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Household Smart Water Metering in Spain: Insights from the Experience of Remote Meter Reading in Alicante

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Academic Editor: Marc A. Rosen
Received: 7 February 2017; Accepted: 2 April 2017; Published: 11 April 2017

Abstract: Since the past few years, the smart city paradigm has been influencing sustainable urban water resources management. Smart metering schemes for end users have become an important strategy for water utilities to have an in-depth and fine-grained knowledge about urban water use. Beyond reducing certain labor costs, such as those related to manual meter reading, such detailed and continuous flow of information is said to enhance network efficiency and improve water planning by having more detailed demand patterns and forecasts. Research focusing on those initiatives has been very prolific in countries such as Australia. However, less academic attention has been paid to the development of smart metering in other geographies. This paper focuses on smart water metering in Spain and, more particularly, documents and reflects on the experience of the city of Alicante (southeastern Spain), a pioneer case of massive deployment of remote reading of water meters at the household level and for large urban customers. Through data and interviews with water managers from the water utility, we 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.

Keywords: smart meters; remote meter reading; water utility; ICT; water demand-side management; South Europe

1. Introduction

The past few years have witnessed an emergence of the smart city paradigm both in the Global North and Global South contexts [1–5]. The smart city is a powerful concept that has captured the attention of urban policy makers, corporations and international institutions, as it promises a new era of optimized infrastructure management that connects in new ways objects, organizations and citizens [6,7]. Information and Communication Technologies (ICT) are championed as the key drivers in this quest for improving urban life, boosting economic competitiveness and enhancing the efficiency of urban systems [8,9]; hence the implementation of different smart technologies at the urban scale, ranging from sensors, ubiquitous computing, smart meters, smart networks, etc., and covering diverse aspects of urban life, from energy issues to health or from waste production to mobility, among many other dimensions. All in all, this has implied the addition of a "digital skin" to the built environment [10].

The urban water cycle has not been alien to the smart city revolution. As a matter of fact, smart city discourses are intensively permeating the water industry. Large water corporations are putting efforts into research, development and implementation of smart technologies with a particular eye on reducing costs and on having a deeper knowledge of water demand to streamline services and thus make possible more accurate demand forecasting. In part, this may be related to the decline in revenue experienced by many companies as domestic consumptions are falling in the urban areas of the developed world. In that context, intelligent or smart metering emerges as the cornerstone of smart strategies in urban water networks, with the promise to revolutionize water supply management and foster customer engagement [11]. Nonetheless, as Boyle et al. [11] argue, the term "intelligent" or "smart" metering is quite ambiguous, as it includes a plethora of different technologies. In their review of smart metering implementation in Australia and New Zealand, Beal and Flynn [12] argue that it is crucial to establish a standardized set of definitions regarding smart metering. As a matter of fact, smart meters can communicate water use readings in real time or very close to real time [11,13]. Four key processes are inherent to smart metering schemes: measurement, data transfer, processing and analysis and feedback of water use data.

In any case, 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 [11]. Smart or intelligent metering first and foremost enhances the understanding of "when", "where" and "how" water is used [11]. Debates on the potential of smart meters can be traced back to as early as the 1980s and 1990s [14]. However, it was in the 2000s where this technology had gained attention, especially in energy and, later, in urban water management. According to Boyle et al. [11], the desire to increase data regarding end-use and time of use of household water and the quest for reducing the (labor) costs for meter reading are two critical drivers that guide the implementation of smart metering schemes. Therefore, smart water meters influence demand management, labor optimization, customer service and the efficiency of Operation and Maintenance (O&M) tasks by utilities [12].

Cole and Stewart [15], using the case of Hervey Bay (Queensland, Australia), show how smart metering schemes enable one to track peak hour, peak day and peak month demand. According to these authors, this information may help to design tariff structures able to modulate peak water demands. In Madrid (Spain), the public company Canal de Isabel II launched in 2008 a continuous monitoring of water use of 300 households. To date, the project has compiled data on 12.8 million of hours of consumption allowing for a better understanding of the moments of peak consumption during the day, week and year, among other aspects [16]. Beyond the possibilities of knowing better user consumption patterns, Sonderlund et al. [13] also highlight the potentiality of providing consumption feedback to consumers in almost real time, which could help to foster water saving behaviors. Smart meters also can assist in reconciling perceived real water end uses among householders [17]. Darby [18] highlights the potential of smart metering for customer engagement by providing feedback on consumer behavior. Liu et al. [19] also stress the potentialities of smart water meter in providing feedback to users resulting in water saving attitudes. Fróes Lima and Portillo Navas [20] propose for Brazil the integration of smart metering data on energy and water use into a single platform to raise awareness among customers. Additionally, a better understanding of peak water demand periods through smart water metering opens up the possibility of dynamic water pricing [21].

Data provided by new metering infrastructure and new information systems create a favorable scenario for data mining and computational intelligence to analyze customer's consumption patterns and, thus, for example, detect water tampering malpractices [22], as well as post-meter leakages [20]. Algorithms play a key role to unravel routing behaviors in water use using smart metering data [23]. Therefore, massive, real-time and continuous information from smart meters opens up the possibilities of data mining approaches to analyze different aspects related to water management. For instance, Laspidou et al. [24] taking advantage of the wealth of data produce by smart water meters, explore patterns of water use in Greece through clustering algorithms. Walker et al. [25] gathering data provided by smart meters from a pilot case study of the iWIDGET (European project aimed at improving water efficiency through the use of ICT) in Greece used both artificial neural networks and statistical analysis to forecast water demand. Smart meters permit high-frequency measurements of water demand at the point of connection [26]. McKenna et al. [26] used Gaussian mixture models and smart meter data from a district of Dublin (Ireland) to propose a robust approach to classifying water demand patterns. Smart meters may make it possible to disaggregate water end use events and thus improve our understanding of household water use [17,27]. Using new methodologies and algorithms to take advantage of the big data continuously produced by new high-resolution smart water meters may also contribute to improving, optimizing and enhancing the planning of water supply networks [28]. Gurung et al. [28,29] show this potential for the case of Queensland (Australia) by modeling water demand patterns for different future development scenarios, including the increased use of efficient appliances and the implementation of alternative water sources, such as rainwater harvesting.

