The smart meters allow to collect real time data for monitoring constantly the level of consumptions. Other works concern more sophisticated alternatives such as Fabbiano, Vacca, and Dinardo (2020) proposes a localization methodology and a new mathematical loss index to compound the flow rate of water within pipes in steady-state conditions.

The case study category also contains sensitivity analysis for testing how change the water end use according with social, environmental or economic factors (Xenochristou, Kapelan, and Hutton 2020; Romano, Salvati, and Guerrini 2014; de Sousa and Dias Fouto 2019). Each one develops a systematic approach based on smart demand-metering data and customer characteristic.

Furthermore, the case studies are used to test the application of advance technologies within the smart water meter sector, as the study of Adamowski (2008) which examine the adoption of Artificial Neural Network (ANN), i.e. an artificial intelligent solution.

The benchmarks are only , and they provide comparative analyses between the smart meter technologies available on the market (Hope et al. 2012). They are focused on technical aspects, such as their effectiveness, durability, and efficiency. The benchmarks are run with the aim to construct a unique conceptual framework containing the principal strengths, weaknesses, and opportunity of improvements for the technologies.

The analytical methods have a high correspondence with the development of dynamic pricing mechanism (Suratin, Triakuntini, and Herdiansyah 2019; Vašak et al. 2014). The simulations are only 3 and their models are important to test innovative technologies, such as fog computing system (Amaxilatis et al. 2020).

The qualitative analyses are grouped within the conceptual framework and literature reviews categories. We have not found any paper that is in line with the definition of conceptual framework, while the literature reviews are 14. The literature reviews are mainly used to provide a clear and comprehensive overview about either the actual state-of-art of technologies (Bollinger and Hartmann 2020; Augustin et al. 2016; Rahim et al. 2020) or the benefits and risks emerging with the smart water meters installation for the customers (Sønderlund et al. 2016; Giurco, White, and Stewart 2010). Finally, a literature review concern the regulatory framework and the role of house managers as middle actor (Peltomaa, Mela, and Hildén 2020) for favouring sustainable practices at household level.

Considering the paper structures, it is possible to sustain that the quantitative analyses are predominant. They represent the 73% of the total. Usually, they are done on a small scale. For example, the research conducted by Stewart et al. (2013) based on 151 Australian households. In the last years, the growing interest for the smart watering metering has brought to the first pilot projects on a large scale. In Italy, an attempt was the analysis made at household level in all the chief town to find out the major determinants of water consumptions by Romano, Salvati, and Guerrini (2014).

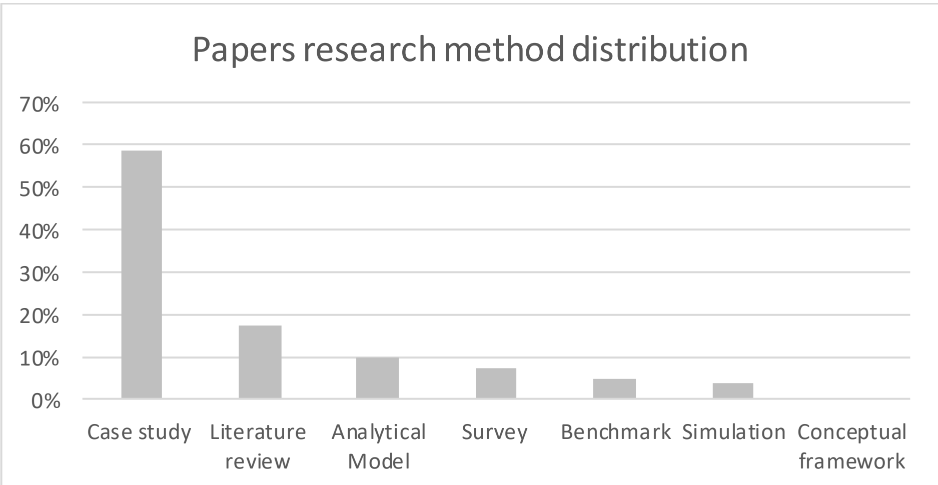


Figure 2.3 - Distribution of papers according to the research method

2.2.3 Themes arising from the review

2.2.3.1 Type of benefits

The digitalization, the advancement of current control and telecommunications systems as well as the lower costs have allowed smart-metering systems to become enablers for a new perspective on the electricity and water businesses changing the client/consumer relationship, generating consistent benefit for both (Fróes Lima and Portillo Navas 2012).

Smart or intelligent meters take advantage of advanced communication capacities and are characterized by three key features on data generation: more frequent, higher resolution and remotely accessible (Boyle et al. 2013). Smart or intelligent metering first and foremost enhances the understanding of "when", "where" and "how" water is used opening a wide range of different benefit for both final users and utility companies.

When considering benefits and savings that smart water metering technologies could generate, it is obvious to find in the existent literature studies focused on a large spectrum of different aspects. The authors firstly tried to identify clusters of benefit which were more common in the articles in order to build an essential classification from which to start. Since some of the articles that were analysed do not focus their attention on the benefit perspective, the authors decided to consider for this analysis only the articles in which at least one benefit was examined. This choice leads us to develop considerations on 66 of the 82 articles that we reviewed. From the analysis of these articles the authors classified smart-water metering benefit in 6 clusters:

- Water recovery
- Effective reading and maintenance
- Effective demand management
- Fraud detection
- Law compliance
- User satisfaction

Water recovery: in recent years, the issue of sustainable water resource management has taken on key importance worldwide because of several concomitant factors, including climate change and population growth, which have significantly reduced water availability and, at the same time, increased water demand (Boyle et al. 2013). Smart water metering allows the integration between water conservation and water management practices to reduce depletion of water resource. Controlling water losses allows for less water to be collected from the environment, generates financial savings by delaying or eliminating the need for costly construction associated with new water sources and reduces the amount of energy spent in treatment (particularly if desalination is involved) and pumping (as well as heating, where applicable) of drinking water and wastewater (Dália Loureiro et al. 2016).

Moreover, several studies showed how a relevant water saving potential can be obtained by providing feedbacks to the users about their water consumption or suggestions on customized water savings practices: (Liu and Mukheibir 2018) investigated how increased frequency of provision of water consumption feedback to the user allows consumption savings that range from 4,2% to 8,5% of total consumption, especially if real-time consumption data are provided. Other studies proved how detailed information provided to householders including leak alert communications and repair advices are valuable tools to achieve water resource savings (Britton, Stewart, and O'Halloran 2013). Smart-water metering is also a key enabler for water-efficient solution, allowing to map the specific consumption of water end use of domestic appliances (tap, shower, washing machine) and thus allowing to prioritize installation of more efficient ones (Carragher, Stewart, and Beal 2012). Finally, smart-metering system can be of a great help in smart cities to regulate the supply of water for effective use of the depleting resource, allowing utilities to monitor quantity and quality of the water distributed, for example cutting down the flow and notifying the user when the water quality is under a certain limit or when the usage exceeds a defined amount (Kalimuthu and Ponraj 2020).

The importance of water saving strategies is greater in countries in which the resource water is scarce, and periods of drought have been experienced; however, the authors expect that the challenges posed by climate change impacts, growing population demands, and constrained sources of water supply will call for the application of integrated residential water demand modeling and management in several countries across the world (Cominola et al. 2015).

Effective maintenance and meter reading: network efficiency depend on variables, such as the age and length of the distribution system, its general state of conservation, the number of connections, meter precision to avoid misreading and fraud. Information and Communication Technologies (ICT) are central hinge in improving efficiency and, above all, smart metering programs with the aim to generalize remote reading of meters, are the vanguard.

From the water utility perspective, new water meters with remote reading enables the detection in almost real time of any leak or breakdown of the system, helping to detect water leakages in the water network and act immediately, instead of going unnoticed for days or weeks as it was common with traditional meters. Indeed, according with the results of a study conducted about a utility company in Alicante, there are foreseen improvement in terms of water efficiency approximately up to 0,5% (March et al. 2017). Moreover, the increased granularity of data collected allows to generate new methodologies and algorithms to calculate the components of real losses (i.e., background leakage, unreported and reported either leaks or bursts) and apparent losses in distribution networks using data collected (D. Loureiro et al. 2014). An interesting study done in 196 schools of Cape Town showed how the installation of smart meters and the simplified detection of leakages can be coupled with basic plumbing maintenance and effortless repairs, resulting in an overall significant saving for the water user (Booysen, Ripunda, and Visser 2019).

Finally, the possibility to remotely read the consumption data benefits allows utility companies to reduce labour costs for meter reading as well as lower health and safety risks from hard-to-access properties requiring reaching over fences or confronting pet dogs (Boyle et al. 2013). The reduction of reading cost that can be achieved thanks to remote reading, has been identified as a key driver for utility companies when evaluating this kind of investments.

User satisfaction: smart-metering systems allow customers to check their online consumption almost in real time, allowing them to calculate the approximate amount of the water bill and helping the user to adequate his consumption for example anticipating changes in consumption-blocks (and hence of higher unitary prices).

The system supports a completely new approach for users toward water consumption, for example, users can set alarms when consumption exceeds a daily volume that may be decided by the customer or setting another alarm for unexpectedly high consumptions (March et al. 2017). Moreover, from the user perspective, the possibility to have a more detailed view on water consumption can be beneficial for managing household repairs, for example Britton, Stewart, e O'Halloran (2013) showed how a communication strategy through which customer where informed of the leakages make them able to repair them quickly, saving time and costs. An important aspect to be considered is the fact that in traditional water system the money payment for apartments and commercial complexes uses a common meter and the bill amount is shared equally, not providing any incentives for residents to conserve water. Adopting smart metering system would allow to overcome this issue, providing detailed and real time information on consumption of each householder. This would also help in the ease of billing and adoption of prepaid payment with the possibility of installing intelligent systems that cut down the water flow and inform the user when the water usage exceeds the limit with respect to the prepaid amount or when there is an anomalous water quality in the distribution system (Kalimuthu and Ponraj 2020).

Fraud detection: meter tampering is defined as a fraudulent manipulation, which implies a service that is not billed by a utility company. This type of losses represents a lack of consumption control for the utility because it does not allow for registering the customer's consumption or provide a proper bill for the service. Although the primary losses for the utility companies are provoked by meter tampering and leaks (with the difference that the latter cannot be charged the customer), the losses also be attributed to meter malfunction or illegal water connection (Monedero et al. 2016). According to March et al. (2017) their study conducted together with a water provider in Spain showed that undetected overconsumption at the household level is one of the most frequent complaints received by the company from customers being charged unexpected high water bill. Since this kind of manipulation was common on traditional mechanical meters because of their physical components' structure, the introduction of smart water metering technology can solve the problem in this sense.
At the same time, the disaggregation of consumption data can be exploited for developing algorithms and techniques that quickly identify outliers in consumption patterns, quickly detecting frauds and manipulations.

Demand management: demand management schemes are viewed as powerful least-cost approaches for conserving scarce water resources by restricting the demand (consumption) for water, motivating people and influencing their water use activities, through a range of social marketing, economic, and other conservation programs. Residential water use does not remain constant, but experiences periods of high and low demand throughout the 24h period and smart-water meters allow conducting high resolution analysis on water consumption, collecting disaggregated data on water flow measurement, enabling a better characterization on consumption profiles (Carragher, Stewart, and Beal 2012). It is beneficial for utility companies that can optimally plan the infrastructure development and have control on the demand peak, opening-up opportunities for capital efficiency (e.g. install smaller diameter pipes, reduce cost of water pumping).

Several studies investigated the correlation between water consumption and a variety of different factors, exploiting the detailed consumption data made available by smart-meters, in order to better characterise demand patterns and optimizing water supply. Adamowski (2008), Cole e Stewart (2013) and Xenochristou, Kapelan, e Hutton (2020) have studied the correlation between water demand pattern and meteorological factors as amount of rainfalls, temperature and humidity exploiting data collected by smart meters in Ottawa, Queensland and UK respectively; Jin Wang, Cardell-Oliver, e Wei Liu (2015) propose an algorithm to automatically discover recurrent routine behaviours for investigating how much water is used by regular water use activities, which occur multiple times in a period; Cheifetz et al. (2017) showed a methodology for clustering user behaviour in terms of water consumption patterns, identifying 8 clusters belonging to different categories of users (residential, commercial, industrial); (Cara D. Beal, Stewart, and Fielding 2013) focus his attention on the relationship between socio-economic (income, gender, occupation) factors and water consumption patterns; finally, many studies aim to recognise what is the effect of dynamic pricing and tariff regulation on water consumption, in order to understand the efficacy of these mechanism for water demand regulation (Vašak et al. (2014), (Suratin, Triakuntini, and Herdiansyah 2019), (Cole, O'Halloran, and Stewart 2012).

Domestic water-demand management may help to reduce water shortages and reduce the growing pressure on the environment. Moreover, it may reduce the necessity for the construction of major infrastructure, reducing the need for new investments, and decreasing costs for this reason, a deep knowledge of the behavior of household users in relation to water consumption is crucial for policy makers and water utilities managers.

Law compliance: in a context of increasing water scarcity, environmental laws strongly encourage water authorities to improve network efficiency and reduce water leaks. In response to the hydrologic drought conditions and additional stress due to population increase and regulatory water restrictions, many policy makers in different countries implement a range of emergency water conservation plans and outdoor watering restrictions to reduce water consumption.

In the study of (Cole, O'Halloran, and Stewart 2012) it's explained how the Wide Bay Water Corporation (WBWC) in Australia was engaged in the formulation of consumption restriction policies and become interested in the concept of Time of Use Tariffs (TOUTs) to target high water users in order to reduce their demand on the system. Smart-metering systems in this sense can play a key role on the implementation of these measures, allowing to catch almost real-time water consumption data, allowing the utility companies to monitor the actual water usage and the user to respect the restrictions without incurring into penalties or fines.

Similar restrictions have been implemented in the city of Los Angeles (USA) where Los Angeles Department of Water and Power (LADWP) implemented a range of emergency water conservation plans and outdoor watering restrictions to reduce water consumption during the 2007–2010 period (Mini, Hogue, and Pincetl 2015b). Even in this case smart-metering technology allows to quantify the impact of these frequent consumption restrictions on single-family residential water use across the City and help policy makers to better define tariffs and regulation.

Another interesting aspect is related to hybrid water systems, advanced metering technology and data analytics across a distributed water ledger, emerging as a new integrated approach to smart urban water management. In these systems rainwater tanks, greywater reuse and garden bores have become popular alternative water systems in many cities, especially in Australia. Smart-metering technology allows to integrate this systems with the "traditional" water network, adopting to develop new concepts such as water credits-debits and water trading, encouraging local water harvesting and conservation measures can enable a more sustainable hybrid water supply system (Fornarelli et al. 2019, Sapkota et al. 2014).

The graph below shows the distribution of benefit in the 66 articles that the authors considered for this analysis (some of the articles investigated aspect related to more than one benefit):

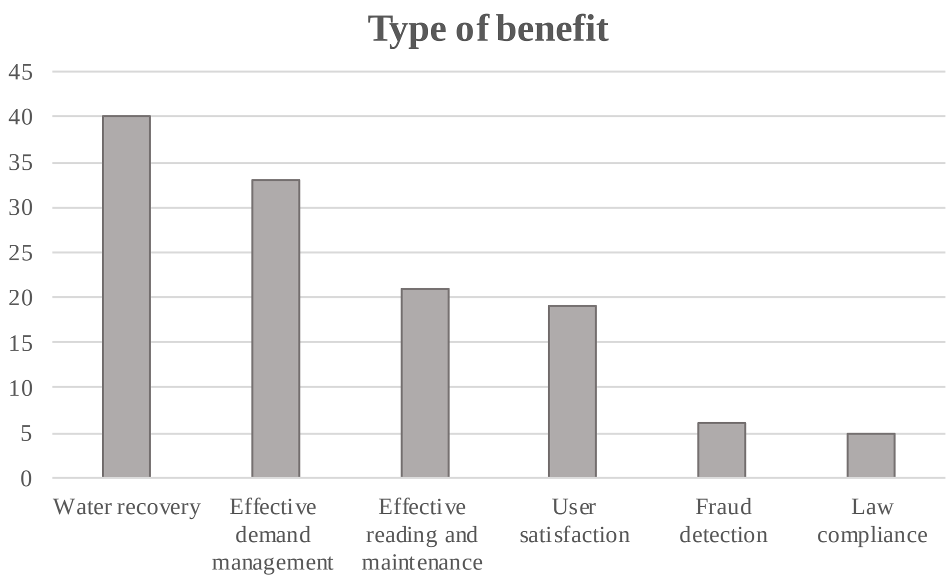


Figure 2.4 - Type of benefit categories and distribution among papers

As we can see, the benefit that more commonly are associated to smart-metering in the water sector are related to water recovery and effective demand management. This probably is due to the increasing attention that people, companies, and policy makers are putting on environmental issues, especially on the water resource, also considering scarcity and shortages that different countries have experienced over time. A consistent amount of articles highlighted benefit belonging to the cluster of demand management and effective reading and maintenance, probably because these are the main drivers that utility companies are considering when approaching to the smart-metering trend, and, as a consequence, many academic studies and practical case analysis have been conducted in that direction.

A fair amount of articles identified the other important aspects that companies and policy makers, together with users need to consider, which is the possible benefit related to user satisfaction; indeed, we are talking about a technology that is developed around the most precious resource that humans need, and of course it's expected that a consistent part of the compensations affects people directly. Finally, we can see that a modest number of articles explore the benefit related to fraud detection, even if it has been described as a common problem in the water sector. This probably is due to the fact that these kinds of aspects are more difficult to evaluate and is not the priority of smart-metering systems. The law compliance related benefit have been entailed by few articles, and this is due to the fact that in many countries policies and regulations are still under development and do not deal with smart-metering.

2.2.3.2 Types of impacts

The impacts of smart water metering have always been a central theme for the technologies' developments and their deployment. A consistent number of papers treats at least an impact or effect resulting from the adoption of smart metering. The trend is explained by the recent introduction of smart water metering within the mass market and their key role for future sustainable water consumptions; technologies that probably will dominate the sector in the next years. In this paragraph is provided a classification with the aim to assess what is the nature of the impact according to three categories: economic impact, environmental impact, and eco-environmental impact.