In sum, smart meters are a central element in the digitalization of water networks [30]. However, as Darby [18] points out, the presumed relationship between smart metering and overall demand reduction is still sustained by little empirical evidence. On the practical side, as exemplified in Table 1 by Béal and Flynn [12] for the case of Australia and New Zealand, there are several unresolved issues behind smart metering schemes, encompassing both economic and technical aspects. Beyond those debates around the advantages and technical issues of smart water metering, critical scholars have warned about the more abstract impacts of water metering in the production of new citizen subjectivities and the changing nature of water supply from a right towards a commodity. In that regard, as Zetland [31] points out, water meters convert passive consumers into "active customers entitled to value for money" (p. 126), the flipside being that they also contribute to the process of converting a common good resource into a private good. Elsewhere, Loftus et al. [32] show how new metering schemes in England can enhance the fundamental role of the household as a human revenue stream for financialized water companies. These are just two critical views on water metering among many, which should deter academics and practitioners from falling into self-congratulatory and techno-deterministic readings of the benefits of smart meters.

Table 1. Challenges and limitations in the planning and implementation phases of smart meters in Australia and New Zealand. Source: adapted from [12] (p. 34).

	Planning	Implementation
1	Difficulty in establishing an organization business case that shows a positive return on investments	Limited industry knowledge and experience in developing projects
2	Few existing case studies showing quantifiable outcomes	Compatibility of meter-communication systems
3	Costs associated with technology and implementation	Unexpected costs/out-of-scope budget adjustments
4	Limited industry knowledge, know-how of suitable technologies and experience in planning smart metering	Difficulties with setting up and managing customer portal systems
5	Recruiting willing participants/households for trial	Technology became quickly outdated
6	Competing and different business case priorities within utility/council	Lack of know-how of suitable technologies
7	General reluctance/lack of interest from internal hierarchy	Ongoing maintenance and operation difficulties that were not foreseen
8	Risk of technology redundancy and not able to future proof	Length of time to acquire, install and commission meters/loggers
9	Lack of information on the best equipment suppliers	Variability in walk/drive by signals
10	Difficulties in obtaining suitable technology	Issues with customer portal/data privacy
11	"Silo" nature of water utilities/councils	
12	Existing industry standards insufficient for business needs	

Notwithstanding the high value of more qualitative contributions from Australia and New Zealand, such as the one by Béal and Flynn [12], our literature review detects that more empirical, qualitative case studies from other geographies are needed to understand the potentialities, but also the problems of this new technology. It is especially important in our view understanding the existing and expected benefits and potentialities, as well as the costs of those new technologies and the problems that water utilities are experiencing in the process of implementing smart metering schemes.

Focusing on southeast Mediterranean Spain, our paper intends to make an original contribution from a rather unheard geographical perspective to a field dominated by both, an Oceania/Australian perspective and by quantitative/technical assessments of the schemes. Qualitative assessments obtained, for instance, in interviews, may offer important insights on managerial problems and challenges that may go unnoticed in more quantitative approaches. In Spain, where household metering has been a regular feature for most cities during the 20th century, smart metering technologies, including remote reading, have been launched in recent years. Remote technologies together with network subdivisions are the best examples of the new smart models of water supply management designed to improve efficiencies in distribution, consumption and billing and also show new business models for companies searching to improve their economic and financial performance in the contexts of declining water use. In the past few years, and after the widespread introduction of the smart city concept in Spain [33], smart water meter has gained central attention as a critical mediator to improve urban water supply planning in the 21st century.

Using the pioneer case of Alicante, where an ambitious plan of remote meter reading began in 2011 with full coverage expected in 2022, the objective of this paper is to shed light on the perceived early and expected advantages and benefits, as well as the problems and costs of smart metering schemes (for end-users) according to the situated and practical knowledge provided by Alicante water managers. The paper is structured as follows. After the Introduction, we present the Methods used (Section 2). Section 3 presents the case study of Alicante, an urban setting characterized by declining water use and recurrent drought problems. Section 4 offers the results of our research, including both the characterization of the water metering scheme and the insights obtained from the interviews with company managers on the perceived existing and expected advantages and benefits, as well as costs of these technologies in Alicante. Section 5 presents the Discussion and the Conclusions of the study.

2. Methods

We held four interviews with company managers and staff of Aguas de Alicante (Aguas Municipalizadas de Alicante, Empresa Mixta (AMAEM)) in May and June 2016 and January and March 2017. Specifically, these interviews involved: the responsible for remote water meter reading, the chief of the commercial management department, a technician of the technical unit of operations and the chief of technical systems. These interviews helped to have an insider technical and managerial perspective on the early existing and expected advantages and benefits, as well as problems and costs of remote smart metering compared to conventional metering. More specifically, we focused on the following aspects: issues experienced during the implementation process of smart meters for different end-users; advantages of the smart meters compared to conventional meters for the company and how this is translated into economic benefits (and new costs) in comparison with conventional meters (CAPEX and OPEX); and the advantages and issues reported by final users to the company. We also obtained detailed data on several dimensions of smart water metering schemes: the evolution of installed and operating smart meters (2011–2016); conventional meters (2000–2016); the number and location of the antennae; smart meters according to use category (domestic use, non-domestic use (private), non-domestic use (city council) and irrigation (city council) (2011–2016); information about the implementation of this technology according to the neighborhoods of the city (percentage of smart meters installed); and data on the evolution of water consumption and of network efficiency.

3. Case Study

The origins of Alicante's water company can be traced back to the Compagnie Genérale de Conduites d´Eaux de Liége, which developed the early modern water infrastructure to water the city at the end of the 19th century. At the turn of the century, the company was renamed Société des Eaux d´Alicante and conserved its headquarters in the Belgian city of Liège until 1921 when, due to the growing presence of Spanish capital in the company, the headquarters were moved to Alicante. In 1926, the Sociedad General de Aguas de Barcelona purchased 90 percent of the shares [34]. Currently, the official full name of the company is Aguas Municipalizadas de Alicante, Empresa Mixta (Municipal Waters of Alicante, Joint Company) (AMAEM), and its ownership is divided into equal shares between the City Council of Alicante and the private company Hidraqua, Gestión Integral de Aguas de Levante S.A., a subsidiary of Aquadom (Suez). Although under the supervision of the public partner, Hidraqua in Alicante enjoys ample autonomy in technical decision-making [35]. Water companies with mixed public and private capital have experienced an important expansion in the last decades on the Spanish Mediterranean coast following this division of responsibilities in which the technical aspects of management (from delivery to billing) tend to remain under private control, while the public part plays mostly a role of general supervision and is responsible for investments in the water cycle infrastructure [36,37].

The main source of water for the city of Alicante comes from the Mancomunidad de los Canales del Taibilla (MCT), a public company created in 1927, which supplies water to some 2.5 million people in 79 municipalities in the provinces of Murcia, Alicante and Albacete. Alicante joined the MCT in 1958, thus obtaining access to the resources of the Taibilla and Segura rivers and, since 1979, to the Tajo-Segura aqueduct. Recently, the MCT has diversified its supply sources through the construction of seven desalination plants. Four plants are owned by MCT and the remaining three by the Spanish public water company Acuamed. Together, they may provide up to 170 million m^3/year of water [38].

AMAEM manages the entire water cycle of the city of Alicante, from supply to sewerage and wastewater treatment. Although in all of these areas, technological advances have been widespread, it is perhaps in the distribution system where more progress has been made. Improvements in the city delivery networks and the ensuing increase in network efficiencies have arguably contributed to the decline of water delivered to Alicante. In 2007, the length of the network totaled almost 1100 km; at the end of 2013, it had expanded an additional 35 km, while 72 km had been renovated. On the other hand, network efficiency rose from 80.49 percent in 1991 to 90 percent in 2015 [39,40] (see Figure 1).

In 2015, AMAEM supplied 22.2 million cubic meters of water to the city of Alicante (336,000 inhabitants) mostly for the domestic sector, followed by the retail sector and other users. Between 2007 and 2015, all uses experienced a reduction with the only exception of municipal uses, which increased slightly. The largest declines have affected the retail and industrial sectors (−25.2 percent and −47 percent, respectively) while the decline in the domestic sector has been smaller (−8.3 percent). The reduction in economic activity after the crisis beginning in 2007–2008 explains to an important extent the reduction in the commercial and industrial sectors. In the domestic sphere, water consumption per capita fell 22 percent between 2004 and 2015 (from 150 down to 117 liters/person/day) obeying multiple interrelated causes, such as more efficient water fixtures and appliances; growing consumer awareness; smaller demographic and economic growth; and also the effects of rising prices and taxes, especially among low-income groups [40].

While one factor probably having a significant influence in all these improvements is the higher cost of the water supplied to AMAEM by the regional provider, technology and new management schemes have arguably led the increase in the efficiency of the network (measured as the difference between water distributed and water billed). Network efficiency depends 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 to these efforts in improving efficiency. We have examples of ICT use in the control of minimum flows at nighttime or leak detection (e.g., iDROLOC, a leak detection system that uses helium as a tracer of leakages without interrupting the water service to the user). In turn, all of these technologies have been integrated into advanced management tools, such as GIS development for the simulation of faulty systems; monitoring of network expansion; decision support systems for network renovation, etc. [39]. However, above all, the cornerstone of this strategy towards the enhancement of efficiency through ICT has been the smart metering program aiming to generalize remote reading of meters. This plan began to be implemented in 2011, and it is expected to reach full urban coverage by 2022. It must be acknowledged, however, the long-standing trajectory of reduction in water use by households in Alicante, and in Spain in general. In this regard, for instance, new personal water-saving habits can be traced back to the mid-1990s as a response to the intense drought of 1992–1996. Likewise, higher water prices often associated with the entrance of private capital in local water supply companies might have also contributed to the decline in consumption.

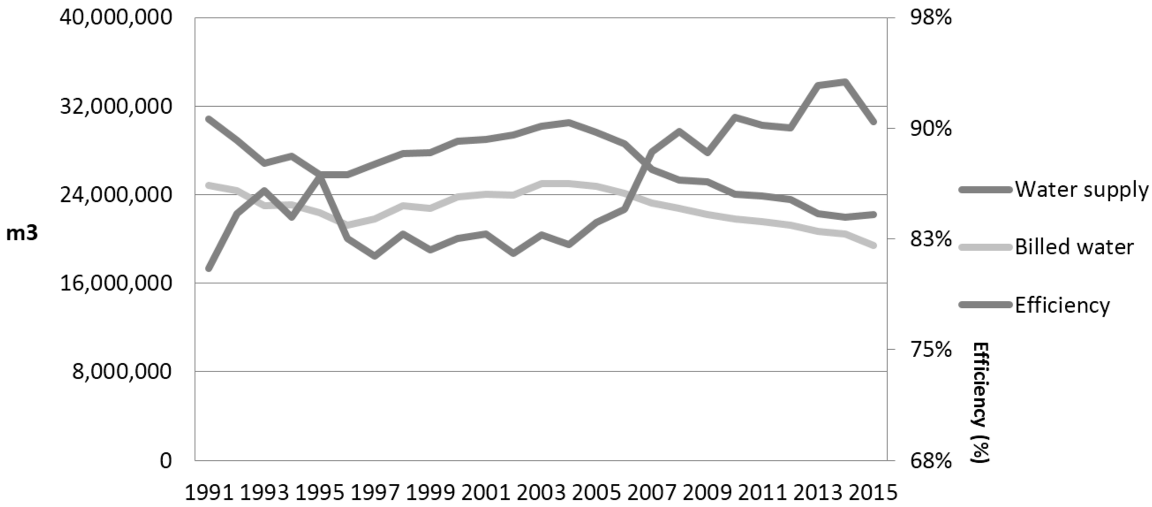

Figure 1. Water supplied, water billed and network efficiency in Alicante, 1991–2015, cubic meters. Source: elaborated by the authors using data provided by Aguas Municipalizadas de Alicante, Empresa Mixta (AMAEM).

4. Results

4.1. Remote Meter Reading Implementation in Alicante

AMAEM has accumulated extensive experience in the generation of smart technologies to increase the efficiency of the urban water cycle of Alicante. A particular milestone in this respect was the creation of the Centre of Control and Remote Activities in 1982, from several projects that began in the late 1970s. The registration and systematization of data about consumption and billing, supply and sewerage networks, etc., has prompted a culture of strong interactions between all of the departments and personnel in the company that has been replicated in nearby municipalities.

The origins of the current smart metering program can be traced back to the 1990s. AMAEM began to experiment with remote meter reading in 1995 in the affluent neighborhood of Vistahermosa, through wiring connected by telephonic devices. Initially, the so-called “walk-by technology” collected data using a portable reader transported by a car or by a worker. However, all of these systems did not work well because 40 percent of the meters were located in the interior of households. In 2011, a new plan for remote reading was launched with the following objectives: to avoid the nuisance of entering into private households to read meters; to eliminate the estimation of consumption when customers were absent; and to anticipate possible situations of leaks and other anomalies in the provision of the service. The plan is to be fully operational in 2022 when all meters in Alicante (approximately 200,000) would be equipped with remote reading devices.

For these purposes, two systems have been developed. On the one hand, within the urban fabric and for apartment buildings and small stores, the remote reading device includes a radio module with a VHF (Very High Frequency) antenna emitting from the free band of 169 megahertz allowing thus a wider reach. Currently, there are 90 antennae in the city, most of them in buildings and other facilities of the same company or of the city council and with a reach of 500 m. Each antenna may receive signals from 1000 to 2000 m, although they are prepared to receive information from as far as 5000 m. On the other hand, for large consumers and isolated water meters, the solution iMeter has been adopted. The latter involves the installation of registration, storage and transmission systems powered by batteries also connected to the company server through GPRS technology.