"**Economic impacts**" category includes all those papers that discuss the financial implication of introduction of smart water meters. They consider both positive and negative aspects. The economic impacts are very important for customers and utilities. The customer choice is strictly related with the technologies market price. Indeed, due to the lower cost of water the firsts projects show the difficulties to recover the initial investment just looking at the savings generated by the smart meters (Sladek et al. 2020). The situation is changing; the continuous efforts to reduce the cost of technologies together with the implementation of non-water benefits are driving the rise of higher returns for customers.
An example is the study conducted by Liu, Giurco, and Mukheibir (2016). It investigates how promote behavioural changes for a more sustainable consumptions through a detailed water-use information obtained via household smart metering. Therefore, it is not limited to physical savings, but it researches a way for favouring more green habits. However, the opinions are still discordant. The study conducted by Montginoul and Vestier (2018) states that providing accurate information and creating favourable intentions are necessary conditions but not sufficient on their own to sustain smart meters adoption. Therefore, it suggests the usage of incentive schemes. Booysen, Ripunda, and Visser (2019) evidence economic savings in the public buildings. It discusses the efficacy of maintenance interventions in schools water network due to the installation of smart meters. The results are positive, the smart meters identify faster eventual leakages

and with few interventions the system is fixed. In that way, it is achieved a good investments payback time (Booysen, Ripunda, and Visser 2019).

As above mentioned, the smart meters have an economic impact even over the utilities. Their economic impacts are mainly valuable in term costs reduction for network management (Shafiee et al. 2020) and design (D. Loureiro et al. 2014).

The smart meters allow real-time demand hydraulic models that constantly monitors the network parameters, as the level of pressure. In that way, they could identify and solve faster eventual leakages (D. Loureiro et al. 2014; Shafiee et al. 2020). Moreover, the personnel required is lower due to the remote control and at the same time, the utilities can gather with higher frequency and accuracy the data about consumptions (Sladek et al. 2020).

"**Environmental impacts**" represent the second category of the classification. The 12 % of papers selected is included in this group. They evaluate the physical savings of the resource with the introduction of smart systems. It is interesting to notice that the oldest study defined as "environmental impacts" has been conducted in 2013 (Stewart et al. 2013). The trend is understandable because in the last decade cases of drought or water shortage occur more frequently and with higher severity (Willis et al. 2013). The water has been always subjected to seasonality, but the climate change and the raising mean temperature have increased the concerns about its conservation (Ramsey, Berglund, and Goyal 2017). The papers within the cluster assessed principally the water savings in the domestic context. They measure the savings in the end usage coming from efficient water devices and understand how they change among different social groups (Makwiza and Jacobs 2017; Davies et al. 2014; Stewart et al. 2013). For example, the papers of Stewart et al. (2013) is focused on the direct savings derived by a smart shower. It is based on a survey that investigates how a digital system could affect the user lifestyle. The quantitative results demonstrated at the dawn lower consumptions through a shower monitoring system, but in the long-term householders inevitably revert-back to old showering habits.

Other works concern new emerging opportunities. The study of Borrero and Zabalo (2020) discuss the adoption of smart meters based on Lora technology to measure the water demand in the agricultural sector. The system is based on a WSN, where each node is a meter that works through a battery. The nodes send data to a gateway that communicate with a central system. The results consist in a quantitative analysis, that highlights the chances to build a reliable and durable network to reduce the consumption in one of the most water expensive industries (Borrero and Zabalo 2020).

"**Enviro-economic impacts**" is the last category. The separate impacts represent most of the papers selected, nonetheless in the literature they have been found studies which address both perspectives. As above mentioned, sometimes the environmental concern is not always sufficient to recover water (Borrero and Zabalo 2020) and in other cases, the economic benefits are not straightforward to achieve (Willis et al. 2013). The advent of smart meters gives the chance to evaluate the two aspects simultaneously (Rougé et al. 2018). Rougé et al. (2018) evaluates the effects of a daily dynamic tariff on the water consumptions. The tariff is computed looking on one end of the spectrum, sub daily peak pricing shifts use away from peak hours to lower a utility's operational and capital expenses. On the other end, the scarcity pricing that reflects the marginal opportunity cost given by the value of leaving water in the river for other uses, human or ecological. This pricing is efficient and leads to greater basin-wide benefits from water allocation. Contrary to enforcing demand reductions while charging water at the same fixed rate, it can also lead to water savings without hurting a utility's finances, since water distribution networks are designed to handle demand peaks, these reductions lead to substantial savings in network design, maintenance, and deferred expansion (Rougé et al. 2018).

Willis et al. (2013) studies the combined effect of efficient devices at households' level. It collects data about a shower heads, clothes washer, and rain-water tank. The results state that they account for 33% of the total residential consumption. Through the application of smart water meters, it is noted that each device could achieve specific water savings. The findings show how a range of sociodemographic factors might influence end use water consumption levels. The most important for Willis et al. (2013) are the location of household, its size, rain-water tank ownership, household income and household makeup. Inside the category is possible to find works with a broader perspective.

For example, the study of Aisa and Larramona (2012) in Alicante trough smart meter data collections and interviews with water managers from local water utility. It shed light on the costs and early benefits, as well as the potentialities and unexpected problems of this technology to contribute to more sustainable urban water cycles. The results considered not only the economic (CAPEX and OPEX) and environmental implications, but also how could change the role of smart meters due to social conditions (Aisa and Larramona 2012).

2.2.3.3 Type of subject

Smart metering emerges as a technology able to connect the water resource supplier and the user, allowing the former to have greater control over consumption, with all the benefits that come with it, and the latter to access a more effective and efficient service, and to have a more active participation in the water service system. For this reason, the application of the new technology affects simultaneously the utility and the user in various ways resulting in significant differences in terms of interesting aspects, key issues and achievable benefits, depending on the perspective from which the new smart systems are observed. Indeed, the reviewed literature adopts different perspectives, and this should be considered to perform a comprehensive analysis. The authors have identified 3 different perspectives, according to the subject that the specific study was considering: utility perspective, user perspective, both.

This classification was possible for almost all the articles reviewed, except 3 of them. They consider generic aspects related to smart metering and thus could not be adequately insert into a specific perspective category.

Utility perspective: smart metering brings significant changes in the provision of a service that has been unchanged for decades. Utility companies are facing an important transition phase, according to (Gurung et al. 2014) the importance of smart water meters as an efficient tool in the management, operation and planning of water infrastructure in the short to medium term is fundamental and the widespread application of smart water meters is foreseeable in the future.

Many aspects are relevant for utilities and the literature has been devoted to exploring the most significant.

In particular, designing and implementing effective water demand management strategies is becoming more and more important to secure reliable water supply and reduce water utilities' costs over the next years and many studies have been conducted in this direction. (Pesantez, Berglund, and Kaza 2020) and (Adamowski 2008) focus on machine learning techniques and artificial neural network to develop demand forecasting method that the utility can adopt to better manage the network and the service; (Aksela and Aksela 2011) define a method based on Gaussian curves for the same purpose, (Gurung et al. 2014) create a methodology using both individual end-use level and hourly demand patterns from the smart meters to carry out water distribution network design and modelling.

Another aspect that from the utility perspective is significant and widely discussed in the literature is related to infrastructure leakage and loss identification.

(D. Loureiro et al. 2014) proposes a new methodology, based on easy to implement algorithms, to calculate real losses and apparent losses in distribution networks using data collected from telemetry systems; (Alkasseh et al. 2013) applies MNF (Minimum Night Flow) and statistical models to locate water losses in the network; (Fabbiano, Vacca, and Dinardo 2020) proposes an innovative technique to detect leakages by monitoring the radial vibrational status of pipes through smart technologies.

The remaining part of studies that take the utility perspective are focused on other important aspects as the fault detection in meters (Perfido et al. 2017, Dália Loureiro et al. 2016) or problems related to the large number of solutions available on the market, and the lack of an open and widely accepted standard, which causes non-trivial problems to water utility companies in term of costs, vendor lock-in, and lack of control on the data collection infrastructure (Alvisi et al. 2019).

User perspective: smart-water metering introduces a new paradigm for water consumers, which are no longer just passive bystanders but become active players in the system. The system allows consumers to be participative and to have more detailed knowledge of what their consumption represents and how changes to their consumption habits may have social and economic impacts. The availability of tools with frequent consumption data, instead of mere monthly readings, represents a great gain about the information currently provided by “traditional” utilities companies (Fróes Lima and Portillo Navas 2012). From this perspective, many studies focus on the issue of educating families in conscious water use and in the possibility of keeping their information up to date, allowing clients to understand the consumption of their residence, recognizing their conditions of use and limitations regarding expenses and comfort. (Liu and Mukheibir 2018) did an interesting study that exploit smart-metering technology to provide information to the user and to understand how consumers’ behavior changes when real-time consumption feedback is provided; (Novak et al. 2018) propose a gamification strategy enabled by smart-meter feedback to involve user in adopting water-saving behaviors; (Stewart et al. 2013) goes in the same direction, focusing on specific domestic water-consuming activities and understanding how the feedback provided through an LCD screen can influence user behavior; (Cahn, Katz, and Ghermandi 2020) examined the effectiveness of online feedback in promoting water-saving behavior engaging water customers from three different cities in Israel in focus groups to analyze their behavioral incentives to conserve water and their preferences for online feedback applications.

The user perspective is taken also in other fields which have been explored by a significant amount of studies, to understand what are the possible barriers for the adoption of smart metering technologies and to investigate how does consumer perceive this new technology; (Montginoul and Vestier 2018) investigates factors that may explain the technology low adoption rate by householders, describing a natural field experiment conducted in a residential suburb in which 261 households were officially informed about the smart metering service and then 77 of them were surveyed to identify potential barriers to the adoption of smart meters; (Ramsey, Berglund, and Goyal 2017) investigate what are the socio-cultural factors that influence water consumption and adoption of water-saving solutions.

Finally, some studies adopt the user perspective to describe how the smart-meter can be adopted for water-saving maintenance and support user in household repairs; (Booysen, Ripunda, and Visser 2019) showed how the implementation of smart-meters in a set of schools in Cape Town, made possible to find losses in the network and repairing them with basic maintenance operations, resulting in a significant economic saving; (Britton, Stewart, and O'Halloran 2013) demonstrated how communication interventions help the user in the repairing household leaks, using smart-metering to identify households with significant leakages and acquiring more tailored information about the water losses.

Both: intelligent metering will be a larger and more influential presence in the urban water sector over the coming decade than it is presently; the challenge is to ensure that its broad scale introduction occurs with a focus on the needs of both customers and utilities. In the longer term, public good must prevail over shorter term profits for vendors of technology and data (Boyle et al. 2013). From this perspective studies aimed to underline and explore those aspects that involve simultaneously users and utilities, putting the attention on issues and implication that smart-metering adoption would generate. In this direction there are many studies that take in consideration the possibility of applying dynamic tariffs for water and understanding how this choice can affect customers and water service providers. (Rougé et al. 2018) provided an economic engineering conceptual framework for smart-meter enabled dynamic pricing, a proof of concept application to London's water supply system and a discussion of some salient features as: benefit at the utility and river basin scales, scarcity pricing and demand reduction; (Cole, O'Halloran, and Stewart 2012) shows the design process of a TOUT (Time Of Use Tariff), examines the infrastructure savings potential derived by network modelling and explores the regulatory framework hurdles to be overcome in order to implement such tariffs in the water industry.

2.2.3.4 Cross classification subject – benefit

In the next paragraph, it is provided a cross classification among the type of benefit and the subject addressed in the articles. As abovementioned, the subjects are divided in utilities and users, while the type of benefit are clustered in 6 categories: water recovery, effective reading and maintenance, effective demand management, fraud detection, law compliance and user satisfaction. It is important to remind that considerations on the type of benefit where feasible only on 66 of the 82 papers, for this reason even this cross-classification is affected by this limitation in the scope.

Anyway, we can say that what emerges from this cross classification is still interesting and can be taken as hinge for further discussion.

Understanding the relationship between type of subject and the type of benefit that he can gain from smart metering is fundamental to determine what are the most significant one and to have a comprehensive view on the theme, especially considering the aim of our work.

The graph below summarises the result of the analysis, highlighting for each subject what are the benefits that, from the analysis of the papers, seem more relevant.

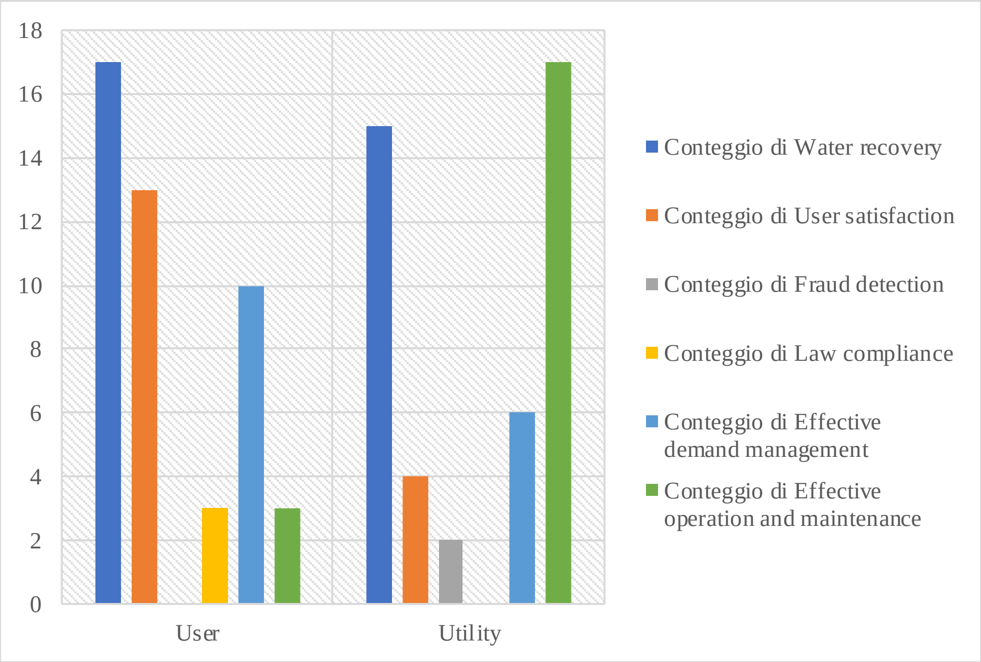


Figure 2.5 - Cross classification benefits - subjects

As we can see the categories of benefit that are more relevant for utilities are quite different from those of the users. Taking the utility perspective the category of benefits that seems more significant and more discussed in the paper is related to effective operation and maintenance: many articles show how smart-metering could enable remote meter reading , fast leakage individuation and fault detection, resulting in optimized time and cost of operations, advantages that can be fundamental for company competitiveness in the next years. The other category of benefit that is relevant for water service providers is related to water recovery: smart metering allows the utility to manage the network in a more efficient and effective way, and thus to reduce the amount of wasted water, a crucial factor especially in regions affected by water scarcity conditions. Moreover, some papers discussed how smart meters can be beneficial in this perspective by fostering the introduction and the adoption of water efficient appliances, hybrid systems for rainwater and waste water collection, that can reduce the overall amount of water taken from basins and water sources. The third category of benefits that assumes importance is related to demand management: smart-metering allows companies to know detailed water consumption data, individuate the demand peak, allowing to better plan the water supply and the design of the network, resulting in cost and infrastructure savings. Moreover, smart metering allows to adopt demand reduction and modulation practices like dynamic tariffs or time of use tariffs (TOUT). Interesting is also the benefit related to fraud detection: a fair amount of papers underlines how the problem of meter manipulation is diffused and smart metering can be an effective solution. From this analysis seems that benefit categories related to user satisfaction and law compliance are less relevant for utility companies.

Assuming the user perspective, the categories of benefit that emerge as more relevant are related to demand management and user satisfaction. The availability of real-time data about consumption, feedback about the water usage, possibility to adjust demand according to different tariffs, have been presented as fundamental factors for the user in order to better understand his water usage and maximise his comfort, economic and environmental needs. Moreover, smart metering enables the customer to have more control over his consumption, fostering the adoption of water efficient solutions and practices, that allow him to save water and reduce expenses. Saving water is another key aspect for the user: the increasing attention towards environmental issues and conscious water consumption can be a key driver for user to accept the new metering systems. Is interesting to see that law compliance benefit are more important for the user than for utilities, for example in countries in which there are restrictions on water usage, smart-meter allow the user to control consumption and not incur in payment of fines. Benefit related to maintenance are less significant for user than for utilities, even if there are still some articles that demonstrate how smart meters can help customer finding problems and facilitating repairs. This analysis aims to better allocate benefit between users and utilities, clarification that will be useful for the definition of a comprehensive model for quantifying benefits and costs.

2.2.3.5 Cross classification impact - subject

Lastly, it is provided a cross classification among the type of impacts and the subject investigated in the articles. As abovementioned, the subjects are divided in utilities and users, while the type of impacts are clustered in economic, environmental, or economic-environmental. The low number of identified papers with a clearly defined type of impact is a limitation (just 40 out of 82 papers). With the scope of a clearer explanation, the next matrix associates each category identified by the dimensions of interest with a letter (A, B, C, D, E, F, G, H, I).

	ECONOMIC	ENVIRONMENTAL	ECO-ENVIRONMENTAL
USERS	A	B	C
UTILITIES	D	E	F
BOTH	G	H	I

Table 2.1 - Matrix with categories identified by cross classification impact-subjects

The articles in the class A represent the 22.5%. They mainly seek to economic benefits arising with smart water meter solutions, in particular they analyse the main decision taken by authorities to increase the user awareness about the theme. Indeed, as just reported in the previous section, an important issue for smart meters installation in the water sector is the low cost of the resource. Therefore, the researchers are conducting several studies to develop incentive schemes that favourite their deployment. Especially in the world regions where the water is a scare resource and they have faced drought periods (Booysen, Ripunda, and Visser 2019; de Sousa and Dias Fouto 2019; Cahn, Katz, and Ghermandi 2020), local governments are introducing new policies. In general, they start from the water price elasticity for the users of a country or a specific city (Marzano et al. 2018), then they change a tariff or the regulatory framework with the aim to support the introduction of smart devices (de Sousa and Dias Fouto 2019; Mini, Hogue, and Pincetl 2015). The category also contains those papers that based their investigations on customer feedbacks for measuring the effectiveness of smart meter solutions and their economic sustainability (Booysen, Ripunda, and Visser 2019; de Sousa and Dias Fouto 2019; Montginoul and Vestier 2018). The studies within the category are usually done at household level (Montginoul and Vestier 2018), even if in literature it has been found a paper concerning the public buildings (Booysen, Ripunda, and Visser 2019).