All new meters, as well as those that need to be changed because of aging, failures, inaccurate readings, etc., are equipped with remote reading. Since 2011, some 20,000 m with remote reading have been installed every year (Figure 2). In 2016, the total number of installed meters with remote reading was 98,228 (compared to 101,108 conventional meters), while those fully operative and transmitting data automatically was 91,122 (Table 2). The gap between the figure of operating meters with remote reading and that of installed meters with remote reading is explained by the fact that it takes some time for the company to achieve a permanent communication signal and coverage. Nine out of ten of them have been installed in private households. As to large consumers, in 2016 and according to AMAEM, all meters already had remote reading equipment installed, including 30 hotels of all categories.

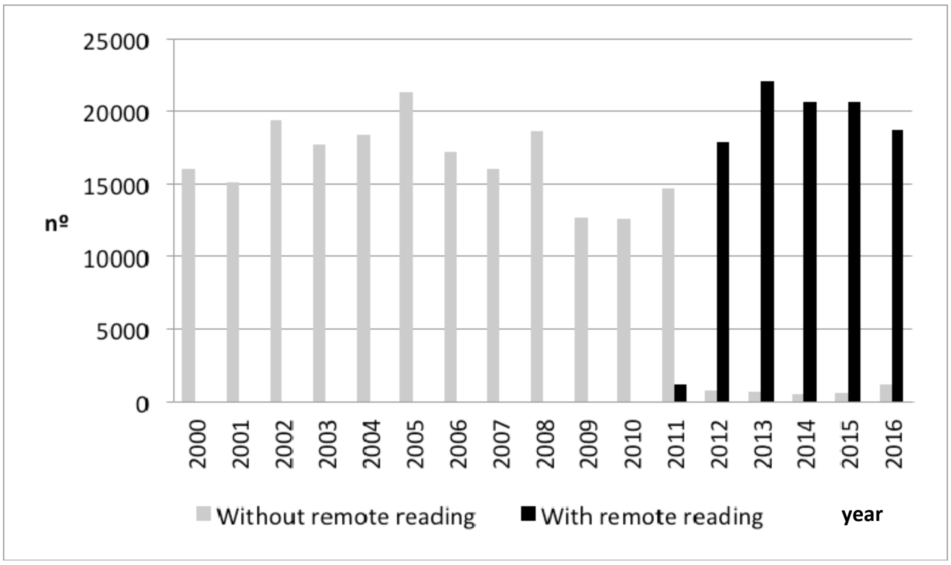

Figure 2. Meters installed annually in Alicante, 2000–2016. Source: elaborated by the authors using data provided by AMAEM.

Table 2. New operating meters equipped with remote reading according to use category. Alicante, 2011–2016. Source: elaborated by the authors using data provided by AMAEM.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
Domestic use	1073	15,446	18,225	16,564	9280	17,104	77,692
Non-domestic use (private)	89	1330	1691	1604	1045	1566	7325
Non-domestic use (city council)	1	4	16	8	19	3	51
Irrigation (city council)	0	14	10	11	32	1	68
Total	1163	16,794	19,942	18,187	10,376	18,674	**85,136**

One final point regards the distribution of remote readers within the city. The areas with a larger presence of meters with remote reading are the suburbs characterized by low population density and new housing projects (Santa Faz, Rabasa, Politécnico, Barrio Granada, Las Vegas-Hotel Hansa and Ciudad Jardín). In the beach areas of the city, about half of the households are equipped with remote reading devices, while in the more industrial suburbs, meters with remote reading barely represent 20 percent of the total. Low-income neighborhoods in the so-called "Northern District" (neighborhoods of Virgen del Remedio, Virgen del Carmen, Juan XXIII and Colonia Requena) show no differences in the installation of meters with remote reading with other, more affluent neighborhoods. However, according to the company, in some parts of the former neighborhoods, the installation of meters equipped with radio transmitters has been disregarded due to problems of theft and vandalism.

One of the key challenges the water utility faces to optimize this technology is the storage and exploitation of the large quantity of data generated by the permanent reading process of thousands of water meters. In households, 24 readings per day are registered, whereas for large users (e.g., hotels), the frequency of reading is four times per hour for a total of 96 registers per day. In Figures 3–6, we show examples of the level of detail that remote meter reading provides to the company for different typologies of users. Figures 3 and 4 present consumption patterns of domestic users living in different housing typologies that result in very different water usages (both in quantity and temporal pattern of consumption). For instance, we observe in Figure 4 a peak of consumption at 6:00 a.m. for garden watering every day but Friday. Figure 5 presents the evolution of water flow demand throughout the week (and for each day) of a hotel; in the figure, we can observe that water demand patterns throughout the day are very similar between days, with the exception of two moments with peaks of consumption linked to punctual operations of the hotel. Eventually, in Figure 6, we present an abnormal case of water flow demand by a large customer that would trigger the attention of the company. Obviously, this massive amount of data requires robust information systems able to store such a continuous flow of data.

On the other hand, in a similar way to the examples reviewed in Section 1 [16,24–26,28], AMAEM deploys consumption prediction algorithms, combining daily water use data with temperature and daily rainfall forecast to predict water demand within a six-day horizon. For longer periods (i.e., monthly forecasting) so-called black box algorithms are deployed. Remote reading through smart metering schemes has permitted calculating daily water balances for more specific time periods, as well as singling out consumption trends according to uses, sectors and neighborhoods. Moreover, complaints about excessive consumption have decreased since customers can see their consumption in real time on the water company website. Furthermore, the company will soon activate an application where the customer will be able to set alarms on their smartphones when readings detect abnormal or too high consumption.

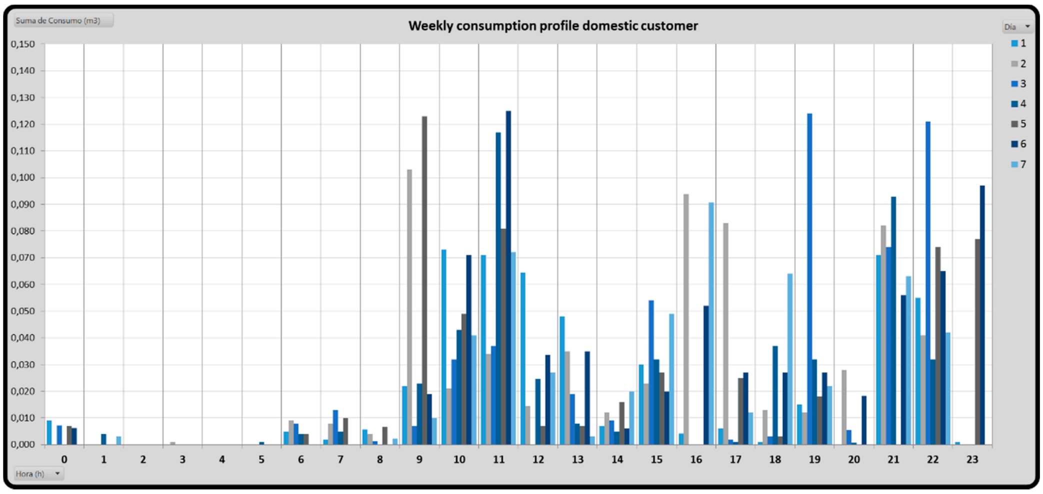

Figure 3. Water consumption hourly profile of an urban domestic customer during a week. Note: the left axis is cubic meters; the horizontal axis is the time of the day; the caption on the right expresses the different days of the week (from Monday = 1, to Sunday = 7). Source: figure provided by AMAEM.

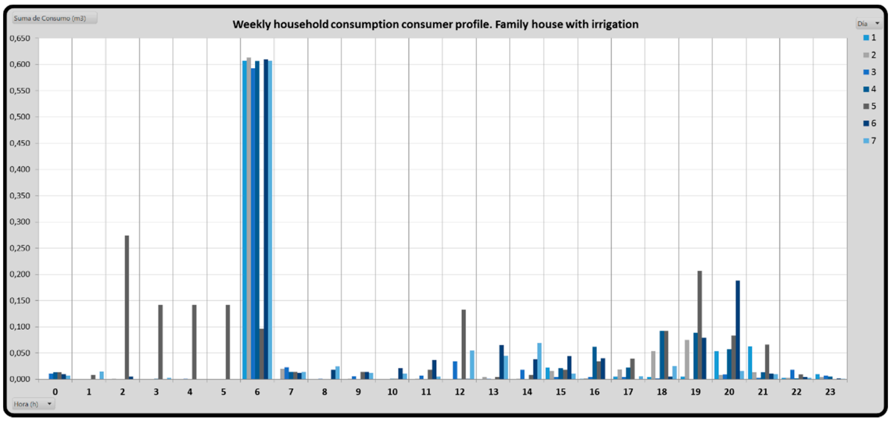

Figure 4. Water consumption hourly profile of a domestic customer during a week living in a detached house with garden. Note: the left axis is cubic meters; the horizontal axis is the time of the day; the caption on the right expresses the different days of the week (from Monday = 1, to Sunday = 7). Source: figure provided by AMAEM.

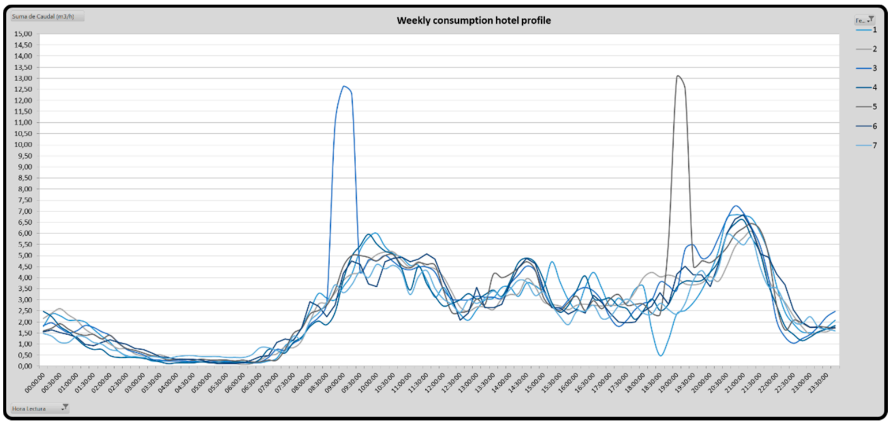

Figure 5. Water flow demand profile in a week of consumption of a hotel. Note: the left axis is cubic meters per hour; the horizontal axis is the time of the day; the caption on the right are the different days of the week (from Monday = 1, to Sunday = 7). Source: figure provided by AMAEM.

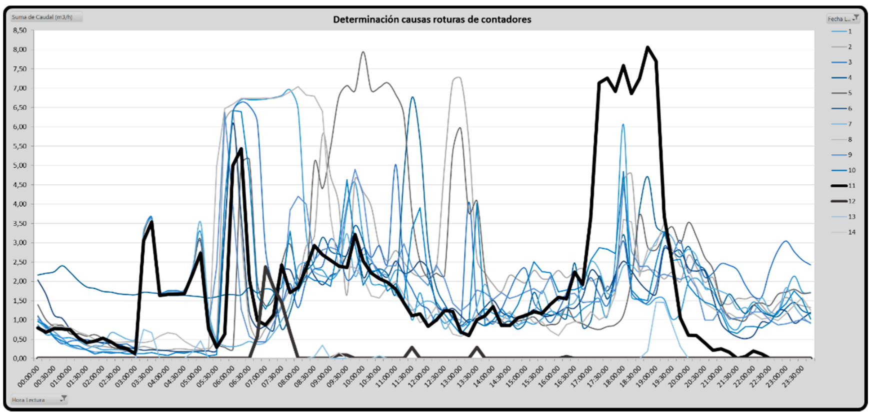

Figure 6. Abnormal water flow demand profile in two weeks of consumption of a large customer. Note: the left axis is cubic meters per hour; the horizontal axis is the time of the day; the caption on the right are the different days of the week (from Monday = 1, to Sunday = 7). Source: figure provided by AMAEM.

4.2. Potentialities and Limitations of Smart Meters from the Perspective of Alicante Water Managers

Several advantages and improvements linked to smart metering deployment were identified during the interviews (see Table 3). These potentialities can be linked to four major themes:

(1) The reduction of water demand and improvements in the efficiency of the water network, as well as the early detection of leakages (both at the network and the end-user scales) and the subsequent economic savings.
(2) The reduction of economic costs related to manual meter reading.
(3) Better knowledge on user's water consumption patterns to inform water planning and new ways of interacting with the user.
(4) The reduction of energy consumption and carbon emissions/carbon footprint.

Most of the advantages concern potential gains derived from more accurate and continuous information and lead, arguably, to greater efficiencies in use and management both for the company and for individual customers. Most of those benefits have been already identified in the literature review (see [11–30]). From the water utility perspective, new water meters with remote reading in Alicante may enable the detection in almost real time of any leak or breakdown of the system, as well as the exact location of distress in the network, as other studies have already documented [20,22]. When the remote reading metering scheme is fully implemented, the Alicante water company foresees an increase of 0.5% in the network efficiency, which could amount up to 0.115 million m^3/year (given the current consumption of 23 million m^3/year). The system helps to detect water leakages in the water network and act immediately; instead of going unnoticed for days or weeks as was common with conventional technologies. These remote meter reading schemes have helped, according to company sources, to "reduce the average time of a water leakage", both at the final point of consumption (customer) and at the network level. This technology also helps to detect cases of anomalous or excessive consumption. For example in 2015, 1800 cases of excessive consumption were reported in Alicante. On the other hand, the company suggests that with this new system, between 120,000 and 140,000 m^3/year corresponding to fraudulent readings could be detected.