The category B has lower articles (5 out of 40). Articles belonging to this category discuss the water end-usage saving due to the implementation of smart devices (Stewart et al. 2013; Willis et al. 2013). The study conducted by Davies et al. (2014) shows that the intelligent smart meter in-home displays allow to track the water consumption of single appliance.

To the category C belongs 4 papers. In this group the studies concern the effect of communication strategies above the consumers (de Sousa and Dias Fouto 2019). The communication strategies are fundamental to implement the smart meters, because due to the lower financial saving, it is necessary to raise the environmental consciousness of the consumer to favourite their deployment. In general, the communication strategies are built upon surveys which discover the most significant drivers that lead the water demand (de Sousa and Dias Fouto 2019; Vašak et al. 2014). For example, the work of (Fróes Lima and Portillo Navas 2012) has the primary aim to underline the importance of user active roles for achieving an effective water saving. The results state that it is still not sufficient to use new efficient devices or a better demand management with smart meter for cutting the water consumptions.

The category D has the same number of papers than category A (9 out of 40). They represent the 22.5 % of the total selected. The papers are focused on economic impact that smart water metering has on utilities. The works show that utilities could engage the smart meter for improving the water loss control (Gurung et al. 2014; Boyle et al. 2013; D. Loureiro et al. 2014). They are important for enhancing the infrastructure planning(Gurung et al. 2014). A deeper knowledge of water network allows to build a fraud detection system (Perfido et al. 2017). For example, the study of (Shafiee et al. 2020) provides a streaming smart data integration through a hydraulic simulation for enabling a dynamic demand assignment. The smart meter usage determines another stream of revenues for utilities. It is a reduction of cost of personnel, because the intelligent data gathering technologies allow that few people might control a huge quantity of devices (Sladek et al. 2020). There are two benefits associated, first the utilities could receive more frequently the information and second, they cut their expenses (Sladek et al. 2020).

In literature, the utilities do not appear interested to environmental impact, indeed in the category E there are solely 3 papers. The first work discusses of a European project conducted in Italy for measuring the smart meters precision, recall and specificity (Luciani et al. 2019). The results show that they are an important tool for utilities to save water. The second is a study about the water recovery due to a new technological solution (Makwiza and Jacobs 2017). It is a sound recording system for identifying the outdoor tap (Makwiza and Jacobs 2017).

The third work considers the importance of intelligent meters for a proper network design. The paper states that utilities tend to overestimate the network size for ensuring the service (Nguyen et al. 2018). Therefore, the introduction of IoT technologies is seen as a tool for re-engineering the network size and it could lead to a more precise forecast of the demand, with the following reduction of pipeline dimensions during the design stage (Nguyen et al. 2018).

The category F count 1 paper. It is the work of March et al. (2017) conducted in Alicante, a pioneer city for smart meter in Spain. The authors used data collected with intelligent solutions and interviews with utilities managers for shading the light on the costs and early benefits, as well as the potentialities and problems of smart meters to contribute at a more sustainable urban water cycle.

The category G has 6 papers. They are focused on water end usage at household level. It allows at utilities to customize the users demand and achieve economic savings (Liu, Giurco, and Mukheibir 2016; Cole and Stewart 2013). In literature, a common solution find within category G is a change of a tariff, for example time of use tariff (Cole, O'Halloran, and Stewart 2012).

The category H and I are less relevant. In category, there is only one paper that discuss the emerging role of smart meters as "point of connection" for an the hybrid system between the decentralized user and the grid infrastructure control by utilities (Fornarelli et al. 2019; Sapkota et al. 2014). Lastly, 1 paper has the characteristics in line with the definition of category I.

The Table 2.2 summarizes the previous analysis.

	ECONOMIC	ENVIRONMENTAL	ECO-ENVIRONMENTAL
USERS	9	5	4
UTILITIES	9	3	1
BOTH	6	1	1

Table 2.2 - Number of papers in each category

2.2.3.6 Approach analysis

The last categorization is the approach analysis. It investigates the authors approach with smart water metering considering three perspectives. The first perspective concerns the papers studying the influence of smart water meters on customers **behaviour**, the second perspective contains the papers that analyse the **technical** features, as technologies or devices properties, and to the third one belong the studies that show how the adoption of smart water meters could affect the **regulatory** aspects. The perspectives are represented as interconnected circles due to their possible interdependence. In this field, considerations from different point of views are important because it is a sector under development, where the comprehensive view is fundamental. The works are assigned to different perspectives according with the main topic discussed, however it could occur that some papers deal with argument characteristics of another topic. The Figure 2.6 shows the distribution of the papers within the three "circles" including their interconnections.

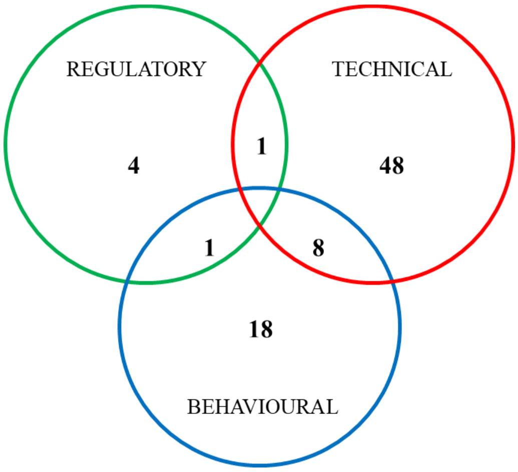


Figure 2.6 - Distribution of papers according to the three approach perspectives

The "**Behavioural approach**" circle contains 28 papers (34%). The authors tackle information by the consumer on their water end-uses with a series of different scopes, such as identify the factors underpinning the demand or understand if there are leakages within the existing infrastructure. Grafton et al. (2011) collects feedback from consumer in 10 countries in order to provide a general knowledge about the aspects with a high impact on the demand. It considers both economic and social dimensions for achieving a precise representation of the context. Following a similar structure, Romano, Salvati, and Guerrini (2014) estimates the most important factors for Italian water demand. More specifically, what emerges from Italian case are the correlation between geographical factors and consumer behaviour. Anyway, several papers underline the need to combine the behavioural features, with the two other circles for providing integrated solutions.

The "**Technical approach**" circle has 60 papers (70%). Mainly, they regard the technological aspects of the intelligent water metering. They discuss about smart meter as a tool for solving the most important issue of management, operations, and maintenance of the grid (Sánchez et al., 2020). Some papers are a critical overview on available technologies within the market (X. J. Li and Chong 2019). They concern the valuable technological performance and, in such cases the economical benchmark to evaluate the most suitable options (X. J. Li and Chong 2019). Inside the technical circle belong several papers that are positioned in the intersection with other perspectives. C.D. Beal and Flynn (2015) is an example of paper which has both behavioural and technical perspective. It is a competition between consumers about the water consumption where the technological features related with collection and analyses of data are mixed with the social factor of competitiveness among users. The scope was to find out an incentive scheme that could increase the consumer participation and the interest toward water metering solutions. Instead, it is not emerged by the literature analysis a paper that investigates the regulatory and behavioural impact.

The "**Regulatory approach**" circle has 8 papers. The low number reflects the leak of a complete framework about the topic. Indeed, the oldest paper found in literature is dated 2014. It could be interpreted as the result of the recent interest about the smart technologies within the water sectors. The regulatory papers are largely derived by decision taken from different local governments, where there have been drought or water shortages problem (Mini, Hogue, and Pincetl 2015). They are often corrective actions, such as either a change in tariff or limitation of water consumption, which are necessary for balancing the water end use and allow an equal access at the water source (Cole, O'Halloran, and Stewart 2012).

2.3 Conclusions and future directions

The water industry is confronted by changing drivers in the sustainable management of urban water. External factors, including the impacts of climate change, drought, population growth and consolidation in urban centres have all been increasing the responsibility on water service providers to adopt more sustainable approaches to urban water management as the era of cheap water fades. The literature review focused on 82 selected papers dealing with various aspects of smart water metering, favouring those articles which highlighted the presence of advantages/disadvantages related to these systems. The publication of the papers is spread over 13 years from 2008 to 2020. Previous reviews were found in the literature, their studies were focused on the technology itself and on possible applications as demand side water management, rather than on the advantages of smart metering. The review has been organized into three main sections: analysis of the main characteristics (year of publication and country of origin), research methods and content of the papers. Most of the articles were very recent, more than half (48 out of 82) were published in the last 4 years. The most recurring countries of the selected papers are Australia, Italy, UK, Switzerland and USA and this fact is consistent with either the countries water efficiency orientation or the diffusion of the smart technologies. For what regard the research methodologies used, the most diffused ones are the case studies (58%), literature review (18%), analytical method (9%) and surveys (7%).

In term of content, different interesting themes were discovered. According to the result, four sub-classification were created. Firstly, the type of subject, from which the paper took the perspective, differentiating the user perspective from the utility perspective. Secondly, the benefit highlighted in the papers were clustered in 6 categories: water recovery, effective operation and maintenance, effective demand management, fraud detection, law compliance and user satisfaction, in order to understand which were the most relevant. Thirdly, the type of impact was analysed, in order to understand if the existing literature focused more on economic or environmental aspects. Fourthly, another classification was done according to the type of approach adopted, differentiating behavioural approach, technical approach, and regulatory approach. The literature shows that advantages related to smart metering are almost equally distributed between user and utility, but with significant differences in terms of benefit category, utilities take most of the value from effective operation and maintenance that smart-metering allows compared to traditional meters, and from optimized demand management; on the other side user benefit more from water recovery and a variety of gains related to user satisfaction. Moreover, from the analysis of the papers emerge that the impacts of smart water metering involve more the utility than the user, in both economic and environmental terms. Finally, the approach of papers is mainly behavioural and technical, with a very limited number of articles that adopted a regulatory oriented approach.

The presented review gives a good picture of the literature available around the theme of water savings in smart metering world. At the same time, it highlights a number of central issues, which has not been completely or adequately tackled by scientific research.

Firstly, the papers are mainly presenting the benefits related to technical aspects and social impacts of smart water meter, while the financial analysis are often reported as superficial estimations. The benefits are not attributable at the single intelligent device but at the implementation of technological solution inside an existing system. Actually, it does not exist a standard technology within the market and it is not clear if a solution could bring always more advantages than others. However, some selected works show that it is possible to exploit more benefits from a solution that combines different perspectives because in that way, it addresses several issues at the same time.

Secondly, there is no track in literature of papers studying which could be the impact of a dedicated regulatory framework for the smart water devices. Moreover, there are just few works that investigate the relations between the implementation of rules by local governments to tackle the water consumptions and the following effect over the water end usage. Therefore, it is not clear in which degree the smart systems might contribute to a higher degree of law compliance. In general, it has been proved only that the intelligent meters can detect fraudulent water usage or excessive consumption in case of water restrictions. Indeed, combining key words for the articles research such as “regulatory framework” and “smart meter”, or “regulations” and “water intelligent devices” have led to any interesting result.

Lastly, few papers provide a precise quantification of the water savings. Moreover, different authors are in discordance for what concern the achievable economic saving or what are the main factors that could lead a water recovery. The differences between the studies’ conclusions are related with the assumptions made by the researchers (being most of the paper based on case studies). In general, there continuous lack of quantitative models for measuring the smart water meter independently by the proposed scenario. Indeed, the majority of the papers analysed ad-hoc formulas and algorithm applicable exclusively for that specific scenario/system and not flexible on different solution.

In conclusion, it is important to highlight that the study might have a series of limitations. Despite the efforts made in the directions of being all inclusive as much as possible, some papers could be not present in this review. Anyway, the authors are confident that the review represent a good and representative study of the literature.

3 Research questions and methodology

In literature are raised several gaps. They could be solved through the research questions. In this work, the research questions are two. The authors have provided them in this chapter. It is important to remind that, the he thesis falls in a broader research context conducted by the Internet of Things Observatory of Politecnico di Milano; for this reason, this work is the outcome of a continuous exchange of knowledge and collaboration with the Observatory in question.

3.1 Research questions

In the huge range of applications of the Smart Metering systems, the purpose of this dissertation focuses on the potentialities this technology has in the water sector, in relation to economic and environmental aspects. Therefore, the thesis has the aim of evaluating the actual benefits these smart devices can bring to the utility, to the final users and, on a larger scale, to the environment.

From the analysis, it emerged that the literature focusses on the evaluation of smart water meter benefits by analyzing existing projects and pilot projects, therefore observing the results starting from a defined and existing solution. On the other hand, utilities and producers give a too simplistic assessment of the potential benefits of the smart solution by retrieving few information about the smart metering system characteristics and the impacts on the consumer's behavior, network efficiency and water resource savings. There is not a precise indicator for utilities intended to implement a smart water metering project about which are the aspects and the implication that could give the biggest savings in that particular circumstance.

Articles focused on comprehensive evaluations of benefits are in most of the cases qualitative or, if quantitative, do not provide any generalization of the results obtained in a specific application, thus making difficult to separate the outcomes from that particular context.

The literature analysis makes clear that the roll-out of smart water meters could generate significant changes in water supply services, both from utility and consumer perspective. Moreover, a wide spectrum of possible benefits and costs emerges, making the cost-benefit analysis process complex and time-consuming.
Therefore, this dissertation tries to fill the hole left in between, aiming at giving to utility companies more precise information about the potential saving of smart metering, providing a general model for computation and quantification of the cost and benefits related to smart metering projects, yet keeping the model more accurate and close to reality as possible.
Moreover, the model has a double application. Since a large-scale application of smart technology could result in a considerable environmental positive impact, the model is also used to provide an estimation of the water resource consumption reduction, considering the application in the Italian scenario. This second purpose gives the dissertation an added value, providing the public institutions a mean for evaluating the possibility to establish incentives for smart metering projects.
The presented introduction led to the formulation of three research questions this dissertation aims at answering to.

RQ1: Do smart metering systems contribute to the improvement of utilities performances in the water sector? If yes, do they contribute significantly in terms of both economic and environmental terms?

The literature presents very few contributions about this topic. There is not deep detail level about how much companies installing smart water systems can get from the investment. Even at European level, there are few CBA (Cost Benefit Analysis) regarding smart water metering projects, differently from smart gas meters and smart electricity meters, which have been deeply evaluated and reported.

RQ2: Which are the most important benefit and cost figures that utility companies need to consider when evaluating smart water metering projects?

To answer this question, it is necessary to evaluate the expected benefits in economic terms, by introducing input variables into the analytical model and checking the results.
Different researchers evaluated the benefits obtained in different projects. However, these outcomes are usually not flexible, thus, the potential benefits are

applicable to that predefined context and not expandable to a general situation. Most of the time the evaluation models consist of simulations, therefore not accessible to companies and customers.

3.2 Methodology

This section contains a description of the several approaches used to answer at the reported research questions. The authors have explained them with the following classification:

- The *review of existing literature* has been an important first step to understand the context and define the border of this work. The literature analysis was useful for providing an introductory knowledge about the smart water meter world and then for narrowing the focus of the dissertation. In the end, the literature review is articulated in eighty-two papers found through two main search engines: Scopus and Web Scholar. In addition, some other papers have been excluded for the reasons before mentioned in Chapter 2.
- The *analysis of secondary sources* for coping with some lack of information in the existent literature. The secondary sources have been used to integrate the acquired knowledges with specific data taken by detailed articles about the topic investigated, reports, white papers, and from producers and retailers' websites. In particular, the secondary sources have been used for a market investigation on the products available, the existent regulatory framework from selected geographical areas, the main producers with their relative technologies and their potential benefits.
- The *analytical model* to evaluate the economic savings for utilities and the environmental benefits, due to eight benefits which could lead the installation of smart meter within the water sector. The analytical model considers the advantages and disadvantages of intelligent solutions, through a dedicated section for each benefit and their relative costs. It aims to evaluate the financial sustainability of an investment on smart water meter and compute the most important economic KPI (i.e. NPV, payback period, IRR). At the same time, it considers the environmental savings in terms of water recovery and the potential lower bill costs for consumers. The model focuses on Italian situation.
- The *interviews* have been important for validating the analytical model and for finding confirmation of the notions gathered with secondary sources. The

interviews have been done with experts and managers of different utilities. In particular, it was necessary to deepen the knowledge on technology costs of smart meters and other technical parameters such as the level of frauds or the number of water restriction violations. Concerning those issue, an interview with MM was held.

- *Survey* to provide a ranking among the benefit of the analytical model. The sample were the companies which collaborate with the authors for the development of solution through the interviews. A weight at different benefit has been important to identify which are the actual most important issues and if the model could respond in an effective way.

The usage of approaches is briefly summarized in table 3.1.

	RQ1: Do smart metering systems contribute to the improvement of utilities performances in the water sector? If yes, do they contribute significantly in terms of both economic and environmental terms?	*RQ2: Which are the most important benefit and cost figures that utility companies need to consider when evaluating smart water metering projects?*
Literature review	X	X
Analysis of secondary sources	X	X
Interviews	X	X
Survey		X

Table 3.1 - Approaches used for each research question

4 Model design

The Chapter 4 is dedicated to the design of a general model to answer at research questions highlighted in Chapter 3. This is an innovative approach that quantify a set of possible benefits related to the adoption of smart water meters. More in detail, the work consists in the formulation of an analytical model based on input variables which belong to consumer and utility domain.

The model evaluates the savings on both economic and environmental perspectives. Its design started with the identification of benefits. Due to a deep investigation, the authors have selected seven most relevant benefits. They have been summarized in the following list:

- Remote meter reading
- Efficient maintenance – Pipe leakages reduction
- Efficient maintenance – Faulty meters
- Demand management
- Arrear consumers control
- Fraud reduction
- Accurate billing

Then they have been modelized in a mathematical framework. The computations have been executed on Excel. In order to provide a complete insight on the system, the model has been adapted to different scenarios.

4.1 Model benefits

4.1.1 Remote meter reading: cost savings and additional benefits

The smart or intelligent meter devices are able to collect measurements related to a specific application field, thus once the data has been gathered by the instrument it must be collected by the utility through the reading process. It is a procedure that nowadays, in many cases, it could still be done manually by operators.