The new metering scheme in Alicante also produces precise and reliable knowledge water use on an hourly, daily, weekly and yearly basis (especially for peaks of demand during summer holidays and local celebrations) (see Figures 3–5). As a matter of fact, the production of more precise knowledge on water use patterns is presented as one of the key features of smart metering in the international literature reviewed [11,13,15]. As experienced in places as different as Madrid (Spain) [16], Queensland (Australia) [15,17,28,29], Dublin (Ireland) [26] or the island of Skiathos (Greece) [24], among many other examples, the advanced analysis of such information through different techniques (e.g., clustering algorithms [24]) may lead to a better understanding of consumption patterns. In Alicante, the detailed and continuous flow of information from new meters is analyzed to identify patterns of consumption, for instance according to household tenure (ownership/rent) and occupancy rate. All of this information serves to, according to our interviews, inform demand forecasting models in a more accurate way, as has also been shown for instance in the iWIDGET project in Greece, using statistical analysis and neural networks to produce robust demand forecast models [26], or in Queensland (Australia), where water demand patterns are modeled for different future development scenarios [28,29]. All in all, according to managers, the system also will help to make more rational and precise interventions in the water network to improve the efficiency of the latter. An interesting finding, which has not been mentioned by the reviewed literature, is that this more fine-grained information may not only contribute to improving water management, but may provide useful information for the provision of other public services. In that sense, the water company of Alicante collaborates with the city council to monitor flats' occupancy in certain areas of the city through the data provided by the remote reading of meters; this may help to design and implement better municipal services, such as domestic waste management.

Alicante's new water metering scheme may also affect the relationships between the company and the customers, improving communication while reducing complaints related to billing issues. As readings are automatized, the company can charge customers real consumptions instead of estimations of consumption. Thus, as Beal et al. [17] argue, smart metering opens the possibility of reconciling the differences between real and perceived water use. Furthermore, Alicante experiences urban sprawl processes with part of the housing stock only occupied in the summer months [41–43]. In this sense, the integration of ICT with water meters could solve one of the major problems with partially vacant homes: the high number of failed attempts (with their concurring economic costs) to read meters because people are absent. This finding is absent in the literature, and we argue that it is especially relevant in certain contexts, for example as an important asset of smart metering in urban and suburban settings with important rates of secondary homes. Moreover, smart metering permits reducing the magnitude of undetected overconsumption at the household level, which has been one of the most frequent complaints received by the company from customers being charged unexpected high water bills. With the new system, the company argues that customers can check online consumption almost in real time, allowing them to calculate the approximate amount of the water bill and helping the user to anticipate changes in blocks of consumption (and hence of higher unitary prices). Smart metering opens up new ways of interaction between the user and the utility and the water flow as Darby [18] and Liu et al. [19] have pointed out. For example, users in Alicante can set alarms when consumption exceeds a daily volume that may be decided by the customer or setting another alarm for unexpectedly high consumptions (i.e., at night time or when the household is vacant).

Reduction of costs is one of the key benefits of the remote reading of water meters in Alicante. Boyle et al. [11] in their exhaustive review of smart metering already pointed out this fact. Beal and Flynn [12] for the case of Australia also showed how smart metering was used to reduce costs by streamlining the efficiency of Operation and Maintenance tasks (O&M) or contributing to labor optimization. In that sense, as recognized by Alicante water company managers, the prospects of cost reduction encompasses economic savings related to increases in network efficiency, as well as the reduction of costs (mostly labor costs) related to meter reading. New opportunities for improving the economic performance of water companies may also arise from remote reading. As other water companies do, AMAEM is struggling with declining revenues after the fall in domestic water consumption of recent years [40,42]. In this sense, and according to the company managers, remote meter reading may not only contribute to reducing operation and maintenance costs for the company (including the regulation of water pressure), but also help in designing more flexible tariff schemes: either rethinking tariffs according to typology of users/consumption patterns or through tariffs differentiating water tariffs according to daily or weekly time periods. This speaks to Vasak et al.'s [21] argument that smart meters open the possibility to introduce dynamic water pricing.

Smart metering could also lead to some environmental benefits beyond the fact of contributing to reducing water demand and water losses. While not widely recognized by the surveyed literature, smart metering may have an impact on energy use associated with the urban water cycle and in turn on their carbon footprints (in the case that energy comes from fossil fuels). First, the reductions in the demand for water resulting from the impact of water metering result in lower energy needs at the water treatment plants (and wastewater treatment plants) and pumping stations as the total flow of water demanded is reduced. For example, elsewhere the water company Aguas de Valencia calculated that its smart metering schemes saves some five million cubic meters of water per year and hence avoids the emission of 600 tons of CO_2 [44]. Second, savings in energy and especially lower carbon emissions are a result of avoiding travel costs associated with manual meter reading. Last, but not least, substituting paper bills by online bills may result in reductions in paper use. Aguas de Alicante has not calculated figures yet, but it could be argued that the savings in CO_2 emissions might be relevant.

Notwithstanding all of the alleged benefits and possibilities, water managers also identified some problems with this technology (Table 3), many of them related to the general challenges and limitations in the planning and implementation phases of smart metering pointed out by Beal and Flynn [12] and presented in Table 1. According to Alicante's water company managers, most of the issues result from a still immature market with high uncertainties in regulation and standardization. The lack of a common standard for these technologies hampers progress in the implementation of smart systems. For instance, interviewees mentioned the disparity in communication, frequencies and information protocols of the different manufacturers of remote reading devices as important issues. Companies are forced to use the devices of a single manufacturer, reducing competitiveness between firms and possible influencing prices, as well. As a matter of fact, the higher investments compared with regular meters with manual reading have been a major issue behind smart water metering deployment in Alicante (see Section 4.3). Paradoxically, as visual inspections are no longer possible, some types of (new) fraud, faulty systems or other problems would remain undetectable by remote reading. Regarding the user's side, as water managers recognized, while there is a large potential for opening up new ways of interaction between utilities and users, managers argue that so far, customers still do not use them to their full potential. On the other hand, company managers also are aware that some social rejection might be derived if privacy issues are not given full consideration. Furthermore, the existing societal digital divide may result in some population groups (such as the elderly) not being able to interact with such technology.