Unlike electricity meters, which are typically mounted on an external wall of the dwelling on a property, most water meters are located inside the property boundary. The utility's technicians often have to manually read meters, a time-consuming task that often involves the address of remote areas, hazardous road conditions, poison ivy and bug bites. The meter reading is a routine activity for utilities. It involves different operators, that are forced to a constant travel around the city districts for addressing customers in order to access at their properties and do the measurements. For that reason, the service providers see the meter reading as a cost- and time-expensive activity, while for the client it could be perceived as a potential bother. Moreover, just a small portion of water bills are not currently based on estimate consumptions and could occur a missed read (e.g. through an inaccessible meter, locked gates, a dog protecting the property) or a misread, for example when the reading is not accurate. The smart water metering could prevent these problems by instantaneously sending water use information directly to the utility company in charge of billing and administration. It eliminates the need for company staff or property owners to take manual readings, thus reducing time and cost for this standard process. This revolution has implication even in terms of vehicle fleet. Smart meters could cut the distances covered by meter readers that are quite significant in some regional areas. Their implementation can reduce the operating cost for the vehicle fleet and the carbon footprint associated to fuel consumptions.

In order to better understand these aspects, it is necessary to make a distinction between walk-by remote reading and network based remote reading (e.g. LPWAN).

- **walk-by remote reading:** in this case smart meter readings are collected by an operator who moves on foot or by car nearby of the meter, using a tablet or PDA that adopts a protocol short-range communication (tens of meters). These measurements are typically collected every 1.5-2 months. They can be considered as a little upgrade compared to manual readings because they make quicker the reading collection process, even if it still requires the physical presence of the operators near to meter site.
- **network based remote reding:** smart meter readings, data and alarms are transmitted through a fixed communication network. It is characterised by concentrators (or gateways) with wide coverage radius (e.g. order of kilometres) even in an urban environment. The data collection occurs very

frequently, till hourly or sub-hourly. It opens a wide range of possibilities for utility digitalization. This configuration has huge impact on operating cost, because it eliminates the need for technicians to travel near customer property except for special readings or unexpected events (e.g. meter failure).

In this work, the authors have developed a formula to quantify the above-mentioned benefits. The authors start from the case studies available in literature about existing applications and have converged the results into a single quantification.

The first application belongs to the Philadelphia Water Department (PWD), who developed an AMI (Advanced Metering Infrastructure) provided by Sensus. Sensus is a large American company with more than 1,7 million customers, that has developed walk-by remote reading infrastructure to deliver smart water technology. The project documentation of refers that "The collection of meter data is as easy as driving down the street. A single meter reader walking a route and entering data manually into a handheld computer can read perhaps 300 meters during an eight-hour shift, assuming he or she encounters no meter access difficulties. By comparison, a single person, driving a Data Command Unit for walk-by meter reading is capable of reading up to 20,000 meters a day".

As we can see the time and thus the cost required for meter reading through this methodology is extremely lower compared to manual system.

Another witness comes from the Toronto Water Department (Canada) which deployed an AMI developed by Neptune that allowed complete remote metering reading, eliminating the need for the staff to take manual readings. The report says that the utility "amalgamated positions and redeployed personnel and identified $5 million in staffing savings through efficiencies".

The city of Pasadena, Texas, targeted a variety of objectives for improved customer service in meter reading. Pasadena's primary goals were elimination of estimated water bills and minimized disruption for customers. The city's manual reading system was said as inefficient, especially where meters were remote or hard to access. The answer was a system that increased the efficiency of Pasadena's water meter reading operations with a leap from a manual meter reading process to an automated meter reading (AMR) solution. The result was a cost cutting for meter reading which has been estimated over 80%. (Smart Energy International s.d.)

In the city of Nashville, Tennessee, the utility company that provides water services decided to deploy SR II water meters and a FlexNet communication network. With this Sensus technology, the utility was able to collect meter data remotely. The company says that “the new system allowed to reduce the cost per meter read by 0,95$, saving $181,000 per month and at the same time, the utility has improved working conditions for technicians”. (Tennessean 2015)

Considering all the information collected from the case studies above-mentioned a model for quantifying the benefit related to remote reading was developed.

The table below shows the main variables for quantification and the main assumptions:

Analytical (walk-by)		
Total number of meters	N	
Salary of the operator	S	*€*
Traditional meters reading rate	R_t	*meters/h*
Walk-by meter reading rate	R_w	*meters/h*
Readings (visit) per year	$Nvis$	*visit/year*
Fixed Network mode	FN	*%*

Table 4.1 - Data on walk-by system

Analytical (fixed network)		
Total number of meters	N	
Salary of the operator	S	*€*
Traditional meters reading rate	R_t	*meters/h*
Readings (visit) per year	$Nvis$	*visit/year*
Distance travelled	D	*km*
Cost per km	C_{km}	*€/km*
Fixed Network mode	FN	*%*

Table 4.2 - Data on fixed network

The economic benefit associated with the remote reading of meter has been computed in two ways. The authors started from the alternatives for collecting the water consumptions with a remote reading system, considering two possible configurations: the walk-by and the fixed network. For each one, they have provided a specific formula.

$$Walk-by: \ \left[N\left(\frac{1}{Rt}-\frac{1}{Rw*Rt}\right)*S*Nvis\right]*(1-FN)$$

$$Fixed\ Network:\ \left[N\left(\frac{1}{Rt}\right)*S*Nvis+C_{km}*D\right]*FN$$

In both cases there is a significant saving that is represented by the improvement of the reading rate R_t (number of meters read by a single operator in the unit of time e.g. hours), which allows the worker to read a higher number of meters during the work shift, resulting in operating cost saving for the utility company. It is important to remark that in the walk-by condition, the reading rate is still lower compared to the fixed-network one, in which the data transfer of the consumption readings is instantaneous. Moreover, the fixed-network configuration includes another saving related to the operating cost of the journey. Since the meters send data automatically trough the network there is no more the need of requiring a fleet of vehicles traveling from home to home to check the readings, implying a reduction in operating cost (fuel, vehicles depreciation, faults and damages, insurance) which clearly enhances the worth of this benefit. This last component of the benefit is represented by the cost per km multiplied by the distance travelled yearly (Ckm*D).

4.1.2 Efficient maintenance - Leakages reduction

The Italian water distribution network is affected by consistent leakages. They represent an important challenge for the utilities and are divided in two levels: leakages located near end-users (or post meter leakages) and leakages located inside the distribution networks. A survey for biennium 2018-2019 conducted by ISTAT has reported a NRW average level in northern regions of 26%, in central 46% and in southern 45%, distributed on the total length of infrastructure, about 500’000 kilometres. In the most critical situations, the water losses overcome the 70% of the water demand, as in the town of Latina. On average, the network loses every day around 22 cubic meter per kilometre, nonetheless the increasing investments in critical areas (e.g. Rome).

In general, the presence of leakages causes water losses and reduction of pressure within the pipes. One-third of the utilities around the world report a loss over the 40% of clean water, but many utilities currently manage the leaks with reactive mechanism, responding only to visible water losses. It is a costly and time-consuming process, due to the large field forces to address the problem after that it occurred. Moreover, it is also risky with water loss going on for weeks or months because leaks could lead to a stop of the service or flooding in a house.

The water loss reduction is a case sensitive data, strictly dependent by a lot of variables that affect the contest of analysis. The most recent case studies available in the literature report an average value for water loss reduction around 4% (Luciani C., Casellato F., Alvisi S., Franchini M., 2019). However, this data is influenced by many factors in particular the aging and deterioration of the network. In Italy, the 60% of the infrastructure has been installed more than 30 years ago, and the 25% of network has more than 50 years.

The introduction of intelligent meters is a concrete solution to reduce the expenditure for repairing operations, provide a more precise detection system, develop predictive modelling to estimate potential future leaks, minimize the time and the number of leakages. The authors distinguish between failures on distribution network, and water losses inside the residential boundaries. The first kind of failures must be addressed by utilities, while the second one is in the attention of the user. The tackle of water leakages and failures in the network has generated significant interest due to the financial cost borne by utilities, the potential risks for public health and the environmental burden associated to wasted energy (Perfido et al. 2017).

According to the Water2020 Report developed by Sensus, a leader company in smart infrastructure service for utilities, also the routine maintenance interventions can be costly and time-consuming. Today, only few water utilities are able to adjust and control the distribution system operations remotely in real time. The utility personnel often must shut off valves manually, slowing repairs, installations, and other standard operations. In addition, the inefficient allocation of human resources leads to higher numbers of repair crew truck deployments and further costs to address the potential issues on a network.

The economic savings highlight the importance of this benefit for utilities, indeed a leakage reduction of 5% might save up to $ 2.4 billion globally. It is a constant process of monitoring that could lead toward an easy and faster identification of leakages, and consequently, a quicker and simpler repair.

A recent survey conducted by Sensus over 182 global utilities showed a potential for repairing costs reduction around 5%. These costs represent an important portion of the operating expenditures for utilities. As reported by REF Ricerche, a company that provides data to support institutions and firms in decision making processes, the yearly operating expenditure in this sector on average is around 95€/ab of which the 16% is required for repairing activities (approx.. 15 €/ab).

Considering all the information collected in literature and through interviews with utility managers, it has been quantified the potential savings on economic and environmental sides arising with the installation of smart meters. The table 4.3 reports the variables used to assess the benefits and their relative assumptions.

Physical variables		
Length of the network	l	*Km*
Total number of users	*Tot*	*ab*
Leakage post - meter percentage	β	*%*
Total water loss	*WL*	*m^3/(km/day)*
Average water loss reduction	WL_{RED}	*%*

Economic variables		
Unitary water price	P_w	*€/l*
Repair costs	C_{REP}	*€/ab*
Repair costs reduction	α	*%*

Table 4.3 - Model variables for the leakage reduction benefit

It is important to remark that, given the complexity of the estimation, the most convenient way to compute this saving is by considering the average cost of repair (C_{REP}), its relative reduction coefficient (α) estimated from the documentation of the projects found in the literature. The same procedure can be adopted for the water loss savings, considering average data available in the literature, or reported in similar projects. The physical variable β represents the share of distribution network leakage over the total amount.

The leakages reduction benefit has been computed with two formulas: the first one quantifies economical aspects while the other describes environmental ones. In particular, the economic savings have been divided among lower maintenance costs and repair costs, as well as a lower quantity of water loss. The formula is reported below:

$$l * WL * \beta * WL_{RED} * P_w * 365 + \alpha * C_{REP} * Tot \qquad (Economical)$$

$$l * WL * 365 * WL_{RED} \qquad (Environmental)$$

On economical side, the authors have been focused only on leakages in distribution network, because of “Vincolo Ricavi Garantiti” (VRG). This retribution system is complex, but its general function is to ensure fixed utilities returns even if an improved post-meter leaks detection system triggers lower levels of consumption at consumer level.

4.1.3 Efficient maintenance – Faulty meters

Thanks to the increased amount of valuable data enabled by smart-metering technologies, there is space for a more accurate monitoring of meter performances. The smart solutions can help utilities on reducing the time needed to identify and fix failures, by flagging water losses and faulty meters earlier. In that way, they will also save costs, because the investment can be directed with more focus toward the proactive maintenance of water infrastructure, that remains a critical in a lot of world regions.

Moreover, another aspect related to maintenance operation is the detection and repair of faulty meters. Smart meter and Intelligent Water Network tools such as 'critical slowing down' (complex systems theory) allows proactive identification of pending failures of metering systems permitting corrective action to be taken, maintaining system integrity. (WSAA, 2014).

In this paragraph, the authors will consider the potential benefit of a better maintenance also for the users. Leakages and that occur post-meter are not take in consideration by utility companies but represent an issue for customers. Post-meter household leakage can occur in any number of different plumbing fixtures or piping within a residential property. This kind of leakages are very common and often are neglected. However, the PRWUS (Pine Ridge Water Utility Society) proposed that the reduction of post meter leakage by 25% would reduce residential water consumption by 1% thus saving 1.7 GL/y (Water Corporation, 2013).

For this reason, post-meter household leakage repair may be one such innovation for water managers to consider. (Britton, Stewart, and O’Halloran 2013) proposed a study that examined the extent to which the staged dissemination of both generic and tailored information on evident water leaks would result in leak repair and ultimately water savings. The result was that a staged communication strategy to householders (n.372) regarding post meter leakage was found to reduce hourly water loss collectively by 89% over a period of three months. 70% of the leaks were repaired by householders for less than AUD$200 and 50% for less than AUD$100.

Householders were happy to be informed of a leak and expressed a desire for future information of this nature.
Finally, it is important to consider that improving the efficiency of the water system is almost always a lower cost option than constructing capital intensive new water supply infrastructure.

Empirical		
Mean time for faulty meter ident. (Taditional)	MTF_t	*months*
Mean time for faulty meter ident. (Walk-by)	MTF_w	*months*
Mean time for faulty meter ident. (Fixed)	MTF_f	*months*
Water tariff	P_w	*€*
Length of the network	l	*km*
Faulty Rate	F_s	*%*
Average water loss	Q_l	$m^3/(h*km)$

Table 4.4 - Model variables for maintenance and network failure identifications

$$\left(\frac{N}{l}\right) * Fs * Ql * 30 * 24 * (MTFt - MTFw) * Pw \quad (Economic)$$

$$\left(\frac{N}{l}\right) * Fs * Ql * 30 * 24 * (MTFt - MTFw) \quad (Environmental)$$

Saving related to simplified maintenance and faster failure identification have a double relevance in both economic and environmental terms. The economic saving is computed by considering the mean time for faulty meter identification (MTF) and the average water loss (Q_l) which occur while the meter is not working properly. The time required for identifying a failure in traditional meters (MTF_t) is approximately assumed as half of the time between two readings (which occurs on average each 6 months), which is equal to 3 months; smart meters which implement walk-by technology allow to spot this failures earlier, with a mean time for meter failure identification (MTF_w) assumed as 1,5 months; smart meters which adopt fixed network configuration allow to reduce this time interval even more, with the possibility to send alert and messages as soon as the failure occurs, allowing to assume a mean time for failure identification (MTF_f) of approximately 1 week (0,25 months). The benefit is translated in economic terms by multiplying the amount of water lost in the failure period by the water tariff (aqueduct quota). The first part of the formula is required to calculate how many meters are displaced per kilometre of network, since the failure rate (Fs) is relative to the number of meters, but the water losses (Ql) are related to the cubic meters lost for each kilometre of network. The coefficient 24 is used to convert hours in days, and the coefficient 30 is used to convert days in months.

4.1.4 Demand management

The smart metering topic is gaining a lot of attention also due to its potential for bringing new ways of demand management (Rougé et al. 2018). The demand management strategies are important for both consumers and utilities. For example, the information generated might encourage consumers behavioural changes that cancel the unhealthy habits, (Britton, Stewart, and O'Halloran 2013) modulating their daily water usage. At the same time the data retrieved with intelligent meter enables the extraction of end-user profiles for the utilities. These are the most evident advantages, but the demand management benefit has also other positive impacts, such as planning new greenfield investments as well as sizing the pumps and valves work conditions. (Vašak et al. 2014)

In literature, the authors have also found some case studies which associate a better demand management with the peak shifting. The peak shifting consists in a change of the daily water demand with the aim of reducing as possible its variability. The variable consumptions have consequences especially on sourcing and effluent costs. (Vašak et al. 2014) Nonetheless, the case studies conducted are just on small scale and all in foreign countries. They are based on several alternatives (e.g. through peak pricing tariff or sensibilization campaigns), that report results in contrast one from the others. For these reasons, the authors have preferred to exclude this additional driver from the benefit.

The potential advantages have been computed in economic and environmental terms, in line with the model perspectives. In literature, the authors have not found any research that conduct a quantitative analysis for this benefit. Therefore, the authors have developed a specific formula to compute it.

In order to be clear, the formula has been divided between efficient solutions and operational solutions. In the next paragraphs, they will be explained.

The **efficient solutions** are those demand management strategies where the smart meters cooperate with water efficient applications or fixtures at household level. The main advantage is the reduction of consumptions indoor and outdoor.

Among the "efficient solutions" is important to mention the emerging role of In-Home-Display (IHD), that have been defined in the Chapter 1 as small electrical devices with a touch screen which are useful to stimulate the consumer on water saving behaviours (e.g. they can emit an alarm signals when it is overcame a consumption level). In many cases, the intelligent meters are paired up with IHD and efficient appliances to inform consumer about real-time water consumption.

On environmental side, the efficient solutions have a consistent impact due to the lower water usage. While for the economic side their impact is null for this work, because in Italy the utilities are subjected to VRG or "Vincolo di ricavi garaniti" that ensures constant returns according with the expected incomes of a quadrennial plan for the operators, even if the water consumptions of clients decrease.

Therefore, a lower amount of billed water does not represent an economic disadvantage for utilities.

The formula and variables used in the model have been reported below.

Efficient solutions		
Average quantity used	Q	m^3/ab
Water consumption reduction	K_{dm}	%
Percentage of water loss	K_{wl}	%
Total number of users	Tot	ab
Unitary water price	P_w	€/m^3

Table 4.5 - Variables for efficient solutions

The most convenient way to model the benefit efficient solutions is by considering the water consumption reduction that they entail.

For this reason, the formulation begins with the product between the average quantity of water used per-capita (Q) effectively during a year (excluding the quantity loss in the network) and the coefficient of consumption reduction (K_{dm}).

The K_{dm} is a case sensitive variable that might depend by a lor of factors, such as sample size, users' attitude, and weather conditions. The authors have considered only the projects with a large sample, that last at least one year and with a casual users' sample involved.

Below it is reported the equation related to the demand management benefit conveyed into efficient solutions.

$$(Q * K_{dm}) * Tot * 365 \quad (Environmental)$$

The “**operational solutions”** concern the demand management strategies that have an impact on the network management. For example, a potential advantage is the reduction of the size of new mains due to the joint effect of peak shifting and demand reduction (Rougé et al. 2018). As a consequence of the peak shifting and flat demand, the quantity of water supplied is less variable smart meter systems are an opportunity for capital efficiency investments, because they allow the installation of smaller diameter pipelines in new development with relative low maintenance costs (Carragher, Stewart, and Beal 2012).

Moreover, using the smart technologies, it possible to build retrofit programs that reduce the peak period demand and the pressure within the existing infrastructure. Crucial network devices such as pumps, valves and track mains are designed to cope with fluctuations in water demand. However, the increasing water demand, especially due to social factors as population increase and economic growth, has raised the need of upgrade interventions on the existing distribution networks (Carragher, Stewart, and Beal 2012). The potential of smart meters could offset the upgrading costs, and in the meanwhile, they may reduce the consumption of water and lengthening the useful life of the system infrastructure (Carragher, Stewart, and Beal 2012).

Finally, the utilities spend around 6% of their OPEX in chemicals for water treatment. (Sensus, 2020), because they need to respect the quality standards of the product supplied. The smart meter could reduce their value of 50%, because fewer losses on one side reduce the quantity of chemicals loss with NRW and on the other side, a demand more stable allow a more precise quantity of chemicals in the water (Sensus, 2020).

Last consideration, the advantages listed above, influence the system with different time scales. Regardless the type of advantage that is considered, the quality of raw data is crucial for achieving consistent results (Cominola et al. 2015). In our comprehensive model for providing a precise assessment of advantages, the authors have used all the information available in literature and public documents. The next table summarizes the required variables and their numerical values.

Operational solutions		
Average cost for chemical treatment	C_{chem}	€/m^3
Chemical cost reduction	K_{chem}	%
Average cost for pumping	C_{pump}	€/m^3
Electricity for pumping	E_{pump}	kWh/m^3
Cost of electricity	C_{el}	€/kWh

Table 4.6 - Variable for operational solutions

Below it is reported the equation related to the demand management benefit conveyed into operational solution.

$$(C_{chem} * K_{chem} + E_{pump} * C_{el} * K_{dm} * 365) * Tot * Q \quad (Economic)$$

The formula encounters the reduction of chemicals costs (C_{chem}) and electricity costs for pumping (C_{pump}), which have been multiplied by the reduction coefficients (Kchem) and (Kdm) in order to quantify the economic saving. The reduction coefficient for the cost of chemicals (Kchem) has been obtained from analysis of projects' reports, while the reduction coefficient for electricity cost for pumping has been assumed equal to the demand reduction (Kdm).

It has not been possible to compute the additional economic savings arising from the implementation of lower size infrastructure because the variables required, as pipes' diameter and valves dimensions, were very case sensitive. However, it is important to remark that in real application cases, even this additional component of the benefit should be considered.

4.1.5 Arrear customers control

The arrear customers represent a critical aspect on smart meters management. They are perceived as a risk for the trust relationship between users and utilities. During the last decade, the phenomenon of consumers in default has become more evident because of the higher frequency of drought and water shortage that have interested several regions around the world. In addition, the recent economic crisis has increased the share of population that is not able to pay the utility bills (water, gas, electricity).

The statistical office of European Union (EUROSTAT) provides an annual overview about income and living condition, where it is registered even the amount of people who are not paying the utility bills on time. The analysis considers all the European countries, and it is based on different aspects, like level of education and labour position. The 20th January 2020, EUROSTAT has published the results of year 2018. Italy registered 4.5% against the 6.6% average value of European countries. However, a report published on June 2019 by REF Ricerche shows that in Italy the water sector is the most affected by the problem of payment in delay opposed to other utilities services (electricity and gas). The issue concerns only 1% - 2% of total users for gas and electricity sectors, while the water sector has really higher percentage with huge distinctions among North, Central and South Italy. Water is considered an essential good for citizens therefore the regulatory framework has a small leeway in front of payments in delay and this could let consumers adopting immoral behaviour, postponing, or not paying the water bills. In Italy, the water service provision cannot be suspended if there are residents who lives in the house. The possible intervention consists in enforcing some water consumption reductions, the most restrictive is the limitation of water usage up to 50 litres per day. It could be put in place if the bills are not payed for several months and the service provider has already urged the consumers with two letters (see Chapter 1, section "Regulatory Framework" for further information on how it works). Therefore, the arrear customers are a problematic challenge for utilities because they face lower income, but at the same time they cannot concretely act to cut the service. The problem damages not only the utility, but also the clients that pay on time. For example, the investments on infrastructure or cost for the management of network are proportionally divided among the users, that will cope with more expensive bills in case of arrear customers. In the last years, the introduction of smart meters has created an alternative to minimize the issue. The intelligent meter systems identify faster the in-default consumers, allowing the remote reduction of the service, saving time, and reducing the costs for the utility to be aware of the payments in delay. Nonetheless, it is still difficult to find out the arrear customers for utilities. In literature, the authors have found only two projects conducted by Italian water utilities. The first has been Acquedotto Lucano which has launched a deployment of intelligent meters in 2012 with the scope of cutting the issue. They monitored their network for five years. Similarly, Acquedotto Pugliese applied smart meters on a small scale. In 2019, the project ended reporting

that 5% of bills were paid in delay. In both cases, the results were positive, because the share of payment in delay was lower than the initial values registered. In the model, the authors have provided a quantitative evaluation for the Italian scenario of arrears clients. The beginning in-default customers (D1), the number of meters installed (Tot), the average water price (P_w) and the average water demanded (Q) have represented the data set.
The next table summarizes the required variables and their numerical values.

Empirical		
Payment in delay	*D1*	%
Payment in delay target value	*D2*	%
Total number of users	*Tot*	
Unitary water tariff	*Pu*	*€/m³*
Average quantity used	*Q*	*l*
Cost of the capital	*i*	%
Number of bills per year	N_{bills}	
Cash Flow	*CF*	*€*
Net Cash Flow	*NCF*	*€*

Table 4.7 - Variable for "Arrear customer" benefit

The formulation of the benefit has been divided in two steps. The first one was important for computing the amount of cash flow (CF) that the utility will receive on delay. It has been reported below:

$$CF = (D_1 - D_2) * Tot * P_u * Q * 365/Nbills$$

In this case economic saving are computed by considering the amount (%) of payments in delay, comparing values before (D1) and after the installation(D2). The term D2 has been obtained by multiplying D1 (delay in payment) for a reduction coefficient (red) triggered by smart meters.
The payments in delay represents delayed cash inflow for utilities, that is fundamental for companies' business. The reduction of payments in delay means a better management of the financial flows and of circulating capital for the utility, which depends on the cost of capital (i). The second steps considered this impact:

$$NCF = \frac{CF}{(1+i)^{1/_{Nbills}}}$$

Finally, the authors have computed the positive financial effect arising with a better circulating capital management, as the difference between the value of the cash flow (CF) and the value of the discounted cash flow (NCF) that they would have if the payment would be in delay.
The result is the formula reported below, that quantifies the benefit:

$$(D1 - D1 * red) * Tot * Q * \frac{365}{N_{Bill}} * \ P_u * (1 - \frac{1}{(1+i)^{1/_{N_{Bill}}}})$$

4.1.6 Fraud detection

Water wastage due to losses from supply and distribution systems can have a significant impact on their performance and economic sustainability. They represent a major drawback for the sustainability of natural resources.
Besides improved knowledge about the components of water losses and the noticeable efforts over the recent years to control this problem, excessive values persist in a significant part of water distribution systems worldwide. Every year in the world more than 48 billion cubic meters of treated water are attributable to non-revenue water.
These losses can be distinguished in real losses that are leaks inside transmission mains, storage facilities, distribution mains or service connections, and apparent losses, i.e. water theft, metering inaccuracies and unbilled authorized consumption.
In particular, the attention over the unauthorized water consumptions is growing among different countries. For example, England and Wales have estimated that their unauthorized consumption correspond at 0.36% of system input volume, while Australian and USA National Reports specifically mention this component of Apparent Losses, which is generally associated with misuse of Fire Hydrants, Fire Service and illegal connections.
The National Reports are also drawing the focus to the problem of customer meter under-registration. They might be defined as manipulation of the meter for registering a lower flow rate. In that way, it results an under-measurement of water

consumed. In Spain (Murcia) class B single jet meters tests in houses show average 6% under-registration, in Bangkok the value has been estimated around 2%, in Morocco the customer interested by meter under-measurement ranges from 10% to 15%. Some countries are seeking to reduce as possible this issue like Malaysia that has set a target value to limit the meters under-registration within 5%,

According to Utilititalia, in Italy, 3% of the total volume of water injected into the network is lost due to unauthorized consumption or unmetered losses.

Meter tampering is one of the most diffused causes of the apparent losses, representing 23% of them. It is defined as a fraudulent manipulation of meter, which implies a service that is not billed by a utility company. This type of losses is quite diffused and represents a lack of consumption control for the utility company because it does not allow correct registration of the customer's consumptions and subsequently, a proper billing of the service. The problem of meter tampering in water distribution is well known to all companies in this sector. There are various fraudulent methods, such as carrying out a direct connection, removing or bypassing the meter. However, the most common method that customers use for illegal manipulation is a strong magnet. The older meters are based on an oscillating piston or disk, which relies on the water to physically displace the moving measuring element in direct proportion to the amount of water that passes through the meter. The strong magnet could slow down or even stop the magnet that drives the register. The detection of this type of fraud is very difficult because it is a non-invasive technique. (Monedero et al. 2016)

New smart meters with remote reading may enable the detection in almost real time of any anomalous use of the system as well as the exact location of trouble in the network. Moreover, many studies show different techniques that can be adopted to exploit smart metering data to spot fraudulent water usage adopting statistical models and machine learning models.

An example of how smart meter can be beneficial in this sense is offered by (March et al. 2017) which reports how an utility company in Alicante was able to take advantage of smart water metering technology to detect cases of anomalous or excessive consumption. Indeed, only in 2015, 1800 cases of excessive consumption were reported in Alicante. Moreover, the company suggests that with this new system, between 120,000 and 140,000 m^3/year corresponding to fraudulent readings could be detected resulting in an additional income for the company in the range of 180,000 - 210,000 €/year, in that particular application case.

The table below provides the list of variables required to model this benefit:

Empirical		
Non-Revenue Water (ante)	NRW_1	m^3/day
Non-Revenue Water (post)	NRW_2	m^3/day
Unitary water cost	P_w	€/m^3
Total number of users	*Tot*	
Average Fraud rate	*F*	%
Water loss	K_{WL}	%
Average quantity used	*Q*	m^3/day

Table 4.8 - Variables for fraud detection

The formulation of the benefit is reported below:

$$365 * (NRW_1 - NRW_2\ ) * F * Tot\ * Q * (1 - K_{WL}) * P_w$$

In this case economic savings are computed by comparing the fraud rate values before (F_{r1}) and after (F_{r2}) the installation of smart devices. The frauds represent a lost in revenue for the utilities and they depend on the average volume of the water used, but not billed (F_w) multiplied by the unitary cost of the resource (P_w). Each smart meter installed can improve the performance of the network managers in spotting water frauds.

4.1.7 Accurate billing

The computation of water bills is a fundamental part of the service provision because it directly affects the relationship between the utility company and the customer. In this phase is absolutely necessary that the quantity of service billed is precisely equal to the actual service consumed by the client. However, in some cases this condition is not verified, and the customer finds inappropriate values for water consumption in the bill, resulting in complaints and juridical procedures to solve the contentious. This led to additional costs for the utility to solve the problem, including the generation of customer dissatisfaction.

The Italian regulatory framework with the resolution 218/2016/R/idr highlighted the need for invoices that correctly meet the actual consumption of water. It has been fully operational since January 2017. This is possible thanks to the implementation of new reading obligations, with at least two attempts per year; new ways and guarantees to encourage self-reading, communicable by phone, web-chat or texting, and the obligation to ensure the installation and proper operation of the meters, and collection of measurement data for 5 years for verification.

The deliberation also introduces standard discipline at national level to ensure greater accuracy in determining water consumption for billing purposes, while also promoting the efficient use of water resources, reducing waste, and increasing awareness of consumption choices.

In this perspective, it emerges the necessity to put in place new metering systems for achieving the goals in a more efficient and effective way.

A smart water network solution that includes smart meters enables e-billing and e-payment options and allows consumers to interact with utilities via web portals for service requests and billing inquiries. Smart metering systems continuously collect data on consumption and eliminate the need of manual reads. On this way, they ensure that consumption is billed accurately and precisely.

Moreover, they guarantee improved metering and billing accuracy, eliminating bills based on estimates. Customers can be informed in near real time of their consumption, reducing the number of customer queries and complaints.

Service agents can exploit rich visual information including near real time data visualization of how much water a customer is using, meaning faster first contact resolution in case of complaint.

Another aspect that can be considered is the fact that customers receiving electronic bills and having to opt out of it to receive a paper bill, reduces the cost of postage, printing and processing manual payments.

As observed by Suez project pilot in Firenze (Italy), the billing accuracy increased and the time for processing bills is extremely reduced (cycle time: reading-billing in less than 1 day), reducing operating costs.

In Melbourne, Australia the City West Water (City of West Water s.d.) utility company was able to improve customer billing accuracy by installing 10.000 advanced metering systems and reduced the number of complaints from 270 to almost none in the period of trial.

Australian State Governments have established independent bodies to assist water utilities, and their customers reach agreement when disputes on various matters cannot be satisfactorily resolved through internal company processes. Typically, these disputes are categorized and include billing complaints as well as credit, customer service, provision, supply, land, privacy, and general enquiry. Among the billing dispute issues, Energy and Water Ombudsman of Victoria (EWOV) identified the following sub-issues: high fees and charges, error, back bill, estimation, concession, refund, metering delay and other.

It is suggested that if digital water metering can achieve a reduction in customer billing complaints for the sub-issues of high error, wrong bill estimation, and delayed metering, then the number of billing complaints that go through to the Ombudsman offices will also be reduced. In Victoria in 2017–2018, these sub-issues amounted to 62% of billing disputes (674 of 1091 cases), which was 35% of all water cases (674 of 1928) (Monks et al. 2019).

Energy and Water Ombudsman of Victoria (EWOV) expect possible reduction of complaints about 35% thanks to the adoption of digital meters, which could lead to significant resource saving in terms of administrative costs for their offices.

Thanks to the interviews with utility managers it was possible to better define the formulation of this benefit and to identify the variables required.

In this case the economic saving is related to two different aspects: the saving in administrative cost for complaints solving, and the saving related to the improved accuracy of the billing process, which reduces the amount of water not billed properly, leading to an increase in revenues.

The final value is computed by considering the amount of complaining customers (CC), multiplying it for a reduction coefficient (K_{compl}) and for the average cost of complaints and inaccurate billing (C_{ompl}), values which have been elaborated from the analysis of the existing literature. The portion of complaining customer (CC) accounts for 0,3% of total, the reduction coefficient (K_{compl}) can be estimated around 70% and the average cost for managing the complaints has been calculated around 50€/complaint.

To model this benefit, a list of required variables is provided in the table below:

Empirical		
Total number of meters	N	*meters*
Cost of complaint	CC	*€/compl*
Average cost of complaints and inaccurate billing	$Compl$	*€/compl*
Reduction of complaints and inaccurate billing	K_{compl}	*%*

Table 4.9 - Variable for accurate billing

The formulation of the benefit is reported below:

$$CC * Compl * Kcompl * N$$

4.2 Model cost

In the Chapter 4, the authors will discuss the main cost figures that affect the deployment of smart water solutions. It will follow the same structure of Benefits section, with a dedicated section for the most relevant types of costs and a deep insight on Italian situations.

The absence of a standard technology for smart solutions on the market (see section 2.2 for a complete explanation) has needed a further division of costs for IT and software according with their features. Instead, for the other types of costs, the authors have not found significant distinctions among the technological alternatives. The cost components are listed in the next paragraphs, and they are grouped considering the typology of the cost and the activities included. At the end of the chapter all the cost defined will be grouped in two categories, to better fit in the analytical model, distinguishing between CAPEX and OPEX.

4.2.1 Installation and device costs

The installation process includes the needed operations for provision of new devices, substitution of old meters and the exceeded of start-up tests. The installation time is roughly the same to that required for traditional meters (Sigfox, n.a.). Nonetheless, the installations costs represent a relevant CAPEX figure for utilities on the meters switching process. In Italy, they are in a range from 70 € till 80 € (Festival dell'acqua 2019). The slightly cost difference is dependent by technological and physical features of the devices, such as the meter diameter, pulse, or the type of connection with the network infrastructure. (Pavia Acque, 2019)

The device cost represents the market price of smart meter. At residential level, in Italy the smart meters market price on average vary from 80 € to 120 €. The variables that affect it are the same of installation costs. In order to provide a reference level, the manual meter cost is around 25 €. (March et al. 2017) The comparison shows an important initial investment required at utilities for launching smart metering projects. In addition, the utilities might join the smart meters with IHD devices for improving their effectiveness. There are several typologies of IHD with different associated costs. Since it represents an optional cost, the authors have decided to simplify the model structure considering only the average market value. It is around 15€.

Nowadays, the European countries are focused on R&D for smart water meters. In particular, they have launched the project Smart.Met, that has been beforementioned in the section on Chapter 1. The aim is the promotion of new demand driven research into the development of new innovative smart meter solutions that fully cater to the needs of utilities, regarding accurate data in real time, readability, interoperability, and cost-efficiency. The Pre-Commercial Procurement (PCP) procedure will allow to direct the research to specific needs, the development of a high-quality product and the opening of new markets for companies. Smart.Met has been carried out under Italian law between 2018 and 2021, where the PCP includes three phases:

1. solution exploration and design
2. prototyping
3. field-testing

The authors have searched information about the cost of PCP phases. Unfortunately, they are regulated with a tender scheme and it has not been possible to discover neither their average value. For that reasons they have not been included in the model costs.

4.2.2 Maintenance cost of network

The introduction of smart meters is an important enabler to streamline the costs of operations and maintenance. (Water 2020) The smart water network could help the automation of routine maintenance tasks on distribution network, with an overall increased up to 20% in terms of productivity. On economic side, it would represent a worldwide utility saving of at least $1 billion and a maximum of $2.1 billion annually. (Water 2020) The cost reduction is mainly caused by real time monitoring of pumps and valves conditions, that allow a faster identification of faults, pre-emptive interventions and consequently, a lower damage.

4.2.3 Cost for communication system and IT system integration

A standard smart metering installation will in most cases include smart water meters, an In-Home Display (or similar device in non-domestic premises) and a communications hub. These devices will communicate with each other via a Home Area Network (HAN).

For utilities that are experiencing the transition to a remote monitoring model, LPWAN connectivity is a convenient choice because of the ease and speed of installation. For those utilities that prefer AMR, FSK modulation, ZigBee or Bluetooth are options but require heavy investment in labor and fleets.

Inside the different low power network, LPWAN is being selected by water utilities because it combines extremely long-range with deep underground and indoor penetration, together with battery lifetimes of up to 15 years. This field of smart metering systems is becoming crowded with LPWAN options which include narrowband IoT (NB-IoT), Sigfox and LoRaWAN.