Table 3. Advantages and limitations of smart meter remote reading: utility managers' perspective. Source: own elaboration from our interviews with company managers.

Advantages	Limitations
For the company - Real-time accurate detection of leaks - Fraud detection - Real-time anomalous/excessive consumption detection - Detection of empty apartments - Reductions in meter reading costs - Precise and reliable knowledge of hourly/daily water consumption (consumption patterns) - Identification of patterns of consumption according to household variables - Reduction of complaints from users: billing always based on real consumption and not on estimations - Reduction of energy consumption and saving in CO_2 emissions	***For the company*** - Lack of a common standard for these technologies - Disparity in communication, frequencies and information protocols of the different manufacturers of remote reading devices - Companies are forced to use the devices of a single manufacturer - High investments - Visual inspections no longer possible
For the user (according to the company) - Online user-friendly information on real-time consumption - Easy calculation of the approximate amount of the water bill in advance - Avoid nuisances of entering in private households to read meters - Users can anticipate thresholds of change among blocks (and hence of unitary price of water)	***For the user (according to the company)*** - "Big Brother effect" and social rejection of the technology - Some segments of the population (e.g., older citizens) may have troubles handling new technologies such as the Internet and virtual offices

4.3. Cost and Benefits of Remote Meter Reading Vis à Vis Conventional Meter Reading

In our interviews in 2017, the company was able to provide some early and approximate figures concerning the economic costs of implementation (CAPEX) and the operation/maintenance (OPEX) of the remote smart meter scheme. Concerning capital expenditures (CAPEX), the remote reading technology that converts conventional meters into smart meters increases by 55 euros the initial cost of each meter (cost of installing a conventional meter: 25 euros); in other words, the substitution of an old meter by a new water meter equipped with remote reading systems rises to 80 euros. Thus, when the plan is fully implemented by 2022 and if there are no substantial changes in the cost of technology, the installation of 200,000 m with remote reading could have a final cost of up to 16 million euros. This figure can be compared to the five million euros of the renewal of existing meters by new conventional ones (a difference of 11 million euros). There is an important caveat to be made to those costs. The water company charges users 0.58 euros per month for the maintenance of the water meter (around seven euros per year). Given that meters are replaced every 10 years, this means that in that period, the user will have paid a total of 70 euros. This figure is rather close to the 80 euros of initial investment made by the company to install the remote reading meter, thus reducing substantially the financial effort made by the company. Therefore, if we assume that the final user is paying most of the cost of the meter during its 10-year lifetime, we could argue that the "real" financial effort made by the company to implement the scheme would be around two million euros.

It is important to mention that some of the costs associated with the implementation of this new system, such as data loggers and data storage facilities, are not assumed directly by the Aguas de Alicante as CAPEX, but this service is leased to another company (of the Aquadom group) and is thus taken into account as operating expenses for Aguas de Alicante (OPEX) (some 1.5 euros per meter per year). Taking into account these figures plus other operating expenses, the approximate OPEX of this new metering scheme is around 2.5 euros per meter with remote reading per year in comparison with the two euros per year of a conventional one. This implies an increase in the OPEX of 0.5 euros per new meter with remote reading. Thus, when the plan is fully implemented, remote reading meters will have an OPEX about 100,000 €/year higher than that of conventional metering schemes (assuming that the difference of operating costs remains at 0.5 euros/new meter/year). This increase in the cost (despite the reduction in the number of workers reading conventional meters, currently from 25 down to 15; at the end of the process, reduced to no more than five workers) obeys the fact that new procedures had to be created and new profiles hired to manage the large amount of data gathered by smart meters, not to mention the data storage costs mentioned before. Nonetheless, it is important to bear in mind that these costs are no more than early rough calculations by the company and that more accurate figures will be available as the plan becomes fully operative.

On the other hand, we can have an early rough estimation of the economic benefits derived from the full implementation of the remote water meters reading scheme. The aforementioned forecast increases in network efficiency (0.5%) once the scheme is fully implemented could suppose an economic savings of some 80,000 euros per year (approximate calculation using current prices of raw water, around 0.69 euros/cubic meter). The avoidance of fraudulent readings could account for some 0.12–0.14 million cubic meters per year; if we take into account an average retail price of water to users of around 1.5 euro per cubic meter, this would suppose some additional income for the company in the range of 180,000–210,000 euros per year once the plan is fully implemented (considering current retail water prices).

Therefore, the two figures combined would add up to 260,000–290,000 euros per year of savings/additional income once the plan is operational and the suggested figures of water savings and detection of fraudulent readings predicted by the company do materialize. If we compare the increases of operating costs of remote reading meters with the increase of economic savings/income derived from the implementation of the plan, we observe a positive balance of 160,000–190,000 euros per year. Nonetheless, there are two important caveats to be made: these future savings derived from efficiency gains are calculated given current raw water prices that may increase in the near future; on the other hand, other benefits remain to be monetized or are still quite undefined at this very preliminary phase of exploitation of the new system. As a matter of fact, some of these benefits are said to be intangible, as they could not easily be turned into economic gains, at least in the short term. In any case, we can argue that important economic savings/additional income may be made if the increases in network efficiency and undetected water consumption detailed in the previous section do materialize. In any case, if we assume that the "real" investment to implement this plan is around two million euros (given that users cover 70 out of the 80 euros of the cost of the meter throughout its 10-year lifetime) instead of 11 million, the positive net gains described above in the 10-year lifetime of a meter will almost cover the investment (Table 4). Nonetheless, we must bear in mind that this is an approximate and tentative balance of the costs and benefits that we have calculated making different assumptions, such as that savings related to increases in efficiency will effectively materialize; that fraudulent water uses will decrease; that future raw water prices and retail water price swill remain constant; and that intangible benefits will not be translated into economic benefits. All of this is to justify that the figures presented could vary widely according to these different situations. In any case, we argue that what is interesting from the implementation of remote reading in Alicante is that it has transcended a strict and immediate economic logic and has aimed to modernize and upgrade the system to cope with the challenges of water management in the 21st century.

Table 4. Summary of the increases in CAPEX and OPEX compared to the increase in savings/additional income for the company.