For water metering applications, which have relatively low data payloads and seldom require low latency or high quality of service, Sigfox and LoRaWAN offer the optimal range, battery life, coverage capability, deployment ease and cost efficiency the water industry requires.

Since these costs are dependent on specific project characteristics as type of communication technology, characteristics of the installation site, number of end-points, number of communication hubs, frequency of transmission, network topology configuration and architecture, it’s really hard to define a general reference value to compute the model.

Referring to the Italian scenario, that is the focus region for the computation and validation of the model, and given the scarce amount of data available, it was possible to gather quantitative information only from a single project: smart metering project launched by Pavia Acque for the installation of 15,000 smart water meters in a small town in Northern Italy.

In this case, considering the project contract, the cost for the supply and implementation of hardware IT systems and software IT systems, together with services for data flow management (measurements, states, alarms) transmitted by smart meters for a period of 36 months, and relative integration with the servers and management system of Pavia Acque, was estimated around 100,000€. Therefore, considering the extension of the project which deploys 15,000 smart meters, the cost for communication system and IT integration can be assumed around 6,70€/meter.

4.2.4 Operating costs for a standalone water AMI management system

The implementation of water AMI has some operating costs associated. Excluding the maintenance and the data security costs that will have a dedicated section, the most relevant OPEX figure is represented by the costs for data loggers.

Water meter data logger is designed for recording daily flow rate from pulse water meter by pulse signal and record pipe pressure value by analog signal. It might be powered either with a battery or through an external energy and it could send data through Bluetooth technology. In literature, it has been complicated the research if a reliable quantitative analysis that compute their values. In particular, any data has been found for the Italian reference scenario. Therefore, the authors have used secondary sources.

The study of March et al. (2017) approximates the total operating costs of this new metering scheme around 2.5 euros per meter with remote reading per year. In addition, it provides a comparison with the 2 euros per year of a conventional one. This implies an increase in the OPEX of 0.5 euros per new meter with remote reading.

4.2.5 Process redesign and staff training

Upon completion of the installation of meters, a training is necessary for the staff of the utility company. Among others, during the training, topics are discussed on the operation of meters, on the export of data, on monitoring data and emergencies, as well as on the proper management of devices. Moreover, the new system requires a completely new operating modality, and a more intense workload on the IT side, including data analysis and data monitoring. On the other hand, the manual work on the operating side, especially for the meter reading process, is extremely reduced. This may require new competences and changes in the staff composition, together with training session held by meter suppliers, IT systems providers and software developers.

Referring to the above mentioned Italian project launched by Pavia Acque, the contract specifies an expenditure of 5,000€ for staff training, which is articulated in training sessions for the duration of 5 days. This cost can be considered an "una tantum" and it is independent from the extension of the project.

4.2.6 Customer service

4.2.6.1 Advertisement costs for educational campaigns

In the last years, the utilities have invested a lot of sources to communicate the value of drinking water to their consumers. The growing attention for environmental issues and the increasing importance of customer service has led to educational campaigns. The water systems and organizations featured hope that by understanding the many factors which contribute to ensuring the delivery of clean and safe drinking water, the public will become more involved and invested in drinking water protection. In the long run, a better-informed and a more active community will be an asset for water sector staff and decision makers. (CEO Water Mandate, 2015)

The study of Shaun et al. (2016) suggests that media and educational campaigns should be utilized also for increasing the public awareness towards smart metering solution. The utilities have several avenues of communication to reach the end-users on national or local level, e.g. social media, online tools, and creative annual water reports. The authors have tried to compute the marketing costs sustained by utilities for an educational campaign on social media and a video platform. They considered the most spread: Facebook, Instagram, LinkedIn, Twitter, YouTube, and Pinterest. They used two KPI, the cost for impression (CPM) and the cost for click (CPC), to provide a valuable benchmark among the alternatives. The CPM is the expenditure that a utility has to face for 1000 of views. Their relative value has been reported in the table below.

SOCIAL MEDIA PLATFORM	*CPC ($)*	*CPM ($)*
Facebook	0.97	7.19
Instagram	3.56	7.91
YouTube	3.21	9.68
LinkedIn	5.26	6.59
Twitter	0.38	6.46
Pinterest	1.50	30.00

Figure 4.1 - Cost for impression and cost for click on most famous social media and online platforms

The data shows a significant cost spread between the social media. It is strictly dependent by several variables such as the average number of post viewers, the daily active users, or the monthly new users. The authors have included the marketing costs inside their model because of their significant effect on consumption reduction. For example, one of the first campaign has been launched in 2006 by Water Sense, a large American company. It helped the water demand reduction through product labelling and tips for water indoor savings. Since the program inception till 2015, it has saved a cumulative 757 gallons of waters (or equally 2857 litres) per each consumer. (CEO Water Mandate, 2015)

Other companies have developed mobile app for a more interactive involvement of their users, like Aqua. It is an American utility, which has developed a web application containing an infographic with 21 clickable conservation tips for rooms around the house. CEO Water Mandate, 2015)

4.2.6.2 Data Management and Privacy

ICT (Information and Communication Technologies) systems including smart metering and grid automation possesses functionality, security and real-time requirements that need to be fulfilled as whole and in a way that is technically and economically feasible. Security threats in smart meter solutions include data tampering in order to manipulate the billing, outage of private data related to the lifestyle and financial situation of customers, and finally manipulation of grid control commands, which can threaten the whole network. Particular challenges arise due the large scale of a smart grid and because system components are widely distributed in the field. For this reason, the components need to be very stable and secure, particularly in the light of cyber security concept. This concept is defined to be aware of threads conveyed by computers and the protection of the assets from modification or damage from accidental or malicious misuse.

There are two European directives that are relevant to data processing in smart meters: the European Data Protection Directive which governs the processing of personal data by data controllers and grants rights to individuals. The European Privacy and Electronic Communications Directive which aim to make it technology neutral. Under these directives a number of requirements concerning data protection is specified. Firstly, personal data processing is allowed only if specific legal purposes apply. Secondly, personal data gathered for one purpose cannot be used for another purpose without permission. Thirdly, there are limitations on the

personal data transfer to other countries. Finally, there is a strict obligation to ensure adequate security.
Referring to the report “Cost Estimates for AMI”, which shows different costs for managing smart meter data, the authors consider three cost components: a data archiving and SAN management software (30.000€), a data archiving server (5.000€) and antivirus software for devices (3.000€).

As explained at the beginning of the Chapter, the authors grouped the cost items into two categories: CAPEX and OPEX.
The capital expenditure (CAPEX) figures represent the initial investment cost required for the project, which follow: smart meter acquisition cost, evaluated between 80€ and 90€ for each meter, installation costs required, evaluated 30€ for each meter, IT costs required for integrating the smart meter park in the organization IT system, evaluated around 6,70€ for each meter and finally the cost for staff training, needed to adapt the organizations practices and skills to the new technology. This last expenditure has been quantified in 5000€, which include all the activities and courses required for instructing the staff, for example how to manage the data acquisition software or collecting reads from smart meters.
The operating expenses are those recurring expenses necessary for running normal business operations. These costs include many different components that come from daily operating activities, data management, ordinary maintenance, extra-ordinary maintenance, and marketing campaigns.
The term that incorporates all the expenses for daily activities, network management and ordinary maintenance is the Cop, that has been estimated through comparison with similar projects, and evaluated around 2,50€/year for each meter. Another important component is represented by the extraordinary maintenance and meter replacement, which is due to battery damage or other causes. According to different sources, this cost figure is quite important and must be considered for all the duration of the project. The last component of the operating expenses is represented by the cost for marketing and sensibilization campaign *(*CPC*)*, which is a lower amount compared to the other cost items.

5 Model applications

The Chapter 5 has the purpose of demonstrating how numerically works the analytical model presented in Chapter 4. It will assess both the economic and environmental savings arising with a hypothetic smart water meter deployment.

In order to provide at readers a complete understanding, the authors have divided the chapter in two sections. The first is dedicated to potential savings, while the second one reports a group of selected performance indicators.

The authors have identified for some economic benefits three values (min, avg, max) and for the cost's figures (i.e. OPEX, CAPEX) two values (min, max). The choice follows a precise reasoning: it has been needed to include the variability that affect this information. In that way, the model has provided more precise results and the authors have had the opportunity to analyse the combination of several values which have generated 6 different scenarios.

The reference case studies are smart meter implementation at household level in Italy. The authors have supposed a meter park of 200'000 devices. The cases base are the installation of 10.000 and 50.000 meters and an average number of 3,3 inhabitants per device due to data gathered from ISTAT. Each case base has two alternatives: "full costs" or "delta costs". In the "Full costs" the authors have considered the substitution of working mechanical meters with smart solution, Using the official document of the Authority, we have computed the average length of network per inhabitants. The data is strongly affected by the density of population in a certain area. It means that within a city is expected a lower length than in a rural area due to the presence of buildings or even skyscraper. Our model uses the average value, but due to the extreme versality of this work, it is sufficient to substitute the data with a more specific one for finding out the length of network in precise context. The formula has been reported here:

$$l = avgAbkm * Tot = 0,073 * 33000 = 240,05\ km$$

Considering the regulatory framework and the existing smart water meter system, the authors have supposed a project lifetime of 10 years. In our model, it will be important the "Aqueduct water tariff" (P_w). It is measured in €/m³ and concerns the cost sustained by customers only for the water resource without the others fixed figures such as purification treatment or maintenance of network. Its formula is the following:

$$P_w = P_u * C_v = 1{,}94 * 60\% = 1{,}16 \text{€}/_{m^3}$$

where P_u is the total price seen by a costumer for a cubic meter of source and C_v is the quota related to aqueduct. P_u is extremely case sensitive, therefore also for this variable, the authors have considered three references corresponding to the lowest, average, and highest values in Italy. The data come from ARERA.

Variable description	Variable	Unit	MIN	AVG	MAX
SII Tariff	P_u	*€/m³*	0,82	1,94	3,79
Aqueduct quota tariff	P_w	*€/m³*	0,492	1,164	2,274

Table 5.1 - Minimum, average, and maximum value of water tariff in Italy

Finally, the authors have used in multiple benefits the variable called "Salary of operator" (S). The data has been estimated from the interviews around 16 €/h/operator.

5.1 Computation of models benefits and costs

The model "digest" the economic variables in input and gives the desired outputs. The steps to achieve results are basically two. The first is the computation of each cost and benefit, the second one is their difference considering the impact of the cost of capital over the future returns. All the cost and benefits are computed on yearly basis. The authors will follow the order of Chapter 4.

5.1.1 Remote reading benefits

Therefore, we start from the meter reading. As explained, it has been divided in two modes: walk-by and fixed network. The first one is the walk-by:

$$N\left(\frac{1}{R_t} - \frac{1}{R_w * R_t}\right) * S * N_{vis} * (1 - FN) =$$

$$= 10000 * \left(\frac{1}{12} - \frac{1}{16 * 12}\right) * 16 * 4 * (1 - 80\%) = 10.000{,}00 \text{€}/_{year}$$

The variables "Fixed Network" (FN) configuration and the two rates of meter readings (R_t, R_w) have been taken from real cases. The second mode calculation is the following:

$$\left[N * \frac{1}{Rt} * S * Nvis + Ckm * D\right] * FN =$$

$$= \left[10000 * \frac{1}{12} * 16 * 4 + 0{,}45 * 3000\right] * 80\% = 53.466{,}67 \ €/_{year}$$

As expected, the fixed network is the most convenient in the benchmark with the walk-by configuration. The authors have supposed that the meter reading is provided by operators of the utilities. However, sometimes they signed a contract with third parties. In that case, it is reasonable to suppose higher cost saving for the service provider.

5.1.2 Efficient maintenance – Pipe leakage reduction

The main variables which affect the benefit are the "Water Loss Level" (WL) and the "Cost for repairs" (C_{rep}). The value of WL is very variable among Italian towns. The last ISTAT report show a range that goes from less than 20% up to 70% in the chief towns. Considering that we are working on a general model for a costs-benefits benchmark, we have used an average value reported by ARERA in 2019. Instead, the C_{rep} has been computed through a product.

$$C_{rep} = OP * \%Rep = 86{,}35 * 16\% = 15{,}60 \ €/_{ab}$$

The OP represents the average OPEX spent by a utility per customer in Italy, while %Rep show the average share of operating expenditure directed to repairing interventions. The OP has been taken from the document "Investimenti nell'acqua: la vera "manovra espansiva" per l'economia italiana" developed by REF Ricerche. The report underlines that the OP value is affected by several factors, like the conditions of the mains. However, as before mentioned, this work has been developed at general level. Therefore, the authors have used only the average value for the Italian scenario. The formula contains P_w that has three values. As a consequence, the multiple values for the variable has determined that the benefit has three results: min, avg, max. The formula shows just the results of the average one, but it is possible to see the others in the Table 5.2.

$$365 * \beta * l * WL * WL_{red} * P_w + \alpha * C_{REP} * Tot =$$

$$= 365 * 4\% * 240{,}05 * 22 * 95\% * 1{,}164 + 5\% * 15{,}60 * 33000 = 110.996{,}92 \ €/_{year}$$

Result		
MIN	AVG	MAX
€ 61.773,38	€ 110.996,92	€ 192.303,67

Table 5.2 - Yearly economic savings due to pipe leakage reduction

5.1.3 Efficient maintenance – Faulty meters

The adoption of smart meters could lead to a reduction of faulty meters, according with specific alarms. The "faulty meters" issue involves both economic and environmental sides. Considering the economic advantage, in this benefit, the authors have distinguished between the two modes of meter readings because the walk-by implies the physical presence of the operator close to the meter. Authors have supposed that it occurs one and a half month (MTF_w), while the fixed network with daily data sent to utility could reduce the time needed to one week (MTF_f). The next formula concerns the walk-by. It will contain P_w, therefore in the table 7.2 are reported three values due to the unitary water price considered. As reference case, the authors have used the average value:

$$\left(\frac{N}{l}\right) * Fs * Ql * 30 * 24 * (MTFt - MTFw) * Pw * (1 - FN) =$$

$$= \left(\frac{10000}{240{,}05}\right) * 2\% * 0{,}917 * 30 * 24 * (3 - 1{,}5) * 1{,}164 * (1 - 80\%) = 192{,}02\, €/_{year}$$

The result is affected mainly by the ratio N/l and the foreseen time reduction. The number "30" and "24" are used to convert the delta mean time for leakages identification from months to hours. Following the same structure, authors have also provided the formula for fixed network:

$$\left(\frac{N}{l}\right) * Fs * Ql * 30 * 24 * (MTFt - MTFf) * Pw * FN =$$

$$= \left(\frac{10000}{240{,}05}\right) * 2\% * 0{,}917 * 30 * 24 * (3 - 0{,}25) * 1{,}164 * 80\% = 1.408{,}14\, €/_{year}$$

As expected, the financial benefit is higher in the second case due to a strong reduction of time for faulty meter identification. In order to compute the total economic advantage, the authors have summed the two contributions.

Walk-by	€ 81,16	€ 192,02	€ 375,13
Fixed network	€ 595,19	€ 1.408,14	€ 2.750,95
TOTAL	€ 676,35	€ 1.600,16	€ 3.126,08

Table 5.3 - Yearly economic savings of walk-by and fixed network meter reading

5.1.4 Demand management

In Chapter 4, the authors have provided the definition and explained the distinction of demand management strategies in two classes: operational solutions and efficient solutions. The operational solutions have an economic impact for utilities determining a cost saving. In particular, the authors have been focused on lower cost for chemical treatment and electricity for pumping water into the mains. The cost for chemical treatment (C_{chem}) may vary among utilities according with multiple factors, like the quantity of water provided. In order to include this variability, we have applied three values following the same structure of P_w.

MIN	AVG	MAX
€ 0,21	€ 0,67	€ 0,91

Table 5.4 - Minimum, average, and maximum cost for chemicals sustained by utilities

The cost for pumping (C_{pump}) has been obtained by the product between cost for electricity (C_{el}) and average quantity required (E_{pump}).

$$C_{pump} = C_{el} * E_{pump} = 0{,}1984 * 0{,}184 = 0{,}0365\, €/_{m^3}$$

The complete formula with the average value of chemicals has been reported here:

$$(C_{chem} * K_{chem} + E_{pump} * C_{el} * K_{dm} * 365) * Tot * Q =$$

$$= (0{,}67 * 10\% + 0{,}18 * 0{,}1984 * 365) * 33000 * 0{,}419 = 3.689{,}99\, €/_{year}$$

The other two results are visible in Table 5.5:

MIN	AVG	MAX
€ 3.503,94	€ 3.689,99	€ 4.021,83

Table 5.5 - Yearly economic savings due to demand management

The coefficient 365 is used to calculate the benefit on yearly basis. The variables that mostly affect the results are K_{chem} and E_{pump} because they are case dependent, with consistent differences among papers read in literature. The authors have used average values taken from the most recent literature reviews.

The efficient solutions have an environmental impact, due to the lower water consumption of users. As reported in Chapter 4, the VRG in Italy ensures fixed return for a quadrennium to utilities. Therefore, a lower demand has not a negative effect on their returns.

5.1.5 Arrear customers control

The arrear customers represent a critical issue for utilities. The water is an essential good, therefore the utilities could not stop the service without following an accurate procedure that requires times and it is cost expensive. The introduction of smart meters may facilitate the remote interventions, with a positive impact over the circular capital of providers. Starting from the actual share of arrear customer in Italy (D_1), we profiled a potential reduction (red). The level of D_1 is very different among regions. In the last ARERA report on 2019, the Authority identified three values of D_1 that represents the foreseen share in North, Central, and South Italy. The forecasts are lower than the real numbers. Starting from the real data, we have estimated the variable "red". Below, it is written the formula using the data of Central Italy. The table 7.4 contains a sum up of the results with all three values.

$$D1 * (1 - red) * Tot * Q * \frac{365}{N_{Bill}} * P_u * \left(1 - \frac{1}{(1+i)^{1/N_{Bill}}}\right) =$$

$$= 6\%(1 - 16\%) * 33000 * 0{,}419 * \frac{365}{4} * 1{,}164 * \left(1 - \frac{1}{(1 + 4{,}11\%)^{1/4}}\right) = 1.427{,}27\ €/_{year}$$

The others most valuable variables are the cost of capital (i) and the number of bills per year (N_{Bill}). The authors have supposed N_{Bill} according with case studies and interviews, while the capital cost has been taken from official Authority documents.

MIN	AVG	MAX
€ 243,80	€ 1.427,27	€ 6.327,82

Table 5.6 - Yearly economic saving due to lower arrear consumers

5.1.6 Fraud detection

The "fraud detection" benefit considers the economic and environmental advantages arising with a lower meter tempering rate (F). The formula about economic side is reported here:

$$(NRW_1 - NRW_2\ ) * F * Tot\ * Q * (1 - K_{WL}) * P_w =$$
$$= (3{,}0\% - 1{,}5\%) * 23\% * 33000 * 0{,}419 * (1 - 43{,}7\%) * 1{,}164 = 11.410{,}41\ €$$

As in the previous cases, the presence of P_w generates three values. The authors have reported just the computation with the average value, but the other results are visible in Table 7.5. The percentage of water losses (K_{WL}) and the daily water demand (Q) change a lot within the country (see Chapter 4). This work is general, so we have used average data.

MIN	AVG	MAX
€ 4.822,96	€ 11.410,41	€ 22.291,47

Table 5.7 - Yearly economic savings due to fraud detection

5.1.7 Accurate billing

It is an economic benefit arising with a more precise evaluation of water usage. In particular, a bill based on estimated consumptions could generate dissatisfaction in the customer and increase the number of complaints that utility has to manage. The data have been taken by both interviews and literature review.

$$CC * Compl * K_{Compl} * N = 0{,}3\% * 50 * 70\% * 10000 = 1.050{,}00\ €$$

5.2 Computation of model cost

The following sections focus on the quantification of the cost figures highlighted in the model, which have been categorised in CAPEX and OPEX. It is important to remark that CAPEX cost figures represent all the capital expenditure necessary for the project, thus a "una tantum" expenditure for the company, that can be considered as initial investment in the computation of the Net Present Value. On the other hand, OPEX cost figures represent all the recurring costs necessary for the operating activities implicated in the project, thus a negative quantity that must be counted year by year in the computation of the Net Present Value.

5.2.1 Capital Expenditure (CAPEX)

As delighted in Chapter 4, capital expenditure figures represent the initial investment cost required for the project, which follow: smart meter acquisition cost (C_{smart}), evaluated between 80€ and 90€ for each meter, installation costs required (C_{inst}), evaluated 30€ for each meter, IT costs required for integrating the smart meter park in the organization IT system (C_{it}), evaluated around 6,70€ for each meter and finally the cost for staff training, needed to adapt the organizations practices and skills to the new technology (C_{train}). This last expenditure has been quantified in 5000€, which include all the activities and courses required for instructing the staff, for example how to manage the data acquisition software or collecting reads from smart meters.

The formulation of the CAPEX is basically the sum of the above-mentioned contributions, the authors have reported the formula here:

$$(C_{smart} + C_{inst} + C_{it}) * N + C_{train} =$$

$$= (80 + 30 + 6{,}70) * 10000 + 5000 = 1.172.000 \ {}^{€}/_{year}$$

Obviously, this cost figure is strongly dependent by the number of meters installed *(N)*, and it can be seen that wider meter park installations require huge capital expenditures, as also reported in different interviews with utility companies of the sector.

Depending on the technology adopted and on the characteristics of the meters, which affect *Csmart*, the capital expenditure varies between the minimum and maximum values reported in the table.

MIN	MAX
€ 1.172.000,00	€ 1.272.000,00

Table 5.8 - Model CAPEX

5.2.2 Operating Expense (OPEX)

The operating expenses are those recurring expenses necessary for running normal business operations. As mentioned in Chapter 4, these costs include many different components that come from daily operating activities, data management, ordinary maintenance, extra-ordinary maintenance, and marketing campaigns.

The term that incorporates all the expenses for daily activities, network management and ordinary maintenance is the Cop, that has been estimated through comparison with similar projects, and evaluated around 2,50€/year for each meter. Another important component is represented by the extraordinary maintenance and meter replacement, which is due to battery damage or other causes. According to different sources, this cost figure is quite important and must be considered for all the duration of the project. The cost for meter replacement is obtained by summing C_{smart} and C_{inst} and multiplying that amount for the number of meters that incur in this problem each year *(N*bat%)*. The term *%bat* represents the percentage of meters that incur in battery problems each year and is strongly case dependent: for the calculations the value has been derived from interviews and scientific papers, with a value corresponding to the 0,5% of meters.

The last component of the operating expenses is represented by the cost for marketing and sensibilization campaign *(*CPC*)* multiplied for the number of campaigns per year *(*N_{adv}*)*, which is a lower amount compared to the other cost items.

The formulation of the OPEX is obtained by summing above-mentioned contributions, the authors have reported the formula here:

$$(C_{op} * N) + CPC * Nadv + (C_{smart} + C_{inst}) * N * \%bat =$$

$$= (2{,}50 * 10000) + 65 * 1 + (80 + 30) * 10000 * 0{,}05 = 38.264{,}60 \ {}^{€}/_{year}$$

Depending on the technology adopted and on the characteristics of the meters to be substituted, which affect C_{smart}, the operating expenditure varies between the minimum and maximum values reported in the table.

MIN	MAX
€ 38.264,60	€ 44.896,60

Table 5.9 - Model OPEX

5.2.3 Results and KPI

In the previous sections, all the benefit and cost items considered in this analytical model have been quantified in detail. As said before, the final result of the analytical model, which aims to support a cost benefit analysis for a generic implementation of a smart water meter park, depends on the different combinations of benefit and cost items. In order to provide a fair and complete overview of all the possible outcomes and to consider some possible variations from expected values, the authors identified 6 "extreme" scenarios, which represent the boundaries of all the possible combinations of benefit and costs items.

As said at the beginning of the Chapter, some of the benefit present three possible outcomes (min, avg, max), depending on the ranges of value associated to the input variables. Same for cost items which present two possible outcome values (min, max). This variability gives rise to 6 possible scenarios summarised in the table below:

		BENEFIT		
		min	*avg*	*max*
COST	*min*	Scenario 1	Scenario 3	Scenario 5
	max	Scenario 2	Scenario 4	Scenario 6

Table 5.10 - Scenario analysed

All the results have been computed and all the considerations have been done for each of the 6 scenarios.

The analysis has been conducted by defining some KPIs that helped us in the comprehension of calculations results.

5.2.4 Computation of KPI's

Firstly, since our aim is to compute a model that can support a cost benefit analysis, the authors have defined three financial KPIs to evaluate better our investment

(PBT, IRR, NPV). Moreover, since the application of smart metering to the water sector has also important implication in terms of water resource savings and environmental performance, the authors have also considered three environmental macro indicators (Absolute Water saving, Relative Water saving, Energy Efficiency) that can help us in the evaluation of the results. In the following section the authors will describe each indicator and check the result for each of the six scenarios.

Net Present Value (NPV)

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in investment planning to analyze the profitability of a projected investment or project.

The following formula is used to calculate the NPV:

$$NPV = \sum_{t=!}^{n} \frac{Rt}{(1+i)^{t}}$$

Where, “Rt” are the net cash inflows-outflows during a single period t (year), “i” is the discount rate that could be earned in alternative investments, “t” is the number of time periods.

In our case, the authors selected a number time periods (years) which is equal to the expected lifetime of a smart meter, 10 years, and evaluated the cash inflows (benefit) and outflows (costs) that occur in this time frame.

The highest value of NPV correspond to the “Scenario 5” in which we considered all the maximum values of benefits and minimum values of costs, while the lowest correspond to the “Scenario 2” in which we considered the maximum cost and minimum benefit.

The resulting NPV for each scenario is highlighted in the following table:

		BENEFIT		
		min	*avg*	*max*
COST	*min*	-€ 430.374,39	€ 41.963,48	€ 839.402,41
	max	-€ 543.684,38	-€ 71.346,51	€ 726.092,42

Table 5.11 - NPV results with 10 k meters

5.2.5 Internal Rate of Return (IRR)

The Internal Rate of Return is a metric used in financial analysis to estimate the profitability of potential investments. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. IRR calculations rely on the same formula as NPV does. In other terms, the IRR represent the highest possible capital cost *(i)*, for which the investment is still profitable. This indicator is computed only for those scenarios which show positive NPV, and the table below summarizes the results.

		BENEFIT		
		min	*avg*	*max*
COST	*min*	-	4,82%	16,76%
	max	-	2,96%	14,40%

Table 5.12 - IRR results with 10 k meters

As we can see "Scenario 5" shows the highest IRR, over 16% which makes the investment extremely appetible even from an investor perspective.

5.2.6 Pay-back Time (PBT)

The payback period refers to the amount of time it takes to recover the cost of an investment. Simply put, the payback period is the length of time an investment reaches a break-even point. The desirability of an investment is directly related to its payback period. Shorter pay-back mean more attractive investments.
It is important to remark that, in our case, the "Scenario 3", shows positive NPV, but the payback-time is considerably long (9 years) which makes this Scenario not attractive from an investment perspective.

		BENEFIT		
		min	*avg*	*max*
COST	*min*	-	9 years	6 years
	max	-	-	6 years

Table 5.13 - PBT results with 10 k meters

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5.3 Environmental Performance Indicators and Results

As explained in previous chapters, Smart metering projects applied in water sector can bring significant benefits in terms of environmental performance and water resource savings. Better network management, enhanced maintenance efficiency and efficacy, simplified detection of leakages and water thefts, all these aspect have a double counting benefit, which is not only economical, but also environmental, which means valuable not only for water providers but for the entire society and natural ecosystems. Even if the quantification and evaluation of these aspects is more complex compared to the economic quantification of benefits, the analytical

model that we developed tries to quantify the potential savings in terms of water and energy savings, adjusting some of the formulas used for economic quantifications.
In particular, the yearly water saving quantification was associated to four of the six benefit highlighted in the model: efficient maintenance – faulty meters, efficient maintenance – pipe leakages, fraud detection and demand management.

5.3.1 Absolute Water Saving

Starting from "efficient maintenance-pipe leakages", the computation of the water saving was obtained by implementing this formula, which is derived from the economic one, but considers only the water amount in cubic meters:

$$l * WL * WL_{red} * 365 * \beta + (1-\beta) * (T_1 - T_2) * WL =$$

$$= 240{,}05 * 22 * 0{,}04 * 365 * 0{,}95 + (1-0{,}95) * (90-7) * 22 = 73.340{,}62 \text{ mc}$$

Another contribution in terms of water savings, comes from "demand management" benefit, which induce a reduction in the total amount of water injected (and lost) in the network. Even in this case the formula is derived from the economic one, but considers only the water saving amount:

$$(Q * K_{dm}) * Tot * 365 =$$

$$= (0{,}419 * 0{,}015) * 33000 * 365 = 75.702{,}83 \text{ mc}$$

Significant water savings are also associated to the "Fraud detection" benefit, which allows to spot water thefts avoiding uncontrolled water spillages. In this case the quantification of the water saving comes from the quantification of water thefts and their possible reduction enabled by smart water metering. The formula used for the calculation is:

$$(NRW1 - NRW2) * F * Tot * Q * 365 * (1 - Kwl)$$

$$= (0{,}03 - 0{,}015) * 0{,}23 * 33000 * 0{,}419 * 365 * (1 - 0{,}437) = 9.802{,}76\, mc$$

Lastly, a lower but still significant contribution comes from "efficient maintenance-faulty meters", which reveals in the faster identification of defective meters, and reduction of associated water loss. The formulation is computed as follows:

$$= \left(\frac{N}{l}\right) * Fs * Ql * 30 * 24 * (MTFt - MTFf) * FN + \left(\frac{N}{l}\right) * Fs * Ql * 30 * 24 * (MTFt - MTFw) * (1 - FN) =$$

$$= \left(\frac{10000}{240{,}05}\right) * 0{,}002 * 0{,}916 * 30 * 24 * (3 - 0{,}25) * 0{,}95 + \left(\frac{10000}{240{,}05}\right) * 0{,}002 * 0{,}916 * 30 * 24 * (3 - 1{,}5) * (1 - 0{,}95) = 1.347{,}70\ mc$$

Summing all the different contributions, we obtain the total annual water saving enabled by the smart water metering project, as reported in the table below:

Benefit	**Yearly water saving associated (m^3/year)**
Efficient Maintenance - Pipe Leakage	73.340,62
Demand management	75.702,83
Fraud Detection	9.802,76
Efficient Maintenance - Faulty meters	1.374,70
Total Water Saving	**160.220,90**

Table 5.14 - Yearly water saving

As we can see from the table the implementation of the project can lead to absolute water savings around 160.220 m^3/year.

5.3.2 Relative Water Saving

To make this figure more significant and comprehensible, the authors decided to compute another indicator which is the Relative Water Saving. This indicator is obtained by dividing the annual water saving for the total annual water consumption, considered as the total amount of water injected into the network (mc/year).

$$RWS = \frac{Annual\ Water\ Saving}{Total\ annual\ water\ consumption} = \frac{160.220{,}90}{Q * Tot * 365} = \frac{160.220{,}90}{5.064.855} = 3{,}18\%$$

5.3.3 Energy Efficiency

Finally, the authors considered another environmental opportunity, associated to the "demand management benefit", which enables, thanks to an optimised peak demand reduction, a lower consumption of pumps and auxiliaries, and consequently, a reduction in terms of electricity consumption. The calculation of this saving is reported below:

$$EE = Epump * Kdm * 365 * Tot * Q =$$
$$= 0{,}184 * 0{,}015 * 365 * 33000 * 0{,}419 = 13.929{,}31\ kWh$$

As we can see from the calculation, the implementation of the SWM project to the reference case would allow a yearly electricity saving up to 13.929 kWh.

5.4 Model application to wider rollouts

In order to understand if the model could be applied also in wider contexts, for example in broad metropolitan areas with high population density, the authors conducted some simulation considering two additional setups. The first setup considers a roll-out of 50.000 meters, involving a total of 165.000 end-users. The second setup considers the same rollouts but with a significant difference. Since the water infrastructure is pretty aged, and the most part of existing mechanical meters are near to their end-of-life, the authors tried to compute the model by assuming that the meter park would be substituted in any case (choosing between traditional meters or smart meters). With this assumption it is possible to considerably modify the capital expenditure for meters' purchase, considering only the differential cost between a traditional meter (costing on average 40€) and a smart meter (costing around 80€), instead of the full cost. The result of the application of these 2 additional steps, gives rise to three new scenarios. In order to understand what the quantitative findings could be, applying the model in these three new contexts, the authors analysed the results by comparing them to the first case, the 10.000 meters roll-out, maintaining the same KPIs and metrics. However, it is important to remark that due to the fact that the roll-out are wider, we need to make some changes in the model's variables. In particular, according to different research and experts' opinions, there are some benefit which become more relevant and interesting when the rollout involves a wider network of meters. Increasing the number of meters, it is possible to conduct district specific analysis that consider multiple data contributions, allowing more efficient detections of breaks and leakages. For this reason, authors decided to increase the water loss reduction associated to the "Efficient Maintenance – Pipe Leakages" benefit from 4% (10.000 meters case) to 5% (50.000-meters case). Similar considerations can be done for the "Fraud Detection" benefit, that can take advantage of increased resolution of data coming from multiple meters in the same area, which allows to spot water thefts and irregularities faster and more efficiently. Consequently, authors decided to reduce the non-revenue water after the installation of smart meters from 1,5% (10.000 case) to 1,25% (50.000-meters cases). These modifications affected the final results, which will be analysed in the next section.

The other benefits included in the model were not affected by significant changes caused by the increase of the roll-out-size.

The tables below show the comparison between the four different roll-out cases, highlighting the economic KPIs used in paragraph 5.15 (NPV, IRR, PBT).

NPV		**BENEFIT**			
		min	avg	max	
COST	Min	-€ 430.374,39	€ 41.963,48	€ 839.402,41	10.000
	Max	-€ 543.684,38	-€ 71.346,51	€ 726.092,42	
	Min	€ 25.703,77	€ 508.074,97	€ 1.322.287,30	10.000 delta
	Max	-€ 14.485,96	€ 468.144,99	€ 1.282.097,58	
	Min	-€ 1.863.520,01	€ 974.865,12	€ 5.816.532,92	50.000
	Max	-€ 2.631.018,61	€ 208.665,26	€ 5.049.034,33	
	Min	€ 688.154,95	€ 3.566.540,08	€ 8.408.207,89	50.000 delta
	Max	€ 487.206,32	€ 3.366.890,19	€ 8.207.259,26	

Table 5.15 - NPV results with 10 - 50 k meters of both full and delta costs

IRR		BENEFIT min	BENEFIT avg	BENEFIT max	
COST	min	-	4,82%	16,76%	10.000
COST	max	-	2,96%	14,40%	10.000
COST	min	4,78%	15,96%	31,76%	10.000 delta
COST	max	3,73%	15,12%	31,03%	10.000 delta
COST	min	-	7,35%	21,11%	50.000
COST	max	-	4,77%	18,03%	50.000
COST	min	8,11%	22,32%	42,63%	50.000 delta
COST	max	6,98%	21,42%	41,83%	50.000 delta

Table 5.16 - IRR results with 10 - 50 k meters of both full and delta costs

PBT		BENEFIT min	BENEFIT avg	BENEFIT max	
COST	min	-	9,58	5,33	10.000
COST	max	-	-	5,89	10.000
COST	min	9,61	5,51	3,21	10.000 delta
COST	max	-	5,71	3,28	10.000 delta

	min	-	8,30	4,51	50.000
	max	-	9,62	5,06	
	min	7,97	4,32	2,45	50.000 delta
	max	8,47	4,46	2,52	

Table 5.17 - PBT results with 10 - 50 k meters of both full and delta costs

As we can see from the results shown in the tables, the returns of these smart metering projects significantly change according to the scenario. In particular, the main difference emerges considering the 10.000 and 50.000 “delta cases”, in which, the reduced cost considered for meter purchase makes the investment considerably profitable compared to the other two scenarios, with an average payback time of 4 years against 8 years of the “non-delta” case. The reason behind that is simply the fact that the smart meter acquisition cost covers more than 60% of the CAPEX, and a reduction of the purchasing cost of the meter has great impact on final values.

This favourable condition of course is not always feasible in real applications, but it is an interesting opportunity that in the next years could drive the investment. In fact, the existing water infrastructure (including meters) is considerably aged, especially in Italy, and a fair share of meters is near to its end-of-life. This condition, together with the Decree 93/17, which introduces the obligation for meters substitution creates space, for promising investment conditions. Since aged meters have to be substituted, the opportunity to get additional advantages sand benefit choosing smart meters will become certainly a fundamental driver for utility companies operating in this sector.