Costs of Meters		
Increase CAPEX remote reading scheme = **11 million euros**	Increase OPEX remote reading = **100,000 euros per year**	Increase of economic savings/additional income remote reading = **260,000–290,000 euros per year**
Note: At the end of its lifetime (10 years), the user has paid 70 out of 80 euros of the cost of the remote reading meter (maintenance fees). We could assume that the "real" cost for the company is then **2 million euros**.	**Net increase of additional savings/income per year related to remote reading = 160,000–190,000 euros per year**	

5. Discussion and Conclusions

Smart metering schemes emerge as a central feature behind the quest for more efficient and sustainable urban water supply networks in the 21st century. Despite the fact that under the concept of "smart meters", we can find an array of different technologies, these all have in common the provision of more detailed, continuous and remote information of water use at the end-point of consumption (household, industry, etc.). Water-scarce countries, such as Australia, have been frontrunners in these initiatives. However, little academic analysis on the development of smart metering exists in other geographies and much less those providing significant qualitative insights from company managers and staff. Spanish Mediterranean urban areas, ridden with severe episodes of water scarcity, have also embraced these technologies, but we know comparatively little about their performance, as well as their benefits and costs. Beyond providing one of the first accounts and a qualitative analysis of the situation of urban smart metering schemes in Spain through the case of Alicante, where an ambitious remote reading of water meters is being implemented, our paper attempts to contribute to the debates on smart metering by providing an original perspective on the potentialities and limitations, as well as the costs and early benefits of these new schemes from a managerial perspective and from a Southern European perspective.

According to the managers of Alicante's water company AMAEM, the main advantages of remote reading of water meters revolve around the following issues: the access to an in-depth and situated detailed knowledge of water use at the household scale for identifying patterns of consumption according to different variables; the reduction of water consumption and the improvement of efficiency of the water network; the reduction of costs (as some human actions will be no longer needed (such as manual meter reading); the possibilities to segment users and develop new pricing schemes that capture the oscillations of water use throughout the day and the week; the potential to engage users in more responsible behaviors; the immediate detection of anomalous and excessive consumption; and other environmental-related benefits. All of these aspects are indicative of a shift of water companies towards the technological aspects of water management that help to increase the added value of their existing activities, instead of embarking on riskier ventures. This, in our opinion, has not been especially emphasized in the literature and is very relevant for areas such as Alicante and elsewhere in Mediterranean Spain, where water companies have to devote human resources to manually read (every 1–3 months) water meters for the household, commercial and industrial sectors.

The intense development of the Spanish Mediterranean coast since the 1960s, and especially during the real estate bubble of the 1990s and 2000s, has resulted in the creation of new, rapidly growing urban natures (gardens and swimming pools) highly dependent on water [45]. In the coast of Alicante the urban area in 1978 was 49,904,151 m^2, while in 2013, it had risen to 221,965,736 m^2 [43]. This real estate boom affects consumption and demand for certain natural resources, including water, especially due to the increased presence of Atlantic plant species (e.g., turf grass) that usually occupy larges area of these spaces [46]. These new metering schemes could help to show residents of those suburban environments in a vivid way the high volumes of water required to maintain Atlantic landscapes in drought-prone areas. On the other hand, and given the significant number of weekend and vacation homes in suburban Alicante, remote reading avoids very time-consuming physical visits that are fruitless many times because customers are absent. Last but not least, residents that have a home in Alicante just for vacation periods would be able to check throughout the year whether there are water losses at their homes.

All in all, and concerning one of the first problems to roll-out such schemes as reviewed by Boyle et al. [11], there is still a lack of full understanding of the whole economic life cycle assessment of smart metering schemes. In Alicante, while the cost of implementing the technology is more or less well defined (CAPEX), the cost of operating them (OPEX) has been calculated, but presents more uncertainties (concerning the exploitation of the data). On the other hand, it remains difficult to have a full perspective on the economic benefits: on the one hand, because the price of raw water may increase in the future (thus increasing the savings linked to efficiency gains); on the other hand, because some of the benefits could not be calculated in the short term or are environmental benefits for the whole society (and not just for the company) that are hardly translated into economic gains. In that sense, this leads us to be very cautious on determining in a precise way the economic return of this strategy for the case of Alicante. The case of Alicante shows that water managers may struggle to identify in advance all of the benefits of the technology and to translate them into monetary terms. These knowledge gaps, especially on the economic benefits of the technology, call for more systematic cost-benefit analysis frameworks, which could help water managers to improve the decision-making process of installing this new technology.

Beyond the cost-benefit issue, it is critical that further reflection is made on the impacts of this new technology on water users. In many Mediterranean Spanish cities, among them Alicante, recent drought episodes and the economic-financial crisis that began in 2007 have resulted in sharp decreases in household income and have led to a contraction in the level of household expenditures affecting water demand and resulting in an increase in the number of people exposed to energy and water poverty [47]. In this context, what smart meters enable, at least in the words of water utilities' managers and technicians, is a higher degree of control and monitoring by customers over their water use. The argument that follows is that by empowering customers with information about their consumption patterns and uses, this will allow them to make informed decisions about how they use water in the future. However, we warn that this could have a negative effect on citizens' behavior, especially on the less well-off and those with already low consumptions. The uncritical interpretation of the continuous information about water consumption (combined with pricing mechanisms) may make citizens obsessed with reducing already low and essential water uses instead of focusing on other household expenses. Therefore, it could be argued that smart metering risks entrenching ongoing processes of commodification of the urban water supply by intensifying the role water prices play in modulating water use even for the most basic uses, as has been pointed out elsewhere by many critical water scholars (see for instance recent debates in Loftus et al. [32] and Zetland [31]). In other words, smart metering may amplify the power of water metering in creating new subjectivities in water users and enhancing the process of turning water into a commodity, whose consumption is strictly modulated by pricing mechanisms.

All in all, the case of Alicante, despite being in its early implementation phase, shows, in qualitative terms, the diverse impacts that smart meters may produce in water management, environmental protection and in the end-user. As Boyle et al. [11] argue, smart metering should not be viewed as an end in itself, but as the potential to meet supply and end-use information needs, which in turn can satisfy sustainable urban water management objectives. As demand-side strategies are being championed over supply-side measures, smart and intelligent metering will probably have a larger and more influential presence in the urban water sector in the near future, especially in drought-prone areas, such as Mediterranean Spain. The challenge is to ensure that its broad-scale introduction does not enhance inequalities in water access and does not penalize the less well-off and those with already low water consumptions, especially in places such as South Europe, where the last economic crisis has had serious impacts on the well-being of citizens.

Acknowledgments: Data from AMAEM has been provided by Antonio Sánchez (Chief of Technical Systems), Francisco Agulló (Chief of the Commercial Administration Department), Vicent Joan Martínez (Technician at the Opearations Unit) and César Vázquez (Responsible of Remote Meter Reading). We thank all of them for their time in the different interviews we carried out. We would like to thank also the help given by the general managers of Hidraqua, Gestión Integral de Aguas de Levante S.A. (Asunción Martínez) and AMAEM (Francisco Bartual).

Author Contributions: H.M. and D.S. designed the structure of paper. A.-F.M. and A.-M.R. carried out data gathering and the interviews in Alicante. H.M. carried out the literature review. H.M. and D.S. wrote the English version of the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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