In the next paragraph it is provided an overview on the projections of the returns curve in progressively wider rollouts. The flexibility of the model allowed us to change the input data in order to get an insight on what would be the estimated returns in wider applications. The first curve shown below represents the returns (NPV) associated to different roll-out scenarios. The curve starts from the 10.000-meters case, which the authors have explored in detail, and projects the simulations till a wider 200.000-meters case.

The second curve shows the returns (NPV) associated to the same progression of roll-out size, but in the “delta case”, starting from 10.000-meters delta until 200.000-meters-delta.

Analysing the curve, it is possible to make some important considerations and suggestions.

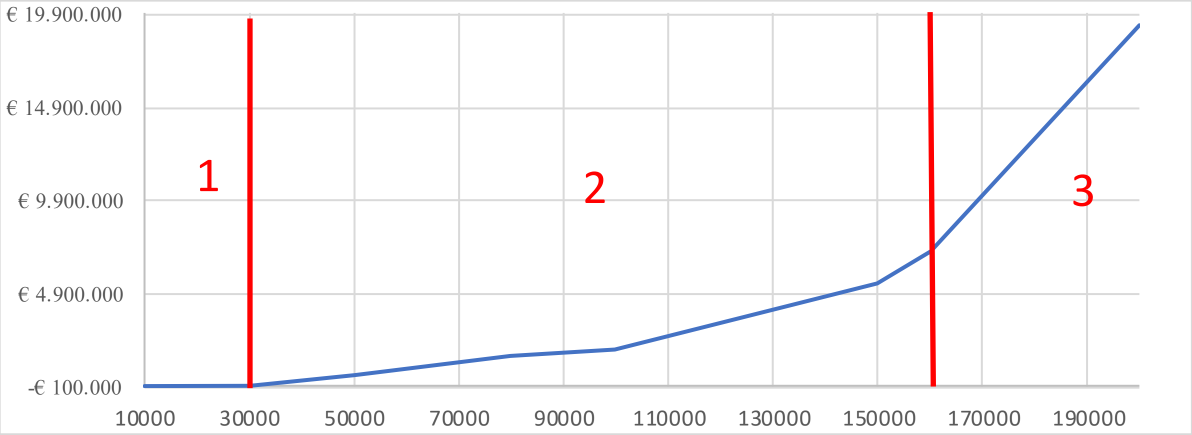

Figure 5.1 - NPV results for different quantities of meter rollout in the full cost cases

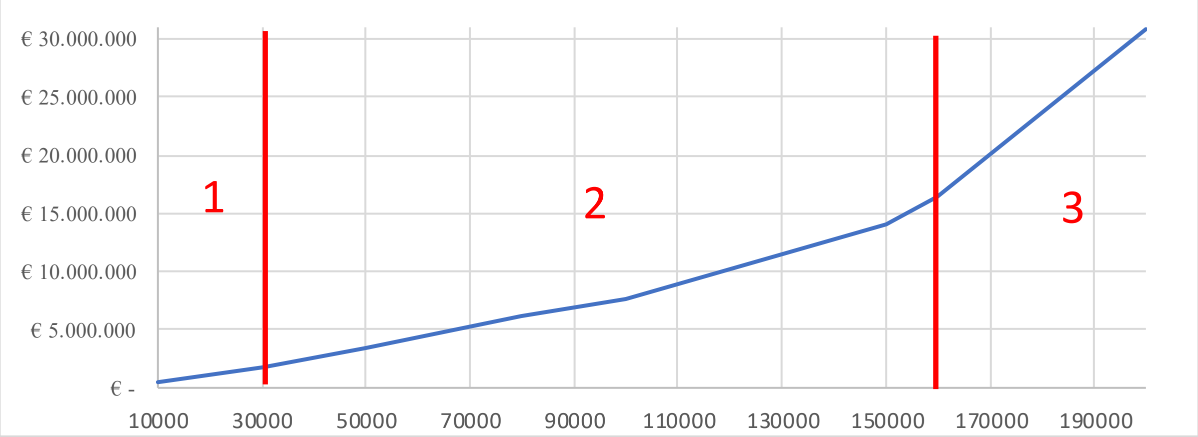

Figure 5.2 - NPV results for different quantities of meter rollout in the delta cost cases

Both curves highlight three different areas in which the increase can be considered approximately linear. Changes in the curves' slope occur passing over the 30.000-meters installations (from area 1 to area 2) and passing the 160.000-meters installations (from area 2 to area 3). The reason behind the first increase of the slope (over 30.000 meters) is the existence of economies of scale which reduce the acquisition cost of the meters (from 80-90€ to 70-75€), thus increasing the profitability of the project.

The second increase of the curve's slope (over 160.000 meters) arise when the smart meters coverage passes the 80% of the total meter park (in our case we supposed the meter park composed by total of 200.000 meters). In this condition, there are additional benefit that arise due to the increased amount and availability of data provided by smart meters. Indeed, there is the opportunity to take advantage of pressure management benefit and to increase the leakage reduction benefit, which have considerable importance in economic and environmental terms.

On the other side we can see that in the “non-delta case”, small installations (10.000-30.000-meters) are not profitable because do not take advantage of scale economies.

To conclude, we can add some considerations about the absolute values of the two curves. As said in the previous paragraph, the “delta case” is considerably more profitable and appealing for companies compared to the “non-delta case”, which means that the substitution of traditional aged meters (>10 years old) should have the priority in order to maximise the value of the investment.

6 Conclusions and discussion

The presented dissertation has the aim of quantifying a cost-benefit benchmark between traditional and smart meters, achievable through the installation of the latter. Although in Italy we are at the early stage of their deployments, the literature shows a growing interest around the topic. In particular, the analysis of several papers has underlined different gaps that we have tried to fulfil. First of all, the models presented in literature are case studies focused on just one or two potential benefits. Secondly, most of the times, they are small-scale experimentations. This represents a barrier, because the models are tailored on specific context and their findings are not adaptable to various scenario. Due to their peculiarity, in some cases the results are even in contrast. Thirdly, only few papers investigate both environmental and economic aspects. Lastly, the scientific research studies the results in the short term, excluding potential benefits that are more profitable in the long run.

The dissertation seeks to bridge those gaps, with an analytical model that evaluates the economic and environmental dimensions, including all the possible benefit and cost into a comprehensive analytical model. In particular, the work presents an innovative approach for computing the savings arising with seven important benefits, highlighted in Chapter 4: remote meter reading, efficient maintenance divided in pipe leakages reduction and faulty meters, demand management, arrear consumers control, fraud reduction and accurate billing.

The model has a flexible structure that allow to adjust itself at different inputs value for a series of characteristics. The model gathers information for example about tariff price, user habits, population density or level of leakages and it is able to provide the relative results. The model adopts the utilities point of view, therefore the benefits have been selected considering their importance for the service providers.

The model quantifies the output for a set of simulated scenarios. In line with the actual small rollout, the case base considers the installation of 10.000 meters, but due to the increasing interest, we have also provided the computation for a 50.000-meter deployment, and we projected results till 200.000 meters deployment in order to compute a complete returns' curve. The innovative tool has space for future developments and it also represents for utilities a decision-aiding tool to take more informed choices. It pushes the smart-metering rollout with incentives or specific tariff schemes, in order to maximise the overall gain for utilities, user and society in general. If necessary, the calculations can be extended and enlarged to include further variables. This aspect could be important to provide a complete assessment of smart water meter technologies and makes the models capable to offer reliable results for each context. For example, an improvement step could be the implementation of the benefit associated to pressure management. The pressure is a critical parameter of the water network and a better control may lead to lower operating costs for utilities but its value is very case sensitive, for example at household level, the quantity required changes if we consider a single-family house or an apartment inside a building. For that reason, the authors have not included it in this general work.

Thanks to the analysis and validations performed, it is possible to answer the formulated research questions.

RQ1: Do smart metering systems contribute to the improvement of utilities performances in the water sector? If yes, do they contribute significantly in terms of both economic and environmental terms?

Actually, the changes of regulatory framework represent the most significative drivers in Italy for companies: in particular the recent standardization of technology among the wide range available and the Decree 93/2017 which pushes the substitution of traditional meters that have more than 10 working years with smart solutions (see Chapter 1 for further details). Our model has confirmed the importance of regulatory framework for supporting the transition toward smart meters, but in the meanwhile, it has also demonstrated the opportunity to catch positive economic returns in some of the different conditions analysed. Moreover, it highlights a positive correlation between the number of meters installed and financial KPI's considered (i.e. NPV, PBT, IRR), which supports wider installation in the next years. In addition, the model reports 3 environmental indicators. Especially when the scenario has negative economic results, they are significant to justify the initial investment. They demonstrate that smart solutions could lead firstly at a consistent saving of water and secondly, they might improve the efficiency of the network. Even in this case, a higher quantity of meters improves the KPI's selected (i.e. absolute water saving, energy efficiency, relative water saving).

RQ2: Which are the most important benefit and cost figures that utility companies need to consider when evaluating smart water metering projects?

In order to answer at the second research question, this section will consider the case base of 10.000 meters because now it is the most in line with realistic smart water meter installation plans, but the next consideration could be extended also for the other cases.

The analytical model clarifies which is the contribution of each benefit over the total returns in economic terms and supports the comprehension of what are the most important factors that characterize these projects for obtaining the optimal results. In parallel, this analysis facilitates the understanding of benefit that do not represent significant levers, avoiding too much attention and resources. In this way it is possible to develop an investment plan that focus on the most convenient benefit and neglects the ones without significant contributions neither in economic terms nor in environmental terms.

The evaluation of percentage contribution of each benefit has been computed as the ratio between economic value of the benefit and the total value of economic savings (sum of all benefits). Since for the majority of benefit the authors identified different values (min, avg, max), the contribution has been calculated for each of them and then, we have selected the average one as reference.

The tables below summarise all the steps that we have followed:

Economic Benefit	MIN	AVG	MAX	AVG%
Efficient Maintenance - Pipe Leakage	45,7%	57,3%	65,7%	56,3%
Meter Reading - Fixed Network	39,6%	27,6%	18,3%	28,5%
Fraud Detection	3,6%	5,9%	7,6%	5,7%
Meter Reading -Walk by	7,4%	5,2%	3,4%	5,3%
Demand management	2,3%	1,9%	1,4%	1,8%
Arrear customer	0,2%	0,7%	2,1%	1,0%
Faulty Meters - Fixed Network	0,4%	0,7%	0,9%	0,7%
Accurate Billing	0,8%	0,5%	0,4%	0,6%
Faulty Meters - Walk by	0,1%	0,1%	0,1%	0,1%
TOT	**100%**	**100%**	**100%**	**100,0%**

Table 6.1 - Economic returns of each benefit over the total savings

Economic Benefit	MIN	AVG	MAX
Meter Reading			
Walk by	€ 10.000,00	€ 10.000,00	€ 10.000,00
Fixed network	€ 53.466,67	€ 53.466,67	€ 53.466,67
Arrear customer	€ 243,80	€ 1.427,27	€ 6.237,82
Efficient Maintenance - Faulty meters			
Walk by	€ 81,16	€ 192,02	€ 375,13
Fixed network	€ 595,19	€ 1.408,14	€ 2.750,95
Fraud Detection	€ 4.822,96	€ 11.410,41	€ 22.291,47
Accurate Billing	€ 1.050,00	€ 1.050,00	€ 1.050,00
Demand management	€ 3.053,94	€ 3.689,99	€ 4.021,83
Efficient Maintenance - Pipe Leakage	€ 61.773,38	€ 110.996,92	€ 192.303,67
TOT	**€ 135.087,11**	**€ 193.641,42**	**€ 292.497,53**

Table 6.2 - Economic returns of each benefit for the three levels

The authors have selected a pie chart for providing a faster and better visualisation of results:

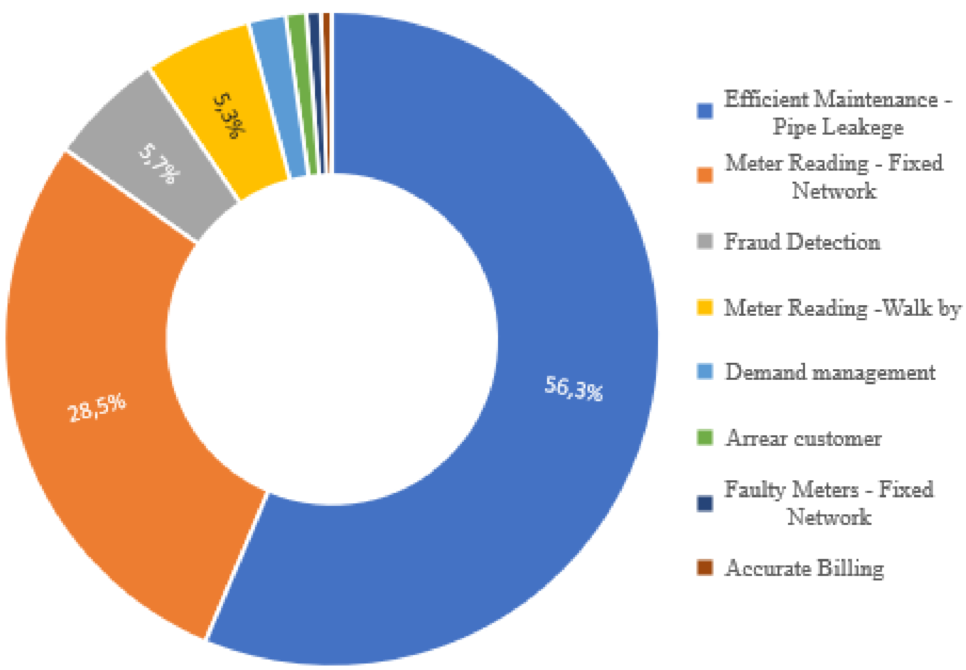

Table 6.3 - Share of average benefit contributions

The chart shows that more than half of the economic returns come from a single benefit: the "Efficient maintenance – Pipe leakage". Indeed, due to the possibility of detecting breaks and leakages in the network accurately coupled with faster repairing activities, allows a reduction of the entity, frequency, and time duration of breaks. The immediate advantage are lower losses. It is important because they represent a huge share of total water fed in pipes according with the official ARERA data. The most recent Authority reports estimate the water loss over 42% of total water supplied. Moreover, an adequate and optimised pressure management enabled by smart water metering infrastructure, increases the overall efficiency of the network. The pressure management is extremely relevant when the water network is old, and it has a high probability of fractures.

The other benefit emerging as relevant is the “Meter Reading”, especially in the fixed network configuration. It accounts for more than 28% of total economic savings. The possibility to carry out remote meter readings allows the cutting of relative operating cost for visiting home-by-home with the operators. This is a significant saving for utility companies, as long as it might be considered a secondary driver for the adoption of these technologies.

Then, the third benefit which represent more than 5% of value is the “Fraud Detection”. It considers the possibility to spot illegal water thefts or water abuses, thanks to big data analytics on district-specific consumption profiles through data gathered with smart water meters.

Finally, among the remaining benefits, the most interesting and promising contribution is provided by the “Demand Management”. It evaluates all the savings that concerns an optimised water consumption abating the costs for water pumping and chemical treatment. It is important to remark that an interesting topic which is not included in this benefit is the optimised pressure management, which was not possible to include in the model due to its complexity, but it could considerably enhance the relevance of the benefit.

The other benefits (“Arrear customers”, “Accurate billing” and “Faulty meters”) actually are not consistent economic advantages for service providers. The sum of their contribution is below 4% of the total value. However, authors believe that their role is still valuable because they introduce simplifications in ordinary utility operations, service efficacy, and customer satisfaction improvements, which were not quantified in the model, but are still important for both companies and users.

As highlighted in Chapter 5, we used the model to get additional insights and information. In particular, the authors tried to understand how the impact of the investment changed considering another important factor: the possibility to substitute traditional mechanical meter which are near to their end-of-life (>10 years old) with smart ones. This premise allowed us to consider the cost of acquisition for the smart meters in differential terms (difference between smart meter cost and traditional meter cost) instead of the full cost, making the investment much more profitable and appetible for utility companies. Moreover, the authors pushed the model even beyond, by projecting the simulations over progressively wider installations. We started from 10.000-meters installation and we analysed the return curves (NPV) until 200.000-meters installation. This wider perspective allowed us to consider other two important factors which enhanced profitability of the investment. First of all, the authors considered economies of scale, which reduce the acquisition cost of meters, when installations are wider than 30.000-meters. Secondly, they considered the additional benefits that arise when the smart meter coverage overcome the 80% of the total meter park (in our case we supposed a meter park of 200.000-meters). This last feature was fundamental to understand the value that the smart meter assume when incorporated into a more extended and articulated system: the smart water grid. This condition enhances economic and environmental benefits not only for the utility company which can get higher returns from the investment, but also for consumers and society as a whole.

6.1 Future research

As above mentioned, the model has been developed from scratch, so it has large potential for further improvements and modifications. It is versatile, and it is opened to adaptations according to circumstances, adding specific variables or formulas. For example, the model could simulate a wider roll outs in a metropolitan city, considering a higher population density, and a specific coexistence of traditional and smart meters. It has been though also for including new categories of benefits that actually are still not present. The authors have just provided the example of "pressure management" that is emerged during different interviews with utilities managers, but in general, further benefits may not affect directly the service providers: like the quantification of sociological factors in monetary terms could be an interesting topic for pushing the smart meter technologies. More informed customers could reduce their demand, avoid the wastes, and improve their satisfaction. A customer responsible consumption restores a positive feedback to environment and society at large. They could lead a higher water resource preservation, diminish the water basins stress. Those factors, included into a comprehensive evaluation, could favourite a more equal access to water resources or an improved equity tariff. Moreover, another aspect that should be explored more in depth is the differentiation between mono-utility and multi-utility installations, and the synergies that can arise, in terms of CAPEX reduction (system integration costs and data management competences) and benefit increase (total service management), when water meters are coupled with electricity and gas meters.

The future developments will overcome the actual limitations and starting from what has been discovered through this dissertation, in the next years are expected interesting and more accurate results can be achieved at 360°. The authors hope that this work could represent an additional step for utilities to enrich their research and provide a starting point to encounter potential benefits.

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